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Marine Energy in the UK

State of the Industry Report 2012

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Contents

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1. Introduction

In 2011 it became clear that the wave and tidal energy industry in the UK had reached a tipping point. As it decisively moved towards commercial viability the industry offered vast improvements in its value proposition, driven by a surge in deployment and a demonstrable track record. As a result we now have proposals for the first wave and tidal arrays and the front running developers are looking to develop multi-megawatt projects.

Increased visibility of project pipelines and improved levels of knowledge within the sector have derisked projects, indicating a pathway to profitability. The flow of manufacturing capability into the industry through the involvement of major original equipment manufacturers (OEMs) has vastly improved the credibility of the industry and we now have several industrial partnerships developing the foremost projects. The involvement of major energy utilities is further evidence of progress as we now have end customers intimately involved in the development process.

The increased attractiveness of the industry to investors is largely due to government support and several high profile demonstrations of commitment. With the provision of increased revenue support, as heralded in the 2011 consultation on Renewable Obligation Certificate (ROC) rebanding, and upfront capital support offered, DECC is working hard to unlock private sector investment. The Scottish Government has been equally engaged and has provided the Scottish Renewable Obligation regime to compliment the upfront capital support of its own. The harmonisation of the revenue support regimes for marine energy is very welcome but it is vital that the government continues to discuss ways of ensuring that the various funding streams are both coordinated and complementary.

The next generation of devices is making an increasingly meaningful contribution to the industry in terms of knowledge and experience acquisition, as new concepts are continually being validated. There are a range of developers with sub-scale devices being tested, helping to fuel cost reduction, drive innovation and contribute towards the reliability of devices. Not only do these latest devices provide new ways of utilizing the immensely varied conditions of the marine environment, they provide further impetus to the industry by creating market pressure and driving the leaders to incorporate cost saving measures.

In February 2012, the Energy and Climate Change select committee, made up of influential MPs, released their report entitled “The Future of Marine Renewables” which urges the UK Government to act decisively to ensure that the UK reaps the full benefits delivered by the wave and tidal sector. At the heart of their report is the recognition that the global industry could be worth £3.7 billion to the UK by 2020. The chance to provide real value to the UK, generate British jobs and catalyze the low carbon industrial revolution are the key motivations behind the positive policies that we have seen from government.

The positive findings of the Marine Energy Strategic Environmental Assessment, backed up by the recent studies by industry and academia, indicate that there is no substantive environmental impediment to the development of the industry. However, we recognize the importance of tackling emerging issues and will continue to engage with environmental and academic groups building knowledge of environmental issues.

The planning system is complex and it is vital that clarity is provided in a timely and thorough way. Marine Scotland’s and Marine Management Organisation’s move to an evidence based approach is welcome, but it should not be implemented in a way which could lengthen the processing times for applications. That said, the signs from the MMO have been positive and Marine Scotland has made progress in consenting projects, approving the largest Tidal Stream project in the world so for in 2011 at Islay.

Noting these developments, it is clear that the Wave and Tidal energy industry is poised to take advantage of the opportunities provided by the UK’s marine legacy. The UK’s science, technology and engineering capability are ideally suited to harness the energy resources in our waters and the government has put the requisite supportive policies in place. It is now up to all involved to take the next steps in its development and move towards deployment at scale. With deployment activity surging in 2011 and set to continue its momentum in 2012, the sector is going from strength to strength and is starting to deliver on its immense potential.

Throughout this report the discussion of the tidal industry is limited to that for tidal stream devices and excludes consideration of tidal range projects or technology.

2. A Year in Policy

The last year has seen a considerable amount of policy activity, as the sector landscape was fundamentally reshaped by the review of the Renewables Obligation regime and the provision of upfront capital support from government. The surge in deployment and the influx of high profile companies into the sector has generated wider interest in wave and tidal technology, with the sector enjoying a heightened profile in the media as a result.

Government has provided a series of positive signals to industry, culminating in the release of “The Future of Marine Renewables in the UK” report by the Energy and Climate Change Committee in February of 2012. This panel of MPs brought together a range of evidence from across the industry to give a summary of the activity in the recent past and propose a future pathway for the development of the industry. They rightly recognized that the funding of the first arrays is a crucial enabler to capturing the industry within Britain and delivering the economic opportunities it holds for the UK economy.

Amongst their most helpful conclusions are recommendations to DECC (Department of Energy and Climate Change) to urgently provide clarity over the Electricity Market Reform mechanism, improve the allocation and management of upfront capital support funds and heighten the ambition of the deployment targets of the industry as outlined in DECC Renewables Roadmap. The report was widely perceived as bringing logical and balanced arguments to bear on the issue of wave and tidal energy development, urging industry to improve its cost reduction targets and work together to increase information sharing.

Furthermore, the Committee identified grid constraints, environmental concerns and a lack of clarity over the planning process as the primary non-financial barriers to the development of the industry. The desire to eliminate these barriers is in line with RenewableUK objectives and is welcomed as a demonstration of support from a high level official panel.

2.1 Financing the future

2.1.1 The Renewable Obligation Regime

The move toward 5 Renewable Obligation Certificates (ROCs) for each megawatthour produced by wave and tidal energy installations, proposed in DECC’s Renewables Obligation Banding Review Consultation in October 2011, was welcomed by the industry. This measure signals government commitment and support for the sector, while enabling the next stage of commercial development. A level of 5 ROCs provides medium term certainty to investors and an enhanced revenue stream for the first commercial projects.

The promise of 5 ROCs is a major element contributing towards the increasing confidence in the sector but it carries an inherent requirement for cost reduction. The industry needs to demonstrate that the cost of energy will fall to a sustainable level to catalyse large scale deployment.

2.1.2 The Electricity Market Reform

The Electricity Market Reform (EMR) was launched in 2010, with the White Paper following in 2011. The initiative was welcomed by the industry. However, government introducing clarity as soon as possible on the supportive EMR regime was deemed absolutely essential. Early visibility over the level of support will ensure continued investor confidence and engagement.

Indeed, the switch to the Contract for Difference with a Feed in Tariff (CfD FiT) mechanism has the potential to provide long term stability to the market and incentivize developers to reduce costs. The CfD FiT would set a “strike price” or a set price for electricity from wave and tidal energy, at a sustainable level linked to the actual cost of producing electricity from the energy of the ocean.

The CfD FiT mechanism would thus reward cost reductions as the margin between the strike price and the cost to the developer would increase. While the banding approach taken to support the development of marine energy in the ROC regime would be carried over into the EMR, the emphasis on cost reduction is important as it drives the marine energy industry to strive for cost parity with more established energy generation techniques.

The EMR is a key policy for the growth of the industry as it holds the potential to provide the long term certainty the industry needs to develop. While the ROC regime is crucial for the medium term development of the industry, the EMR will be in place during a crucial period (post 2017) for the industry. It is hoped that the mechanism will build on the momentum gained from the ROC regime and consolidate the UK’s global lead. However, too great a reduction in the support level would jeopardize our first mover advantage and put the British industry at threat. While we recognize the need to provide value to the consumers of electricity and a timeline for cost reduction, we believe that any reduction in the level of support should be linked to the level of deployment achieved and thus the continued demonstration of successful electricity generation.

2.1.3 Marine Energy Array Demonstrator – Department of Energy and Climate Change

DECC has provided £20 million pounds from its Low Carbon Innovation Fund to develop wave and tidal energy projects in the United Kingdom. The Marine Energy Array Demonstrator (MEAD) fund aims to develop the first commercial arrays by enabling leading developers to move from single device testing to array projects. The MEAD fund is crucial to the development of the industry as it closes the funding gap for the capital intensive first arrays and provides the opportunity to develop the knowledge and capability of the industry. Importantly, the fund is limited to 25% of the total capital needed to develop a project, in line with European Union state aid laws.

2.1.4 Marine Renewables Commercialization Fund – Scottish Government

The Scottish Government has recognized the opportunity in its coastal environment and has put an array support scheme in place. The £18 million Marine Array Commercialisation Fund (MRCF) is geared towards developing the commercial viability of the industry and is set to put the industry on the pathway to profitability. Its main objective is to provide a stepping stone to unlocking the potential 1.6GW Pentland Firth and Orkney Waters leasing round. The MRCF represents a step change in Scottish funding and is very much aligned to requirements of industry. Further funding for the development of infrastructure critical to the development of the industry is set to consolidate Scotland's current leading position and remove constraints around the capacity to deliver projects.

2.1.5 Funding innovation

Research and development plays a key role in developing devices suitable for the harsh and incredibly varied marine environment. It reduces costs by developing solutions to the difficulties of operating under the sea and bringing forward concepts that enable heightened deployment. Improved knowledge helps to mitigate the impacts of marine energy installations and eliminate the remaining barriers to the commercialisation of the industry.

The UK is a leader in the area of innovation and the development of the marine energy industries provides an opportunity to take advantage of its excellent academic and engineering capabilities. Traditionally, the UK has failed to commercialise promising technologies and allowed other countries to benefit from advances it has made in the pre-commercial phase. The government is determined that this should not happen to marine energy and has provided a range of initiatives aimed toward retaining the benefit of the advances the UK has made up until this point.

The Technology Strategy Board is a key player in this area and it's most recent funding call, "Marine Energy - Supporting Array Technologies," targets crucial areas with the potential for significant cost reduction. Furthermore, its Offshore Renewables Catapult is helping the industry vault the innovation gap by coordinating the R&D agenda, aligning the outputs of academia with the requirements of industry and providing a mechanism for connecting the various parts of the value chain. The ongoing contribution of the Carbon Trust, Energy Technologies Institute and the enterprise bodies, amongst others, should not be underestimated and provide key strategic direction to the innovation agenda.

2.1.6 The Green Investment Bank

When the government initially laid out its vision for the Green Investment Bank, it pointed towards the revolutionary role it would play in catalyzing the low carbon industrial revolution by supporting early stage technologies. As the GIB has developed, it has become clear that it will begin providing debt financing on a purely commercial basis. This change in the original vision for the bank has compromised the ability for it to have a real impact on bringing marine energy projects to market before 2016. This was confirmed in the written ministerial statement, where marine energy was not identified as a priority sector. It is important that the GIB provides a stronger message to investors and demonstrates the government's commitment to supporting this promising sector. RenewableUK plans to continue educating officials at BIS and elsewhere of the importance in recognizing the huge potential of marine technology as advocated by the independent Committee on Climate Change.

2.2 Removing the barriers to deployment

2.2.1 Strategic Environmental Assessment

In 2010, DECC extended the scope of its Strategic Environmental Assessment (SEA) to include the wave and tidal industries. Aimed at enabling development through the eradication of barriers, the SEA process is a vital component of the drive to fully understand the marine environment and the potential impacts that marine energy extraction could have. The SEA report was developed based on extensive analysis and a 12 week public consultation on the findings, which closed on the 12th of May 2011. Following the publication of the post consultation report in October 2011, DECC concluded that there are "no overriding environmental considerations to prevent the achievement of our draft plan of leasing…wave and tidal installations. Thus the SEA paves the way for future leasing rounds of marine energy and lays out a suitable plan for interaction with other users of the marine environment. It reiterates the need to implement...appropriate measures that prevent, reduce and offset significant adverse impacts…" This approach to achieving a streamlined development process enables mitigating actions proportional to the impacts of small arrays and single devices in the short to medium term and a framework for identifying and dealing with more significant impacts as the industry expands. Furthermore, the environmental report highlights that siting and consenting processes for offshore renewable energy developments must remain flexible to allow for technological innovation, including any mitigation measures.

2.2.2 Marine Planning

The Marine Management Organisation and Marine Scotland are making consistent progress towards a transparent and equitable consenting process. Crucially, the switch to an evidence based approach will help to ensure that consenting facilitates the right kinds of developments in the right areas. It is important that they base their decisions on sound science and need to remain mindful of the potential delay to projects and placing unnecessary barriers in the path of development. It is vital that all actors maintain a stake in the process as the marine spatial planning framework gets redesigned.

The redefinition of sustainable development in British law, the Habitats Regulations Appraisal and the implementation of Marine Conservation Zones and Marine Protected Areas can go a long way to protecting the wealth of the marine environment. However, care needs to be taken to ensure that these important initiatives do not inhibit the growth of the industry by adding unnecessary and exorbitant costs onto projects that will contribute significantly to the carbon reduction agenda.

2.2.3 Grid and transmission charging

The location of the UK's marine energy resources poses a challenge as the transmission network has historically been built out towards thermal power stations rather than areas of high renewable resource. Furthermore, the current transmission charging regime penalises energy installations far from the centres of population. While the mainland has a well developed grid, the islands are penalised and can face transmission charges up to 7 times more expensive than those on mainland Britain. A rebalancing of the charging regime is required to facilitate the expansion of the renewables industry.

Ofgem has engaged the entire energy industry through its Project TransmiT, which is attempting to make transmission charges fairer and less skewed towards traditional energy generation technology. Project TransmiT is expected to issue proposals in the spring and RenewableUK has input into these. However, it remains to be seen what charging regime Project TransmiT will recommend for the islands, and certainly RenewableUK believes there will be further work to be done regarding the offshore charging regime.

Plans for several offshore interconnector cables are welcome, with improved cabling connecting the different countries and regions of the United Kingdom. The subsea Western and Eastern HVDC cables or "bootstraps" are set to revolutionize offshore energy generation with improved transmission options to all parts of the UK.

Additional international interconnectors will be welcome as they enable international trade in electricity, thereby allowing energy to flow from where it is most economically produced to where it is most needed. The recently confirmed France – Alderney – Britain connection is planned to allow an additional 4GW of interconnector capacity and holds interesting possibilities for the sharing of energy resources.

2.3 Facilitating framework

2.3.1 The Role of the Crown Estate

The Crown Estate plays a crucial role in supporting development of wave and tidal projects, which primarily consists of leasing project sites in UK waters. To date, it has leased 33 sites for projects of a range of sizes and purposes, from engineering test and demonstration facilities for single prototypes through to commercial project sites with several hundred megawatts potential capacity. Currently underway is a tidal stream energy leasing round in the Rathlin Island and Torr Head strategic area off Northern Ireland, which has potential for 200 MW of projects.

As well as providing leases, The Crown Estate works closely with developers to actively support the project development process. It has committed to invest £5.7m in 'enabling actions' to accelerate and de-risk development of the flagship Pentland Firth and Orkney waters schemes; is encouraging best practice in health and safety; and undertaking an initiative to improve knowledge sharing. Later in 2012, The Crown Estate is planning to run an industry consultation on future wave and tidal leasing, informed by new analysis of the scale and distribution of wave, tidal stream and tidal range resources across the UK.

Significantly, The Crown Estate is taking steps to make it easier for small firms to enter the wave and tidal industry by reducing the requirement for parent company financial guarantees. For projects that have already won rights in the Pentland Firth and Orkney waters, the option is now available for parent company guarantees to be reduced from £25 Million to £5 Million.

2.3.2 World leading testing facilities

Our testing facilities are a crucial element of the industry and provide a way for developers to bring forward their development trajectories. The European Marine Energy Centre, the National Renewable Energy Centre and the WaveHub provide a nursery for the advancement of devices and the environment to identify and eradicate problems prior to array deployment. The implications for cost reduction and proving of concepts should not be underestimated as our testing facilities enable us to remain at the forefront of these crucial areas.

2.3.3 Marine Energy Parks

The Marine Energy Park initiative provides a focus for industry and investment by coordinating the activities in a given region. Areas with concentrations of capability and supply chain companies will benefit from improved integration of the various levels of government, and the heightened profile, that the Marine Energy Parks enable. The South West Marine Energy Park was launched in Bristol on the 23rd of January and another is planned for the Orkney Waters.

2.3.4 Marine Energy Programme Board and Marine Energy Group

The Marine Energy Programme Board is an important engagement mechanism which enables DECC to consult industry on the most important issues facing the industry. Recent activity has included the structuring of the MEAD fund, collation of industry positions and the development of the marine energy parks.

This Scottish government Marine Energy Group provides a similar forum for those developing projects in Scottish Waters and has done important work in shaping the MRCF and providing coherency to the funding landscape as a whole.

2.3.5 Deployment targets and the DECC Renewables Roadmap

DECC's Renewable energy road map indicates that 300MW of marine energy will be installed by 2020. Developer appetite has been at a level of around 1.6 GW, which is a significantly more ambitious target. The discrepancy between the targets laid out in the roadmap and industry position statements prompted the select committee to call for a "more visionary approach" to boost confidence in the sector.

2.4 Key policy requirements

The policy framework underpinning sustainable growth in the industry has been put in place but challenges remain. Uncertainty is the biggest hindrance to the growth of the industry and confidence in the ability of the industry to deliver needs to be enhanced. While government has shown dedication in supporting the industry, there are several areas that require immediate action to secure the long term viability of the Wave and Tidal Energy industry.

RenewableUK asks the government to:

- Enable investment and cost reduction for a sustainable industry by providing urgent clarity and an appropriate strike price level in the Electricity Market Reform.
- Support the development of the first arrays with correctly targeted, coordinated and appropriate funding streams.
- Take positive and proactive action to minimise key project risks such as underwriting costs, grid infrastructure limitations and environmental constraints.
- Support innovation to ensure continued improvements in reliability and costs.

