WAVE & TIDAL ENERGY: STATE OF THE INDUSTRY

Report to ClimateXChange

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CAELULUM

aquatera
environmental services and products

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List of Acronyms

AEA	Atomic Energy Authority
AEP	Annual Electricity Production
ADCP	Acoustic Doppler Current Profiler
AHH	Andritz Hammerfest Hydro
ARL	Atlantis Resources Limited
AWS	Archimedes Wave Swing
BEIS	Department for Business, Energy and Industrial Strategy
BERR	Department for Business, Enterprise and Regulatory Reform
BiMEP	Biscay Marine Energy Platform
BOOT	Build, Own, Operate and Transfer
BREXIT	British Exit (from the European Union)
CAPEX	Capital Expenditure
CCS	Carbon Capture and Storage
CEGB	Central Electricity Generating Board
CfD	Contract for Difference
CRL	Commercial Readiness Level
CSR	Comprehensive Spending Review
DECC	Department of Energy and Climate Change
DG MARE	Directorate General for Maritime Affairs and Fisheries
DOE	Department of Energy
DTI	Department of Trade and Industry
EMEC	European Marine Energy Centre
EU	European Union
EU ETS	European Union Emissions Trading Scheme
ECGD	Export Credit Guarantee Department
EPSRC	Engineering and Physical Sciences Research Council
EVE	Ente Vasco de la Energía
EV	Electric Vehicle
FaBTest	Falmouth Bay Test site
FEA	Finite Element Analysis
FES	Future Energy Solutions
GHG	Greenhouse Gas
GIB	Green Investment Bank
HAT	Horizontal Axis Turbine
HIE	Highlands and Islands Enterprise
HMS	Hebrides Marine Services
ICIT	International Centre for Island Technology
IEA	International Energy Agency
IRR	Internal Rate of Return
LCOE	Levelised Cost of Electricity
LEC	Levelised Energy Cost
MCT	Marine Current Turbines
MEAD	Marine Energy Array Deployment (Fund)

MRCF	Marine Renewables Commercialisation Fund
MRDF	Marine Renewables Deployment Fund
MRPF	Marine Renewables Proving Fund
NAREC	New And Renewable Energy Centre
NASA	National Aeronautics and Space Administration
NFFO	Non-Fossil Fuel Obligation
O&M	Operations and Maintenance
OCT	Open Centre Turbine
OEA	Ocean Energy Advisors
OEM	Original Equipment Manufacturer
OES	Ocean Energy Systems
OIC	Orkney Islands Council
OPEX	Operating Expenditure
OREF	Orkney Renewable Energy Forum
OTEC	Ocean Thermal Energy Conversion
OWC	Oscillating Water Column
PFOW	Pentland Firth and Orkney Waters
PLOCAN	Plataforma Oceánica de Canarias
PPA	Power Purchase Agreement
PTO	Power Take Off
RO	Renewable Obligation
ROC	Renewable Obligation Certificate
ROV	Remote Operated Vehicle
RWE	Rheinisch-Westfälisches Elektrizitätswerk AG
SEA	Strategic Environmental Assessment
SIB	Scottish Investment Bank
SPR	Scottish Power Renewables
SRO	Scottish Renewables Order
SRTP	Scotrenewables Tidal Power Limited
TCE	The Crown Estate Scotland
TEC	Tidal Energy Converter
TGL	Tidal Generators Limited
TRL	Technology Readiness Level
TSB	Technology Strategy Board
TTC	Tidal Test Centre
WATES	Wave And Tidal Energy Support (Scheme)
WEC	Wave Energy Converter
WEP	Wave Energy Prize
WES	Wave Energy Scotland
WETS	Wave Energy Test Site

1 Overview

1.1 Report Objectives

ClimateXChange commissioned this report with the following objectives:

- To better understand the current state of the UK marine energy industry
- To chart recent activity in the sector (e.g. development of new components and subsystems; demonstration of single devices; deployment of first arrays; involvement of utilities and large engineering firms)
- To investigate the deployment pipeline and the market
- To explore policy initiatives, political signals from the UK Government and devolved administrations and the availability of market pull instruments.
- To set UK development in the context of global activity (taking into consideration the availability of market pull instruments and incentives in other countries)

1.2 Methodology

In undertaking this research, we draw on several public data sources (see References), alongside interviews with a small sample of Scottish-based industry stakeholders (Appendix C) and our own industry knowledge.

The research has concentrated on current industry activity that is most pertinent to Scotland, but with a global perspective to look at the deployment pipeline and market. This is detailed in section 2, with an overview of wave and tidal technology developers contained in Appendix B.

Section 3 considers policy initiatives and political signals, while section 4 details the development to date of the wave and tidal sector within Scotland and the UK.

We note that this work has not involved a systematic and robust survey of all those involved in wave and tidal stream energy in the UK, so cannot be construed as a comprehensive industry view, but nevertheless we believe it provides useful insight to the state of the tidal and wave energy industry in UK in 2017.

2 Current state of the industry

We have undertaken an analysis of global installed capacity, based on published data sources (for example OES, 2016). Since most projects are first of a kind demonstration projects, with emerging plans for expansion or upgrade of existing installations, the picture is quite fluid. Installation of generating capacity does not necessarily mean that such capacity is generating continuously or indeed will continue to generate after completion of test programmes. Equally, there are some ambitious plans for expansion of capacity in future; we exclude these here because of our focus on near term prospects.

2.1 Active projects/ project sites in the UK

Active projects in the UK (meaning those where installation or operation activities have occurred or are occurring over the past 18 months) currently comprise approximately 9MW for tidal stream and <1MW for wave energy. Most activity has been located at the European Marine Energy Centre (EMEC) in Orkney:

Table 1 Active projects in the UK

Type	Company	Location	Turbine	Capacity (MW)			Status
				Complete	Partial	Planned	
Tidal	ARL/ MeyGen	Pentland Firth	3 x HS1500 1 x AR1500	6.00		6.00	Operational. 2.6GWh generated by Oct 17.
	Current2-Current	Fort William	1 x scale prototype	<0.10			Nov 16: Tests carried out mounted on vessel.
	EC-OG	EMEC	1 x Scale SPH	<0.05			Apr 17: Test at Shapinsay scale test site.
	OpenHydro	EMEC	1 x OCT6	0.25		4.00	Operational; turbine installed in Jul 06. 2x 2MW planned.
	Minesto	Strangford Lough	1 x 3m scale prototype	0.03			Autumn 2016: 3kW generated in 0.8m/s current velocity.
	Nautricity	EMEC	1 x CoRMaT	0.50			Installed in April 2017
	Nova Innovation	Shetland	3 x M100	0.30		>0.30	Operational: EU funding for second phase of three turbines.
	SRTP	EMEC	1 x SR2000	2.00		2.00	Nov 17: record for fastest 1GWh at EMEC. Mk2 2MW planned.
	Sustainable Marine Energy	EMEC	1 x PLAT-O		0.1	1.00	Jun 16: Rock anchors installed, wet test completed.
		Connel	1 x PLAT-I	0.28			Nov 17: commissioning prior to shipping to SE Asia
	Tocardo	EMEC	8 x T2		2.0		Feb 17: Foundation System installed, 1.4MW RO accredited.
Wave	Albatern	Mingary Bay	6 x Squid	0.05			Project on hold.
	CorPower Ocean	EMEC	1 x ½ scale			0.05	Due to be tested in Scapa Flow scale test area (2017/18)
	PolyGen	FaBTest	1 x Volta	n/a			Full-scale deployment test carried out July-Nov 2015
	Laminaria	EMEC	1 x LAMWEC			0.20	Sept 17: Raised €2m for full-scale test at EMEC (2017/18)
	Seatricity	Wave Hub	1 x Oceanus2	0.16			Hydraulic test in Jun 2016, now decommissioning moorings
	Wave-tricity	Milford Haven	1 x Wave-rower	n/a			Currently testing off Milford Haven, Wales

	Wello Oy/ Fortum	EMEC	1 x Penguin	0.50		3.00	First generation Mar 17; 150 days operation to August

Many of these projects have only recently been installed as test projects using single devices; and hence are still building up a track record as “first of a kind” installations. Figure 1 provides an overview of currently active UK projects/ project sites and some of those planned in the near term.

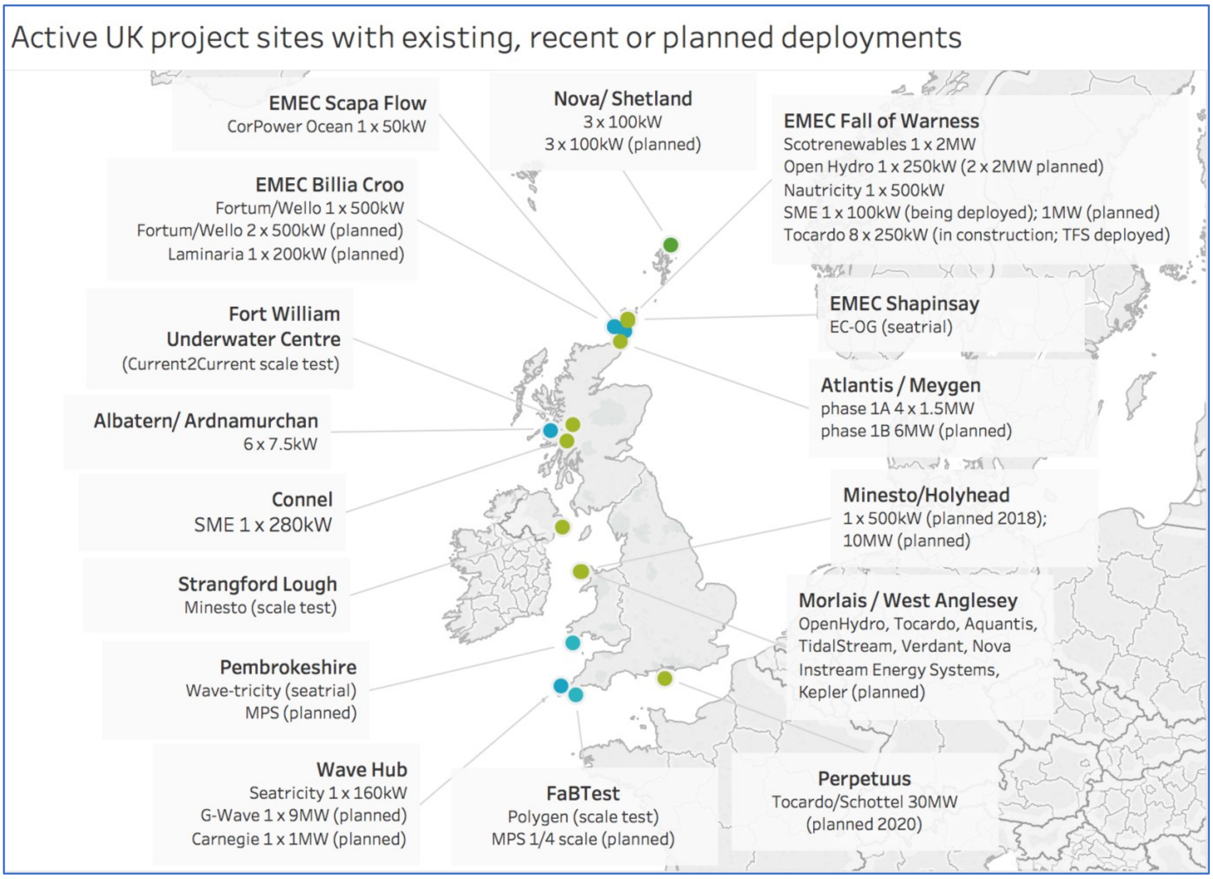

Figure 1 Overview of active project sites [Green = tidal sites; blue = wave sites]

2.2 Active global project sites

Figure 2 shows currently installed capacities by country. The UK currently has the highest installed capacity for wave and tidal stream energy combined, although Sweden and China have larger installed projects for wave power. Appendix A provides a list of projects worldwide and maps of their locations. This has been compiled from various sources[1] including the IEA Ocean Energy Systems report 2016 (IEA-OES, 2016) and other public data (Pacific Northwest National Laboratory, 2017) (Aquatera and Caelulum, 2016), (Renews, 2017), (IRENA, 2014), (EMEC, 2017a), (EMEC, 2017b) and individual company websites.

2.3 Electricity generation performance

To date, the leading tidal stream energy project worldwide has been the Marine Current Turbines (MCT) Seagen project in Strangford Lough, Northern Ireland[2]. This produced ~10GWh over a period of six years from a 1.2MW dual turbine installation.

[2] Now being decommissioned by ARL, who acquired MCT from Siemens

For wave power, the leading project has been the Ente Vasco de la Energia (EVE) Basque Country, Mutriku breakwater project, which has generated 1.3GWh over a period of five years. This project is still in operation and uses sixteen 18.5kW turbines supplied by Voith Hydro Wavegen.

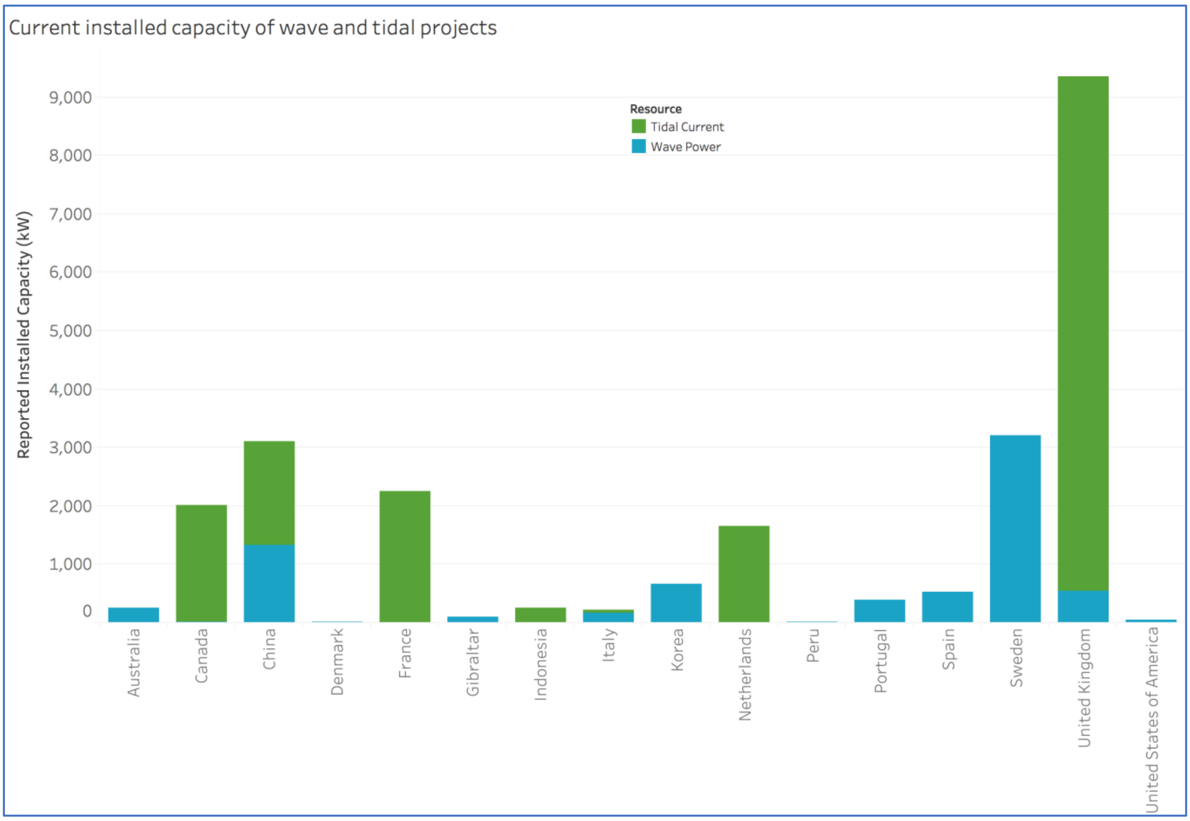

Figure 2 Current reported installed capacity worldwide

In Scotland, the first tidal machine to generate >1GWh was the Andritz Hammerfest Hydro (AHH) HS1000[3] tidal stream turbine, installed at EMEC in November 2011 which generated 1.16GWh from 2012 to 2014. This was then followed by the GE/Alstom (formerly Rolls Royce) TGL turbine, also tested at EMEC, which generated 1.2GWh from 2013 to 2015, following an earlier 500kW turbine tested at EMEC in 2010-12 which generated >200MWh. The recently installed commercial MeyGen 6MW project, which uses three AHH turbines and one ARL AR1500, has been reported to be nearing 2GWh generation at the end of August 2017[4].

For wave power in Scotland the highest generation was achieved by the Wavegen Limpet onshore project on Islay which operated from 2001 to 2013 and generated 493MWh in the period 2006 to 2013. For offshore wave power, the highest generation was achieved by the Pelamis E.ON/ Scottish Power P2 project (two 750kW machines) at EMEC in Orkney which produced a figure of 250MWh over a period of 2-3 years.