With these actions the government can secure the development of the industry within the UK, delivering real economic benefit and catalyzing the low carbon industrial revolution. By implementing a supportive, coherent and long term strategy it can build confidence in the industry and help unlock the private financing that will be required to drive commercial development.

With the industrial partners building momentum and eliminating risk in their projects, it is vital that we seize on the opportunity we are presented with and drive the United Kingdom into a future powered by our own resources and ingenuity. We look forward to representing the industry set to revolutionise the way the world generates electricity.

3. Finance and Funding

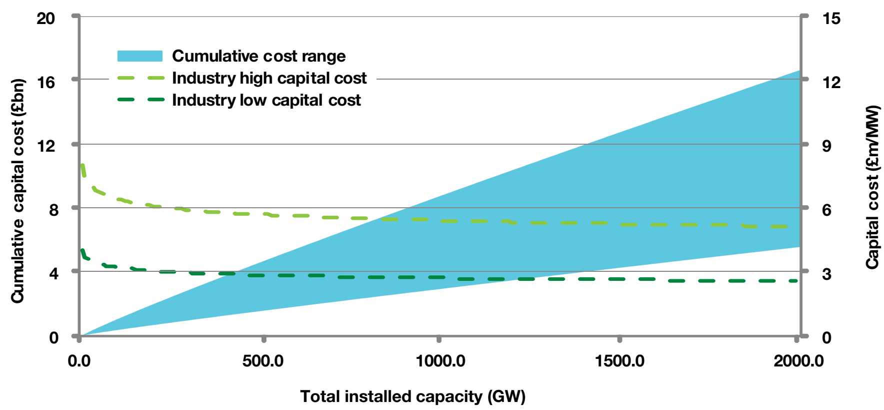
Significant capital support funds were utilised by the wave and tidal industry in 2011 from sources such as the Energy Technologies Institute (ETI), the Carbon Trust, the Technology Strategy Board (TSB), the WATERS fund from Scottish Enterprise and the South West Regional Development Agency. The Marine Renewables Deployment Fund ended in March 2011 after providing £19.5 million of funding, which focussed on developing devices and infrastructure for sea testing.

In 2011, Siemens increased its ownership share of Bristol-based Marine Current Turbines from 10 to 45 per cent, before announcing its intention to take a 90 per cent share in February 2012. Alstom also moved to take a 40 per cent equity share in Edinburgh-based AWS Ocean Energy and Andritz has increased its stake in Hammerfest Strøm from 33.3 per cent to 55.4 per cent; the company will now operate as Andritz Hydro Hammerfest. These investments sit alongside previous investment by ABB in Aquamarine Power and Rolls Royce in Tidal Generation, for example.

There have also been successes in attracting funding for project development. Barclays Capital invested over £3 million in Aquamarine and Morgan Stanley took a 45 per cent share in the Meygen project consortium to develop the Inner Sound in the Pentland Firth. Utilities continue to broaden their involvement playing a project development role, partnering device manufacturers throughout the product development phase and offering a collaborative approach with others in the industry. An example of this collaboration is the shared maintenance agreement between Pelamis and both Scottish Power Renewables and E.ON Climate and Renewables for their European Marine Energy Centre (EMEC) test projects.

The key challenge for the industry now is successfully deploying and operating small arrays of devices. The decision to award five Renewables Obligation Certificates (ROCs) per MWh generated from both wave and tidal across UK projects enables such small-scale projects, a key step towards a commercially competitive industry. This challenge is also reflected in more recent funding programmes, such as the Marine Energy Array Demonstrator programme from DECC, and announced funding from ETI and TSB.

Figure 3.1: Cumulative Project Funding Requirements. *Source: BVG Associates.*



Previous research from RenewableUK has indicated that £1 of public money invested in the sector has unlocked £6 of private investment. Public support of the sector remains crucial at this stage but, as the industry grows and costs fall, a lower level of support will be required to capture the economic benefits the sector will yield. The size of the opportunity is vast and the "Channeling the Energy" report identifies an annual value to the UK of £3.7 billion by 2020. The potential to develop projects in UK waters could provide real economic benefit to our economy. In addition, the sector has the potential to create up to 10,000 UK jobs by 2020. Our existing marine energy supply chain and marine engineering capability is set to form the foundation of future jobs as capital investment drives demand for construction, installation and maintenance services.

3.1 Private and public funding requirements

The capital and operating costs for wave and tidal projects deployed in high energy offshore areas are significant. There is a significant change in funding requirements between small-scale, laboratory and tank testing of devices and full scale, grid connected sea trials. Figure 3.1 indicates investment requirements from both private and public sources of around £5 billion to achieve a 500MW total installed capacity with initial small projects likely to have higher costs per MW. It also indicates potential capital cost projections on a per MW basis; these are based on work completed for the Channeling the Energy report by RenewableUK.

Utility and large industrial organisation involvement in the wave and tidal sector is justified by the potential for long term returns from cost-effective energy generation at commercial scale, with significant potential for sector growth.

3.2 Enhanced Renewables Obligation banding

As an indicator of the Government's long-term commitment to the wave and tidal industry, following a period of uncertainty, it was proposed in October 2011 that the number of ROCs allocated per MWh generated from wave or tidal energy devices in England and Wales will increase to five from 1 April 2013. The same multiple will also be implemented in Northern Ireland, moving the offering from two to five ROCs. The result will be consistency across UK and increased market attractiveness, creating significantly more potential sites that are economically viable. Only the SROC multiple for wave power, already at five, has not increased.

It is recognised that this level of support makes UK the most attractive market for wave and tidal power in the world.

The industry has called on the Government to build on current confidence levels and clarify the support that will be available through the Electricity Market Reform (EMR) programme. This maximise the chance of sustainable and efficient movement towards competitive industrial scale deployment through long term investment. The principles and levels of support under the proposed feed in tariff scheme from 2017 onwards will require discussion and agreement latest during 2013 to maintain confidence in the sector.

3.3 Infrastructure and innovation investment

Funding is needed for both project implementation and research and development. As the industry focus shifts to multiple device arrays, so will the funding landscape. Table 3.1 lists the funding programmes for device and small scale array installations that are likely to be available in UK during 2012, while Table 3.2 lists current research and development activities more focussed on next generation technology innovations.

The infrastructure funding programmes have been formulated through industry consultation to reflect key areas of focus for the next stage of development. Common topics include project infrastructure that is non-device specific, such as electrical cabling and subsea equipment, foundation and mooring technology, deployment and operational procedures and port and vessel requirements.

The UK is one of the leading global centres for research and development in marine energy technology. Key testing and research is carried out at such facilities as:

- European Marine Energy Centre (EMEC) in Scotland, providing grid connected test berths for full scale wave and tidal devices and scale sites for pre-prototype devices.
- The New and Renewable Energy Centre (NaREC) in North East England, providing facilities such as tank testing and a drive train test rig
- South West Marine Energy Park's wave array offshore test site WaveHub, and the off-grid scale test facility FabTest in Falmouth.

Table 3.1: Infrastructure and Innovation Investment		
Fund	**Scope**	**Funder**
Low Carbon Innovation Fund: Marine Energy Array Demonstrator	£20 million fund focused on the development of arrays. The fund will be used to support two projects testing devices in array formations.	DECC
Taking wave energy to 10MW	An investment to improve the cost competitiveness and long-term viability of wave power.	ETI
Low cost tidal stream arrays	An investment to support design and demonstration of a commercial scale tidal stream array.	ETI
Marine energy: Supporting array technologies	£10.5m investment in innovations that can meet the challenges posed by array deployment.	TSB, Scottish Enterprise and Natural Environment Research Council (NERC)
Saltire Prize	£10 million for the team that achieves the greatest volume of electrical output in Scottish waters over the minimum hurdle of 100GWh over a continuous two year period, using only the power of the sea.	Scottish Development International
WATERS 2	£6 million to promote research and development activities in Scotland, focusing on bringing wave and tidal power devices to commercial application.	Scottish Enterprise
Marine Renewables Commercialisation fund	£18 million to support the development of prototype devices for use in commercially viable arrays.	The Scottish Government
European New Entrants' Reserve (NER) 300 Fund	€4.5bn total NER300 funds will be provided to various energy technologies including wave and tidal energy projects. Up to 50 per cent funding is provided for projects that will generate grid connected power to cover project implementation costs.	European Commission

Table 3.2: Current Publicly Funded Research & Development Activities		
Programme	**Scope**	**Organisations**
SuperGen UK Centre for Marine Energy Research (UKCMER)	A large, collaborative research programme, it involves the Robert Gordon University, Edinburgh University, Heriot-Watt University, Lancaster University and Strathclyde University. Academics are working alongside 20 national and international marine energy and electricity supply companies to tackle challenges of sustainable power generation and supply.	The Sustainable Power Generation and Supply Initiative (SUPERGEN Marine)
7th Framework proposal for EU Research (FP7)	An EU wide collaborative research programme focussed on a wide range of activities, including wave and tidal energy.	European Commission
Various research programmes	UKERC has developed tools to help policymakers and researchers review the current status of UK energy research and development, and identify the key research challenges.	The UK Energy Research Centre (UKERC)

4. Project Status

In 2011, the UK's grid connected capacity grew from 2.9MW in 2010 to 5.6MW in 2011, an increase of over 90 per cent. Initial phases of deployment are also underway for another four devices. It is anticipated that 2012 will see the grid connection of seven new devices at EMEC and the first deployment in Ramsay Sound, giving an anticipated doubling of grid connected capacity to reach a total capacity of over 11MW.

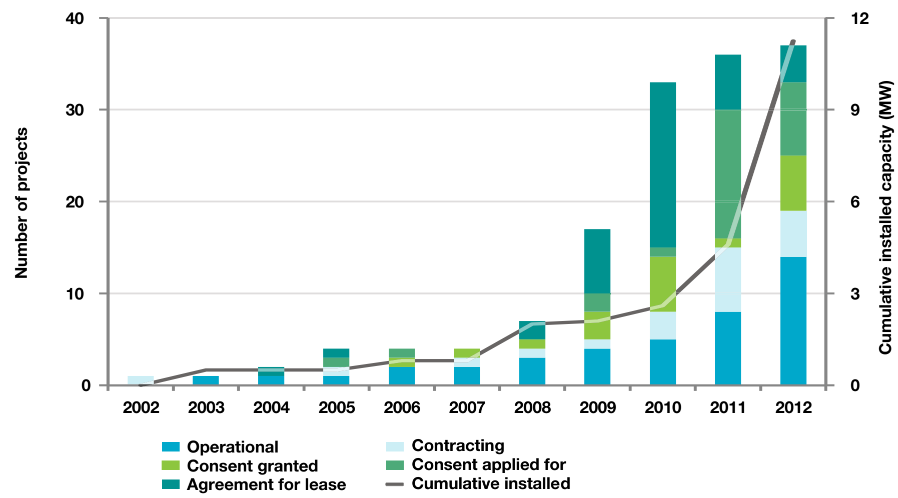
In 2011 we saw the following devices connected to the grid at EMEC:

- Hammerfest Strøm (now Andritz Hydro Hammerfest) HS1000 1MW tidal device at the Fall of Warness berth.
- Atlantis Resources AR1000 1MW tidal device at the Fall of Warness berth.
- Pelamis P2 0.75MW wave device at the Billia Croo berth.
- In addition to this, the following devices made significant progress towards grid connection.
- Aquamarine Power completed the offshore installation work for their 0.8MW Oyster 800 wave device.
- ScotRenewables carried out a test deployment on their 0.25MW SR250 floating tidal device.
- Voith Hydro began foundation installation for their 1MW Clean Current tidal turbine.
- A second 0.75MW Pelamis P2 was delivered ready for deployment.

In 2012, we expect to see (at least) the following:

- The devices currently progressing construction work at EMEC to begin generating power to the grid.
- Aquamarine Power to complete fabrication work for their second device at EMEC, an Oyster 801 unit.
- Tidal Generation will replace their 500kW unit with their 1MW tidal device, as part of the ETI-supported REDAPT project.
- Seatricity and Wello will install their wave devices at the Billia Croo test site in EMEC.

Figure 4.1: Status of Known Projects by Year. *Source: BVG Associates.*



- Tidal Energy will complete the first tidal deployment in Welsh waters with the Deltastream 1.2MW device in Ramsey Sound off Pembrokeshire.

The accelerating progress in development and implementation of wave and tidal projects is shown in Figure 4.1 There is now a healthy pipeline of projects leased and in planning.

4.1 Project Case Studies

The following pages feature projects that are currently operational or due to become operational in 2012. All projects are grid-connected and feature full scale devices that are likely to make up the small scale arrays of the coming years. Each case study examines the background of the project, its development timescale, device to be used, key learning objectives, details of key suppliers and contracts let and funding sources. Ultimately, all of these projects are moving towards realising reductions in cost of energy to enable deployment and operation on a commercial basis; specific learning objectives include:

- Refining and developing design through deploying second generation equipment and components for testing.
- Collecting long term performance and reliability data to inform techno-economic models and technology development.
- Developing and trialling cost-effective and safe installation methodologies.
- Increasing understanding and monitoring of environmental impacts to inform planning process for future deployments.
- Identifying cost-effective methods for operating and maintaining offshore assets through both design development and innovation in working practices.

Project Case Studies

Andritz Hydro Hammerfest: HS1000 deployment

Device manufacturer: Andritz Hydro Hammerfest
Development company: Andritz Hydro Hammerfest
Location: Falls of Warness, EMEC, Orkney
Rating: 1MW
Device: HS1000
Installation date: December 2011
MWh to March 2012: Confidential

Device description

Horizontal axis, pitch regulated, three bladed turbine, installed in line with the flow with no yawing system. The device is seabed mounted using a gravity based foundation.

Background

The HS300 prototype in Norway has completed 17,000 hours of testing, accumulated production of 1.53GWh with 10,000 hours of ordinary production, operating at 98% availability. This has led to the installation of a full scale pre-commercial device, in cooperation with ScottishPower Renewables, which will be fully operational in early 2012 and facilitate testing and product certification.

Learning

Experience gained in installations using a barge and construction vessel in severe environmental conditions which will be valuable experience when the Sound of Islay array is developed. Maintenance requirements and techniques have been learnt from the operation of the HS300 which will be applied to this project.

Supply chain

Local content has been used on this project, including using Arnish Yard, near Stornoway, Lewis, for the construction of the substructure. Converteam supplier of key electrical systems.

Next steps

The EMEC installation will lead to product certification of the device and further testing. Andritz Hydro Hammerfest will work alongside ScottishPower Renewables, installing arrays at its leased 10MW Islay site, starting in 2013 for completion in 2014 (consent granted by Marine Scotland in 2011) and 95MW Duncansby Head site.

Funding sources

Andritz Hydro recently increased its share holding to a majority stake at 55.4 per cent. The project has been mainly equity financed but has also received funding from public sources including Carbon Trust MRPF funding, minor R&D funding from Scottish Enterprise and from Innovation Norway.

Aquamarine Power: Oyster 800 demonstration array

Device manufacturer: Aquamarine Power
Project developer: Aquamarine Power
Location: Billia Croo, EMEC, Orkney
Rating: 0.8MW installed (further 1.6MW planned)
Device: Oyster 800
Installation date: 2011 – 2013/14
MWh to March 2012: Confidential

Device description

Oyster is a near shore wave-powered pump which pushes high pressure water to drive an onshore hydro-electric turbine. The pump is a buoyant hinged flap which is almost entirely underwater and pitches back and forth due to wave motion.

Background

This project is designed to demonstrate the feasibility of installing multiple Oyster devices in arrays and to understand array configurations. The array will consist of three 800kW Oyster devices connected to a single onshore 2.4MW generator. The first Oyster 800 was installed at the EMEC in 2011. In February 2012, Aquamarine Power was granted consent to install a further two devices - Oyster 801 and 802 at the same location.

Learning

Aquamarine Power's Oyster 800 maintains the three key design principles of its first Oyster device, simplicity, survivability and shore-based electricity generation. Aquamarine Power has used data and lessons learnt from Oyster 1, which was installed at sea in 2009, to deliver reductions in the cost of energy through improved power generation, simplified installation and reduced routine maintenance requirements.

Supply chain

To date, Aquamarine Power has worked with over 40 companies in Orkney during the installation of Oyster 1 and Oyster 800 and has spent over £3m directly in the Orkney economy. Local partners have included environmental consultants Xodus Aurora based in Kirkwall and Heddle Construction who carried out onshore construction. In addition, Aquamarine Power's Oyster 1 and Oyster 800 have both been fabricated in Scotland, by Isleburn and Burntisland Fabrications respectively.

Next steps

The effects of deploying the devices in arrays will be monitored. Aquamarine Power will then look to establish further small arrays followed by larger commercial projects. Existing interests include:

- North west Lewis. 10MW demonstration lease and 30MW commercial lease secured May 2011. 40MW development site identified and Section36 and marine licence application submitted to Marine Scotland.
- West coast, Orkney. Exclusive lease option of 200MW granted for the Brough Head site March 2010 in partnership with SSE Renewables (Brough Head Wave Farm Limited, BHWFL).
- Involvement in project development for Ireland (Westwave) and West coast USA (Oregon Wave Energy Trust).

Funding sources

Aquamarine Power has secured over £70m in equity, grants and debt to date including:

- Equity funding – more recently from SSE Venture Capital, ABB Technology Ventures and Scottish Enterprise. The company is also seeking one further investor to co-invest with the existing equity providers.
- Grants – £5 million from UK Government's MRPF administered by Carbon Trust, £3.15 million from WATERS.

Debt – Aquamarine Power secured a £3.4 million loan from Barclays Corporate in September 2011. The loan will be repaid using revenue from operating Oyster 800.

Atlantis Resources Corporation: AR1000 deployment

Device manufacturer: Atlantis Resources Corporation
Development company: Atlantis Resources Corporation
Location: Fall of Warness, EMEC, Orkney
Rating: 1MW
Device: AR1000
Installation date: 2011
MWh to March 2012: Confidential

Device description

The AR1000 is a 3-bladed fixed pitch horizontal axis turbine with active yaw mechanism and direct drive permanent magnet generator, variable speed drive and export via medium voltage (3.8kV) cables to an onshore substation.

Background

This full scale demonstrator was installed in 2011. It was retrieved from EMEC in November 2011 and will be transported to Blyth in time for the spring opening of the Narec 3MW drive train testing facility. Atlantis holds a berth at EMEC until 2015 and will return to the test site following testing at Narec.

Learning

The 2011 deployment at EMEC identified opportunities for design improvement and as such the device is at the Narec test facility where design upgrades will be made along with assessments into nacelle efficiency, control system validation, thermal analysis of internal components and device reliability.

Supply chain

The nacelle and major power train components were fabricated, assembled and commissioned at the SMD facilities in Wallsend, Newcastle. Final assembly took place at Invergordon. Design analysis of the AR platform was contracted to Lockheed Martin. Around 75 per cent of spend on development of the AR1000 device has been in the UK.

Next steps

Atlantis Resources Corporation has an exclusive turbine system supply agreement with the consortium, MeyGen Limited, a joint venture between Morgan Stanley (45%), International Power (45%) and Atlantis Resources Corporation (10%) which is dedicated to developing the Inner Sound tidal site in the Pentland Firth, for which they have a lease from The Crown Estate. Meygen wish to deliver a 398MW tidal farm by 2020. It is also seeking project development opportunities on a global basis.

Funding sources

Recent funds have come from a Marine Renewables Proving Fund (MRPF) grant of £1.85 million from the Carbon Trust which was awarded specifically to support the design and manufacture of a 1MW nacelle, next generation blades, control system and gravity base sub structure.

E.ON Climate and Renewables: Pelamis P2 deployment

Device manufacturer: Pelamis Wave Power
Development company: E.ON Climate and Renewables
Location: Billia Croo, EMEC, Orkney
Rating: 0.75MW
Device: Pelamis P2
Installation date: 2010 Q4
MWh to March 2012: Confidential

Device description

The Pelamis P2 is a second generation device; it is a semi-submerged floating device that faces into the direction of the waves. Five tube sections are joined by universal joints which allow flexing in two directions with identical, independently operating hydraulic power take-off systems in each joint. (See device case study)

Background

Designed and built by Pelamis and owned by E.ON, the P2 machine is the first of a second generation of Pelamis wave energy converters and the first wave machine to be sold to a utility for operation in the UK. The machine will be operating at EMEC alongside a similar P2 machine owned by ScottishPower Renewables. The two utilities have a working agreement to maximise the learning from operating and maintaining the machines as a wave farm.

Learning

The Pelamis machine has continuously ran all generators for sustained periods and demonstrated a full ‘wave-to-wire’ conversion efficiency of well over 70%, which was the target for the P2. The Pelamis machine has been absorbing bursts of power in excess of 3MW. These highly variable peaks have been converted into a smooth 30 minute average electrical output of 170kW with peaks up to 300kW, in line with expectations for this stage of the tests.

The new installation and removal systems, developed with the support of the Carbon Trust, have been implemented, completing smooth and safe connection and disconnection of the machine whilst in conditions up to 2.25m significant wave height.

Supply chain

The tubular modules were fabricated in Fordoun near Stonehaven by Neptune Deeptech. Final assembly and testing was carried out at Pelamis Wave Power’s Leith facility. The P2 was designed to utilise standard hydraulic and electrical equipment throughout the machine wherever possible.

Next steps

The learning and experience gained from the project will be used by E.ON in the development of a 50MW wave farm located to the north of EMEC. The project could see up to 66 Pelamis machines connected to the UK grid and was awarded an agreement for lease from The Crown Estate in 2010.

Funding sources

The P2 device was purchased by E.ON with additional project funding coming from the Carbon Trust’s MRPF, the TSB, and Scottish Government’s WATERS fund.

Marine Current Turbines: SeaGen deployment

Device manufacturer: Marine Current Turbines
Development company: Marine Current Turbines
Location: Strangford Lough, NI
Rating: 1.2MW
Device: SeaGen
Installation date: 2008
MWh to March 2012: Over 3,000

Device description

The SeaGen device is a horizontal axis turbine comprising twin axial flow rotors of 16m diameter, each driving a gearbox and generator. The structure is surface piercing so that the drive trains can be raised clear of the water for easier maintenance access.

Background

The SeaGen 1.2MW device was the first grid connected tidal energy converter in UK waters. The device is located in a water depth of 24m LAT. The site was selected as it experiences tidal flows in excess of 3m/s, has sufficient water depth and provides good access to the device.

Learning

Continued learning is occurring about efficient access and maintenance of key components during the operation of SeaGen. Detailed failure modes and effects analyses are being carried out to identify reliability issues and mitigations, implementing these on SeaGen and/ or subsequent devices.

Improvements in device reliability have been achieved, for example, a second generation drive train designed for improved maintainability and reliability was installed in March 2011 and second generation blades with improved root casting interfaces will be fitted on subsequent devices.

Supply chain

The Strangford Lough device was assembled and tested at Harland and Wolff and blades were supplied by Aviation Enterprises. O&M support has been provided since installation through local vessel operators and technicians. Mojo Maritime have provided ongoing advice on offshore operations and methodologies.

Next steps

MCT has two array projects planned for installation around 2014. The Kyle Rhea project, between the Isle of Skye and the Scottish mainland, will feature four uprated 2MW SeaGen devices. An agreement for Lease was secured with The Crown Estate in April 2011. The Anglesey Skerries project, off the north west tip of Anglesey, North Wales, is being developed with RWE npower renewables. It will consist of five devices with a total capacity of 10MW. The agreement for lease was secured with The Crown Estate in October 2011.

MCT also holds an agreement for lease of the100MW Brough Ness site in the Pentland Firth. In the Bay of Fundy MCT plans to work alongside Minas Basin Pulp and Power to install the SeaGen “U” system with three rotors, rated at 3MW.

Funding sources

Siemens recently acquired a 90 per cent share of MCT. It will play a key role in securing funding for future projects. MCT met the qualifying requirements for the Marine Renewables Deployment Fund (DECC) and accessed funding from the Marine Renewables Proving Fund (Carbon Trust) as well as having received support from DTI.

OpenHydro: Open-Centre Turbine testing

Device manufacturer: OpenHydro
Development company: OpenHydro
Location: Fall of Warness, EMEC, Orkney
Rating: 0.25MW
Device: Open-Centre Turbine
Installation date: 2006
MWh to March 2012: Confidential

Device description

The Open-Centre tidal stream turbine is a seabed mounted device that consists of a rotor, duct, stator and generator. Water passes through the duct to the slow moving rotor with a hole designed to enable marine life to pass through. This is the only moving part. The permanent magnet generator is housed in the duct around the rotor. (See device case study)

Background

The 0.25MW OpenHydro device currently installed at EMEC is a scale prototype to facilitate research of the concept. This is the seventh iteration of the 6m scale turbine.

Learning

The twin pile test rig enables future generations of the turbine to be installed at the same location. Completing seven iterations of the prototype device has helped to improve reliability of the device and has enabled the company to practice and improve installation processes. This is valuable in helping to make array scale deployment cost-effective and efficient. Given the nature of the device, it was found that the appropriate installation equipment did not exist and so the vessel OpenHydro Installer was specially constructed.

Supply chain

Local companies that were contracted for the project include Orkney Towage and Isleburn. OpenHydro has stated that the UK will be able to meet most of its supply chain requirements with the exception of specialist items such as magnetic materials.

Next steps

The focus for the next year is to expand the business to the commercial stage and to improve device reliability and cost effectiveness. The project pipeline consists of four 16m diameter turbines in an array at a Brittany site for EDF with first installation in 2012, a license in the Pentland Firth for a 200MW joint venture with SSE Renewables and a joint venture project with Bord Gáis Energy to develop a tidal energy farm off Northern Ireland. The company also has a portfolio of independent projects in the USA and Alderney.

Funding sources

Funding has come from the Scottish Enterprise WATERS budget (first round) at £1.85 million, Bord Gáis Energy acquired a share for £1.7 million and DCNS acquired an 8% holding in OpenHydro for an investment of £11.7 million in January 2011.

Pulse Tidal: Pulse-Stream 100 testing

Device manufacturer: Pulse Tidal
Development company: Pulse Tidal
Location: River Humber Estuary
Rating: 0.1MW
Device: Pulse Stream 100
Installation date: 2009
MWh to March 2012: Confidential

Device description

Pulse-Stream is an oscillating hydrofoil tidal stream device. It extracts power from tidal currents using horizontal blades which move up and down. This movement drives a gearbox and generator through a crankshaft. (See device case study)

Background

The scale prototype project in the mouth of the River Humber was undertaken to prove the concept in the offshore environment. The shallow water site (9m deep) and the near shore location were chosen for installation and grid connection reasons. Electricity was exported to Millenium Chemicals, a large plant on the south bank of the estuary.

Learning

Pulse Tidal have learnt a lot about mechanical linkages and how to manufacture and install a device. Additional work has been carried out on the power train and the focus of the next device will be increasing reliability, and reducing the cost of installation and maintenance access.

The project identified that there were no significant environmental impacts and the energy capture efficiency was higher than modelled.

Supply chain

This project was successfully completed by a number of UK-based companies including: IT Power (engineering), Senergy Econnect (electrical), Corus (construction), Humber Work Boats (construction and installation) Briggs Marine (operations) and Designcraft (blades).

Next steps

The Pulse-Stream 100 will be fully decommissioned and the company will complete the detailed design of the 1.2MW machine. Finance needs to be secured to build this device, which is planned to be deployed at Kyle Rhea in Scotland, where the EIA scoping work has been completed.

Funding sources

Seven million pounds of EU FP7 grant funding has already been secured for the shallow water project at Kyle Rhea which will cost £20 million.

The company is supported by a number of angel investors and small funds, along with IT Power and Marubeni, and has raised £3.2 million to date in equity, grants and loans.

Scotrenewables Tidal Power: SR250 testing

Device manufacturer: Scotrenewables Tidal Power
Development company: Scotrenewables Tidal Power
Location: Fall of Warness, EMEC, Orkney
Rating: 0.25MW
Device: SR250
Installation date: 2011
MWh to March 2012: Not yet grid connected

Device description

The SR250 is a floating tidal stream turbine. The main structure comprises a cylindrical tube to which horizontal axis rotors are attached via hydraulically retractable legs. The system's compliant mooring system allows installation in water depths of around 100m. (See device case study)

Background

The SR250 is part-way through a 24 month testing programme which started in April 2011 at the EMEC Fall of Warness Tidal Test Site in Orkney. Testing to date has allowed for extensive systems and component testing and has verified the concept at full-scale. Notable milestones to date include generation of full power during a series of tow trials and deployments. The SR250 is the precursor to the 2MW device. SR250 testing will culminate in a period of continuous grid-connected operation in 2012.

Learning

Scotrenewables installed the SR250 mooring system and electrical cable at EMEC, gaining experience applicable for future projects outside of the testing facility. This installation work, transporting the device, tow testing and connecting the SR250 has enabled Scotrenewables to learn how to handle and operate the equipment at sea. All operations to date have avoided the use of more expensive, specialist vessels.

Learning accumulated during the designing, building, outfitting and installing of the 250kW machine has been retained within the design team.

Supply chain

Scotrenewables is based in the Orkney Islands and is a majority locally owned company. The SR250 device was manufactured by Harland and Wolff Heavy Industries in Belfast.

Next steps

The company has a 10MW commercial demonstrator planned. The first SR2000 turbine will be ready for an initial trial deployment at EMEC in 2013. Consent applications will be progressed for a pipeline of 10-30MW. A detailed baseline design has been completed for the 2MW next generation machine for which contracts are looking to be placed during 2012.

Funding sources

The company previously received financial backing from the Carbon Trust and the Scottish Government through the WATERS scheme for design, construction and installation of the SR250 at EMEC. Scotrenewables has also attracted substantial investment from Fred Olsen Renewables and global energy company TOTAL.

ScottishPower Renewables: Pelamis P2 deployment

Device manufacturer: Pelamis Wave Power
Development company: ScottishPower Renewables
Location: Billia Croo, EMEC, Orkney
Rating: 0.75MW
Device: Pelamis P2
Installation date: 2012
MWh to March 2012: Not yet installed

Device description

The Pelamis P2 is a second generation device; it is a semi-submerged floating device that faces into the direction of the waves. Five tube sections are joined by universal joints which allow flexing in two directions with identical, independently operating hydraulic power take-off systems in each joint.

Background

The machine will be installed at the European Marine Energy Centre (EMEC) in Orkney, alongside the E.ON machine as part of a unique cross-industry collaboration project. The two machines will operate in tandem as a two-machine wave farm, with information gathered from the trials used to support the development of larger commercial-scale projects currently under development by both ScottishPower Renewables and E.ON off the coast of Orkney.

Learning

Under a working agreement between ScottishPower Renewables and E.ON, both machines will generate to the national grid from their adjacent berths at the European Marine Energy Centre off Orkney, with PWP's local operations base providing monitoring and maintenance support.

In addition to carrying out similar proving activities relating to generation, deployment and retrieval the focus of this deployment will be to understand the interaction of the two devices, despite not sharing subsea infrastructure.

Supply chain

The transportation and lift were carried out by Mammoet. Fabrication and testing was carried out at Pelamis Wave Powers Leith facility. The P2 was designed to utilise standard hydraulic and electrical equipment throughout the machine wherever possible.

Next steps

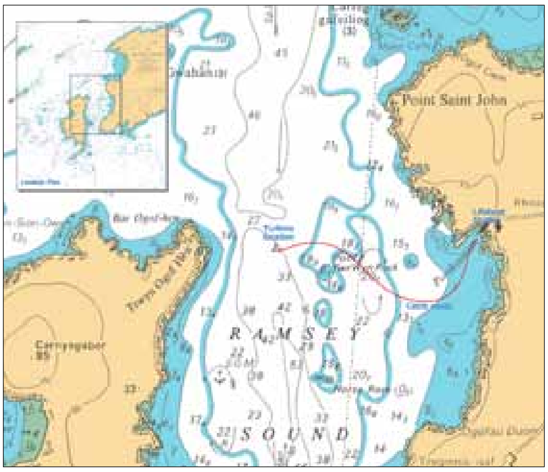
The experience gained from this project will play a vital role in ScottishPower Renewables' plans to install 66 Pelamis machines in a 50MW project off Marwick Head in Orkney, for which an agreement for lease has been awarded by The Crown Estate

Funding sources

The P2 device was purchased by ScottishPower Renewables with additional project funding coming from the Carbon Trust's MRPF, the TSB and Scottish Government's WATERS fund.

Tidal Energy: DeltaStream testing

Device manufacturer: Tidal Energy Ltd
Development company: Tidal Energy Ltd
Location: Ramsey Sound, Pembrokeshire, South West Wales
Rating: 1.2MW
Device: DeltaStream
Installation date: 2012
MWh to March 2012: Not yet installed



Device description

The project will utilise the 1.2MW full scale DeltaStream device that consists of three horizontal axis turbines positioned on a common frame and gravity foundation. (See device case study)

Background

Ramsey Sound is located on the South West coast of Wales and is an area with dynamic environmental characteristics, including high tidal currents, and it is a Grey Seal breeding site. The micro site within Ramsey Sound chosen for the DeltaStream demonstration lies within 31.5m of water (at LAT), 1.2km offshore from the Pembrokeshire mainland and 300m east of Ramsey Island. Following completion of the EIA and subsequent completion of the Environmental Statement an application for a Marine License and Section 36 consent was submitted in 2009. In March 2011 these consents and licenses were granted by the Welsh Ministers and Secretary of State and TEL is intending to deploy the first full scale DeltaStream device later in 2012.

Learning

The DeltaStream Demonstration at Ramsey Sound is Wales' first full scale tidal stream project and is located in a highly sensitive environment. This has led to a number of issues regarding the environmental knowledge within the industry and particularly the potential risk of collisions with sea life. The results from the environmental monitoring programme will be disseminated throughout the industry.