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[3] This was a larger version of the HS300 which was installed in Norway in 2004. The HS300 has itself been reported to have generated 1.5GWh into the grid (over a longer period of time). (EMEC, 2017c)

[4] Turbines were installed between November 2016 and January 2017; there was a period of downtime from April to July whilst all the turbines were returned to shore for improvements. The fourth AR1500 turbine was reinstalled in late September with full production expected at the end of Q3, 2017. MeyGen have stated that the project is on track to achieve a capacity factor of >40%, implying a maximum annual generation of 21GWh/year with no downtime.

Figure 3 and

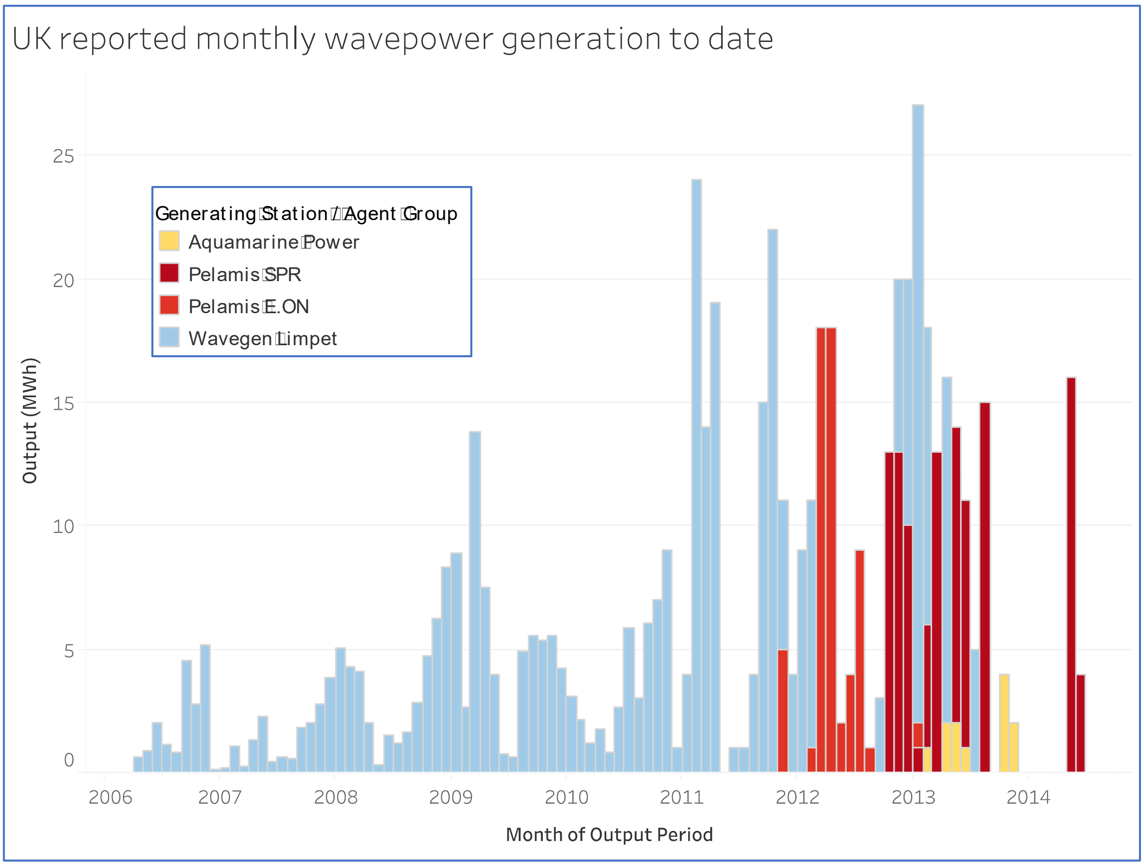

Figure 4 show electricity generation by month reported to Ofgem for all UK tidal stream and wave power projects respectively to date[5].

[5] Note that there are instances where known generation has not been reported to Ofgem.

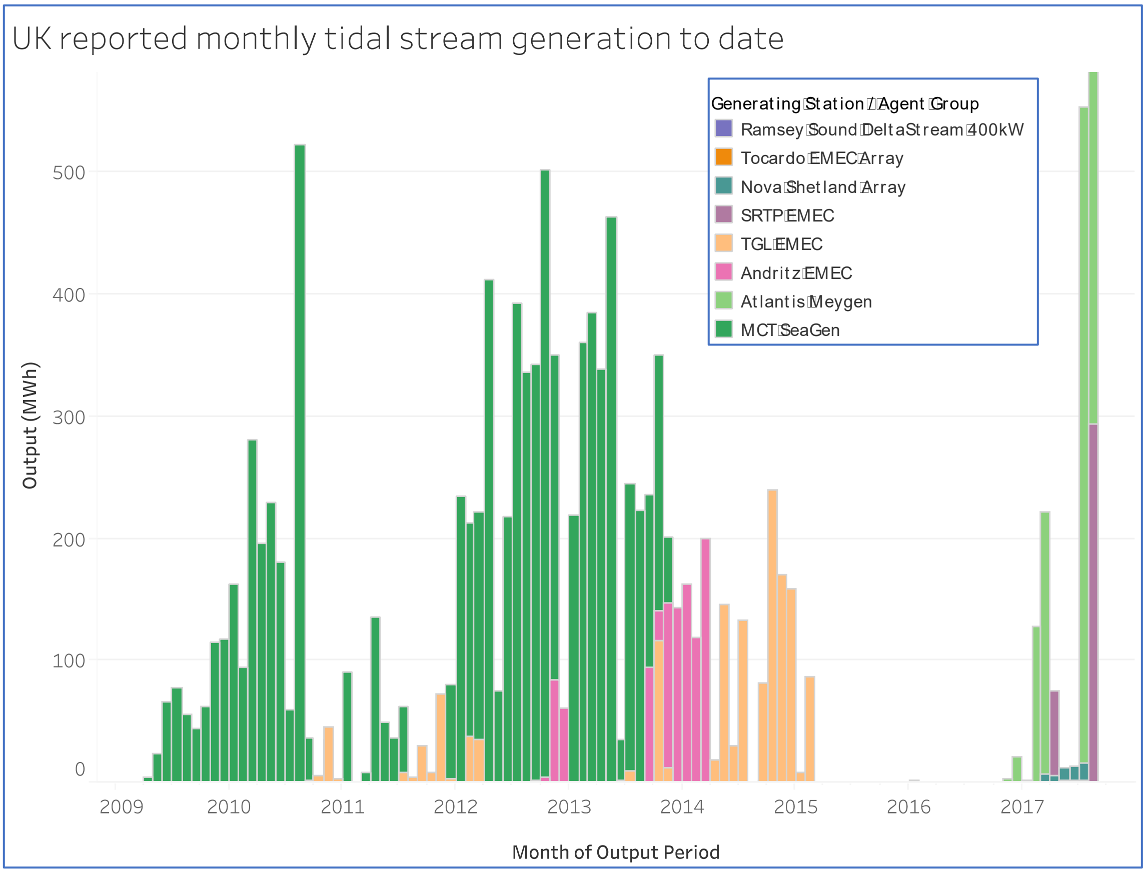

Figure 3 UK reported tidal stream generation by month

Prototype projects are not necessarily run to achieve maximum annual electricity yield but rather to prove the power curve and other operating characteristics (installability, control, reliability etc). In addition, the revenue produced is likely to be substantially smaller than the costs of operating these projects due to the high fixed costs of running a small first of a kind project. In the case of the Pelamis project, the total duration of machines installed on site was 11,847 hours (16 months) and of this time, only 5,972 hours (8 months) were spent generating. For MCT's Seagen it was reported that the machine was capable of producing 7GWh/year if it had run continuously[6].

[6] It is often unappreciated what can be normal for new engineering prototypes; in March 2005 General Electric announced it had reached a milestone of 8,000 hours operation (equivalent to one year) for its new frame 9H turbine at Baglan Bay in Wales. However, the system was originally shipped to site in December 2000 and began operating in early 2002, meaning it had taken more than four years from delivery on site to achieve this first one year operating milestone - and this was an iteration of a previous model, not an entirely new concept.

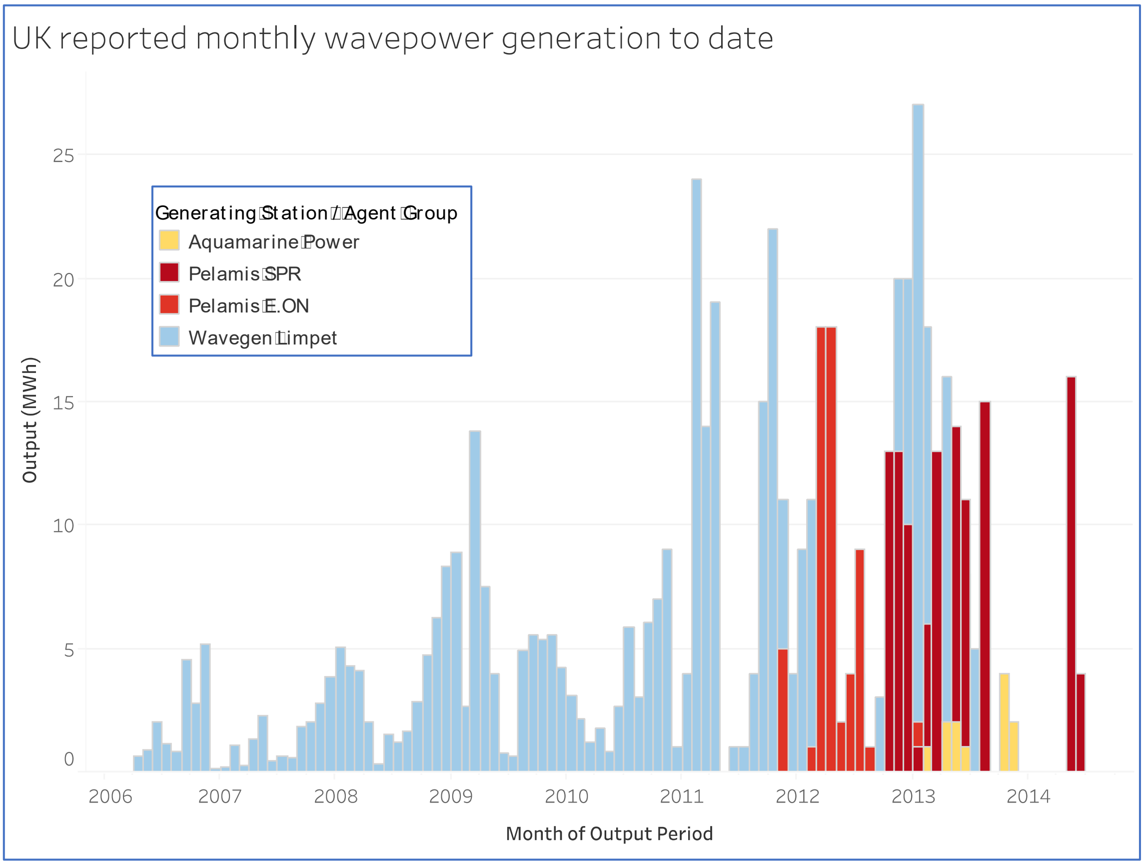

Figure 4 UK reported wave power generation by month

To give a better overall picture, **Error! Reference source not found.** shows total cumulative generation for all marine renewable projects that have reported publicly (via Ofgem data). As such, it should be noted that this is not a complete picture as some developers are hesitant to release commercially sensitive data.

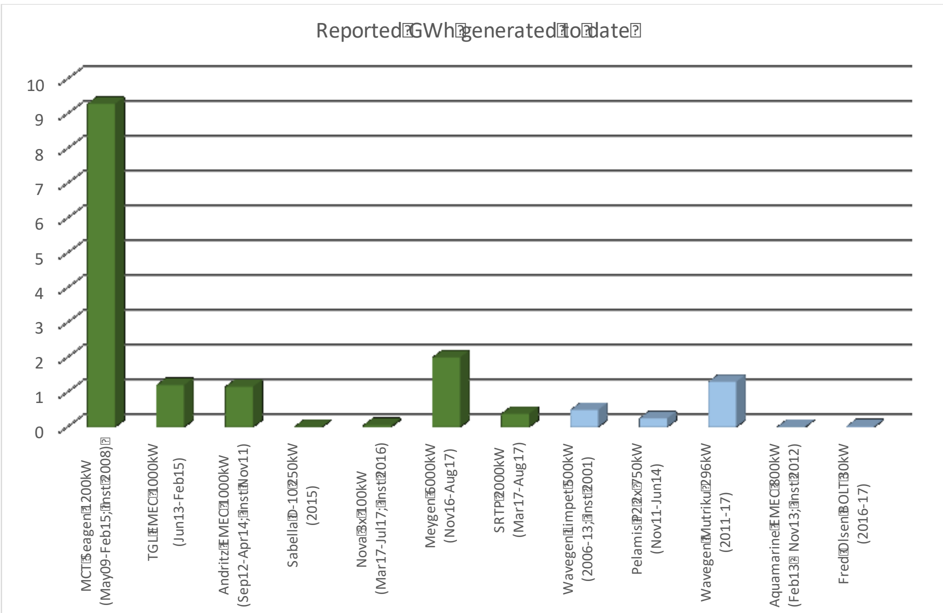

Figure 5 UK reported energy generation (GWh) to date for each project (green bars = tidal; blue bars = wave)

Error! Reference source not found. shows this output annualised for each developer. This is a little subjective because precise data on hours operated are not available (only months in which generation occurred), so this is likely to err on the low side. It should also be noted that the annualised output of operational projects, such as Nova Innovation's Shetland project, Scotrenewables EMEC installation and ARL's MeyGen project, may well increase over time.

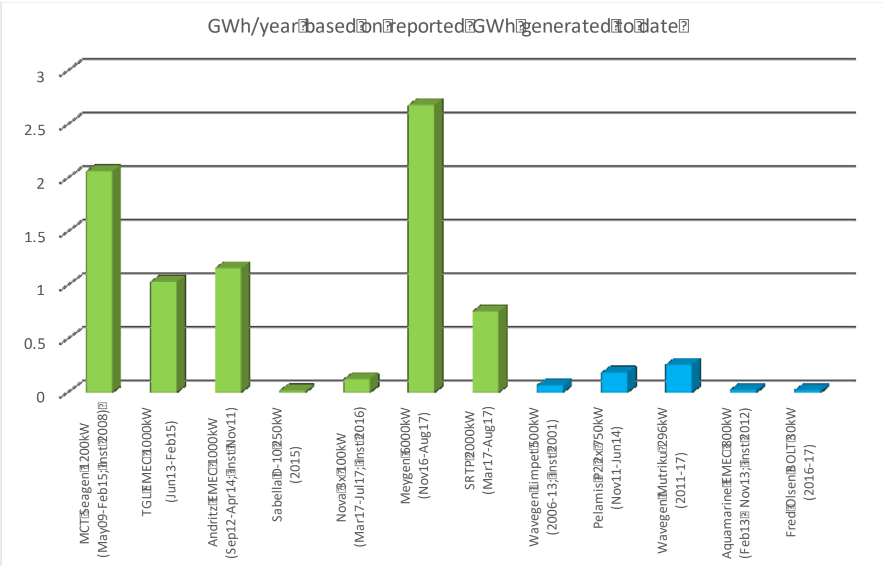

Figure 6 Annualised outputs for each developer (green bars = tidal; blue bars = wave)

Finally Figure 7 compares achieved net capacity factors - the ratio of average output to rated output (calculated based on installed operating hours). Comparing capacity factors provides a way of comparing sizes of machines with different ratings, although the achieved capacity factors will also depend upon the wave or tidal resource at the test location and the machines may also be over (or under) rated for the location. For some of these projects these are likely to be significant under-estimates of the power curve (ie performance independent of availability/downtime or operational constraints). For example, in its best month Seagen achieved a capacity factor of 59% (522MWh) compared to 15% as the long-term average including downtime (see Figure 3).

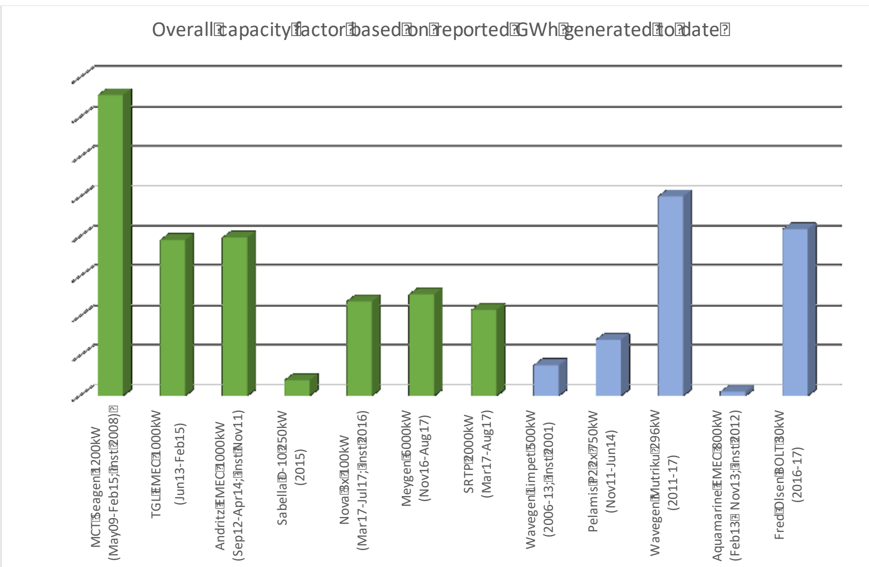

Figure 6 Estimated capacity factors (relative performance) (green bars = tidal; blue bars = wave)

Comparing machines on this basis shows that both the EVE and Fred Olsen WECs have performed comparatively well over a reasonable period of time. In a similar fashion, one would expect these figures to improve for projects currently operating. For the ARL MeyGen project, reported monthly output figures have been increasing as improvements have been made to machines and these have been re-deployed on site.