During detailed design TEL observed that significant loading effects are imposed on the device by turbulence and wave action. TEL employed detailed load calculations, scale model testing and carried out a number of turbulence flow measurements at the site to ensure that this phenomenon is fully understood and catered for.

Supply chain

Tidal Energy Limited is carrying out a comprehensive procurement process to source the design, supply of components and contractors to fabricate and install the demonstration device. Contracts have been awarded to Atkins for design integration, UK based DesignCraft for rotor supply, GE Energy for generator and electrical systems and Siemens for the gear system. Tenders for the fabrication contract have been received and the preferred contractor will be identified in the near future. The first phase of onshore preparatory work was completed in February 2012 by Raymond Brown.

Next steps

Once the device is installed in Ramsey Sound environmental and performance data will be collected for the life of the license. This data will be used to inform future device and project developments for the move to a commercial demonstration array of up to 10MW. TEL is also interested in carrying out accelerated life testing of the drive train and is seeking further funding to support such technology development.

Funding sources

Tidal Energy Limited is funded by its majority shareholder, Eco2 Ltd, together with grant funding and support from private and public organisations. The DeltaStream Demonstration project in Ramsey Sound will cost £ 11 million and WEFO has approved £ 6.4 million of ERDF funding towards it. Additionally, Cranfield University is providing over £1 million of funding and the Carbon Trust will provide just under £400,000 towards environmental monitoring.

Tidal Generation: DeepGen III testing

Device manufacturer: Tidal Generation
Development company: Tidal Generation
Location: Fall of Warness, EMEC, Orkney
Rating: 0.5MW
Device: DeepGen III
Installation date: September 2010
MWh to March 2012: 215

Device description

The TGL Deep Gen III device is a 500kW three-bladed upstream tidal turbine that extracts energy during both flood and ebb tide using an active yaw system. The nacelle is attached to a tripod foundation which is pinned to the seabed. (See device case study)

Background

TGL was formed in 2005 to design, develop and manufacture tidal stream turbines. In 2009 it became a wholly owned subsidiary of Rolls-Royce. Following significant product development, the EMEC Fall of Warness test site was selected as the first sea deployment of the turbine to enable proving of design and deployment methodologies.

Learning

Over 200MWh have been generated at a rated power of 500KWe. A significant amount has been learnt about the operation and characteristics of the machine, the nature of the tidal flow, waves and weather impact at EMEC, as well as corrosion and bio-fouling issues. The deployment and retrieval method has been proved to be viable during a single tidal slack period of 30 minutes, as has the ability to carry out operational activities with low cost vessels.

Supply chain

The turbine is supported from Hatston Quay in Orkney. In 2008 and 2009, the device was assembled at Rolls-Royce facilities in Dunfermline, drawing on in house engineering expertise extensively. Mojo Maritime and Ramboll have been commissioned to develop foundation concepts.

Next steps

The 500kW device will continue to generate until it is replaced by the 1MW turbine to be deployed in June 2012 as part of the ETI ReDAPT project. This will undergo a two year testing programme.

It is planned to deploy a number of 1MW units in a small array during 2013/14 and larger arrays by 2018. TGL is anticipated to be one of the technology suppliers for Meygen's 400MW Inner Sound project, part of the Pentland Firth and Orkney waters lease award.

Funding sources

Rolls-Royce has provided R&D and capital support to date that has been complemented by ETI funding of £6 million towards the ReDAPT project.

Voith Hydro Ocean Current Technologies: Voith HyTide 1000-13 testing

Device manufacturer: Voith Hydro Ocean Current Technologies
Development company: Voith Hydro
Location: Fall of Warness, EMEC, Orkney
Rating: 1MW
Device: Hy Tide 1000-13
Installation date: 2012
MWh to March 2012: Not yet grid connected

Device description

The Voith HyTide device is a seabed-mounted horizontal axis tidal stream turbine. The three symmetrical blades capture energy from the tidal stream on the ebb and the flood flow without pitch and yaw requirements. (See device case study)

Background

Voith Hydro Ocean Current Technologies and RWE Innogy commenced preparatory works at the Fall of Warness site at EMEC in Summer 2011 by installing the mono pole for their 1MW tidal turbine which will be installed in 2012 through the joint venture company Voith Hydro Ocean Current Technologies. Having completed scale trials in South Korea the turbine will undergo a three year full scale trial operation.

Learning

The focus of testing for the EMEC installation is to prove the performance characteristics of the 1MW turbine and improve the design's reliability. It provides an opportunity to develop and refine deployment and retrieval approaches for the turbine and foundation.

Supply chain

Cooperation partner BAUER Renewables manufactured and installed the foundation. Installation of the mono pole foundation is completed, using the offshore construction vessel North Sea Giant. Mojo Maritime conducted an operational installation and O&M study for Voith Hydro to outline options and methods for use at EMEC.

Next steps

Following completion of the three year trial period and feasibility studies of small array sites, there are plans to deploy farms of approximately 100MW in South Korea near Jindo and in European Waters. It is likely this will be preceded in phases, starting with small arrays as part of the 100MW site.

Funding sources

The total investment is approximately £11.8 million with £1.7 million having been awarded through the Marine Renewables Proving Fund. As part of its venture capital activities, RWE Innogy owns 20 per cent of the joint venture company Voith Hydro Ocean Current Technologies by way of an equity interest. Voith Hydro is the majority shareholder holding 80 per cent.

Voith Hydro Wavegen: Limpet testing

Device manufacturer: Voith Hydro Wavegen
Development company: Voith Hydro Wavegen
Location: Islay
Rating: 0.5MW
Device: Limpet
Installation date: 2000
MWh to March 2012: Confidential

Device description

The Limpet device is a shore-mounted oscillating water column which has been tuned to capture energy from annual average wave intensities of between 15 and 25kW/m. It comprises an air chamber with an opening below the water and two counter-rotating Wells turbines.
(See device case study)

Background

The shore-mounted Limpet 500 was installed in 2000 and is grid-connected. This device is also used as a developmental facility, to demonstrate new systems and improve power output, such as testing a variable pitch turbine. The Limpet was developed in cooperation with Queen's University Belfast.

Learning

Successfully generating electricity with this Limpet device since 2000 has enabled Voith Hydro Wavegen to gather significant volumes of data on the device performance and operational characteristics. An availability of over 90% was achieved from 2006 to 2010. Maintenance and service techniques have been developed and improved during this period that can be applied to this and future deployments.

Supply chain

Voith Hydro Wavegen made successful contracts with many UK-based companies during construction and operation of the device. They have also succesfully exported their technology from the UK to, for example, the Mutriku breakwater project in Spain.

Partners and contractors included Charles Brand, Scottish Hydro-Contracting, Queen's University Belfast, IST Portugal and Kirk McClure Morton.

Next steps

The technology is actively seeking commercial project development opportunities including developing nearshore technology. The near shore OWC will sit directly on the seabed in a nominal mean water depth of 15m. Wavegen was granted consent from the Scottish Government in 2009 for the 4MW Siadar Wave Energy Project on the island of Lewis.

Funding sources

The Limpet 500 was developed with EU support and The Siadar Wave Energy Project is supported by the Scottish Government's WATERS funding scheme, having received £6 million.

Wello: Penguin testing

Device manufacturer: Wello
Development company: Wello
Location: Billia Croo, EMEC, Orkney
Rating: 0.6MW
Device: Penguin
Installation date: 2012
MWh to March 2012: Not yet grid connected

Device description

The Penguin is a floating asymmetric vessel which houses an eccentric rotating mass. The device is shaped so that waves passing it cause the mass to rotate on a vertical shaft and this motion is converted to electricity. (See device case study)

Background

Scale model tests have been completed at the Ship Laboratory of Helsinki University of Technology, and at the Gulf of Finland. The 1:8 scale prototype, "Baby Penguin" and its mooring arrangement survived storm conditions during testing. The full scale Penguin is at Lyness Wharf, Orkney, and is being prepared for installation on an EMEC test berth in 2012 for a year-long test programme.

Learning

In September 2011 the Penguin underwent an installation rehearsal to develop and refine the methodology for the final installation.

Testing of the "Baby Penguin" verified the technology survival in storm conditions; however, the Penguin sustained some damage in a storm in December 2011 while lying along Lyness Wharf quay which resulted in learning about the transportation and storage of the device.

Supply chain

Cooperation Partners of the Penguin are: EMEC, VEO, The Switch, Hydac, J+S, Riga Shipyard, INA FAG Schaeffler Group and Seaproof Solutions. The device has been built in the Riga Shipyard in Latvia and the entire deployment programme of the project at EMEC is managed by Orkney-based companies. The team is led by Stromness-based consultancy Aquatera and new marine operations management company, Orcades Marine.

Next steps

The Penguin will be installed and grid connected at EMEC in 2012 and will be tested for a year. Subject to full scale testing Wello will identify and develop project opportunities globally.

Funding sources

Wello has received €5.5 million in addition to investments from VNT Management and Veraventure and Tekes (the Finnish funding agency for technology and innovation).

5. Device Types

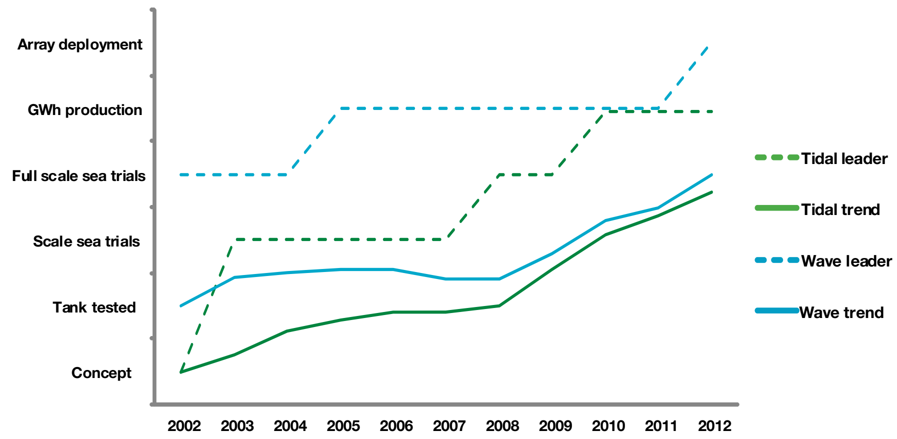
Marine energy offers a vast scope for innovation and new device concepts, with over 200 concept designs in the sector.[1] By the end of 2011, however, only ten devices had been deployed in UK at full scale and with grid connection. This section details the range of technology types that are available and presents case studies of the most mature technologies from 12 tidal device manufacturers and eight wave device manufacturers. These organisations are all currently testing a full-scale grid-connected device or are actively developing such a project.

Figure 5.1 below indicates the status of both wave and tidal sector device development in terms of the market leader in each year and the average status of the device concepts covered by this report. For some devices, this history goes back over 10 years. The journey started earlier for the average wave device considered and has in general been faster for tidal devices, as shown by the trend lines. Early stage investigations were carried out for wave energy feasibility in the 1970s which, although most were abandoned, provided a starting point when the sector was reinvigorated in the 1990s.

The more rapid maturing of tidal devices is in part due to greater concept convergence. The majority of tidal devices undergoing sea trials are based on a horizontal axis turbine design with two or three blades, although successful trials have been completed with other designs. One factor influencing the greater consolidation of tidal devices is the more predictable nature of the energy resource compared to wave energy. Another factor is the high level of understanding of the horizontal axis turbine design principles that has been developed through successful application in the wind sector, although it is recognised that there are very significant differences between harnessing wind and tidal energy flows.

In the wave sector, we have seen several factors influencing greater divergence in technology. The difference between shallow and deep wave resources is significant in influencing both design and technology selection for specific sites. The highly complex nature of the energy resource is also relevant as power is influenced by the height, period and direction of the waves.

Figure 5.1: Device development milestones for selected devices. Source: BVG

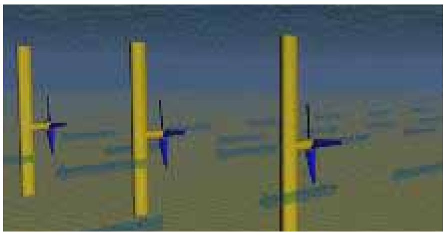


Tidal Devices

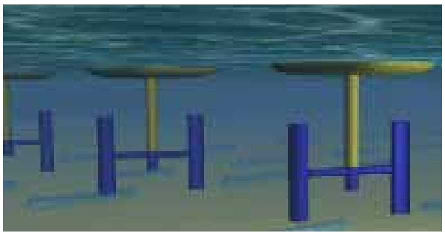
5.1 Tidal device principles (device classification by EMEC)

Tidal devices exploit kinetic energy in the tidal flow of water caused by the interaction of the gravitational fields of the earth, moon and sun. Tidal currents are magnified by topographical features, such as headlands, inlets and straits, or sea bed channels. Many of the devices that use these currents are broadly similar to submerged wind turbines. Sea water is around 800 times denser than air but average flow speeds for viable projects are of the order of one fifth of corresponding wind speeds, giving a power density of around 5-10 times. This means that for a tidal device of the same rating as a wind turbine, the rotor will be smaller. Individual tidal devices are unlikely to reach the same rated power as offshore wind turbines; however, as to have sufficient space to deploy such large devices requires development of deeper water sites that generally have less significant tidal flows. EMEC has identified four main types of tidal energy convertors that are outline below.

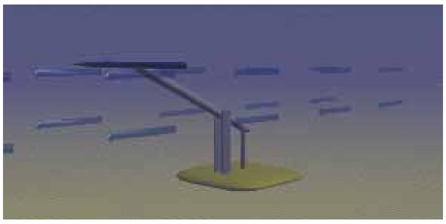
Tidal energy device concepts (graphics courtesy of EMEC)



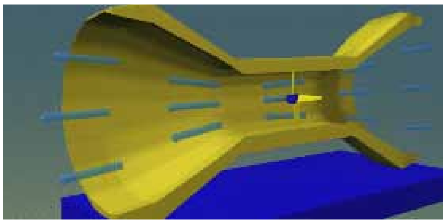
The flow of water turns the rotor by generating lift due to the flow around the blades. This rotational movement is used to generate electricity. The device can be housed within a duct to accelerate the flow through the rotor, thus increasing energy capture.



This device extracts energy in a similar way to a horizontal axis turbine, but the axis of rotation of the rotor is vertical and perpendicular to the flow of water. Some vertical axis turbine concepts work by the principle of drag rather than lift.



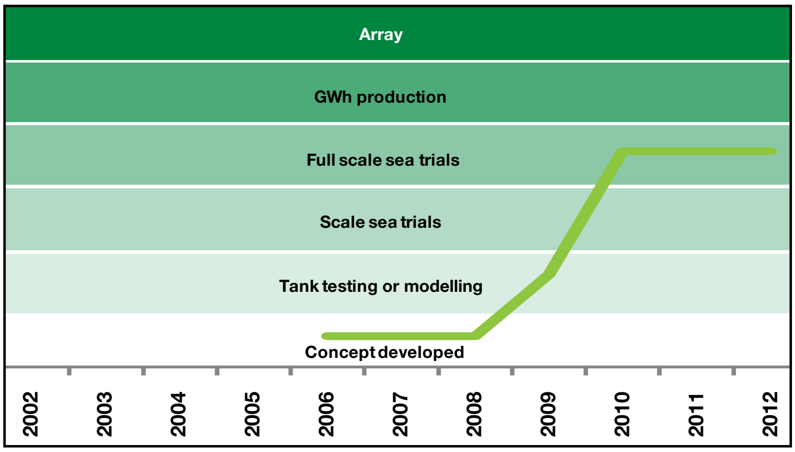
A hydrofoil is attached to an arm. The flow of water around the hydrofoil causes it to oscillate by generating lift. This oscillating movement is used to generate electricity.



A duct has the effect of accelerating the flow through the narrowest section. This flow causes a pressure differential that drives an air turbine. The rotational movement of the turbine is used to generate electricity.

AR1000

Manufacturer: Atlantis Resources Corporation
Type of device: Horizontal axis turbine
Status: Full scale device
Current location: Narec
Rating: 1MW



Device description

The AR1000 is a 3-bladed fixed pitch horizontal axis turbine with active yaw mechanism and a direct drive permanent magnet generator with variable speed drive. Power is exported via medium voltage (3.8kV) cables to an onshore substation. Higher efficiency blades than on the previous device have been introduced along with marine fouling treatment and structural improvements. The AR1000 has a rated for flow velocity of 2.65 m/s.