2.4 Overview of technology companies

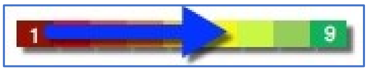

Figure 7 TRL assessment

Appendix B has been compiled to provide an overview of technology companies in the UK wave and tidal sector and their recent activities. The overview contains 50 companies, compiled from a database of more than 100 companies. The companies selected are those that have relevance to Scotland by undertaking or planning to undertake activities in Scotland and the UK, or those that can be considered to be significant internationally[7].

Whilst equal prominence is given to each company in the overview it should be noted that there is a wide variance in staffing, funding obtained to date and the stage of technical development. An independent indication of each company's TRL is provided for each company, although it should be noted that this is somewhat subjective, being based solely upon publicly available information. In principle, the higher the TRL number, the closer a technology is to being ready for the purpose it is intended; the publicly available evidence for this is based on the reported stage of testing (eg tank test, scale test, full scale, electricity generation, prolonged operation) although this in itself is not necessarily an indicator of eventual success. In addition, technology progression for a particular concept does not necessarily follow a linear process, so some caution is required interpreting these indications of TRL.

Indeed, it is worth considering the history of TRL assessment. TRLs were first established by NASA (Mankins, 1995) as a means of measuring how far a technology was from being deployed in space. They have since been adopted in many fields of innovation, including the EU's Horizon 2020 innovation programme. A criticism (Héder, 2017) of the current approach is that one of the original underlying concepts applied to space flight TRLs has been lost. This is the existence of an additional 'Technology Flight Readiness' requirement – the readiness level when a component is eligible for a space mission. This is not addressed in contemporary applications where a judgement is made wholly based on the entire system without necessarily considering the impact of individual components on system effectiveness.

For marine renewables key issues (TP Ocean, 2016; Wave Energy Scotland; ICOE2016, 2016) that have to be tackled include:

- Survivability [*ability to survive under marine conditions*]
- Reliability [*ability to perform a required function under marine conditions],* also dependent upon:
    - Availability [*ability of an item to be in a state to perform a required function under marine conditions*]

[7] Whilst active in this area, Chinese companies are not included as information is not readily available.

    - Accessibility and
    - Maintainability
- Installability
- Operability
- Cost effectiveness

These areas require design and systems engineering at a high level and, at a lower level, components able to meet fulfil these requirements. Careful design (for example using a process known as Failure Modes and Event Analysis [FMEA]) can eliminate or mitigate the effects of failure of single components, but ultimately it only through component and whole system testing that these elements can be verified and optimised over time. Even with well-established technologies, changes made to components and systems with the aim of improving cost and performance can sometimes bring a risk of worse performance due to factors that may not have been anticipated until implemented and demonstrated. This is not necessarily captured by contemporary TRL assessment.

Notwithstanding the limitations inherent in TRL assessment, a summary of the TRL levels of the companies contained within the overview is shown in Figure 9. None of the companies are yet believed to be at TRL9, the highest level, although some can be considered to be close. As can be seen there is a wide variance in TRL with a somewhat higher number of tidal companies at the highest TRLs but equally a mixture of both wave and tidal throughout. It is difficult to infer from this how far companies are from commercialisation; theoretically the higher the TRL level, the closer the companies are to proving their technology sufficiently that they could be commercially exploited; however, this will also depend upon cost, performance, continued investment and the market price available. Certainly, in order to be able to reach higher TRL levels implies a certain level of financial investment in design and testing that is unlikely to have been forthcoming if the commercial prospects were not seen as being attractive (and in particular if such finance has been privately sourced).

Also it should be noted that the technology overview does not include a significant number of supply chain companies such as those involved in component supply, marine operations, design, verification, consenting, surveying and other services and products which are vital to delivering marine renewables.

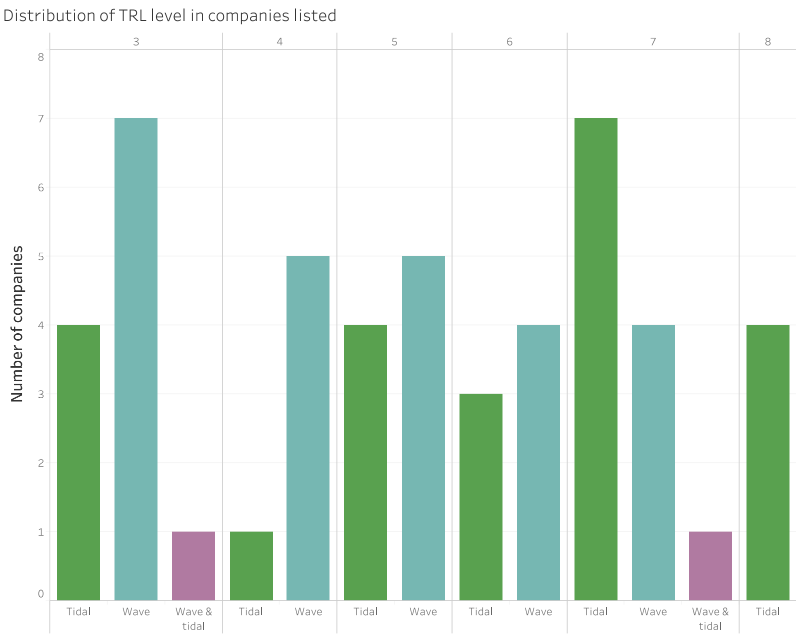

Figure 8 Distribution of TRL levels in companies listed (independently assessed)

The picture presented in the technology overview is quite diverse, both internationally and in terms of technological approaches being made to harness wave and tidal energy. Scotland - as a favourable location - has factored in the plans of many of these companies; in part, this is due to:

- Scotland’s reputation for supporting marine renewables
- Scotland’s wave and tidal resource availability
- WES funding programmes (for wave)
- EMEC and the Orkney supply chain’s strong track record
- Scotland’s academic facilities and capabilities; and
- EU funding available for testing (eg at EMEC or Flowave) from programmes such as Marinet and Foresea

Of particular note is the wide range of supply chain companies that have been involved in various WES projects and companies from outside the sector that have been brought in.

2.5 Industry interviews

A number of industry stakeholders were surveyed to obtain their perspectives on the current state of the industry. These included technology developers, project developers, supply chain companies, academics and those involved in public agencies. Full survey results are given in Appendix C.

2.5.1 Technology Readiness

Of the developers surveyed, none yet felt they had achieved energy convertor technology at TRL9.

In terms of numbers, there are more tidal developers who are either generating or expect to be generating electricity soon, supporting the notion that the tidal sector is more advanced and vibrant.

2.5.2 Funding & Commercial Readiness

The developers have attracted a mixture of private and public funding with investments ranging from tens of thousands to tens of millions of pounds. Developers think they will need to attract significant further investment. Half of the developers surveyed are targeting their company being profitable (defined as making a margin on equipment or electricity sales) within 1-3 years with the remainder being 3-5 years or >5 years. Collectively if all developers surveyed were to succeed, the estimated midpoint capital investment of those surveyed will be of the order of £300m in technology and project development, project build and operation and other activities. Whilst it is unlikely that *all* those surveyed will succeed, the amount is indicative of the level of investment required for a successful new energy sector to develop and is comparable with other sectors in the past. The ability to raise such funding, particularly from the private sector, will however depend upon there being a clear route to market.

A key challenge for the sector is to become profitable; only when this occurs can the sector be self-sustaining, even if dependent upon a supported tariff.

2.5.3 Obstacles to Progress

The most significant non-technological obstacle to progress in wave and tidal energy identified by developers – from a shortlist of pre-defined answers - was 'the lack of an electricity price that can sustain investment in projects', followed by 'lack of government prioritisation, strategy and support' and 'lack of investment'. In comparison, issues with grid, consented project sites and the availability of grant funding were ranked lower. The issue with the lack of a clear price signal is that it is very difficult to make an investment proposition based upon an unknown, particularly where a technology has yet to be market proven.

That said, some developers are trying to find ways to move forward despite this, including targeting of niche markets. In at least one case, a developer (ARL) has bid for a Contract for Difference (CfD), though they were unable to bid a price that was competitive enough with the mature offshore wind sector, and compatible with the available budget, in order to be successful[8]. Successful bids may, however, be possible in the future with grant funding lowering the capital cost. Feedback from most developers was that the UK government's decision last year to remove the 'minima' allocation of CfD contracts for wave and tidal energy was wrong and will hinder the sector's development. The minima would have guaranteed a minimum level of deployment for which money would be specifically allocated, with a CfD at fixed price of £310/300/MWh (31/30p/kWh) for wave and tidal respectively. Without the ring fenced allocation, marine renewables have to compete with the more mature – and cheaper - offshore wind sector and against significantly larger projects with associated economies of scale. Winning bids in the most recent allocation round had prices between £57.50- £74.75/MWh (5.7-7.5p/kWh).

In terms of technological obstacles, the biggest obstacles identified by developers from a shortlist of predefined answers were the lack of performance warranties and technology without proven reliability.

2.5.4 The Investment proposition

Developing a new energy technology requires an investment to be made. The investment may be private, public or a combination of the two. Public investment can be in the form of subsidies for energy production. Crucial to justifying this to the potential investor (whether public or private) is the expected return on investment and whether this balances the risks associated with investing.

For the public, this return on investment may be cheaper or more secure energy in the future or environmental, economic and industrial benefits if the products and services are home grown.

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[8] See (ARL, 2017) for Atlantis' statement on the CfD auction result. It appears that due to the pay-as-clear nature of the auction, the bid from Atlantis for MeyGen 1c would have broken the budget overall even though there was sufficient budget left to afford the project on its own. See (EDGE, 2017) for further explanation.

Certainly, without historic public investment in the form of premium tariffs for market deployment, the cost of zero carbon wind and solar generation would be much higher than would otherwise be the case. Generally, interviewees thought that the attitude of the public towards funding research and development in wave and tidal is favourable, which has been borne out by other surveys in the past[9].

However, most interviewees thought that the 'investment proposition' was not understood by the public or by the UK Government but was understood by the devolved administrations and the European Commission. This indicates a continued need to win 'hearts and minds' for the sector to make the case for public investment to stimulate private investment.

2.6 Common issues

In this section, we examine common issues that can act as barriers to the development of the wave and tidal sector.

2.6.1 Levelised cost of electricity (LCOE)

The LCOE, also known as the Levelised Energy Cost (LEC) is the net present value of the unit-cost of electricity over the lifetime of a generating asset. It is often taken as a proxy for the average price that the generating asset must receive in a market to break even over its lifetime. A high LCOE is a significant barrier to progress in wave and tidal energy, given the much lower LCOE for mature renewable technologies such as solar photovoltaic and wind. This section examines the key metrics that underpin LCOE and which are a focus for improvement to reduce cost.

Within the categories of Capital Expenditure (CAPEX), Operating Expenditure (OPEX) and Annual Electricity Production (AEP) the LCOE of a wave or tidal energy converter depends upon the following factors:

Element	Dependent upon	Typical target values
CAPEX	• Installed initial cost of the Energy Converter • Cost of associated balance of plant (submarine cable, substation, monitoring equipment)	• *For offshore wind, typical would be £3-£3.5m/MW installed*[10]
OPEX	• Annualised cost of equipment, staff, vessels and O&M base required to service the Converter • Annualised cost of spares and any mid-life refits • Other operating costs such as lease and permit costs, insurance and other services • Decommissioning costs at the project's end	• *2-6% of Capex/annum for a commercial scale project*

Yield (affecting AEP)	• Resource energy density
	  ○ for wave energy measured in kW/m width of wave, dependent upon wave height and period
	  ○ for tidal energy measured in kW/m^2, dependent upon tidal velocity
		• *10-40kW/m on average in regions of interest*
		• *2-3m/s; 4-14kW/m^2 on average in locations of interest*

[9] Ocean Energy had the lowest proportion of those surveyed opposing its use (4%) in the first 2012 DECC Public Attitudes Tracker. (DECC, 2015)

[10] 580MW Race Bank project cost £1.7bn (£2.93m/MW) – expected completion 2018; 92.4MW Aberdeen Bay project cost £300m (£3.24m/MW) – expected completion 2018. (Clean Energy Pipeline, 2017)

Element	Dependent upon	Typical target values
	• Energy capture ○ For wave energy, how much of a wave front is captured and absorbed in different sea states ○ For tidal energy, how much kinetic energy from the tidal flow can be absorbed across different tidal cycles	• *cf Point Absorber theory (can be wider than machine width)* • *cf Betz law (limits the theoretical maximum to 59% of the kinetic energy available)*
	• Energy conversion - The proportion of electrical energy generated from energy absorbed • The energy transmission - the proportion of electricity lost in transmission to shore/grid	• *eg >50-80% efficiency (dependent upon PTO losses)* • *eg <5%*
	• Yield may also be expressed as a 'capacity factor'; this is the percentage of the Converter's electrical rating that is produced on average considering resource variability over the year.	*For onshore wind turbines in the UK: 25-30%; for solar PV 10-15%; ie a 1MW onshore wind turbine may produce on average 250-300kW over the year; offshore capacity figures are higher.*
Reliability (affecting AEP and OPEX)	• The Energy Converter 'availability' – the proportion of time a converter is available to generate	*For a modern wind turbine: 99%; offshore, falling to: 95%*
	• This in turn depends upon the Converter's 'maintainability' – how quickly a Converter can be fixed when there is a problem that prevents or reduces generation	*From <1 day to several days*
	• This in turn can depend upon the Converter's 'install-ability' and/or 'accessibility' – the sea conditions (weather windows) required for recovery/installation or intervention and the equipment required to do this	• *Eg accessibility possible in wave heights of <1-2m* • *Eg vessel costs from £3k - £300k/day, dependent upon nature of work*
The cost of finance (affecting the discount rate)	• The overall project discount rate, dependent upon: • The gearing, the proportion of project investment that is debt • Debt interest rate • Debt repayment terms • The desired return on investor equity	• *Mature technologies: 6-12%* • *Mature technologies: 80-90%*[11] • *Typically: 2-6%* • *Eg: 10 years* • *Dependent in part on perceived risk/opportunity. Eg: >>10%*
Survivability (principally affecting design and thus CAPEX)	• The ability of the Energy Converter to withstand and survive extreme conditions on site. For a WEC, this might typically be the ability to withstand a 1:100-year storm wave. If the machine remains in-situ, the factor of safety applied to this design criteria clearly impacts upon CAPEX cost; if too conservative the cost of the machine may be higher than necessary; if not then the cost of energy will be unacceptably high due to the loss of the machine.	*This is a binary condition for LCOE; however, it may be expressed as an economic failure rate, eg an acceptable non-survival rate of (say) 1 in 10,000 machines*
Longevity (affecting economic lifetime of	• The project/equipment lifetime. This is also influenced by the cost of finance/ project discount rate. The higher this is, the less important long-term revenues are to the investment case.	*Typically >15-20 years*

[11] For projects with higher perceived risk, less debt or no debt may be available meaning the project discount rate must be higher to maintain the equity investor's targeted return, all other things being equal. However, in addition the equity investor may also require a greater return because of the risk profile, particularly if it is not clear whether a subsequent 'follow-on' project is viable (because of a lack of market tariff for example).

Element	Dependent upon	Typical target values
the system)	However high returns are not necessarily easy to achieve	
Project size (affecting CAPEX and OPEX per MW installed)	• Project economics are strongly influenced by the size of a project; small projects tend to have proportionately higher balance of plant costs and O&M costs; for example, the cost of installing a 300kW or 3MW cable is only weakly dependent upon the cable capacity; similarly the cost of establishing an O&M base has a certain fixed cost whether a project is 300kW or 3MW.	*UK Round 1 offshore wind projects: 30-60MW* *Today: 500-1000MW is typical.*

A crucial need for the sector is to establish these performance metrics in order to facilitate and underpin commercial investment in projects. Linked to this is the need to have a market which can accept the cost of energy produced; this may be a high value market (eg an offgrid application) or a politically supported market (eg if grid connected).