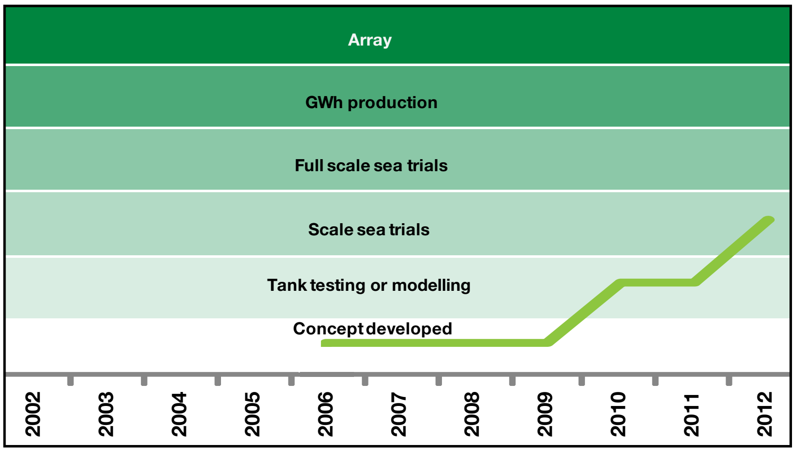
The Atlantis Resources Corporation approach is to reduce the complexity of the turbine, thus decreasing the number of potential failure points. A proprietary male and female 'stab' connection arrangement allows for fast retrieval of the nacelle without having to recover the foundation structure.

Status

Following deployment of the twin rotor AK-1000 in 2010 the AR-1000 was successfully deployed and underwent sea operations during summer 2011. The device has been retrieved and is undergoing testing at Narec prior to deployment to EMEC again to continue generating later in 2012.

BELUGA 9

Manufacturer: Alstom Hydro
Type of device: Enclosed Tips (Venturi)
Status: Full scale prototype
Current location: Tank test
Rating: 1MW



Device description

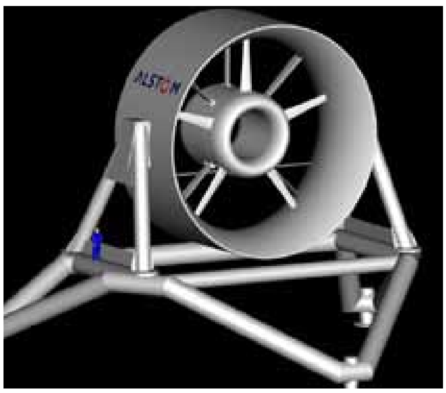
The BELUGA 9 is designed to operate bi-directionally in tidal flow. The direct drive, flooded permanent magnet generator and fixed pitch blades are shrouded by a diffuser duct, intended to correct directional changes in flow, control turbulence and increase the velocity of the water reaching the blades. The device has been designed with as few moving parts as possible to reduce the need to access the device for maintenance. The central hole is designed to allow marine wildlife to pass through and regulate the flow to enable reduction of turbine spacing in arrays.

The device is 20m in height and 13m in diameter, sits on the seabed (either with a gravity base foundation or piled, depending on site conditions) and is designed for water of depth 30m and a peak water velocity of 3.5 – 4.0 m/s.

Status

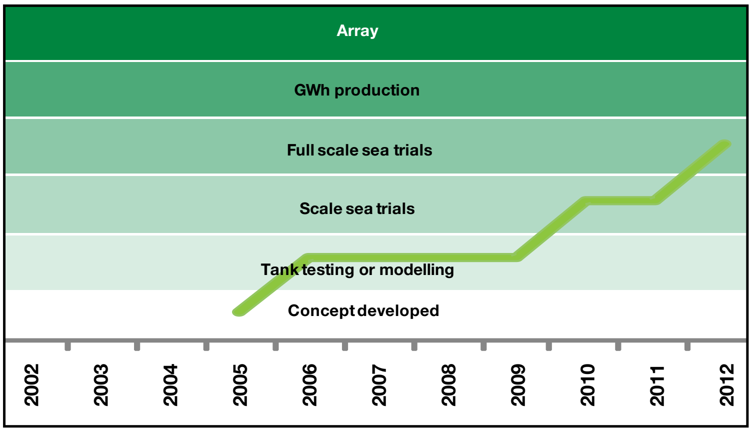
The full scale concept is currently undergoing uni-directional performance testing in tank conditions with plans for installation in the Bay of Fundy in 2012.

A variant device, the Orca 7, will be developed for medium flows of 3.5 m/s in 40m water depths. The Orca 7 is expected to be developed to enable full scale testing in Brittany in 2013.



Deep Gen IV

Manufacturer: Tidal Generation Ltd
Type of device: Deep Gen IV
Status: Full Scale
Current location: EMEC
Rating: 1MW



Device description

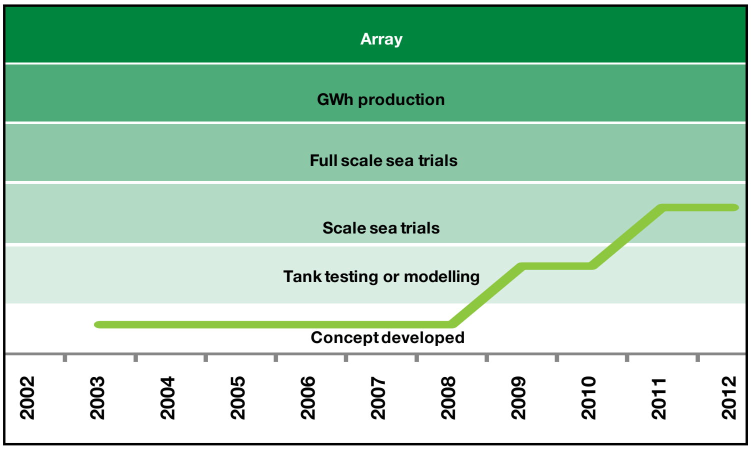
The TGL concept is a three-bladed upstream tidal turbine that extracts energy during both flood and ebb tide using an active yaw system. The nacelle is a buoyant design to enable towing to site and it is attached to a lightweight tripod foundation which is pinned to the seabed. A mechanical clamp facilitates yawing powered by a rear mounted thruster. Once locked to face the flow, the turbine cuts in at 1m/s and reaches rated power at 2.7m/s. For higher flow speeds the blade pitch and generator torque are regulated to maintain the turbine's rated power. A gearbox is used to drive an induction generator, and a frequency converter, step up transformer and wet mate link complete the generating system. The turbine will output grid compatible 6.6kV 3-phase power.

Status

DEEP-Gen IV (DG4) is a full scale 1MW device which will form the basis of the TGL commercial product offering. It is currently in final assembly at the Rolls-Royce Dunfermline facility in Edinburgh, and will be deployed at EMEC in June 2012. TGL is collaborating with developers, including Meygen, with the intention to supply devices to large array projects within the next five years, working with further industrial partners to improve the value proposition and develop the products customers require.

Deep Green

Manufacturer: Minesto
Type of device: E Other
Status: Scale prototype
Current location: Tank test
Rating: 0.5MW



Device description

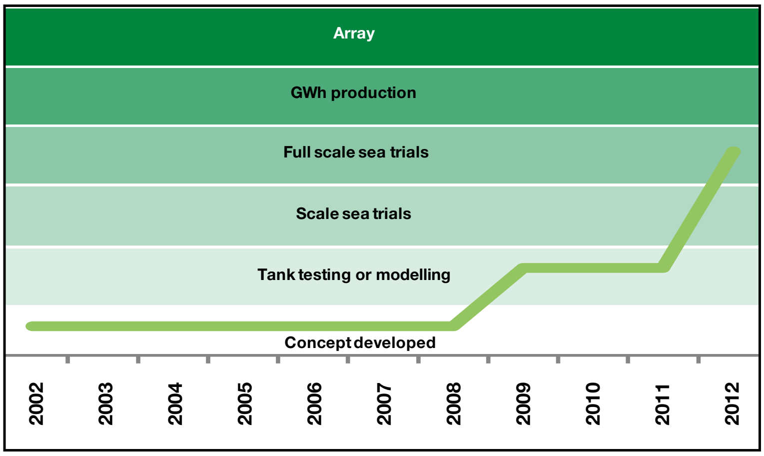
The wing is attached to the turbine and gearless-generator arrangement, with a rudder and servo system at the rear of the device. The device is tethered to the seabed in an arrangement that accommodates the power cables and communication system and is connected to a conventional mooring rig. The wing generates lift which moves the device at speeds up to ten times that of the water flow and the rudder is used to steer the device in a figure-of-eight path. As this happens, the rotor is turned as the device passes through the water, generating electricity. It is designed to be economical at sites with deep water and low velocities. Deep Green is recoverable for servicing and maintenance and has a mass of less than seven tonnes per 0.5MW unit).

Status

Minesto is continuing to model the device and test scale prototypes to develop the technology, prove reliability by getting hours in the water and develop confidence and acceptance in the concept from project developers. A 1/10th scale device was installed in Strangford Lough in 2012 as a precursor to a 1/3rd scale device and then full scale device which is rated at 0.5MW. New capital was recently injected by the company owners and a £0.5 million grant was awarded by the Swedish Energy Agency for R&D operations. Funds have also been made available through the Carbon Trust as part of the Applied Research programme.

DeltaStream

Manufacturer: Tidal Energy Ltd
Type of device: Horizontal axis turbine
Status: Full Scale Demonstration 2012
Current location: Ramsey Sound
Rating: 1.2MW



Device description

The DeltaStream device is a 1.2MW unit which sits on the seabed without the need for a positive anchoring system. It generates electricity from three separate horizontal axis turbines mounted on a common frame. This avoids piling or significant seabed preparation.

The use of three turbines on a single 350 tonne and 36m wide triangular frame produces a low centre of gravity enabling the device to satisfy its structural stability requirements, including the avoidance of overturning and sliding. Each turbine is an upflow three blade design with hydraulic yawing system to turn to face the oncoming tide and enable generation on both the ebb and flood tides.

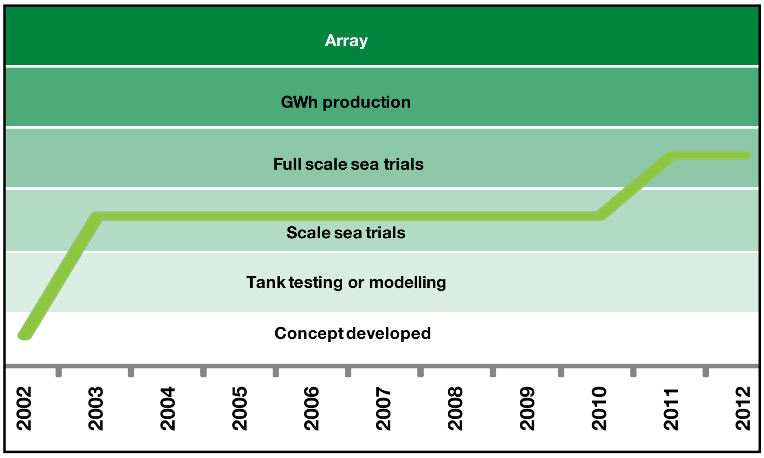
Status

Following a period of design development including modelling and tank testing at Cranfield university a full scale device is planned for deployment in Ramsay Sound, Pembrokeshire in December 2012. Licenses for the site were granted by DECC and the Welsh Government in March 2011. A significant proportion of contracts have been awarded for the manufacture of the device and project construction.

Following a successful 12 month technical and environmental test of the device, TEL will develop a pre-commercial array at a site yet to be confirmed.

HS1000

Manufacturer: Andritz Hydro Hammerfest
Type of device: Horizontal axis turbine
Status: Full scale prototype
Current location: Falls of Warness
Rating: 1MW



Device description

Horizontal axis, pitch regulated, three bladed turbine, installed in line with the flow. A nacelle houses the gearbox, asynchronous generator and control systems, and subsea cables export energy back to shore. There is an onshore frequency convertor. The device is seabed mounted using a gravity base foundation. The turbine is heavily instrumented to serve as a platform for future research and development activities. This will help drive improvements in reliability and efficiency and enable reductions in the cost of energy over time.

Status

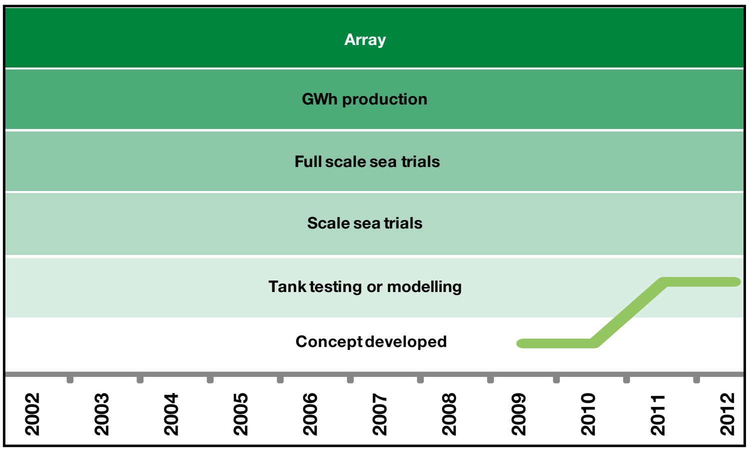
The HS1000 is a full-scale pre-commercial device following on from the HS300 which was successfully installed, tested and operated as a scale prototype. It is currently installed at EMEC where measurements for product certification will take place in 2012. This is in preparation for the 10MW Islay array (lease granted and EIA submitted) which will begin construction activities in 2013 with ScottishPower Renewables and the 95MW Duncansby Head array.

Kawasaki 1MW tidal turbine

Manufacturer: Kawasaki Heavy Industries
Type of device: Horizontal axis turbine
Status: Full scale prototype, 2013
Current location: Billia Croo, EMEC, Orkney
Rating: 1MW

Device description

The 1MW device is a horizontal axis turbine mounted on the seabed with power take-off through a gearbox and permanent magnet generator combination. The turbine has active pitch and yaw control to ensure maximum energy extraction from both flood and ebb tides. For the EMEC deployment a gravity base will be used, however alternatives are under consideration for future deployments. Kawasaki Heavy Industries are developing the design to simplify the device deployment and retrieval methods.



Status

KHI plan to test a 1MW prototype device at EMEC in 2013. The 1MW turbine design will be evolved following this testing phase to be suitable for multiple device arrays both in the UK and globally

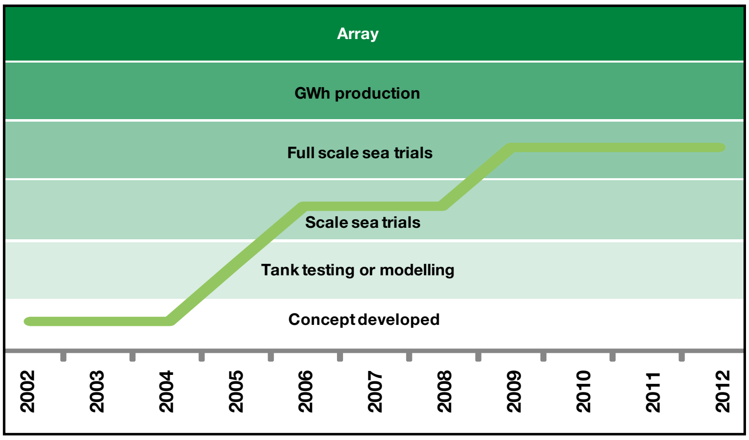
Open-Centre Turbine

Manufacturer: OpenHydro
Type of device: Enclosed tips
Status: Full scale
Current location: EMEC
Rating: 0.3MW

Device description

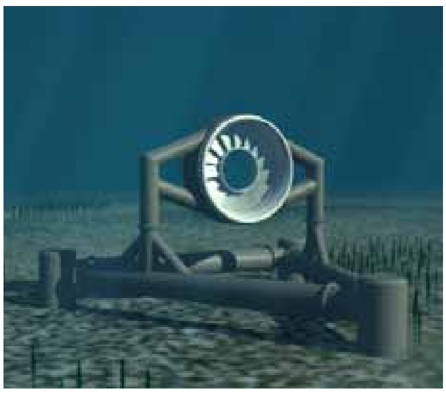
The Open-Centre tidal stream turbine is a seabed mounted device that consists of a rotor, duct, stator and generator. Water passes through the duct, utilising the Venturi effect, to the slow moving rotor with a hole to enable marine life to pass through. This is the only moving part. The permanent magnet generator is housed in the duct around the rotor.

The device has been designed to be scalable. There is no gearbox and there are no seals, which reduces the number of total components .



Status

In 2006 an Open-Centre Turbine was installed on a seabed mounted test rig at EMEC and in 2008 the installation of a second seabed mounted turbine took place adjacent to this using the OpenHydro Installer vessel. OpenHydro have also deployed a 1MW (10m diameter) device in Canada and plan to install a 16m device in Brittany 2012.