In terms of the current state of the industry, technologies are currently unable to compete in grid connected markets without subsidy. This should not be a surprise as bulk electricity supply is a commodity market and it would be unprecedented for a new energy technology to be able to be able to do so. In the UK the wholesale market price for electricity is 4-5p/kWh but this market price would be unlikely to stimulate new build of *any* generation technology. The consumer price for electricity is typically 12-15p/kWh. New generation wind and nuclear projects have (or had) CfDs at around 9-10p/kWh. New fossil fuel projects can only proceed with a subsidy from the Capacity Mechanism (paying for installed capacity with a commitment to generate for a certain time) which is not available for renewables.

Price for marine renewable electricity
The strike price for marine energy of ~30p/kWh which has been sought by most in the sector is high compared to the market price (5p/kWh) but relatively low compared to the feed-in tariffs for wind and solar which stimulated their development at a similar stage of maturity. Indeed, just seven years ago the price paid for solar PV generation in the UK was 42p/kWh. Similarly offshore wind was 15p/kWh but the cheapest winning bid in the last CfD round was 5.7p/kWh. In the case of marine energy to provide such a price incentive would likely have minimal impact on consumer bills due to the small quantity of generation incentivised; it could also be expected to fall relatively quickly as was the case with wind and solar. However politically this argument has not been won and at present marine energy projects must seek to compete with offshore wind which is now a very mature sector in comparison.

As noted above the reliability of energy converters is a key factor in the LCOE. Currently the proven track record of reliability of energy converters is relatively short; more operational hours are required to improve this and iterate and improve components and methodologies, including bench testing of components. However one of the best ways of stimulating this is via market deployment as has been seen with wind turbine development (see Section **Error! Reference source not found.**). Whilst the LCOE for bulk grid connected markets remains uncompetitive there are other niche markets which may tolerate a higher LCOE where marine renewables can potentially be better integrated than alternatives.

2.6.2 Project site availability

To sell machines to a customer requires a) the LCOE to be acceptable, b) the performance to have been appropriately verified and c) a viable project site that has already been developed. This requires:

- A viable resource
- A determination of the resource with high confidence, typically by sourcing data, numerical modelling and then by physical measurement on site.
- Infrastructure
- Access to customer (eg grid and grid capacity)
- Marine operations infrastructure – appropriate vessels
- Consents and permits
- Appropriate environmental studies to have been carried out in accordance with legislative and other requirements
- Leases/The legal right to use the public domain (seabed, sea area, foreshore) for the purposes of marine energy generation

Typically developing a project may entail gathering a year or more of baseline environmental data, detailed resource analysis, seabed characterisation, planning and consent (assuming that an agreement for lease has been obtained in advance of this) (see Figure 9). For offshore wind projects the costs of project development prior to final investment decisions being made can be of the order of £10m; the timescale would normally be >3 years. A marine project may cost less by virtue of being smaller however timescales are likely to be similar. Hence to justify this level of investment and time a reasonable certainty has to be had about whether there is a route to market. This is compounded under the current CfD system where planning consent and grid connection has to be in place prior to applying for a CfD (which may or may not be successful) whereas under the previous RO system (or feed-in tariffs), there was no risk of not obtaining the revenue. Indeed it may be argued that the only reason the current CfD system can work is because of the overhang of projects already partly or fully developed where the investment in project development has already been sunk.

Wave and tidal energy are both variable but highly forecastable. Wave energy levels may be forecast up to 3 days in advance with a high probability of success; in the case tidal energy, the resource is almost totally predictable.

Grid availability affects the route to market and is a key consideration for investors in technologies and projects. Without a clear route to market, investment will be difficult to secure for grid connected technologies, hindering development.

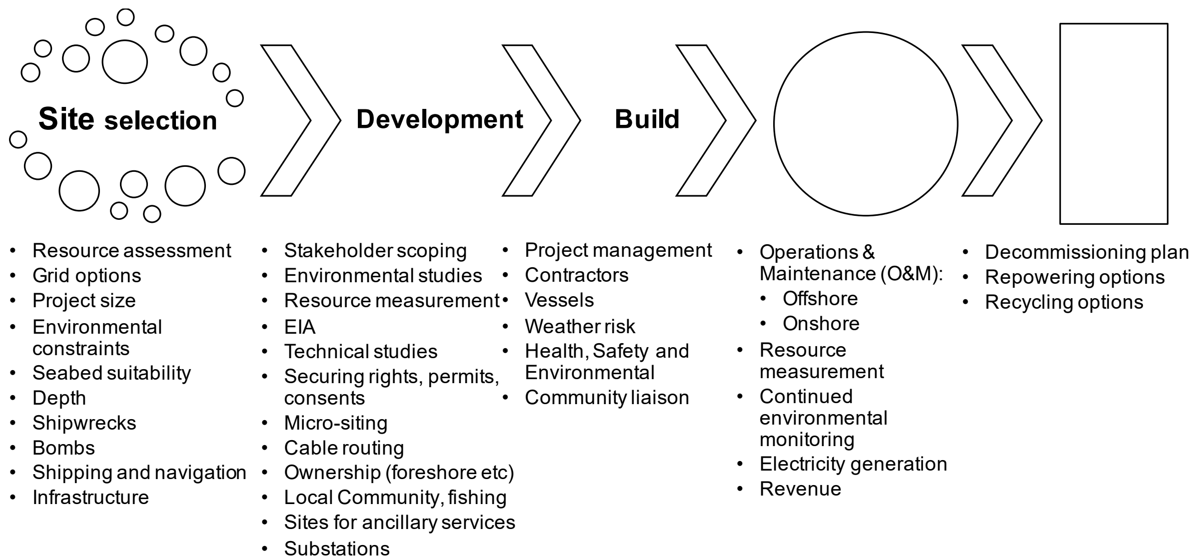

Figure 9 Process of selecting and developing an offshore project through to build, operation and decommissioning

2.6.3 Supply chain and enabling technologies

Developing marine energy projects also requires a well-developed supply chain with the necessary skills and experience to support marine renewable projects. Parallels may also be drawn with the wind industry where early machines were supplied with tractor gearboxes. As the wind industry scaled up so the supply chain invested; to produce a 100kW+ machine from the initial 50-80kW machines the gearbox suppliers could see that there was a market and invested to produce a version that met these requirements. The sector has thus grown through incrementally improving performance through investment by the supply chains in new product iterations, reducing the cost of energy. Some of the enabling technologies for marine energy include:

- Subsea power hubs with switchgear for collecting power and stepping up voltage for transmission to shore
- Improved installation methods to reduce cost and improve operating windows
- Cabling suitable for wave and tidal project locations
- Vessels capable of meeting requirements at acceptable cost
- Monitoring technologies

2.6.4 Infrastructure

A lack of suitable infrastructure can be a key limiting factor for establishing marine energy capacity; equally the provision of appropriate infrastructure can be a key enabling factor. This infrastructure is related to the type of energy being provided (wave / tidal) and the scale of energy production that is planned.

Examples include ports, piers, cranes, quayside facilities, laydown areas, office accommodation and grid infrastructure.

3 Context and policy environment

3.1 Global context

The wave and tidal energy opportunity is considered to be major in global terms. The International Energy Agency (IEA OES, 2017) has estimated the total worldwide theoretical wave energy and tidal energy resource (including tidal range) as being 29,500TWh/year and 1,200TWh/year respectively. In comparison, global electricity demand is currently ~20,000TWh/year (Caelulum Ltd., 2017).

3.2 European context

There is positive support for marine energy across several coastal states in the EU and within the European Commission in Brussels - marine energy was included within the Strategic Energy Plan Integrated Roadmap in 2012 (European Commission, 2017). Finance for innovation is also available (European Investment Bank, 2017).

As the European Energy Union plans comes forward, the ability to 'trade the variability' in renewable output across borders should be increased, allowing greater penetration of renewable electricity in the EU mix. There should be ready markets for both marine generating equipment and marine power produced in the UK, assuming a suitable trading relationship is negotiated before the UK leaves the EU and marine renewables can deliver electricity cost-competitively.

EU policy also affects areas such as emission targets, environmental quality targets, conservation management, licensing and permitting processes, social standards and human rights, economic development in economically stressed areas, etc. The uncertainties around these issues are likely to make investment in marine energy and the development of new and existing projects more uncertain.

While the UK is exiting the European Union, the actions of the Commission to support marine technologies will still have effect. The EU Research and Development programmes, such as Horizon2020, have been an important and growing source of funding, stimulus for progress and opportunity for collaboration and relationship building. The UK Government has expressed a desire to remain part of the Horizon 2020 programme but this will depend upon the final terms for exit.

3.3 UK context

The previous Renewables Obligation (RO) was a significant driver of UK renewables development and generation from 2002, with generation of 83TWh/year from renewables in 2016 from an installed capacity of 35.7GW (BEIS, 2017). Electricity Market Reform (EMR) was the UK Government's revised policy to incentivise investment in secure, low carbon electricity and improve affordability for consumers. The Energy Act (2013) introduced various mechanisms (a capacity market, Contracts for Differences) to ensure security of supply and provide long-term revenue stabilisation for new low carbon initiatives. Two CfD auctions have been held to date, contracting over 13 GW.

The UK's Climate Change Act commits the UK government to reducing greenhouse gas emissions by at least 80% of 1990 levels by 2050. Alongside significant investment in energy efficiency measures, National Grid estimates that an increasing in Electric Vehicles (EVs), heatpumps etc. could lead to a 25% increase in demand for electricity by the middle of this century (National Grid, 2017).

However, in relation to marine renewables, the ring-fenced allocation of funding to guarantee deployment of marine renewables (the 'minima' criteria) was removed in 2015. This change meant that marine renewables had to compete with more mature sectors such as offshore wind, with substantially lower cost of electricity generation.

3.4 Scottish context

Over the past 15 years Scotland has been largely successful in establishing and implementing a pathway to decarbonising its electricity sector by 2020. By 2016, the equivalent of 54% of Scottish electrical demand was met from renewable electricity generated in Scotland, a fivefold increase from 2001, and surpassing that produced by nuclear power in Scotland (Scottish Government, 2017c) (Scottish Government, 2017b). The 2009 Climate Change Act provides a legal requirement for the Scottish Government to enact policies to achieve an 80% reduction in GHG emissions by 2050 (from the 1990 level), with a new Bill expected to increase this target to at least 90% (Scottish Government, 2017c). The publication of the Scottish Government's draft Energy Strategy builds on this and presents the challenge of similarly decarbonising the transport and heating sectors which together make up 78% of Scotland's energy demand (Scottish Government, 2017b). This suggests a much larger requirement for renewable power in the future, particularly if carbon-free electricity is used for transport and heat (e.g. in the form of electric vehicles, electrolysis to produce hydrogen, electrically driven heat pumps and resistive heating[12]). The closure of Scotland's existing nuclear generation and the limited potential for continued onshore renewable development may well open opportunities for significant harnessing of Scotland's wave and tidal energy resources. Given the pace of marine energy industry development to date it may be some years before wave and/or tidal energy are significantly contributing to Scotland's electricity generation capacity. However, progress is being made.

3.5 Policy mechanism overview

In terms of the overall policy environment, development of marine renewables can be characterised by three key elements:

- Market drivers: Broad policy targets (eg for general renewables or carbon reduction targets)
- Market pull: Specific market enablement measures (marine energy production based incentives, tariffs)
- Technology push: Specific targeted grant programmes for marine energy

Each of these has been influenced by programmes enacted at a Scotland, United Kingdom and European level respectively.

3.5.1 Market drivers

The European Union has set targets for the percentage of energy that must be delivered by renewables by 2020 which were agreed by member countries, including the UK. The EU Emissions Trading Scheme (EU ETS) sets a price for carbon. The UK also has a carbon floor price and, as previously noted, the UK and Scotland have commitments to reduce GHG emissions.

3.5.2 Market pull

Energy policy is largely reserved to the UK government. However, matters which are not reserved, including the promotion of renewables, planning and other specific levers are devolved to the Scottish Government. In the past this included a short-lived Marine Supply Obligation followed by a subsidy framework offering multiple Renewable Obligation Certificates (ROCs) for each MWh generated in Scotland for wave and tidal energy. The established regime of five ROCs provided a notional income level around £300 per MWh[13]. This was eventually followed and adopted by the former Department

[12] In National Grid's 'two degrees' future energy scenario which meets the UK's carbon reduction commitment an increase in UK renewable generation from 34GW to 110GW (a >3x increase) is suggested; also included is 20GW of nuclear generation, which under current policies would not be installed in Scotland (National Grid, 2017).

[13] The base price for electricity was £50-60/MWh with the value of a ROC being around £50/MWh. 5 x ROCs plus the base price of electricity is ~£300/MWh (NFPA, 2017)

of Enegry and Climate Change (DECC) for the whole of the UK. However, under the current Electricity Market Reform (EMR) framework, CfDs are now set by the Department for Business, Energy and Industrial Strategy (BEIS), the successor to DECC.

3.5.3 Technology push

Grants are or have been available from a variety of agencies at Scottish, UK and European level, including the enterprise agencies (Scottish Enterprise, Highlands and Islands Enterprise), InnovateUK and research and development programmes such as the EU's Horizon2020 Programme (European Commission, 2017a). For wave energy, the Scottish Government established WES which is fully funded by the Scottish Government and can provide up to 100% funding to eligible technology projects to support the development of wave energy in Scotland (Scottish Government, 2017d).

3.5.4 Devolved administrations policy issues and opportunities

There appears to be much support for marine energy in the devolved governments (particularly Scottish and Welsh), though they have limited policy levers available to them. In the past the Scottish Government could set production incentives for marine renewables via the Renewables Obligation Scotland. Within the current policy framework the ability to do this has been removed.

However there remains the potential to support marine renewables through targeted funding (such as the allocation of €100m of EU structural funds in Wales (Marine Energy Wales, 2017) and to further develop initiatives such as WES in Scotland.

Also of note in Scotland are the plans to set up a publicly-owned, not-for-profit energy company that would purchase renewable energy and sell to the consumer at as close to cost price as possible (The Independent, 2017).

The devolved administrations have administrative control over consenting, and in Scotland, over leasing sites also. This could allow these administrations to ease the path of marine energy developers, though these issues have not been seen as the main barriers to progress. Some uncertainty persists from how the current EU nature conservation regime will be translated into UK law, and how this will affect consenting in the future.

4 History of the development of the wave and tidal sector to date

4.1 Timeline

Table 2 provides a summary of key events in the development of the wave and tidal sector in the UK from a policy and funding perspective.

Table 2 Key events in the development of wave and tidal energy in the UK

Date	Key events	Associated impacts and activities
1970s	Wave energy R&D started in response to the 1973/4 oil crisis, work done by the Central Electricity Generating Board (CEGB) and academia.	Development of Salter's Duck, increasing understanding of waves with benefits to offshore oil and gas sector.
1980s	Wave energy R&D halted by UK government[14]	Sizewell B nuclear construction started, intended to be the first of many but derailed by significant cost overruns and delays.
1998	First premium tariff for wave energy allowed to be bid under SRO3 (NFFO).	Three small projects awarded tariffs (Wavegen, Pelamis & Seapower).
1999	Parliamentary Marine Foresight Panel Report published (DTI, Office of Science and Technology, 1999).	Test centre recommended in report
2001	DTI admits closing wave R&D programme in 1980s was 'a mistake' (Hansard, Science and Technology Committee, 2001). Installation of Limpet at Islay.	Limited R&D funding available from DTIs 'new and renewable energy programme'.
2002	RO introduced replacing Non-Fossil Fuel Obligation (NFFO)/Scottish Renewables Order (SRO) – 'one size fits all' – more costly technologies must wait until all cheaper technologies are deployed first[15].	First Renewable Realities event held in Orkney attracting international interest. Pelamis raises £7.5m in venture capital for build of a full-scale prototype.
2003	Energy white paper produced. Innovation review produced suggesting need for R&D funding of marine renewables.	2003 white paper stated that no 'farm' multi-machine projects in marine energy would happen until after 2015 and only after progress was reviewed in 2010.
	EMEC established, four wave berths. Wave Hub first proposed	Led by strong support from Scotland. Funded by SG, HIE, OIC and DTI
2004	First electricity generated from offshore wave power.	750kW Pelamis wave power prototype P1 installed at EMEC.
	Oxera models deployment potential of 5000MW of marine by 2025 for DTI under an 'enhanced marine' scenario	Enhanced marine included capital grants of 50% to 2009; thereafter 20% to 2015.
	DTI neglects to consider marine renewables in its oil and gas focussed Strategic Environmental Assessment (SEA)	In response Scottish Executive initiates Marine renewables SEA as without this no commercial projects can proceed
	Patricia Hewitt announces that there would be a £50m Marine Renewables Deployment	As a result, DTI prevents Technology Strategy Board (now InnovateUK) from funding marine

[14] "The programme was radically scaled down in 1982, after an internal, and unpublished, government report predicted that wave energy would never deliver electricity at a competitive price." (Science and Technology Committee, 2001)

[15] Renewable technologies benefitted from receiving a ROC for each MWh generated in addition to the market rate for electricity. Typically the market rate for electricity was £40-50/MWh (4-5p/kWh) with the ROC price being similar. The combined value therefore could be £80-£100/MWh (8-10p/kWh). This was different from the previous SRO/NFFO scheme where technologies such as wind and wave would bid for a price but only within their technology group, hence wave was not expected to directly compete with wind.