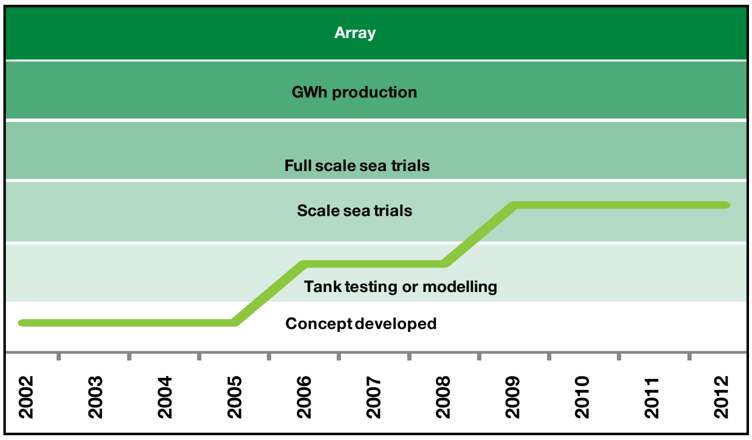
Pulse-Stream 100

Manufacturer: Pulse Tidal Ltd
Type of device: Oscillating hydrofoil
Status: Scale prototype
Current location: Decomissioned from Humber
Rating: 0.1MW

Device description

Pulse-Stream is an oscillating hydrofoil tidal stream device. It extracts power from tidal currents using horizontal blades which move up and down. This movement drives a gearbox and generator through a crankshaft. This approach enables the blade length (and therefore power generation capacity) to be comparatively large in a given water depth; Pulse-Stream can produce 1.2MW in 18m of water, with potential to scale up to 5MW in 35m of water. Two Pulse-Stream machines can be installed on each foundation, offering up to 10MW installed capacity per foundation in a water depth of 35m.

The turbine rises out of the water to facilitate observations, learning and maintenance.



Status

The Pulse-Stream 100 device is a scale prototype which was deployed in the Humber in 2009 and operated through to 2012. This proved the technology concept and enabled Pulse Tidal to learn from installing their device in the marine environment. The commercial device will have a buoyant base, which allows it to be commissioned onshore and then floated to site. On site, it will be connected to a pre-installed foundation and flooded, leaving it fully submerged in operation. For maintenance, the hull can be de-ballasted, bringing the machine back to the surface, where it forms a stable maintenance platform. The preliminary design for this 1.2MW device has been completed, with detailed design underway. The next step is construction and installation, ahead of performance testing and deployment into arrays.

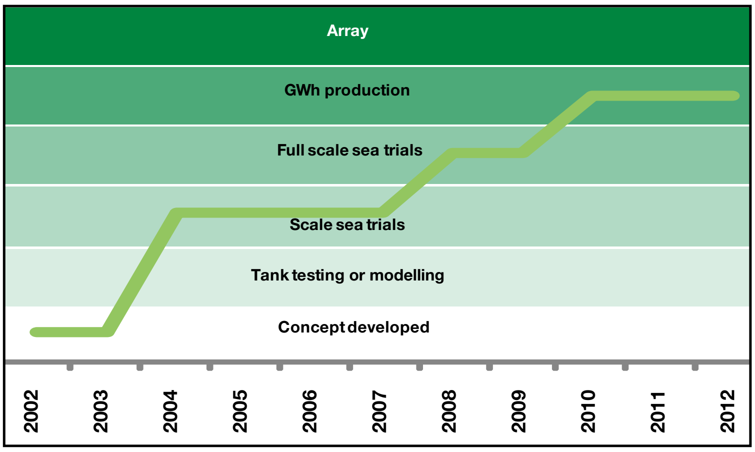
SeaGen

Manufacturer: Marine Current Turbines
Type of device: Horizontal axis turbine
Status: Full scale device with second generation components
Current location: Strangford Lough
Rating: 1.2MW

Device description

The SeaGen device comprises twin horizontal axis rotors of 16m diameter, each driving a gearbox and generator. The generator output is rectified, inverted and exported to the distribution grid (in the case of the Strangford Lough project) via a step-up transformer. Twin turbines are independently operable. The rotors have full span pitch control such that they can generate on flood and ebb tides. There is no yaw system.

The structure is surface piercing so that the drive trains can be raised clear of the water for easier maintenance access.



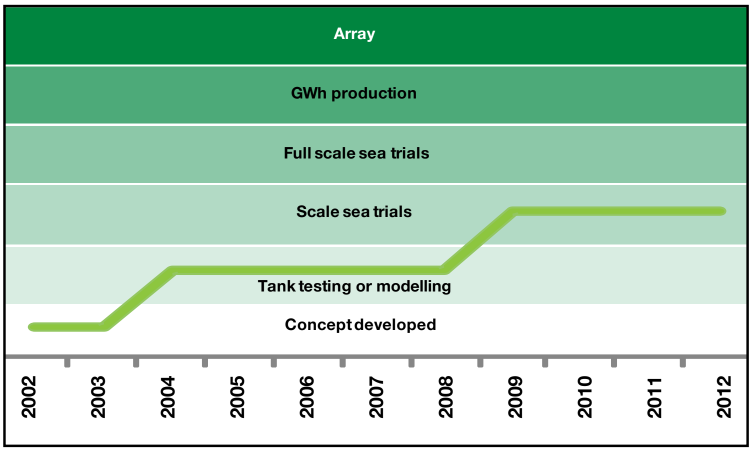
Status

The SeaGen design is based on experience gained from the first UK sea tested tidal energy converter, SeaFlow. SeaFlow was a single rotor 300kW experimental turbine that was installed 3km north east of Lynmouth on the North Devon Coast in May 2003 and decommissioned in October 2009. The design of a 2MW version suitable for array deployment is now complete.

Since installation in 2008, the SeaGen device has undergone modifications that most recently included replacement of one of the drive trains with a second generation unit. The SeaGen design will be used for the proposed Skerries and Kyle Rhea deployments. A non-surface piecing variant is under development that could form the basis of future arrays.

SR250

Manufacturer: Scotrenewables
Type of device: Horizontal axis turbine (A)
Status: Scale prototype
Current location: EMEC
Rating: 0.25MW



Device description

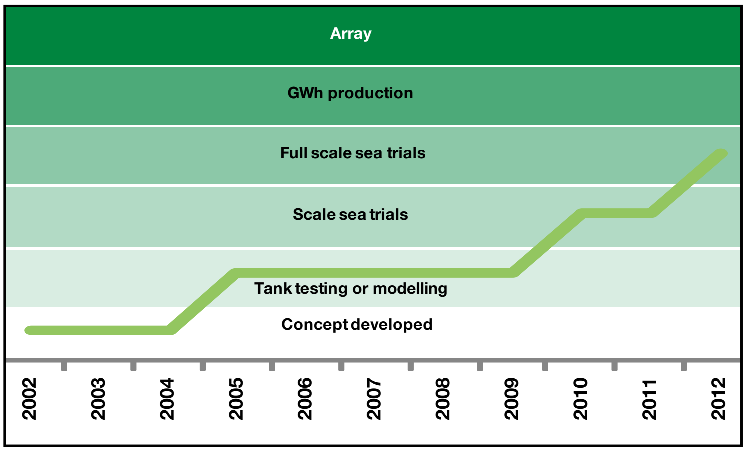
The Scotrenewables Tidal Turbine (SRTT) is a floating tidal stream turbine. The main structure of the SRTT is a cylindrical tube to which dual horizontal axis rotors are attached via retractable legs. Two counter-rotating rotors extract the kinetic energy of the tidal flow which is converted to electricity though the power take-off system. The system has two configurations; operational with the rotors down to generate power and transport or survival mode with rotors retracted whereby loads are reduced in heavy seas. The system is designed to be installed, operated and maintained using a multi-cat workboat. No specialist vessels are required at any stage in the product life cycle. The SRTT is also suited to deployment in river flow.

Status

The SR250 was launched in Orkney in March 2011, and is currently undergoing a 24 month testing programme at the EMEC Fall of Warness tidal test site. Longer term grid connected deployments are planned for Spring / Summer 2012. A baseline design for the next generation 2MW SRTT has been completed and the company is looking to place contracts during 2012 for manufacture.

Voith Hy Tide 1000-16

Manufacturer: Voith Hydro Ocean Current Technologies
Type of device: Horizontal axis turbine
Status: Scale prototype
Current location: EMEC
Rating: 1MW



Device description

The Voith HyTide device is a seabed-mounted horizontal axis tidal stream turbine. The three symmetrical blades capture energy from the tidal stream on the ebb and the flood flow without pitch and yaw requirements. Electricity is generated using a direct drive, permanent magnet assembly. The device is lubricated with sea water.

Ideal site characteristics in which to install the device and mono pole foundation are a minimum peak current speed of 3m/s and water depth of at least 30m.

Status

A first turbine of this type, a 1:3 scale 110kW device is currently being installed by Voith Hydro Ocean Current Technologies in the South Korean waters. There are plans to deploy a farm of approximately 100MW offshore in South Korea near Jindo.

Voith Hydro and RWE Innogy completed preparatory works at EMEC in summer 2011 with the turbine installation due in autumn 2012 for a three-year trial operation.

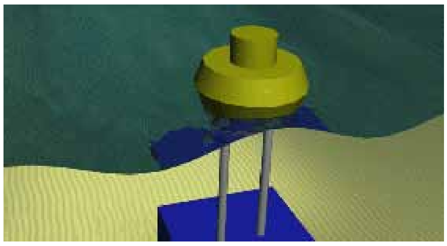
Wave Devices

5.2 Wave device principles (device classification by EMEC)

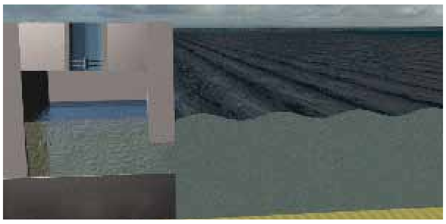
Waves are created by the interaction of wind with the surface of the sea, sometimes over very long distances. The size of the waves is influenced by wind, the local seabed bathymetry (which can focus or disperse the energy of the waves) and currents. Waves offer a large source of energy which can be converted into electricity by a wave energy converter (WEC). Some wave energy converters have been developed to extract energy from the shoreline, others from waters offshore, some with a hydraulic power take-off system and some with an electrical power take-off system. EMEC has identified six main types of wave energy converter that are outlined below.

Wave energy device concepts (graphics courtesy of EMEC)

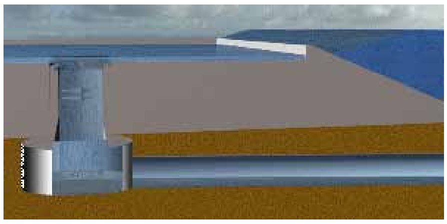
The motion of waves causes the elements of the device to move relative to each other. This oscillating movement is used to generate electricity.



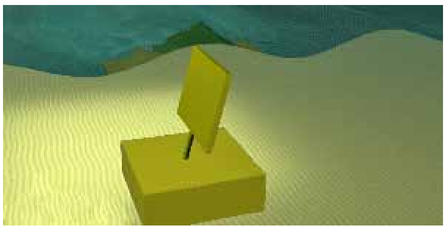
The motion of waves causes the floating element to move relative to the anchor point. This linear oscillating movement is used to generate electricity.



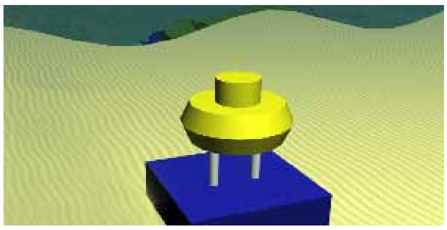
A water column is formed using a partially submerged, hollow structure. The motion of the waves causes the water level to rise and fall and this movement is used to compress and force air through a turbine. The rotation of the turbine is used to generate electricity.



By positioning of guides interacting with waves, water is forced upwards and into a reservoir before returning back down to the sea via a low head turbine. The rotation of the turbine is used to generate electricity.



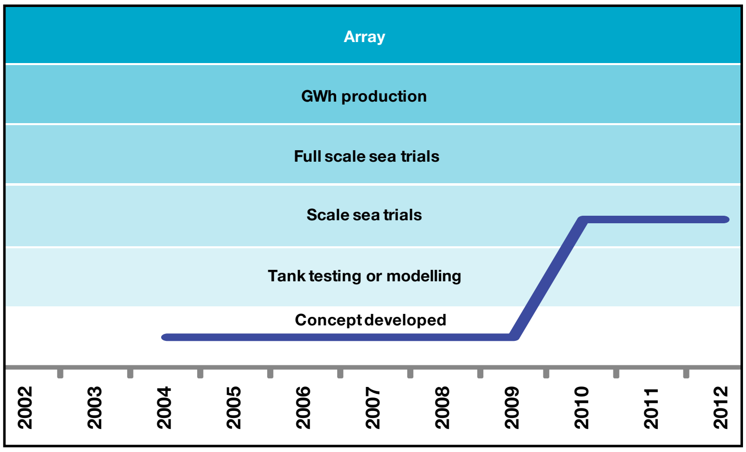
The motion of wave surges causes the device to move with a pendulum-like motion. This oscillating movement is used to generate electricity.



The motion of the waves causes the sea level to rise and fall above the device, inducing a pressure differential. The alternating pressure is used to pump fluid to turn a hydraulic motor. The rotation of the motor is used to generate electricity.

AWS-III

Manufacturer:
AWS Ocean Energy
Status: 1/9 Scale prototype
Current location: Loch Ness
Rating: 2.5MW (full-scale proposal)



Device description

The AWS-III consists of a number of inter-connected flexible wave energy absorber cells mounted on a common floating structure. The flexible membrane absorbers convert wave energy to compress air within each cell as a wave is incident on the cell. The compressed air is used to drive a turbine connected to a generator.

The device is slack moored in water depths of around 100m using conventional mooring spreads which reduces wave loadings on the device. The sealed air system ensures that there are no moving parts, increasing survivability and the ancillary systems are protected within a hull which can be accessed for practical maintenance and inspection.

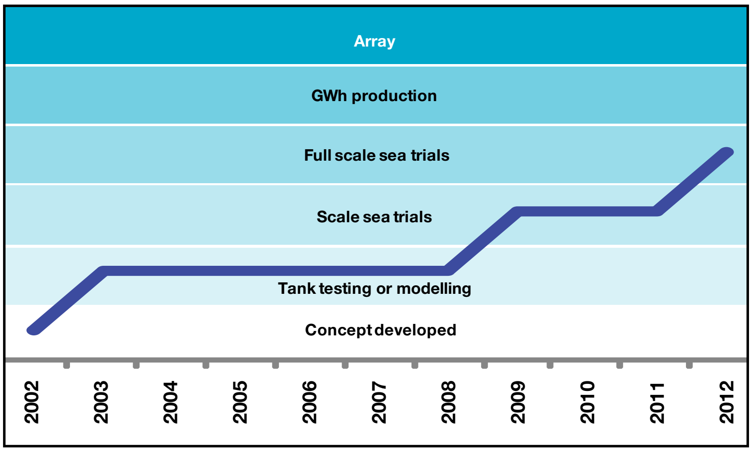
Status

AWS is backed by Alstom who recently signed a joint venture agreement with SSE Renewables for the development of a 200MW wave energy farm at Costa Head, north-west of the Orkney mainland. It is intended that this project uses the AWS-III wave energy converter technology.

AWS is conducting a programme to deliver and qualify the AWS-III technology for the first phase of Costa Head which is expected to be deployed in 2016. Accordingly, AWS expect to deploy a full-scale 2.5MW prototype AWS-III at EMEC in 2014 and are currently constructing full scale components including a full wave absorber cell for testing during 2012. This work is supported by the Scottish Enterprise WATERS grant scheme.

BOLT 2

Manufacturer: Fred Olsen
Type of device: Point absorber
Status: Full scale
Current location: SW England
Rating: 0.25MW



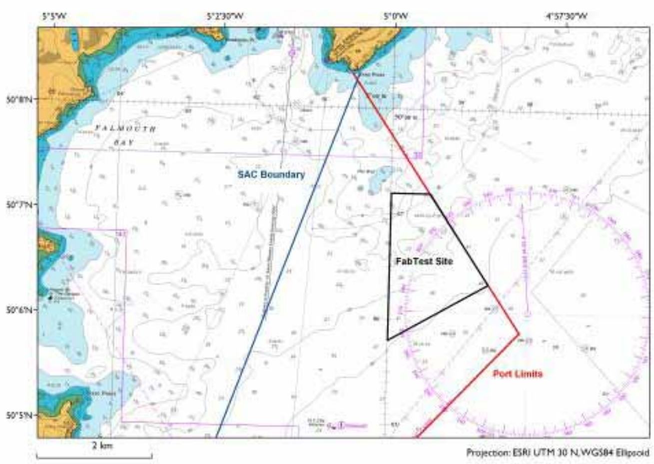
Device description

The BOLT 2 device is a near shore, moored, floating point absorber. The unit is manufactured in composites and steel. Each unit may be autonomous or remotely operated.

Status

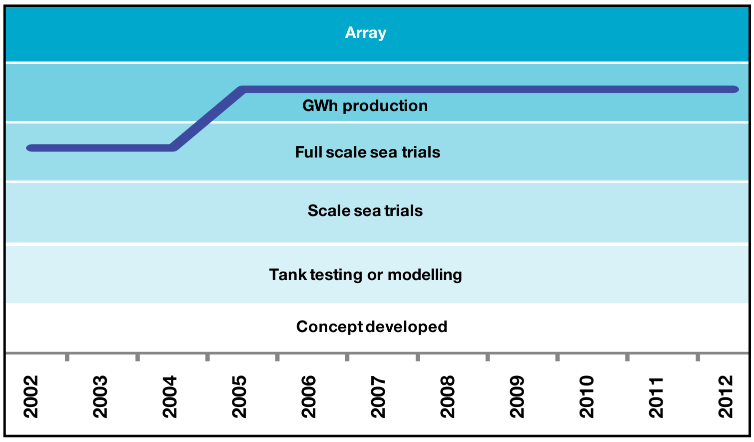
Fred Olsen has tested a scale device in Norwegian waters since 2008. A prototype is planned to be launched at FaBTest in Cornwall during 2012. BOLT 2 received funding through the TSB to manufacture and deploy the prototype, working with private sector and academics.