Date	Key events	Associated impacts and activities
	Fund.	renewable technology development.
2005	Marine Renewables Deployment Fund (MRDF) rules established by Future Energy Solutions (FES)/Atomic Energy Authority (AEA) Technology. 20% grant limited to £5m; revenue limited to 7 yrs/£4m but both could not be utilised to full extent. Lengthy delays claimed due to need for EU approval (although this is disputed by the EU).	Onerous entry requirements and not investor friendly (making a return on investment was not allowed). Total Department of Trade and Industry (DTI) R&D funding for all wave and tidal device R&D from 1998 to 2005: £9.2m.
2006	MRDF opens for calls. EMEC completes tidal berths at cost of £7.2m. First grid connected tidal stream energy converter at EMEC. DTI offers £4.5m towards Wave Hub (DTI, 2007a).	Despite some utility investors willing to provide 80% of the capital costs of marine projects, no companies are able to meet MRDF funding rules and draw down funding.
	Government announces intention to band the RO (DTI, 2006).	Recognition that the existing policy of only bringing forward the most developed technologies first was flawed.
2007	Consultation to band the RO ("Reform of the Renewable Obligation") (DTI, 2007b)	Ernst & Young modelling for DTI indicates that 5 x ROC required for marine initially (Ernst & Young, 2007) however Government's preferred option is not to support wave and tidal energy with a dedicated band.
2008	Government creates five bands for the RO in its response to the consultation.	Offshore wind in 'post-demonstration' band to receive 1.5 x ROC. Wave and tidal stream grouped with other technologies in 'emerging' band to receive 2 x ROC from April 2009. (BERR, 2008a)
	First 3 multi-machine wave farm installed in Portugal for private developer under €9m contract, with €1m grant to build substation.	Private investment stimulated by Portuguese feed-in tariff of 25€c/kWh; Marine Supplier Obligation established in Scotland (forerunner to ROC multiple for marine).
	UK Renewable Energy Strategy Consultation launched to determine how to meet the EU target for 20% energy from renewable sources. Questioned how RO could be adapted to ensure that it effectively supported emerging technologies as well as existing ones. (BERR, 2008c)	Associated Redpoint modelling for BERR indicated that with proposed 2 x ROC band no marine renewable capacity would be deployed by 2020. (Redpoint Energy Ltd, 2008)
	Launch of £10m Saltire Prize	
2009	Implementation of RO banding, but only at 2xROC for marine	Intentionally not set at the level necessary to stimulate marine renewable deployments[16] As a result E&Y revises down its forecast of marine deployment by 97% for 2020 (BERR, 2008b)
	£22m MRPF created, allows commercial investment in prototypes; SG also provides £13m WATES fund	Support for building of prototype wave and tidal energy machines in the UK
	The Crown Estate initiates Pentland Firth and Orkney Waters leasing round	1600MW of project sites leased

[16] "it is not the Government's intention through banding to provide all projects with exactly the support level they need as this would not incentivise developers to site and build economic projects" "We propose, therefore, to set the banding of these technologies so that they are provided with a target level of costs that they can aim for with a prospect of support for an economic business case." (DTI, 2007b) also (BERR, 2008a)

Date	Key events	Associated impacts and activities
2010	£42m MRDF withdrawn. SG provides £13m WATERS1 funding.	
	Wave Hub test site installed	Further modelling carried out for DECC by E&Y confirming need for 5 x ROC (Ernst & Young / Black & Veatch, 2010)
2011	June 2011 DECC announced £20m MEAD funding available.	Intention of supporting two array projects to be supported with additional funding from GIB (which was not forthcoming).
	ROC multiple established for wave and tidal energy	Support available for 20 years at a level of ~30p/kWh
2012	Multiple ROC to be removed and replaced with unknown level of CfD.	Despite the RO banding just established, new evidence needed to support the price.
	Call opens for MEAD. Array must expect to generate 7GWh/year (ideally 10GWh/year). Project must be energised and operating by 31 March 2016 but all grant payments must be made before 31 March 2015. SG provides £8m WATERS2 funding	Marine Current Turbines and MeyGen apply for funding from MEAD (£10m each). Projects must be already developed or developed exceptionally quickly to qualify and must have grid connection; risks over uncertainty on timescale for project development and market with closure of RO.
2013	SG provides £13m MRCF funding	
2014	Strike price for marine confirmed at £305/MWh (30.5p/kWh) – similar to RO level, but only for 15 years (25% less revenue than that under the 20year RO)	Various players exit the market (eg Siemens, Pelamis, Aquamarine) – only half MEAD funding allocated (£10m to MeyGen)
2016	Strike price £310/300 and then £300/295/MWh respectively for wave and tidal but minima removed; wave and tidal must compete with offshore wind in the same emerging technologies pot	Small-scale wave and tidal projects will only obtain a CfD if they can compete with mature technology GW scale offshore wind projects; successful bids likely to be <<10p/kWh

4.2 UK public funding

A summary of all UK public funding spent on wave and tidal energy is presented in Figure 10. These funding sources include:

- All DECC expenditure over £500 2010-15
- Previous DTI/BERR/DECC programmes
- Scottish Government
- Technology Strategy Board/ InnovateUK
- Crown Estate
- Highlands and Islands Enterprise
- Scottish Enterprise
- Research Councils e.g. the Engineering and Physical Sciences Research Council (EPSRC)
- European Regional Development Funds (ERDF)/Welsh European Funding Office (WEFO) /SW England Regional Development Agency (SWRDA)

The red bars indicate grants for industrial R&D and technology prototypes, the purple bars are non-grant funding (loans or contracts), yellow is academic R&D and blue is funding is that supported infrastructure such as EMEC, Wave Hub, NAREC and FloWave (~£100m). Note that funding allocated to the sector is higher than this but includes funding that was never spent (such as the MRDF) or where recipients were unable to meet grant conditions to draw down grants (eg Siemens who were unable to develop and secure and grid connection for their Skerries project in the time allocated according to government budget cycles[17] and as a result the grant was removed (Renews, 2014).

[17] "The availability of any funding is restricted to the CSR period and therefore all grant payments need to be

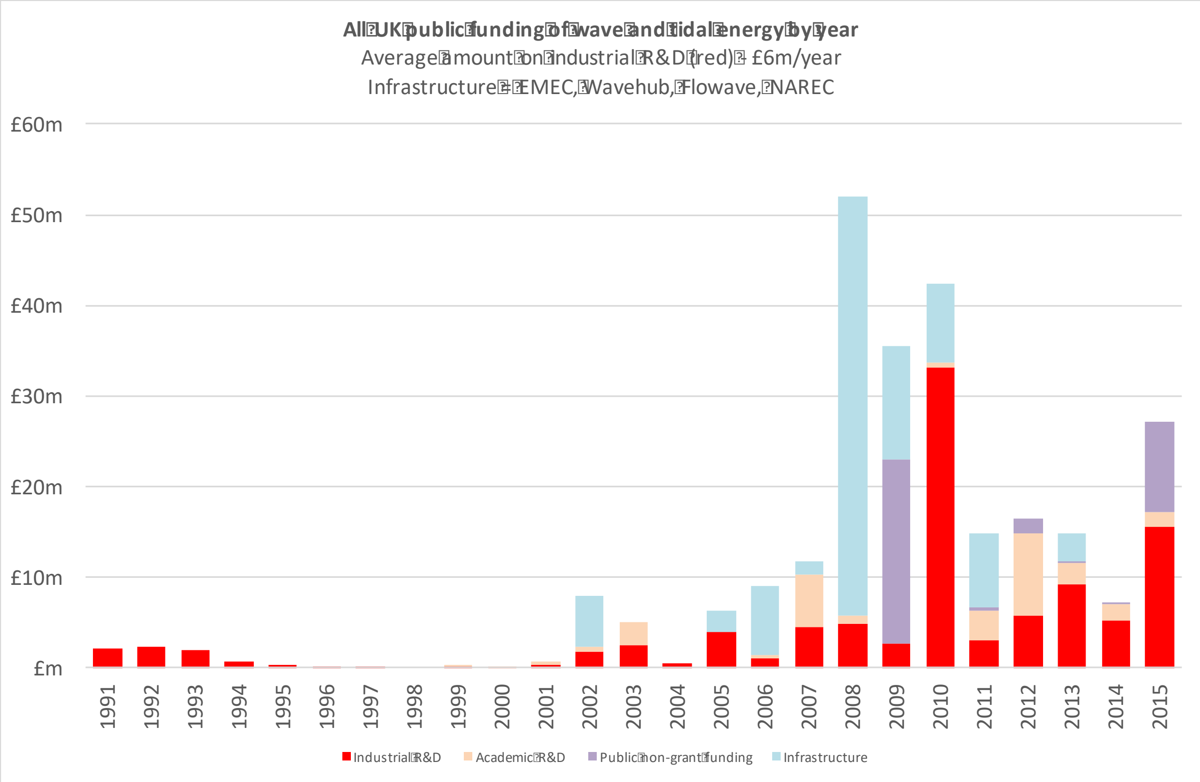

Figure 10 All UK public funding of wave and tidal stream energy by year

The UK has seen little enthusiasm for market enabling mechanisms for wave and tidal energy: these were thought to be too expensive, despite their immature status and the limited impact on consumer costs. It took until 2011 for the UK government to provide a tariff at a level that matched the government's commissioned evidence of what would be needed to support wave and tidal generation projects (via the banded Renewables Obligation). The planned removal of the RO and the introduction the following year of the new Contract for Difference mechanism for zero carbon generation (primarily to support nuclear projects) with an unknown level of support created significant uncertainty for investors. It is the authors' view that the subsequent reduction in tariff length to 15 years from 20 years for all non-nuclear projects under the CfD mechanism effectively reduced the revenue available to repay the initial investment by 25%; this in turn affected investor appetite who in many cases could not see how further investment in technology and projects could be justified. To date the UK has provided 31,778 ROCs for marine energy in the UK at a total cost of £1.6m[18].

5 Conclusion

Currently the wave and tidal sector is at an early stage of development, both technically and commercially, relative to other established renewable energy technologies such as solar photovoltaic and onshore/offshore wind. Technically it has been proven that wave and tidal energy converters can deliver electrical power into the grid, which was not the case only a decade ago. The track record of demonstrated performance at this stage is quite limited, although notable advances have been made in the past 12 months, particularly in tidal stream energy. Deployed capacity is also small both in the

made by the 31st March 2015", DECC MEAD Discussion Paper 22nd November 2011. MEAD opened in April 2012 with a closing date for applications of 1st June 2012. The rules required that to qualify a project needed to have in place: an agreement for lease, a grid connection agreement, finance, a formal scoping letter from relevant consenting bodies and baseline environmental monitoring already commenced. Grid connection had to be completed before 31 March 2016. (DECC, 2011)

[18] Caelulum analysis of Ofgem ROC/REGO register. Assumes ROC price of £50/MWh.

UK and globally, but several companies have ambitious plans for market expansion.

A small number of companies have received income from selling marine energy converters to customers or from self-developed generation projects. In most cases the scale of such projects (being either first stage or development projects) is such that a positive return on investment is unlikely at this stage. A key target for the sector is to become financially self-sustaining, whereby profits generated from: (a) the sale of marine energy converters can be reinvested in continued technical development; and/or (b) electricity sales from generation projects can be reinvested in continued project development. In this way, a virtuous circle of investment and deployment can occur to optimise and drive down the cost of energy. For this to occur depends on both the technology development and access to a market at the cost of generation. Historically to bring forward emerging renewable technologies, feeder markets have been created which have largely been politically driven. It is difficult to find any example where a new energy technology has been created through R&D alone and able to compete directly against much more mature technologies without having had some niche or feeder market deployment first, in order to drive down costs.

Against this backdrop, in wave energy, WES is playing a vital role in continuing to develop wave energy technologies and to foster a greater understanding of the technical challenges to be overcome. In tidal energy, good progress is being made with some of the world's leading technologies and projects based in Scotland with ambitious plans for expansion.

Within the wider supply chain, companies have benefitted from selling services and components to the marine renewables sector both locally and internationally. Scotland is widely seen as a 'go to' for many countries interested in harnessing their marine energy resources. However, as with technology developers, there have also been substantial supply chain investments that have as yet not have been able to show a return on investment.

Similarly, we have seen reasonably-sized investments in the development of project sites; obtaining consents, undertaking environmental and technical studies, seeking grid connection agreements, and technical and commercial assessments. Clearly the investment required to undertake this work can only be recouped once a project is able to reach a financial close and proceed to construction. At this stage, the project developer may be able to recoup their investment by selling the project or by continuing as a project shareholder, able to receive income from the project.

To develop a new energy technology requires drive, enthusiasm and investment. Most investment to date in the wave and tidal sector in terms of the supply chain, technology and project development has come from the private sector. This has been stimulated by government policy and market signals. For continued progress to be made this needs to be built upon to mobilise further private investment.