This test will be expanded with array testing and trial grid connection at a suitable location, potentially at WaveHub.



Limpet

Manufacturer: Voith Hydro Wavegen
Type of device: Oscillating water column
Status: Full scale
Current location: Islay
Rating: 0.5MW



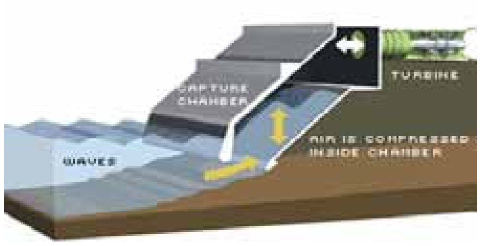
Device description

The Limpet device is a shore-mounted oscillating water column which has been tuned to capture energy from annual average wave intensities of between 15 and 25kW/m. It comprises an air chamber with an opening below the water. The wave action moves the water level up and down the air chamber, compressing the air.. The air flow is captured by two counter-rotating Wells turbines, which each have a 250kW generator, on each surge and ebb of the wave.

Its shoreline location avoids offshore construction, installation and service requirements.

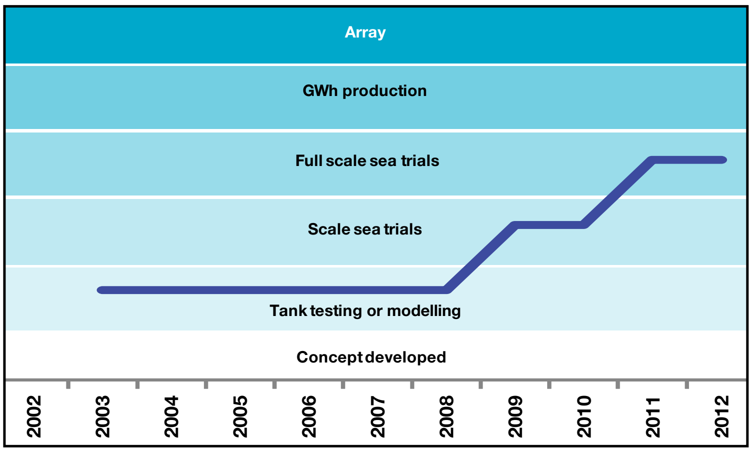
Status

The Limpet 500 was installed in 2000 and is grid-connected. This device is also used as a developmental facility, to demonstrate new systems and improve power output, such as testing a variable pitch turbine. A near shore application of the technology is under development.



Oyster 800

Manufacturer: Aquamarine Power
Type of device: Oscillating wave surge converter
Status: Full scale prototype
Current location: EMEC
Rating: 0.8MW



Device description

Oyster is a nearshore wave-powered pump which pushes high pressure water to drive an onshore hydro-electric turbine. The mechanical offshore device is connected to the seabed in around ten metres water depth, typically within a kilometre from the shore facility. The pump is a buoyant hinged flap which is almost entirely underwater and pitches back and forth due to wave motion. This drives two hydraulic pistons which pump high pressure water through a subsea pipeline to shore to drive the hydro-electric turbine.

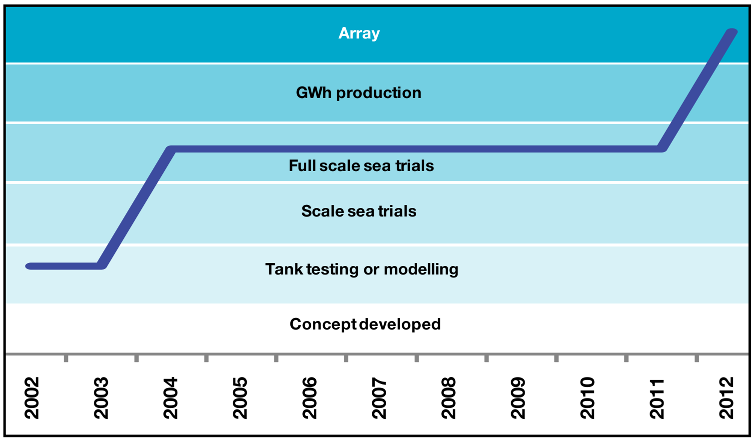
Key design features of the Oyster are that there are no offshore electronics, electricity generation equipment is located onshore using hydro-electric equipment (existing technology) and the submerged nature of the device reduces visual impact and wave loading in extreme waves.

Status

The first full-scale 0.315MW Oyster was installed and grid-connected at EMEC in 2009. The device withstood two winters and delivered over 6,000 offshore operating hours. The full-scale next-generation Oyster 800 device was installed in 2011.

Pelamis P2

Manufacturer: Pelamis Wave Power
Type of device: Attenuator (A)
Status: 2nd generation full scale
Current location: North Berth, EMEC
Rating: 0.75MW



Device description

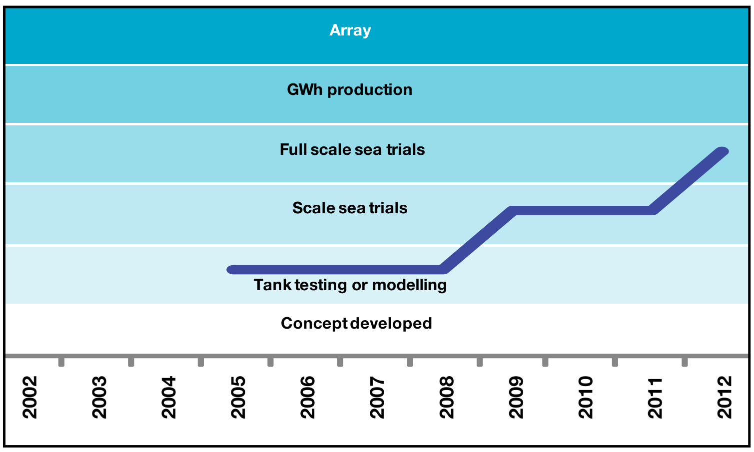
The Pelamis is a semi-submerged, floating device that faces into the direction of the waves. Five tube sections are joined by universal joints which allow flexing in two directions with identical, independently operating hydraulic power take-off systems in each joint. As waves pass down the length of the machine, the tube sections move relative to each other and hydraulic cylinders in the joints resist the wave-induced motion, pumping fluid into high pressure accumulators. This allows generation to be smooth and continuous. The resistance can be controlled to optimise the device for use in varying wave climates. A standard subsea cable and equipment is used to connect the device / array of devices to shore. A Pelamis is anchored to the seabed by a slack, chain catenary system with a yaw restraint line.

Status

The first Pelamis machine (P1) was installed in 2004 and 2011 saw the manufacture of the sixth full scale machine and second utility customer (E.ON and ScottishPower Renewables). Vattenfall has also committed as a third. The E.ON P2 Pelamis is operating at EMEC with the ScottishPower Renewables P2 Pelamis soon to be installed alongside.

Penguin

Manufacturer: Wello Oy
Type of device: Other (G)
Status: Full scale
Current location: Billia Croo, Orkney, EMEC
Rating: 0.6MW

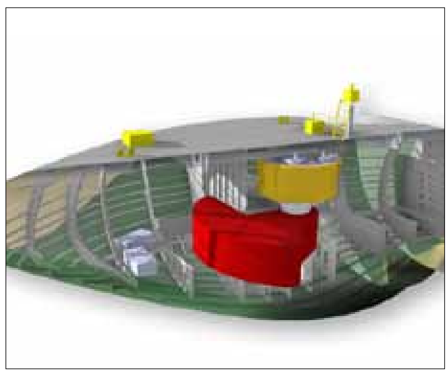


Device description

The Penguin is a floating asymmetric vessel which houses an eccentric rotating mass. The device is shaped so that waves passing it cause the mass to rotate on a vertical shaft and this motion is converted to electricity. The 1600 tonne vessel, approximately 30 meters in length, is held in place by three wires anchored to the seabed below. Only about two meters of each unit is visible above the surface. All operational parts are housed inside of its protective cover.

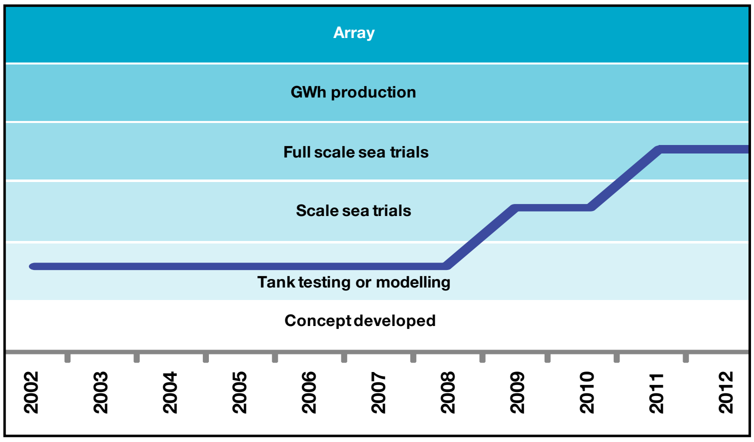
Status

The 1:8 scale prototype “Baby Penguin” The 1:8 scale prototype, “Baby Penguin”, was tested in Finland and the full scale Penguin is at Lyness Wharf, Orkney. It is being prepared for installation on an EMEC test berth in 2012 for a year-long test programme.



PowerBuoy – PB150

Manufacturer: Ocean Power Technologies
Type of device: Point absorber (B)
Status: Scale prototype
Current location: Invergordon, Scotland
Rating: 0.15MW



Device description

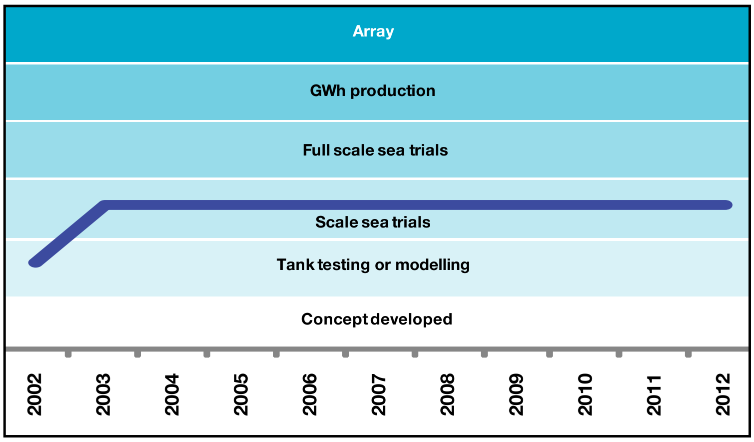
The PowerBuoy is constructed as two main hull elements, the spar and the float. The spar is designed to remain as stationary as possible whilst the float responds actively and dynamically to wave forces. The difference in motion between the two hulls is captured as mechanical energy and converted via onboard generators. The intent of the PowerBuoy control system is to tune the response of the system to maximise power capture from each wave. Conventional mooring systems are used to tether each PowerBuoy.

Status

Ocean Power Technologies has been active in the USA and Spain and has projects for both England and Scotland. It is committed to Wave Hub, Hayle, with a proposed array and successfully deployed the PB150 PowerBuoy off Invergordon in April 2011. During this project tests focused on issues such as examining the response of the structure and mooring system in the offshore environment and the power production, using real-time data and wave data from a nearby resource buoy.

Wave Dragon

Manufacturer: Wave Dragon
Type of device: Overtopping
Status: Sea-installed scale prototype
Current location: Denmark
Rating: 1.5 MW



Device description

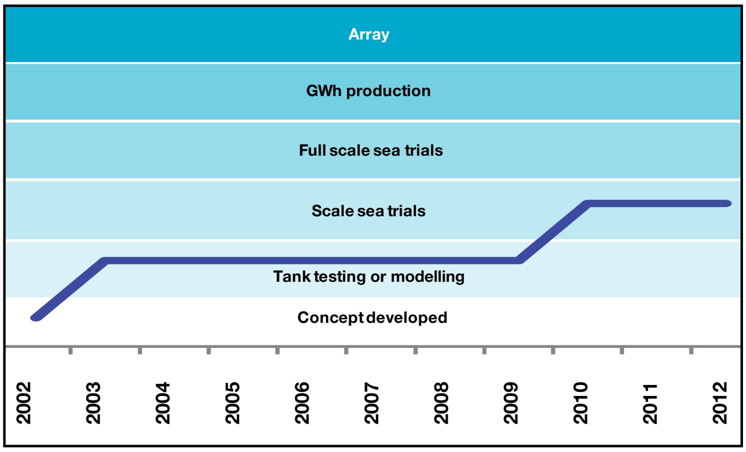
The Wave Dragon is a floating overtopping wave energy converter with wave-reflecting wings. Waves are channeled up an adjustable ramp to a reservoir, creating a head differential. Water is then passed through a number of low head propeller hydro turbines to generate electricity. This means that there are few moving parts, aimed at reducing maintenance requirements. The device is slack-moored to the sea bed.

Status

A 1:3 scale 1.5 MW device was installed offshore at Nissum Bredning in Denmark from 2003 - 2010 to model how the device behaves in the North Sea climate. Wave Dragon intends to install a pre-commercial demonstrator off the coast of Milford Haven, Wales and has submitted an Environmental Impact Assessment and application for consent.

WaveRoller

Manufacturer: AW Energy
Type of device: Oscillating wave surge convertor
Status: Scale prototype
Current location: Portugal
Rating: 0.8MW (per plate)



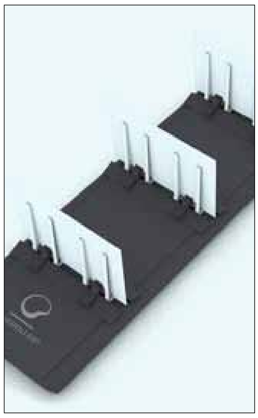
Device description

The WaveRoller device is a flap anchored to the seabed at its base. The back and forth movement of the wave surge moves the flap, transferring the kinetic energy to piston pumps, which feed into an onshore generator system. The nominal capacity of a single commercial-scale flap ranges between 0.5MW to 1MW, depending on the wave resources available on the site. The plant construction is modular; therefore, it offers a high level of scalability.

The WaveRoller is designed such that large waves pass above the device, thus reducing extreme loading. Other design considerations are accessibility for maintenance, simple installation through using a float and submerge method and minimal visual impact on the deployment site.

Status

The first prototypes were designed as early as 1999. Open sea trails started in 2004 and included deployment in the Gulf of Finland, at EMEC and at AW-Energy's own testing site Peniche, Portugal. The latest demonstration farm consisting of three 100kW WaveRoller units is to be deployed also in Peniche, Portugal, during the second quarter of 2012. The company has already secured all the necessary permits and holds a licence for 1MW grid connection.



6. UK and Abroad

The wave and tidal sector extracts energy from naturally occurring, abundant and clean resources. Globally, it is estimated that there is 180TWh[2] of economically accessible tidal energy and over 500TWh of economically accessible wave energy available annually. The tidal resource is heavily dependent on local seabed geometry, and wave energy relies on areas of sea where the wind can interact with the sea surface over long distances (a long fetch).

As an island, the UK has substantial natural wave and tidal energy resources. Despite having less than one per cent of the world's population, it has been estimated that UK waters contain around 15 per cent[3] of the world's economically accessible tidal resource and over 10 per cent of the world's economically accessible wave resource.[4] This tidal resource is estimated at 29TWh, and wave is 50TWh.[5]

6.1 UK position

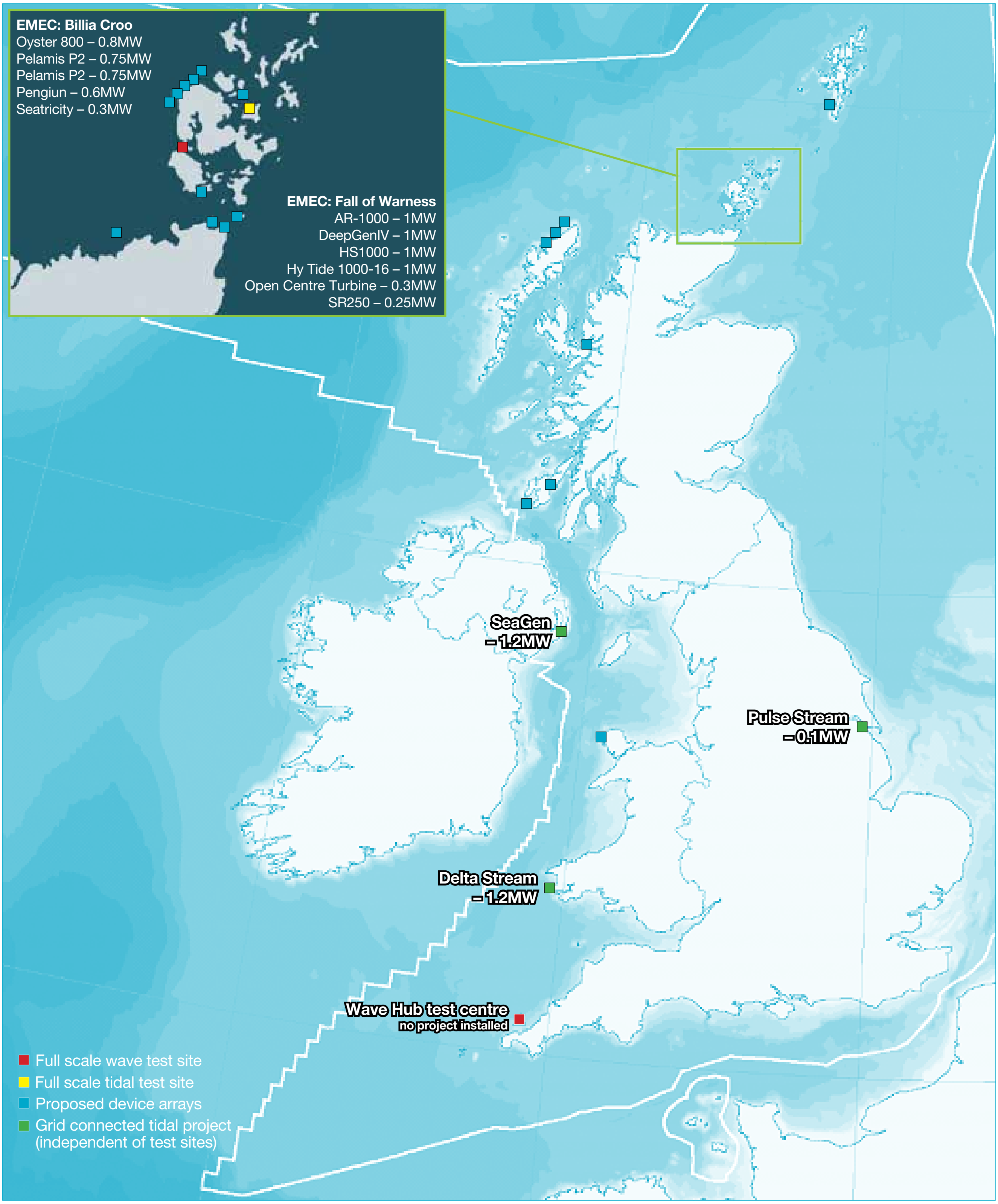
The UK is regarded as the world's leading market for both wave and tidal project development. It has:

- A significant share of the global economically accessible wave and tidal resource.
- Industry leading testing infrastructure in place at EMEC, Narec, WaveHub and FabTest.
- A market support mechanism ithat is regarded as the most attractive tariff currently available.
- Frameworks for project leasing and consenting that are being proactively developed in consultation with project developers, The Crown Estate and statutory planning bodies.

In March 2010, The Crown Estate announced that it had entered into agreements for the lease of projects with a potential capacity of up to 1.2GW, split equally between wave and tidal projects. In October 2010, a further 0.4GW of tidal energy was added. This leasing activity far exceeds current planned capacity in any other single country. The Crown Estate report *Pentland Firth and Orkney waters: How the projects could be built* provides an overview of the activity required to deliver this target along with details of individual leases.

The successful deployment of this planned 1.6GW of wave and tidal energy is, however, dependent on successfully proving individual devices and the subsequent deployment of small demonstration arrays. The Crown Estate has undertaken separate individual leasing activities to enable these single and multiple device deployments. Figure 6.1 indicates current areas of activity around the UK. It is expected that the first small arrays (5-10MW) will begin installation in 2013 with several operational by 2016. The move to equalise ROC awards between Scotland and the rest of the UK will influence the development rates of projects in both English and Welsh waters.

Figure 6.1 The Crown Estate current wave and tidal activity



6.2 Global developments

The EU member states have a target to deploy around 2GW of marine energy by 2020, while the USA and Canada are coordinating approaches to develop markets and commercialisation. Across Europe there is a significant ambition to develop marine energy, notably in the countries on the Atlantic arc (UK, Ireland, France, Spain and Portugal).
Between 2002 and 2006, support totalling €17.3 million was provided to nine wave power demonstration projects, ranging in size from €0.8 million to €2.4 million per project. In the Seventh Framework Programme (FP7), the European Commission has invested n over the past four years €20 million in four demonstration projects (three wave projects and one tidal project), and €21 million on "soft actions" including environmental monitoring. Table 6.1 lists any countries that have publically announced plans for wave and tidal deployments or that have disclosed details of devices currently under test.

6.3 Export

The UK is quickly building a track record in the design and manufacture of wave and tidal devices and construction and operation of projects that put it in a strong position to export this capability to other markets. The potential for this export could be hindered by requirements for local content in some markets technology knowledge is likely to be highly valued.

Marine Current Turbines and OpenHydro have both secured leases in the Bay of Fundy in Canada. Ocean Power Technologies and Aquamarine Power will deploy devices to the US market and Pelamis, along with other developers, is in negotiations to supply devices in other parts of Europe. EMEC has also been approached by New Zealand and Australia to collaborate with plans for their respective marine energy test programmes.

The Energy and Climate change select committee has identified a large export opportunity for the UK. Based on research by the Carbon Trust, it has stated that the value of the global industry would be of the order of £340 Billion by 2050. The UK's Share of this market could be as high as £76 Billion if action is taken to foster the marine energy capability within our borders. The correct policy measures, including an enabling level of support provided through the Electricity Market Reform mechanism, could catalyse a low carbon industrial revolution and provide real value to the UK on the longer term.

6.4 Import

The industry-leading market conditions in the UK have already attracted device and project developers to the UK to test devices and develop projects. Hammerfest Strom now has its development and design team headquartered in the UK following relocation from Norway and organisations such as Kawasaki, Siemens, ABB and Alstom have taken interests in UK-based manufacturers and projects.

Table 6.1 Global Project Development

Country	Wave	Tidal	Description
Australia	Installed		Ocean linx and Carnegie have deployed units with plans for further device deployment in arrays.
Canada		Installed	FORCE (Fundy Ocean Research Centre for Energy) in the Bay of Fundy, Nova Scotia is the centre for testing of tidal device with: • Initial deployments of a 1MW OpenHydro device by Nova Scotia Power complete • Negotiations ongoing with another two developers; using MCT and Alstom Hydro technology.
China	Installed		1MW wave device installed in Guanzhou province with significant plans for additional capacity.
Denmark	Installed		Testing of a scale Wave Dragon device has been ongoing at the Nissum Bredning test facility since 2003.
France		Planned	In 2012 EDF plan to install the first of four OpenHydro 2MW turbines in Brittany.
India		Planned	The state of Gujurat is planning installation of 50MW of tidal stream capacity. With the next five years
Korea		Installed	Tidal stream capacity installed at Jindo Uldolmok in 2009 with plans for 100MW once device technology has been tested and proven.
New Zealand		Planned	Plans to harness tidal energy in the Cook Strait in place since 2008 when initial consent was awarded.
Norway	Installed		Testing complete in 2010 for a tidal sail technology at Lukksundet.
Portugal	Installed		Three Pelamis P1 devices were installed off the coast for a short period of time. Significant long term plans for wave energy still active. The WaveRoller device is currently being deployed.
Spain	Installed		Developments along Northern Spain at Cantabria include testing of an OPT PB40 dVevice with plans for small arrays.
Sweden	Installed		Uppsala University has conducted wave energy tests at the Lysekil test site since 2005 with long term plans to deploy large arrays.
USA	Installed	Installed	West coast US has active development programme for the installation of wave energy devices focussed in initially around Oregon. This complements the existing test deployment of OPT in Hawaii. New York's East river has housed a single Verdant 1MW turbine with plans for large arrays in the coming years.

7. Industrial Partnerships

The entry of large-scale industrial organisations into the wave and tidal sector is seen both as a positive sign for the commercial status of the industry and a necessary step to ensure timely ramp up of supply chain capability to deliver this what will be needed in this growing market. Device manufacturers by necessity must grow from small technology incubator organisations to large scale suppliers of commercial power generation equipment. To do this successfully, the practices and approaches of other industrial sectors must be applied.

It is a natural development for existing device manufacturers either to partner with organisations with the necessary experience or grow their own internal capability. The move of ABB, Alstom, Andritz, Siemens, Voith Hydro and others to invest in the industry show that this partnering is taking place. The device-specific technical knowledge and experience of deploying and operating wave and tidal devices is retained by the device manufacturer but the industrial partner typically brings:

- Financial security and assurances that will support the attraction of further private and public sector funding.
- Access to a experienced resources to cover technical issues and to manage the higher volume production activities.
- Support from an established supply chain to increase competition for supply.
- Experience engaging with governments, stakeholders and suppliers to facilitate project development, manufacture and construction activities.

7.1 Industy Case Studies

ABB

Relevant market: Power and automation
Base location: Switzerland
UK presence: Manufacturing since 1988
Global turnover: £27 billion (2011)

Profile

ABB is a global leader in power and automation technologies that enable utility and industry customers to improve their performance while lowering environmental impact. ABB's capability includes low, medium and high voltage products including DC transmission and high voltage switchgear. They are also active in offshore power technology and process automation.

Involvement

ABB Technology Ventures invested £7m in Aquamarine in 2011. A new office has been established in East Kilbride that will act to serve the expanding renewable energy markets including wave and tidal. ABB has capability in power transmission and automation both onshore and offshore that places them in a strong position to supply this growing industry. ABB has also supplied Pelamis Wave Power with specially designed generators.

Alsthom

Relevant market:
Power generation and transmission
Base location: France
UK presence: Manufacturing since 1889
Global turnover: £18 billion (2011)

Profile

Alstom is a global leader in the world of power generation, power transmission and rail infrastructure. Alstom provides turnkey integrated power plant solutions and associated services for a wide variety of energy sources, including hydro, nuclear, gas, coal and wind, and it offers a wide range of solutions for power transmission, with a focus on smart grids.

Involvement

Alstom has a dedicated Ocean Energy base in Nantes, from which the development of their Ocean Current turbine is being led. They have also acquired a 40 per cent stake in AWS Ocean Energy and entered a joint venture with SSE for the Costa Head Wave Project in the Pentland Firth. Alstom aims to develop a leading position in both wave and tidal energy to complement its position in the hydro and wind sectors.

Andritz

Relevant market:
Relevant market: Hydro power and process technology
Base location: Austria
UK presence: Various
Global turnover: £4 billion (2011)

Profile

International technology Group Andritz is a globally leading supplier of plants, equipment, and services for hydropower stations, the pulp and paper industry, solid/liquid separation in the municipal and industrial sectors, the steel industry, and the production of animal feed and biomass pellets.

Involvement

Andritz Hydro increased its ownership of Hammerfest Strøm to a majority in March 2012. Tidal energy sits as a complementary sector to its hydro power operations, which includes the supply of turbines to the world's largest tidal barrage at Sihwa, India. Andritz Hydro will be involved in both project and device development alongside other key shareholders.

Siemens

Relevant market: Power generation and transmission
Base location: Germany
UK presence: Manufacturing and sales
Global turnover: £60 billion (2011)

Profile

Siemens has a heritage in power generation and transmission including a market leading position in the offshore wind as a wind turbine manufacturer. General skills and experience lie in design development, manufacturing and industrial scale procurement.

Involvement

Siemens owns a 90 per cent share of Marine Current Turbines, including both device and project pipelines. It is looking to support the shift to industrial scale output of tidal energy devices and to gain early mover advantage in this emerging area. Tidal energy sits as a complementary sector to its wind power division and general energy activities.

Rolls-Royce

Relevant market:
Power systems & marine propulsion
Base location: UK
UK presence: Manufacturing since 1884
Global turnover: £11.3 billion (2011)

Profile

Rolls-Royce, a world-leading provider of power systems and services for use on land, at sea and in the air, has established a strong position in global markets - civil aerospace, defence aerospace, marine and energy and nuclear.

Involvement

Rolls-Royce acquired Tidal Generation Ltd in 2009 and are actively involved in the development of both device and project portfolios. It is looking to support the shift to industrial scale output of tidal energy and to gain an early entry advantage in this emerging area. Tidal energy is complementary to it power generation and marine sector activities currently.

Voith

Relevant market: Power generation and transmission
Base location: Germany
UK presence: Manufacturing and sales
Global turnover: £5 billion (2011)

Profile

Voith operates in energy, oil and gas, paper, raw materials, and transportation and automotive markets worldwide. It manufactures paper machinery, hydroelectric equipment for power generation and drive and braking systems for industry, rail, road, and marine markets.

Involvement

Voith Hydro own a majority stake in both a wave and tidal technology. The Voith Hydro Ocean Current Technologies joint venture is looking to deploy a 1MW tidal turbine at EMEC and develop project opportunities globally. Voith Hydro Wavegen owns took over the device development of Wavegen in 2005, including UK and overseas portfolio. Marine energy is complementary to their core hydro business.

8. Future Challenges

Through engagement with industry, we identified the following key challenges for the sector:

- Bringing the lifetime cost of energy down through reduction of both device CAPEX per MWh and OPEX per MWh, based on a clear understanding of the factors that influence these costs. Improving reliability, maximising generating performance and minimising the cost of installation and operation are key components of this.
- Further developing the additional infrastructure (balance of plant, installation and maintenance equipment) required to implement small and large scale arrays.
- Developing a UK supply chain with the necessary skills and capacity to deliver rapid growth in the sector and to capture the socioeconomic benefits of the industry in the long term.

These will be achieved through a combination of improvements in technology and supply chain, including through the involvement of larger industrial players and drawing on experience from parallel sectors including wind, oil and gas, aerospace and commercial fishing.

There are wider issues that will affect the long term viability of the sector, along with other renewable energy technologies, that the sector is very much aware need to be resolved as soon as possible, namely:

- Electricity Market Reform – Alongside competing technologies, the marine sector must put forward clear messages on the status of the industry and requirements for ongoing support to continue its growth. The movement of industrial partners into the sector will support the justification of enhanced funding but a clear pathway for cost of energy reduction must be developed.
- Working with stakeholders to improve processes relating to assessment and mitigation of environmental impact as part of the consenting process.
- Long term grid infrastructure planning, including interconnectors between Scottish Islands and agreement on transmission access charges.

9. Getting Involved

The wave and tidal sector growth required to deliver UK and global targets is significant and a wide range of skills and services will be required to develop a sustainable and successful industry. If you are interested in becoming involved in the sector or learning more in the first instance please contact RenewableUK:

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9.1 Industry directory

Device manufacturers involved in the industry and featured in this publication are:

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Aquamarine Power	Neil Davidson – info@aquamarinepower.com
Atlantis Resources Corporation	Oliver Wragg – info@atlantisresourcescorporation.com
AW Energy	Tomasz Mucha – info@aw-energy.com
AWS Ocean Energy	Simon Grey – info@awsocean.com
Fred. Olsen Renewables	Tore Gulli – renewables@fredolsen.no
Andritz Hydro Hammerfest	Stein Andersen – contact@hammerfeststrom.com
Marine Current Turbines	David Ainsworth – info@marineturbines.com
Minesto	Anders Jansson – info@minesto.com
Ocean Power Technologies	Tim Stiven – info@oceanpowertech.com
OpenHydro	Sue Barr – info@openhydro.com
Pelamis Wave Power	Richard Yemm – enquiries@pelamiswave.com
Pulse Tidal	Bob Smith, CEO – info@pulsetidal.com
Scotrenewables Tidal Power	John McGlynn – info@scotrenewables.com
Tidal Energy	Chris Williams – info@tidalenergyltd.com
Tidal Generation	Rob Stevenson – info@tidalgeneration.co.uk
Voith Hydro Ocean Current Technologies	Wolfgang Maier – ocean.enquiries@voith.com
Voith Hydro Wavegen	Matthew Seed – enquiries@wavegen.com
Wave Dragon	Hans Christian Sorensen – info@wavedragon.net
Wello	Heikki Paakkinen – info@wello.eu

10. End Notes

1. EMEC, Wave Developers, www.emec.org.uk/wave_energy_developers.asp; EMEC, Tidal Developers, www.emec.org.uk/tidal_developers.asp

2. The Carbon Trust, Future Marine Energy, 2006.

3. The Carbon Trust, Accelerating marine energy, 2011.

4. Energy Technology Systems Analysis Programme, Marine Energy (Technical Brief E13), Energy Technology Network, May 2010.

5. The Carbon Trust, Accelerating marine energy, 2011.

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Our vision is of renewable energy playing a leading role in powering the UK.

RenewableUK is the UK's leading renewable energy trade association, specialising in onshore wind, offshore wind and wave & tidal energy. Formed in 1978, we have an established, large corporate membership ranging from small independent companies, to large international corporations and manufacturers.

Acting as a central point of information and a united, representative voice for our membership, we conduct research; find solutions; organise events, facilitate business development, lobby and promote wind and marine renewables to government, industry, the media and the public.

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