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Appendix A Global projects

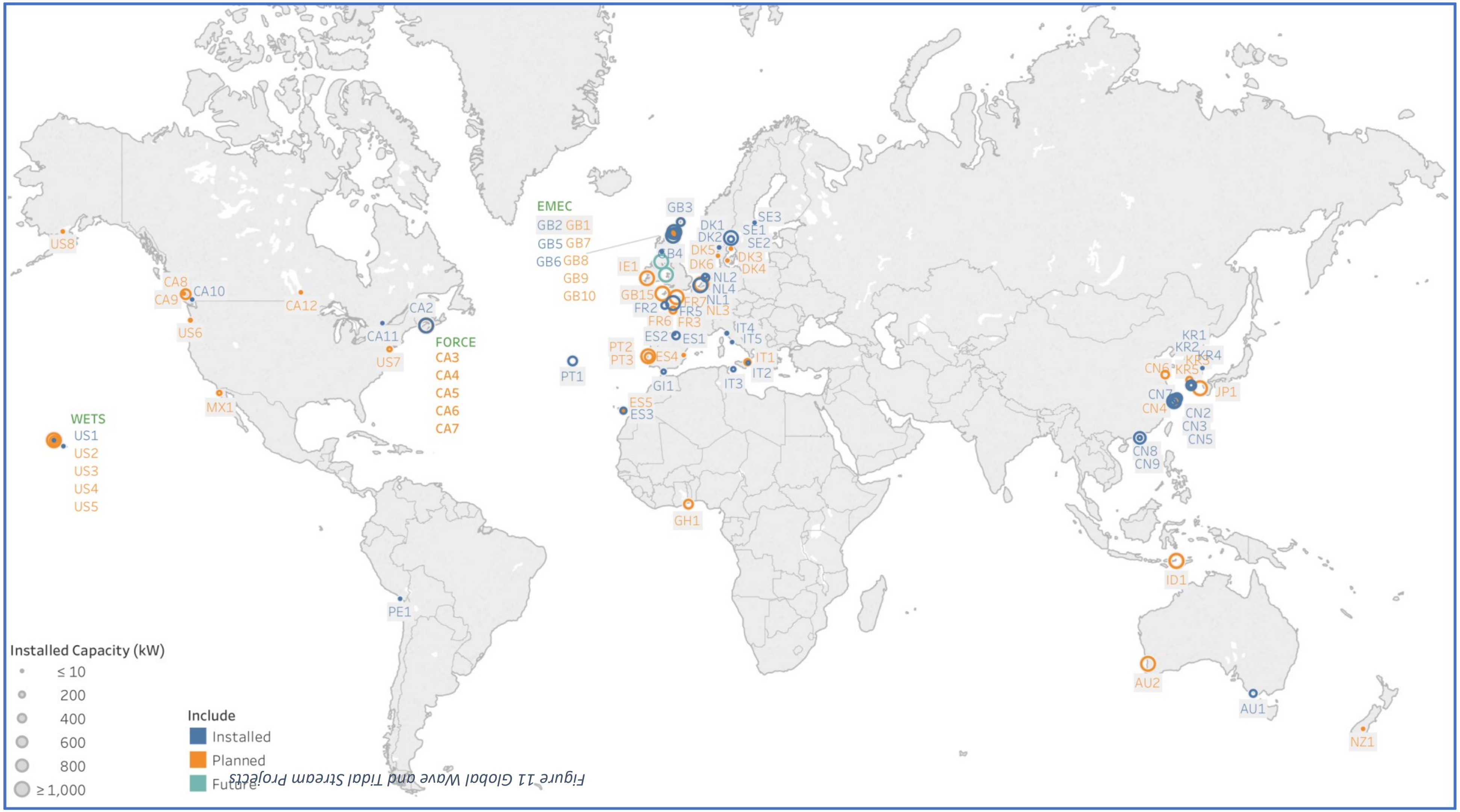


Figure 11 Global Wave and Tidal Stream Projects

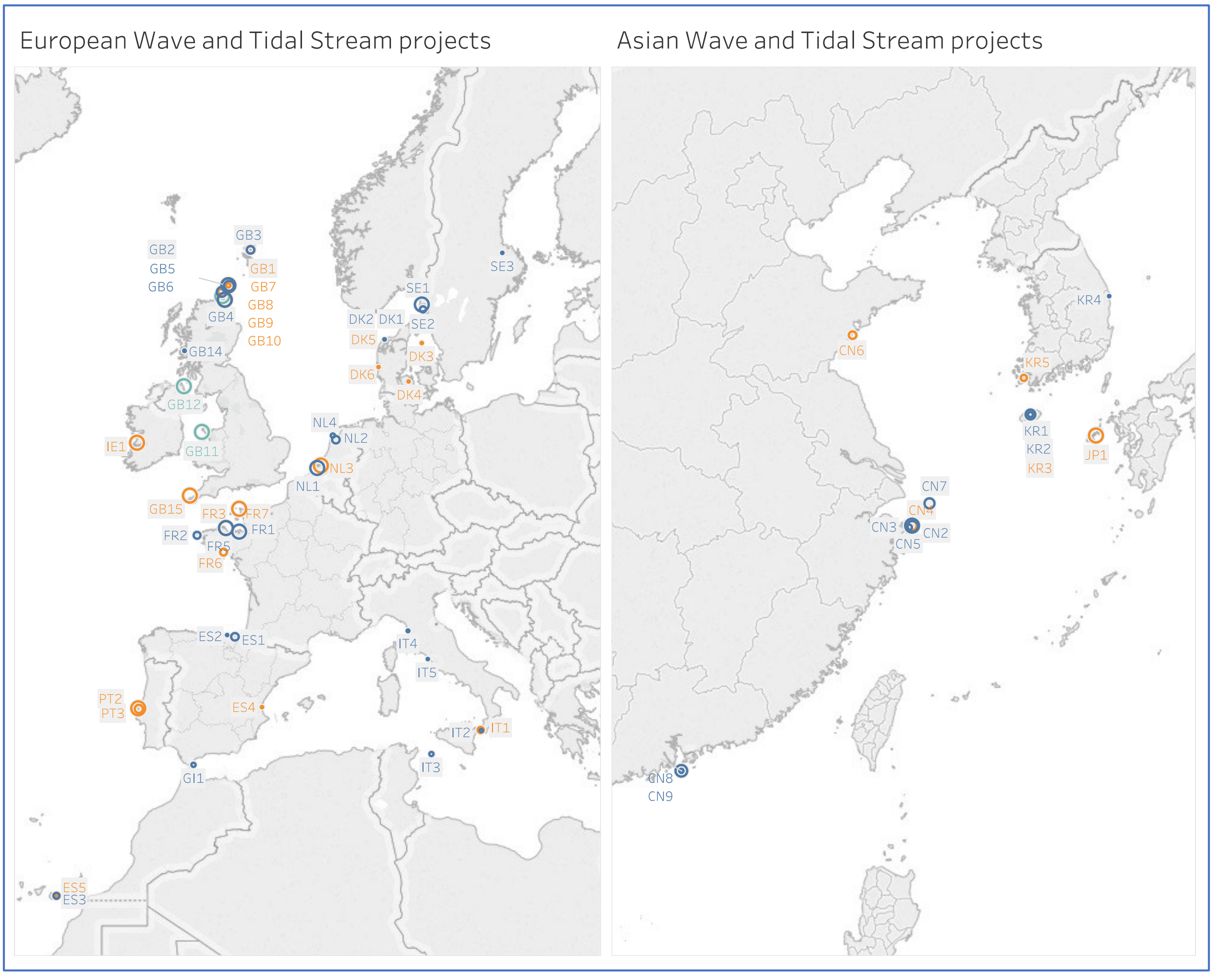


Figure 12 European and Asian wave and Tidal Stream projects

A.1 Tidal Stream project sites

Currently approximately 16.5MW of tidal stream has been reported installed to date (including projects in the UK) with a further 20.8MW planned to be deployed in the near future (orange text in table).

Table 3 Global Tidal Stream project sites

Country	ID	Project	Place	Status	Capacity (kW)
Canada	CA2	Cape Sharp Tidal Venture/ OpenHydro	FORCE Nova Scotia	2 MW installed in 2016; operational and grid connected	2,000
	CA3	Cape Sharp Tidal Venture/ OpenHydro	FORCE Nova Scotia	2 MW planned deployment in 2017	2,000
	CA4	Black Rock Tidal Power / Schottel	FORCE Nova Scotia	Planned deployment in 2017 – 5 MW total	5,000
	CA5	Minas Tidal Limited Partnership / Tocardo	FORCE Nova Scotia	Planned deployment in late 2017 – 4 MW total	4,000
	CA6	Atlantis Operations Canada	FORCE Nova Scotia	Planned deployment in 2018 – 4,5 MW total	4.5

Country	ID	Project	Place	Status	Capacity (kW)
	CA7	DP Marine Energy / Andritz	FORCE Nova Scotia	Planned deployment in 2018 – 4,5 MW total	4.5
	CA8	Mavi Innovations	Blind Channel Resort and Marina	Planned deployment in late 2017 (may be >22kW)	22
	CA9	Water Wall Turbine	Dent Island, British Columbia	Deployment in 2016 – 500 kW total	500
China	CN2	LHD Tidal Current Energy Demonstration Project	Zhoushan, Zhejiang Province	Operational; total installed capacity is 3,4 MW. Power generation >170MWh	1,000
	CN3	Zhairuoshan Tidal Energy Power Demonstration Station	Zhairuoshan Island, Zhejiang Province	Operational; 120 kW tidal current turbine +60 kW tidal current turbine. >30MWh	180
	CN4	Zhoushan Tidal Current Energy Demonstration Project	Zhoushan, Zhejiang Province	Consent authorised	450
	CN5	Daishan Tidal Current Technology Demonstration Station	Zhoushan, Zhejiang Province	2×300 kW tidal current turbine installed	600
	CN6	Zhaitang Island Hybrid Power Station	Zhaitang Island, Shandong Province	Demonstration project has been concluded	300
France	FR2	Sabella D-10	Ushant, Fromveur race	7 month operations, produced 10MWh. On maintenance/upgrade.	250
	FR3	Oceanquest	Paimpol Bréhat	Consent authorised; Variable depths, low sensitivity to current orientation	1,000
	FR5	Pampol-Bréhat / Open Hydro	Paimpol Bréhat	16m OpenHydro technology, 2 turbines, installed	2,000
Italy	IT1	GEM	Strait of Messina	Consent authorised; Planned 2018	200
	IT2	KOBOLD	Strait of Messina	Deployed in 2000	60
Korea	KR5	KIOST TEC/Active-controlled HAT	Uldolmok	Planned to operate in 2017	200
Nether-lands	NL1	Tocardo tidal turbines	Eastern Scheldt barrier	Operational; Tocardo T2 turbines	1,250
	NL2	Tidal Test Centre	Den Oever	Operational; Tocardo T2 turbines	300
	NL3	Pentair fairbanks Nijhuis	Grevelingendam	Planned for 2017; Part of the planned TTC (Tidal Test Centre)	1,000
	NL4	Bluetec	Texel Island	Operational; Tocardo T2 turbine (1)	100
New Zealand	NZ1	Vennell Marsden	Otago	Array design technology; conceptual stage	n/a

Country	ID	Project	Place	Status	Capacity (kW)
United Kingdom	GB3	Nova Innovation M100	Shetland	Fixed horizontal axis turbine (3 x 100kW)	300
	GB4	Atlantis Resources Ltd/ Andritz Hydro Hammerfest	MeyGen, Scotland	Fixed horizontal axis turbine (4 x 1.5MW)	6,000
	GB5	EMEC/ Scotrenewables SR2000	EMEC, Falls of Warness, Orkney, Scotland	April 2017: peak power of 2MW; 18MWh over 24 hrs continuous generation	2,000
	GB6	EMEC/ Nautricity	EMEC, Falls of Warness, Orkney, Scotland	Installed in April 2017	500
	GB7	EMEC/ Sustainable Marine Energy	EMEC, Falls of Warness, Orkney, Scotland	Rock anchors installed, wet test completed	100
	GB8	EMEC/ Tocardo tidal turbines	EMEC, Falls of Warness, Orkney, Scotland	Temporary Foundation System installed, accredited for ROC payments for 1.4MW	2,000
	GB9	EMEC/ OpenHydro	EMEC, Falls of Warness, Orkney, Scotland	Marine Scotland consent received for 2x 2MW, no timeline defined at present	4,000

A.2 Wave Power project sites

Approximately 7.2MW of wave power projects have been reported as installed to date (including projects in the UK) with a further 10.5MW planned to be deployed in the near future.

Table 4 Global Wave Power project sites

Country	Map ID	Project	Place	Status	Capacity (kW)
Australia	AU1	BioPower	Port Fairy	Installed Port Fairy with O-Drive	250
	AU2	Carnegie	Garden Island	1MW CETO6 planned following 240kW CETO5 test in 2015 and 80kW CETO4 in 2011	1,000
Canada	CA10	Mermaid Power	Keats Island, British Columbia	Operational; rated 11 kW at 32 inch waves	11
China	CN7	Shengshan Island Isolated Hybrid Power Demonstration Station	Shengshan Island, Zhejiang Province	Operational: 300 kW wave energy, 150 kW wind turbines, 50 kW bioenergy, 25 kW solar thermal	525
	CN8	GIEC Wanshan Island Isolated Hybrid Power Demonstration Station	Wanshan Island, Guangdong Province	Installed: 300 kW wave energy, 100 kW wind turbines and 300 kW solar panels	700
	CN9	CSIC710 Wanshan Wave Energy Demonstration Project	Wanshan Island, Guangdong Province	Installed	100
Denmark	DK1	Wavepiston	DanWEC, Hanstholm	Installed	12

Country	Map ID	Project	Place	Status	Capacity (kW)
	DK2	NEMOS	DanWEC NB, Hanstholm	Operational	1
	DK3	CrestWING	Kattegat	Consent authorised	30
	DK4	Weptos	Lillebælt	Consent authorised	6
	DK5	Resen Waves	DanWEC NB, Hanstholm	Consent authorised	1
	DK6	ExoWave	Hvide Sande havn	Consent authorised (<1kW)	<1
Ghana	GH1	Seabased	Ada Foah	Was working on a first phase in 2015	400
Gibraltar	GI1	Eco wave power	Gibraltar	Installed, 5MW planned	100
Ireland	IE1	Westwave	Killard	Planning permissions	5,000
Italy	IT3	ISWEC	Pantelleria, Sicily	Deployed in 2016	100
	IT4	H24 WEC	Marina di Pisa	Deployed in 2015	50
	IT5	REWEC-3	Civitavecchia Harbour, Civitavecchia	Operating in 2017; 136 chambers for 20kW each (2.7MW total)	20
Korea	KR1	Yongsoo WEC / OWC	Jeju	Started operation in 2017. 2 x 250kW	500
	KR2	INWave WEC / Onshore-based disk buoy	Jeju	In operation since 2015	135
	KR3	KRISO Floating WEC / Pendulum Utilizing Standing Waves	Jeju	Consent authorised; planned to deploy in 2018	300
	KR4	Hwa Jin WEC / Heaving semi-spheres with hinged arm	Uljin	Operated in 2016	30
Mexico	MX1	WEC device Exclusive High-Tech (DINA)-UNAM	Ensenada, Baja California	Consent authorised; under development for its test at an open sea site.	100
Peru	PE1	Atmocean	ilo	2015, Atmocean deployed two full size component systems off the southern coast of Peru	10
Portugal	PT1	Pico Plant	Azores, Pico	Operational since 2007	400
	PT2	AW-Energy/Waveroller	Peniche	350 kW consented and deployment planned for 2017; 1 MW consented	350
	PT3	Bombora Wave Power	Peniche	Planned; preparation of consenting phase submission	1,500
Spain	ES1	Mutriku wave power plant by EVE	Mutriku, Basque Country	Operational; more than 1.3 GWh produced during 5 years of operation	296
	ES2	MARMOK-A-5 by Oceantec	BiMEP, Basque Country	Under test -Floating OWC device	30
	ES3	UNDIGEN+ by Wedge Global	PLOCAN, Canary Islands	Under test since 01/2014 - Direct Drive Technology	200
	ES4	Butterfly by Rotary Wave	Valencia	Decommissioned; grid-connected device expected in 2017	7

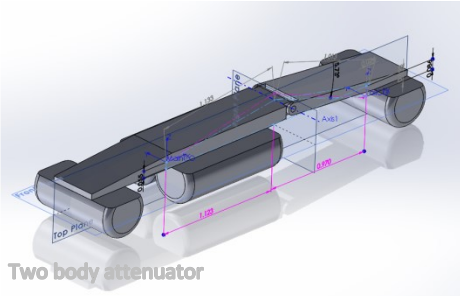
Country	Map ID	Project	Place	Status	Capacity (kW)
	ES5	WIP10+ by EnerOCEAN	PLOCAN, Canary Islands	Consent authorised; in combination with Offshore Wind (capacity TBD)	0
Sweden	SE1	Sotenäs/point absorber	Sotenäs, Sweden	OEA states as operational (but according to website, the project ended in Feb 2017)	3,000
	SE2	The Lysekil wave energy research test site	Lysekil, Sweden	Operational	200
United Kingdom	GB1	Laminaria	EMEC, Billia Croo, Orkney, Scotland	Consent authorised; deployment in 2017	100
	GB2	Fortum/Wello	EMEC, Billia Croo, Orkney, Scotland	Operational since March 2017	500
	GB11	EMEC / Corpower Ocean	EMEC, Scapa Flow, Orkney, Scotland	Due 2017	50
United States of America	US1	AZURA Wave	Hawaii	Installed	20
	US2	Fred Olsen Autonomous Sea Power/ BOLT Lifesaver	WETS, Kaneohe Bay, Hawaii	Operational; 17.9 MWh energy produced, 165 days of uninterrupted power production as of end 2016	30
	US3	Northwest Energy Innovations/ Azura	WETS, Kaneohe Bay, Hawaii	Planned project with secured berth at an established test site; MW-scale device in development; deployment planned for 2019	1,000
	US4	Ocean Energy (OE) USA/OE Buoy	WETS, Kaneohe Bay, Hawaii	Deployment at the 60m berth at WETS planned for fall / winter of 2017.	500
	US5	Columbia Power Technologies/ StingRAY	WETS, Kaneohe Bay, Hawaii	Planned project with secured berth at Navy WETS test site	140
	US6	Resolute MarineTM Energy/ SurgeWEC	Camp Rilea, Oregon	Planned project with secured berth at an established test site	50

Appendix B Marine Renewable Technologies

The following companies have been selected to provide an overview of the state of the wave and tidal sector and builds on similar reviews carried out in the past[19]. This list of 50 companies has been compiled from a database of 100 companies with those being selected having or intending to have activities in Scotland or the UK or are significant internationally.

[19] RenewableUK State of the Industry reports 2010-13. See for example (RenewableUK, 2012)

4c Engineering


Two body attenuator

Wave

4c Engineering is an engineering and technology development company specialising on delivering solutions to the most challenging of problems. Based in Inverness, Scotland and partnered with 4c Design, their staff and associates bring together significant experience in mechanical engineering, mechatronics, marine energy technology, prototyping and industrial design.

Working with AWS & Seapower (Ireland) in WES NWEC and PTO projects. April 2017:Succeeded in passing to Stage 2 of WES NWEC (£660k).

Albatern


Squid and WaveNet

Wave

Albatern has developed an array-based technology using linked wave devices designed to be an alternative to diesel generation in fish farms and other off-shore applications. A sophisticated multi-generator power-take-off system is used to optimize power generation in varying wave conditions. The company's focus is on maximising power yields and reducing costs with standard repeated components and easy transport, deployment and maintenance. Collaborating with Marine Harvest.

Oct 2016: Albatern installed its WaveNet array featuring six 7.5kW Squid devices at a fish farm off Ardnamurchan. Funded by £720k from WES.

Andritz Hydro Hammerfest


HS Series turbines

Tidal

ANDRITZ HYDRO Hammerfest (AHH) has more than 15 years of knowledge and experience in hydropower, wind energy, as well as the offshore oil and gas industry, The company strives to be the leader in the development of technologies capable of providing full turnkey solutions to customers by harnessing the high energies and predictable power potential of tidal streams. AHH completed the testing of its HS1000 turbine at EMEC. The company has a UK subsidiary based in Glasgow with shareholders Andritz and Iberdrola.

Nov 2014: Andritz won order for 3 x AHH turbines for ARL MeyGen project. Jan 2017: installation of all three turbines completed. July 2017: Following shore based improvements, two turbines reconnected to MeyGen project with third to follow in August.

Aquantis


AQ Series Turbines

Tidal

Formed in 2011. Founder Jim Dehlsen has long history in the development of wind turbine technology, founding Zond (acquired by GE). Aquantis Turbines convert the kinetic energy of either gyre or tidal ocean currents to electric power. The turbines integrate well proven power generating technology with a stable spar buoy vessel, moored to anchors on the seabed. The power generating system is driven by an upstream rotor with variable pitch blades. Surface entry to access to all systems for O&M. Aquantis has nine patents issued and three in process.

Oct 2016: Signed berth agreement with Morlais Marine Energy's proposed West Anglesey Tidal Zone. Nov 2016: One of ten companies to be recommended support from €11m EU FORESEA programme to test at a test centre.

Atlantis Resources Ltd. (ARL)

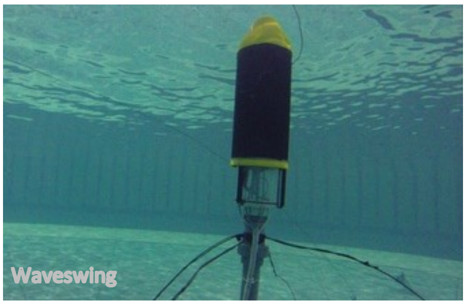

AR1500

Tidal

Singapore registered ARL has commercial and project development teams based in Edinburgh, an operations base located at Nigg Energy Park in Invergordon and a turbine/engineering services division in Bristol. It is the developer of the £51m MeyGen project. The company has two turbine models for sale, the 1.5MW AR1500 system designed by Lockheed Martin Corporation and the 1.5MW SeaGen U turbine originally designed by Siemens Plc. The first phase of ARL's flagship MeyGen project uses 3 x AHH turbines and 1 x ARL (Lockheed) turbine.

Feb 2017: Completed Phase 1a of Pentland Firth MeyGen project (4 x 1.5MW turbines). April 2017: Ofgem accredited for 5 x ROCs per MWh generated (~£300/MWh for 20 years). End of Aug 2017: Cumulative generation approaching 2GWh. Has €16.8m EU grant for 2nd 6MW phase.

AWS Ocean Energy

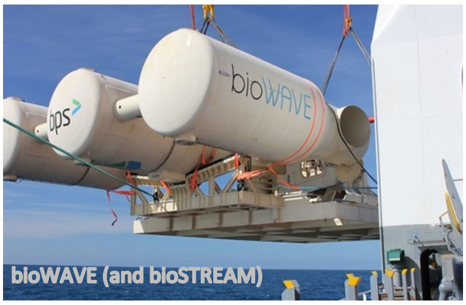

Waveswing

Wave

AWS Ocean Energy and predecessor projects have been developing marine energy systems for over 20 years. They work with customers and development partners to produce solutions to offshore power needs from isolated power supplies for remote communities and aquaculture through to the multi-MW AWS-III utility-scale wave power generator.

AWS Waveswing runner up in US Wave Energy Prize. Partner with 4C on WES PTO and NWEC projects. £720k WES funding for 2nd stage PTO.

BioPower Systems PTY Ltd



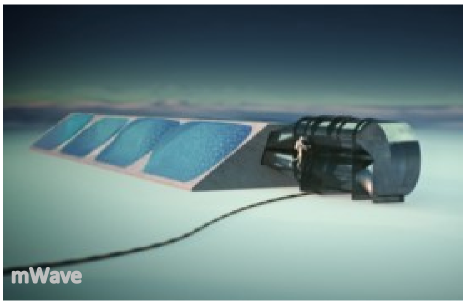
bioWAVE (and bioSTREAM)

Wave

Establised in 2006, BPS has three marine energy technologies inspired by nature: The bioWAVE wave energy converter, the O-Drive self-contained power conversion module and the bioSTREAM for tidal currents, without rotating blades. Further projects aimed at improving the technical and commercial performance of all BPS products are being investigated. Ultimately, the aim of the company is to deliver its products to micro-grid, off-grid, and island customers and to utility-scale projects connected to distribution grids.

Dec 2015: 250kW full-scale, grid connected bioWAVE installed at Port Fairy with O-Drive. A$21m project with $11m ARENA funding. Feb 2017: new subsea cable installed

Bombora Wave Power


mWave

Wave

Founded in 2012, Bombora is located in Perth, Western Australia. Bombora'a mWave converters deliver environmentally friendly, large scale energy for national electricity grids. Bombora wave farms can be deployed in coastal locations throughout the world. Bombora strives to create renewable energy solutions with a positive impact on our environment and our community. The company plans to deploy its first full scale device in Peniche, Portugal during 2017.

Bombora is preparing for a staged installation of an mWave wave farm at Peniche in Portugal commencing in 2017, working with Portuguese organisation WavEC.

Carnegie Clean Energy Ltd

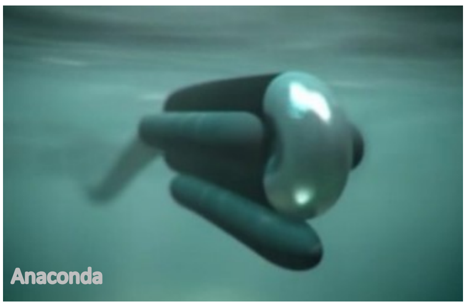
CETO

Wave

Carnegie Clean Energy Limited is an Australian, ASX-listed (ASX: CCE) wave energy, solar energy and battery storage project developer. It is the developer of the CETO Wave Energy Technology and is also owner of battery/solar microgrid EPC company Energy Made Clean (EMC). Their West Australian grid connected array has 14,000 operating hours.

CETO Wave Energy UK Ltd is a Scottish registered company participating in the WES programme. In Nov 2016 CCE was awarded a £9.6m ERDF grant for the 1st phase of 15MW project at Wavehub.

Checkmate Seaenergy


Anaconda

Wave

Formed in 2007. The company's concept consists of a distensible rubber tube anchored to the seabed that floats just beneath the surface head to sea, where bulge waves are excited by passing sea waves. The device is continually squeezed by passing sea waves. These waves form bulges in the water-filled tube and travel down its length developing the power to drive a turbine generator in the stern.

April 2017: Won stage 2 NWEC contract from WES worth £727k.

Corpower Ocean

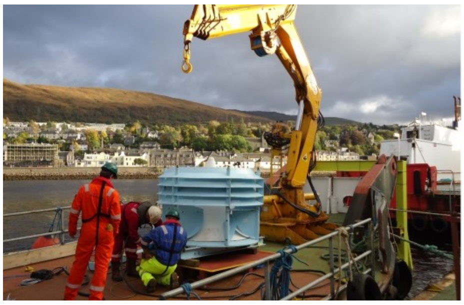

C-WEC

Wave

Founded 2009. CorPower Ocean concept includes unique mechanical design, inspired by the pumping principles of the human heart. This is combined with advanced control algorithms that make the converter oscillate in resonance with incoming waves. Active phase control enables 3 times increase in power absorption compared to conventional passive wave power buoys.

Recommended support from FORESEA programme. Testing at EMEC. Nov 2016: EC funding of €4m for Waveboost project

Current2Current



Tidal

Current2Current's tidal energy converter is designed to be very compact enabling operation, maintenance and installation costs to be minimised. A simple construction, the omni-directional converter works on the principle of redirecting the flow vertically through a shrouded turbine. The turbine has a low cut-in speed, suitable for micropower applications. Current2current are now preparing an extended test programme for their prototype platform and moving forward with a pre-production prototype device.

Sept 2016: Secured £100k grant from SE for £260k project. Nov 2016: Testing conducted offshore West Coast of Scotland at the Underwater Centre in Fort William.

EC-OG


Subsea Power Hub

Tidal

The Subsea Power Hub is a delta array of turbines or Ocean Generation modules, harnessing the energy within ocean currents to produce autonomous electrical power for multiple applications. This patented technology provides autonomous power to subsea infrastructure, reducing cost through efficient installation and removing the capital expenditure associated with electrical cables. In simple terms, each module is an underwater battery unit with integral charger. Each module consists of a turbine, generator, battery pack and electrical conditioning system.

Dec 2015: Secured £1.2m R&D grant from SE for £3.9m project. Apr 2017: Testing Subsea Power Hub at EMEC's Shapinsay sound test site.

EEL Energy


EEL Tidal Energy Converter

Tidal

The patented EEL turbine technology produces energy by coupling fluid flow with an undulating structure. The membrane undulates under moving fluid pressure. This periodic motion is transformed into electricity by an electromechanical system. Industrial production of a 230t, 15m x 15m 1MW machine at 2.5m/s is targetted for 2020. The machine has a low start up velocity of 0.4m/s. A 1:6 protoype has been tested at Ifremer and industrial production is scheduled for 2020.

Following the encouraging results of its scaled tidal energy converter testing, EEL Energy has informed it will deploy the device off Brittany to validate its performance in real sea conditions. (TET)

Floating Power Plant


P80 combined floating wind and wave platform

Wave

Established in 2004, Floating Power Plant is a clean-tech company that designs, develops and provides a unique floating patented platform for wind and wave energy. The company states it has developed the world's only offshore-proven combined floating wind and wave device to have delivered power to the grid. Plan for Katanes Floating Energy Park in Caithness and Dyfed in Wales

Have Scottish subsidiary based in Edinburgh, Caithness project in pipeline

Fred Olsen

Wave

Fred. Olsen has developed technology for conversion of ocean waves into electricity for more than sixteen years. Since 2000, the company has built and operated five different wave energy converters in three different countries. Accumulated over 61.000 hours of in-sea operation, 13.000 hours of energy production and 33.000 kWh of electric energy.

Have UK subsidiary. Deployment of BOLT Lifesaver at WETS outside Marine Corps Base Hawaii was completed March 12th 2017.

G-Wave

Wave

Founded 2006, G-Wave LLC is developing the Power Generation Vessel, rated at 9MW. The vessel is 72 meters long, 22 meters high, and weighs ~13,000 tons. The company has global patents in generating power using dynamic tuning, the design of arrays and components for power take off. G-Wave is investing substantially in block building hulls and automating electronics assembly. The company is collaborating with Plymouth University's COAST labs for wave tank tests.

Feb 2017: 9MW project at Wavehub planned to be installed July 2018. Conducting tests at COAST laboratory, Plymouth. May 2017: MMO licence granted

Grey Island Energy Inc

Wave

Grey Island Energy is a Canadian based company that is pioneering a proprietary wave energy extraction device for commercialization around the world. The patent pending SeaWEED™ is a 750 kilowatt ocean wave energy converter that sits on the surface of the ocean and converts ocean waves into clean renewable energy. This electricity is then sent to a subsea hub allowing for distribution to any number of applications.

The company has developed a 1/16th scale protoype and conducted multiple wave tank tests. Aug 2015: Announced opening of Scotland office in Isle of Lewis

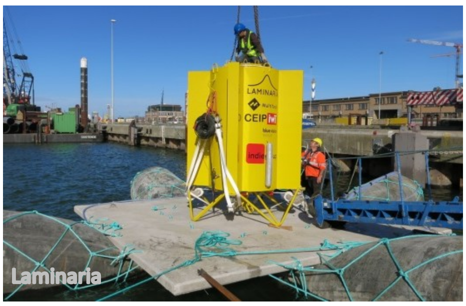
Joules Energy Efficiency

Wave

The innovative WaveTrain device consists of three mechanically linked floating oscillating water column modules. Each module oscillates on an inclined plane and drives a pneumatic turbine power take-off system. Mechanical linkages between adjacent modules will permit self-reaction that encourages motion in the inclined plane.

WES NWEC Stage 1 programme - tested at FloWave

Laminaria



Wave

The laminaria WEC's vertical surface interacts with the horizontally travelling wave energy. As the result of this movement the Laminaria will be subjected to a tilting and translating motion which is transferred through the mooring ropes to the generators. Laminaria are taking part in the LAMWEC project which seeks to develop and test a 200kW Laminaria wave energy converter (WEC), through complementary research and test activities aimed at defining all the design improvements needed for upscaling the prototype tested in the North Sea.

Testing at EMEC in 2017. Feb 2017: Tank tests at Plymouth. Also recommended support from €11m FORESEA programme for testing

Magallanes Renovables

Tidal


2MW Tidal energy platform

Established 2009. The Magallanes Project is based on a floating steel-built trimaran which incorporates a submerged section where the hydrogenerators are fitted. This platform is anchored to the sea bottom by two mooring lines, to the bow and stern. As this floats, it does not involve any construction on the sea bottom and so it can be installed in any area in the world. This offers low maintenance costs since it makes it possible to access the platform for checking, repairs or any other operation, by boat or ship.

Nov 2014: Deployed 1:10 scale 'ATIR' prototype at EMEC's Shapinsay Sound test site supported by the EU-funded MaRINET project. 2MW device planned to be deployed and tested at Vigo and EMEC in 2017-18.

Marine Power Systems

Wave


WaveSub

Based in Swansea. Marine Power Systems Ltd was founded in 2008 by Dr Gareth Stockman and Dr Graham Foster with the sole purpose of developing and bringing to market the WaveSub wave energy converter. The WaveSub is claimed to have the potential to substantially reduce the costs associated with energy generation from waves. MPS has completed two Phases of the development of the technology and are currently carrying out Phase 3.

Oct 2015: MPS received £2m grant European Regional Development Fund through the Welsh government. Dec 2016: 1/4 Scale machine being built in Pembrokeshire with expected deployment at Falmouth's FaBTest in 2017.

Minesto

Tidal

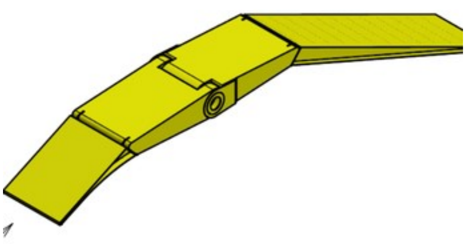

Deep Green

Minesto's Deep Green Technology has a wing that pushes the turbine through the water in a figure of 8 sweeping a large area at a relative speed several times the underwater current. The speed has a cubic relationship to the power production, hence the electricity produced by the power plant's generator is several hundred times greater compared to if the turbine would be stationary. By adding this step of energy conversion, Minesto expands the global ocean energy potential.

Have UK subsidiary in Wales. May 2015: Minesto secured €13m ERDF funding via the Welsh European Funding Office for 'Deep Green'. First commercial scale 0.5MW installation planned in Holyhead Deep in 2018 with expansion to 10MW and then 80MW.

Mocean

Wave


Mocean WEC hinged raft

The Mocean WEC consists of two hulls connected by a hinge. Wave forcing and the bodies' dynamic responses causes a relative motion about the hinge that drives a generator. The novelty is in the shapes of the hulls, which are characterized by sloped submerged nose and tail.

Testing at Edinburgh University's FloWave test tank. April 2017: Won 2nd stage WES NWEC contract worth £730k.

Nautricity

Tidal


CoRMaT

Nautricity has developed a contra-rotating turbine turbine to extract energy from tidal streams - CoRMaT, suitable for deployment in water depths of 8 to 500m. CoRMaT is a second generation device, the result of extensive research and development carried out at the prestigious Energy Systems Research Unit at the University of Strathclyde. CoRMaT uses two closely spaced dissimilar rotors, moving in opposite directions.

2015: WES feasibility study with University of Strathclyde investigating the application of a direct drive, contra-rotating generator to different WEC architectures. April 2017: installed a 500kW CoRMaT turbine at EMEC . Won FORESEA award.

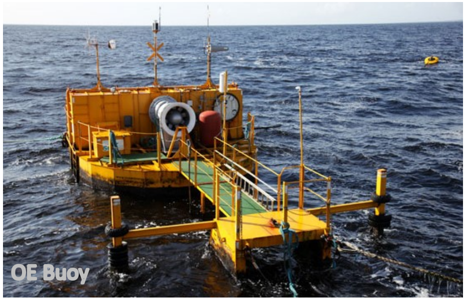
Nova Innovation

Tidal

In 2014 Nova successfully deployed and generated tidal electricity to the grid with their Nova 30 tidal turbine. Nova delivered all aspects of this project: seabed lease; onshore and offshore consents; grid connection; turbine design, build, deployment and operation. In 2016 they installed the world's first offshore tidal energy array, deploying two Nova M100 turbines in the Bluemull Sound and exporting power to the Shetland grid. The technology is a two-bladed seabed-mounted horizontal axis turbine. The most recent device (the M100) has 100 kW rating.

Aug 2016: UK's first tidal array, in Shetland. Oct 2016: Berth agreement for Morlais/ West Anglesey. July 2017: EU Horizon2020 funding announced of €14.9m to extend its Shetland array to six turbines (from three 100kW M100 turbines). Agreement for Lease for N.Wales project at Bardsey Sound.

Ocean Energy



Wave

The OE Buoy has been designed around the oscillating water column principle. To ensure survivability the platform has only a single moving part. The OE Buoy has undergone three full phases of scaled testing, from 1:50 scale to 1:4 scale. The result of over 10 years of research and development is that the 1:4 scale OE Buoy has only a single moving part (the turbine supplied by DresserRand) and has now completed over 3 years of rigorous testing in Atlantic waters at the Galway Bay test site in Ireland.

Aug 2017: OE are planning to let contracts for the build of a 1MW full-scale machine in Sept. This will be tested at the US Navy WETS in Hawaii in 2018/19. Following this, the intention is to transport this to EMEC for testing in 2019/20.

Ocean Power Technologies

Wave

OPT's proprietary PowerBuoy® technology is based on a modular design and has undergone and continues to undergo periodic full-scale ocean performance validation. OPT specializes in advanced autonomous (not grid connected), cost-effective, and environmentally sound ocean wave based power generation and management technology. The PowerBuoy system integrates patented technologies in hydrodynamics, electronics, energy conversion, and computer control systems to extract the natural energy in ocean waves.

Apr 2017: PB3 deployed off Kozu-shima island in Japan, under 6mth lease to Mitsui Engineering and Shipbuilding. June 2017: OPT announced that the performance of the PB3 had met requirements after 8 weeks of testing with peak power of 2kW.

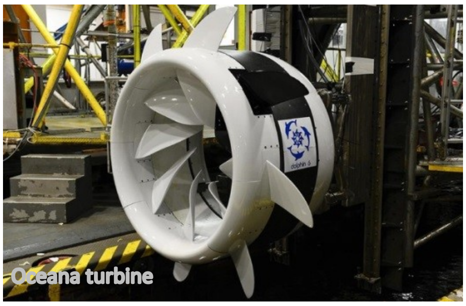
ORPC

Tidal

ORPC is commercializing tidal and river power systems using a patented technology platform - the turbine generator unit or TGU - as the core component. The four-turbine TidGen® TGU is secured to the ocean floor using either a fixed bottom support frame (BSF) or a buoyant tensioned mooring system (BTMS), which incorporates a pod, or wing, above the TGU that provides buoyancy and is secured to the sea floor using an innovative tensioned mooring system.

ORPC has deployments in Cobscook Bay in Maine and the Kvichak River in Alaska. Nov 2016: €3.2m, ORPC Ireland-Led Project. June 2017: Completed full-scale testing of water-lubricated bearing system and associated driveline components at Univ. of Maine.

Oceana Energy Company



Tidal

Oceana and U.S. Navy engineers developed the Oceana turbine to collect the most energy from a given column of water. The device is built using new materials and adjacent technologies that will withstand harsh seas. The device is an open centre turbine with eight balanced blades on a rotating ring which comprise the only moving part in the turbine. The ring rides on magnetic bearings and does not need a gear box to transfer electrical power.

Nov 2014: Oceana Energy registered a UK subsidiary in Edinburgh. Nov 2016: Oceana tested their device in the Tanana River near Nenana, Alaska.

OpenHydro


Open Centre Turbine

Tidal

OpenHydro's design philosophy is to keep the turbine as simple as possible, resulting in a device which has a low cost and low requirement for maintenance. OpenHydro's commercial scale turbine is 16 metres in diameter and is rated at 2MW. The turbine weighs approximately 300 tonnes and is predominantly a steel assembly. The company has 1.7GW of projects in development.

10,000 operating hours at EMEC. Jan 16: First 16m turbine installed off Britanny coast for EDF, second following in May. Oct 16: Berth agreement with Morlais West Anglesey Tidal Zone. Nov 16: Turbine installed and connected in Canada (Cape Sharp Tidal).May 17: 2 x 2MW planned for EMEC.

Oscilla Power


Triton Wave Energy Converter

Wave

Oscilla Power's Triton wave energy converter (WEC) is a two-body point absorber. The company undertook a variable damping linear power take off project with WES combining a linear hydraulic 'gearbox' with a conventional or an advanced linear generator.

UK entity Oscilla Power Ltd, based in Glasgow. Completed stage2 PTO project with £0.5m funding from WES with EMEC as subcontractors. Jun 2017: Washington Dept of Commerce awarded $1m for R&D.

Polygen

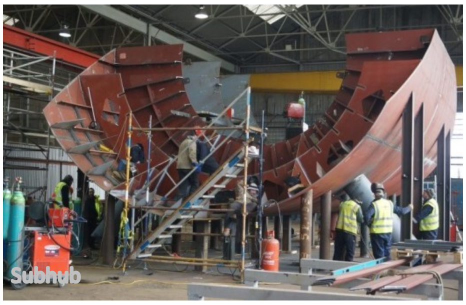

Polygen Volta

Wave

To showcase the remarkable properties of polyethylene, PolyGen are developing a wave energy converter (WEC) made almost entirely from HDPE.

Completed test of Polygen Volta at FaBTest, Falmouth. Funding of £209k from WES structural programme to look at advanced rotational mouldings.

QED Naval


Subhub

Tidal

Subhub is QED Naval's flagship project. The Subhub is a foundation structure for wave and tidal turbines. QED Naval completed all the feasibility assessments of the Subhub tidal turbine platform using its suite of design tools. They have also completed a successful tank testing program on the validation model using 30cm diameter perforated disc to act in the similar manner to a turbine.

Based in Edinburgh. Recommended for FORESEA award for testing at EMEC.

Quoceant


Automatically Inflatable and Stowable Volume concept

Wave

Quoceant are specialists in technology innovation, offering a range of professional services in engineering, design, operations, project planning, economic modelling and market review. The team's background was in developing the Pelamis Wave Energy Converter, offering a unique combination of experience, knowledge and capability highly applicable to the wave, tidal and offshore wind sectors and have worked together since 1998.

Working in WES Materials, NWEC and PTO programmes and have carried out landscaping project for WES in control systems as well as a knowledge capture project from the Pelamis WEC.

Renewable Devices Marine

Tidal

RD Marine is currently developing the OtterTM range of turbines – by using our expertise in generating power from fluid flow we are prototyping scaled systems in rivers to eliminate all technical risks before launching the off-shore tidal system. The 10kW River OtterTM will provide electricity generation in medium sized hydro flows using the same technology as the larger 1MW Sea OtterTM turbine which will operate in deep sea marine tidal stream flows.

Based at Roslin outside Edinburgh. Aug 2016: Conducted sea trials of Capricorn Marine turbine in Firth of Forth.

Capricorn Marine Turbine

Repetitive Energy Company

Tidal

Currently building a range of different size Vertical Axis Turbines for deploying in multiple environments. Through extensive testing in the past seven years, REC has formed close relationships with independent test centres and specialists across the UK. They are currently in discussion with various potential technology partners and funders to enable them to move forward in the development of their products.

N/A

Schottel

Tidal

Depending on the current velocity, one SIT produces between 54 and 70 kW rated, grid-ready electric power based on rotor diameters between three and five meters. Thanks to its modular approach, a higher overall power can be reached with a larger number of turbines. SIT can be implemented in rivers, sea straits and tidal races offshore in jetty, floating or submerged platforms in varying quantities. SIT is a flexible component which can be used with different platform types as on-going projects show.

Involved with SME, QED and others. UK subsidiary Tidal Stream Ltd. Nov 2016: Partnership announced with Perpetuus Tidal Centre (PTEC) off the Isle of Wight for 30MW project shared with Tocardo commencing 2020.

Schottel Instream Turbine (SIT)

Scotrenewables Tidal Power

Tidal

Founded in 2002, Scotrenewables turbine utilises a highly innovative floating platform with integrated retractable rotors for low cost access. From 2003-2009, the company tested its technology at increasing scales, supported by investment from TOTAL, Fred Olsen and ABB Technology Ventures. In 2011, the company launched the SR250 250 kW, the first large scale floating tidal turbine in the world. This was then followed by the SR2000 2MW in 2016. The company currently employs 25 staff with offices in Orkney and Edinburgh.

The grid connected SR250 underwent a 2½ year testing programme at EMEC, with >4,000 hours of deployment. Feb 2016: Won €10m EU Horizon 2020 funding for Mk2 optimised SR2000. April 2017: The SR2000 reached peak power of 2MW; generated 18MWh within a 24hr continuous testing period.

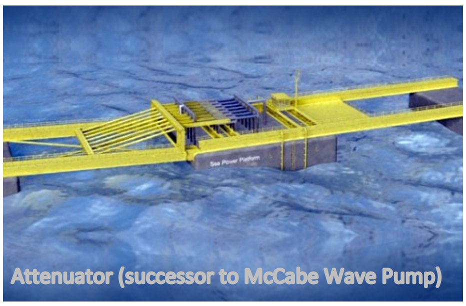
SR2000

Sea Power Ltd

Wave

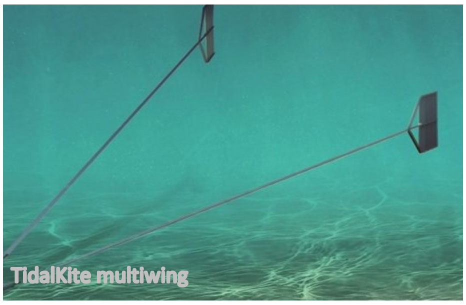
Sea Power Ltd is a progressive marine R&D and engineering company located right at the world's most energetic wave energy resource. Sea Power Ltd has invented, designed and developed a Wave Energy Converter device known as the SeaPower Platform in 2008.

Successfully won stage 2 WES Novel Wave Energy Converter grant (as partner to 4C) worth £720k



Attenuator (successor to McCabe Wave Pump)

SeaQurrent



Tidal

SeaQurrent develops a completely new approach for harvesting tidal energy. Their technology makes it possible to generate clean electricity from low velocity water streams with high efficiency. The team is supported by specialized contractors, companies, and knowledge institutes including Technologie Centrum Noord Nederland (TCNN) and the University of Groningen (RUG). The Province of Fryslân has provided a first grant for the project.

Recommended support from €11m FORESEA programme to test at a test centre

Seatricity

Wave

Seatricity's Oceanus zero carbon technology captures wave energy to generate electricity or produce fresh water from the sea. Investment of £4.5m in the company to date.

Successfully trialled full scale device at Wavehub in Summer of 2016. Previously tested at EMEC.

Sustainable Marine Energy

Tidal

Sustainable Marine Energy Ltd (SME) is a marine engineering company, focused on bringing a cost-effective solution to the tidal energy market. PLAT-O is SME's tidal platform. Built to host four tidal turbines underwater, SME planned to deploy at EMEC in 2017. PLAT-I is a variant designed to float on the surface, for less aggressive sites, supporting island communities.

Apr 15: SME signed up to a berth at EMEC to deploy 5x PLAT-O systems in a 1MW array over 2 yrs. Jun16: Rock anchor install & wet test of 100kW PLAT-O at EMEC. Feb 16:Purchase of 16 x 62kW Schottel turbines. Aug 17: 268kW PLAT-I to be tested Connel Sound before transport to Singapore demo site.

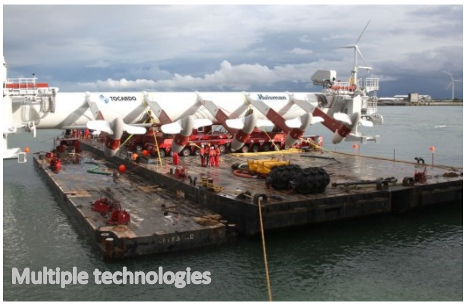
Tidal Stream Limited

Tidal

TRITON is a tidal energy platform system developed by TidalStream Limited, now a subsidiary of Schottel Hydro. It offers tidal turbine developers a deployment and operation system that could halve the cost for their turbines than can be provided by single installation systems. The platform is adaptable and a range of turbine types can be accommodated, providing the installation and maintenance base that will reduce costs and enable safe operating conditions.

The first full-scale Triton 2.5MW system using 36 Schottel turbines is being manufactured for deployment at the FORCE test site in Canada and client Black Rock Tidal Power. Oct 2016: Signed berth agreement with Morlais Marine Energy's proposed West Anglesey Tidal Zone.

Tocardo Tidal Power



Tidal

Formed in 2008, Tocardo states it has been commercial since 2012 when the first turbines and universal floating systems were sold to clients in Nepal, Japan and Canada. The company has ten tidal turbines connected to the grid and operational with five offshore projects under development in the UK, Canada and the Netherlands. Tocardo is designing a Universal Foundation System (UFS) suitable for 5 turbines under the InToTidal project, funded by the EU's Horizon 2020 R&D programme.

Oct 16: Morlais berth. Nov 16: Perpetuus 2020 30MW Isle of Wight agreement. Jun 17: Ofgem Renewables Obligation accreditation given for 1.4MW deployment at EMEC, providing ~£300/MWh, after previously grid-connecting Temporary Foundation System under the FORESEA programme.

Trident Energy

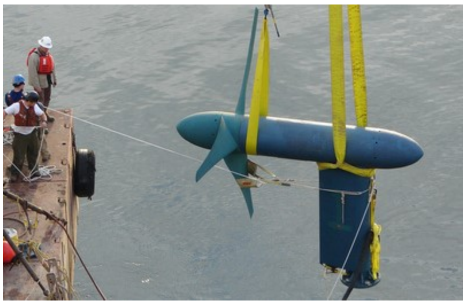

Power Pod II/ WaveDrive Direct Drive Linear Generator

Wave

Trident Energy is an independent developer of enabling technology for the offshore renewables industry. We have developed "PowerPod" using our patented and low cost, highly controllable linear generator that converts reciprocating motion directly into electricity. The company is currently developing a small wave energy generator that can be attached to other offshore infrastructure to provide autonomous off-grid power.

Jan 2016: Lead in £475k Stage 2 WES PTO contract for 'WaveDrive', now complete. Oct 2016: Working with AWS (in WES NWEC programme) to include Trident's PowerPod II.

Verdant Power



Tidal

Verdant Power systems employ underwater turbines to generate clean energy from the currents of tides, rivers and manmade channels. The company has been selected by the US Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) to continue a project advancing the TriFrame™ mount and associated installation and operations procedures with $3.75 million of second-phase funding.

Mar 16: Established Verdant Isles Ltd. – a joint venture to develop tidal energy projects in Ireland and the United Kingdom. Oct 2016: Signed berth agreement with Morlais Marine Energy's proposed West Anglesey Tidal Zone.

Wello Oy

Penguin

Wave

The converter is designed to respond to the movement of waves. The asymmetrical shape of the Penguin's hull creates a gyrating motion in the waves which makes the rotator inside the hull rotate. The power train from wave to electricity is direct without any mechanical or hydraulic gears in between to cause loss of efficiency.

Won €17m EU Horizon2020 funding for Clean Energy from Ocean Waves project with Fortum for three machines at EMEC. Apr-17: first electricity generated into grid at EMEC. Aug 2017: Operational for 150 days since March.

WITT


200W WITT

Wave

A patented, completely scalable (cm to mtrs), affordable energy harvesting technology that uses a 3D pendulum to convert 6 degrees of freedom into single rotation of a flywheel to produce electricity. First application is intended to be boats and buoys and small scale marine power applications. (Tank testing done with InnovateUK, Gibbs Gears, Shaeffler, OREC, Universities of Southampton, Bristol, Plymouth, Mojo Maritime DNV GL)

Apr 2016: Raised £2.4m via crowdfunding. Tested 200W unit at Southampton Uni

Zyba


CCell Oscillating Wave Surge Converter

Wave

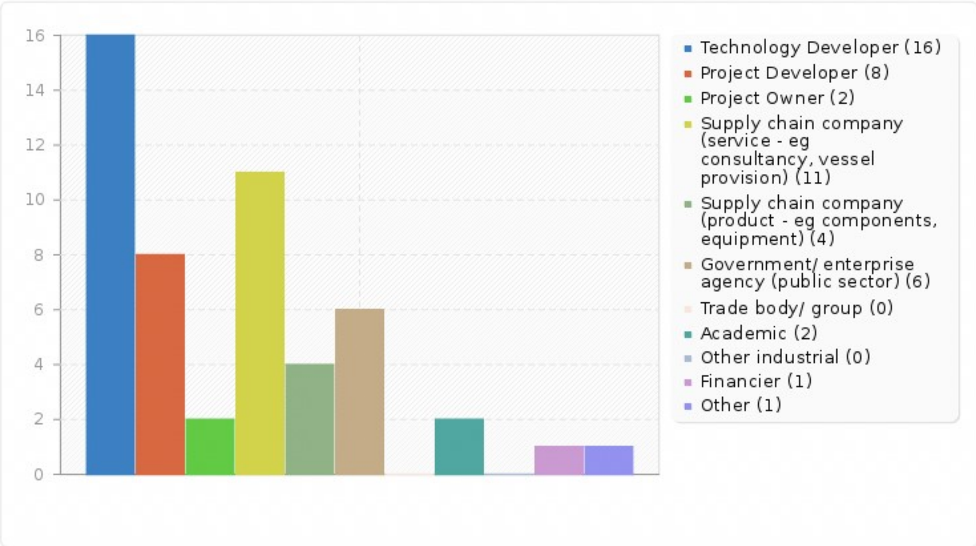
Zyba's CCell is an oscillating wave surge converter (OWSC) designed to maximise the energy extracted from ocean waves through an innovative curved paddle. Laboratory tests of the Mark 1 CCell paddle have demonstrated a four-fold increase in performance-to-cost ratio compared to other flap-based wave energy converters (WECs). A curved paddle improves hydrodynamic performance, and provides additional strength.

Feb 2016: Zyba awarded £256k from WES NWEC programme to paramaterise the CCell WEC and through successive numerical simulations optimise its shape for a range of sea conditions. Won support from FORESEA programme for intended testing at EMEC.

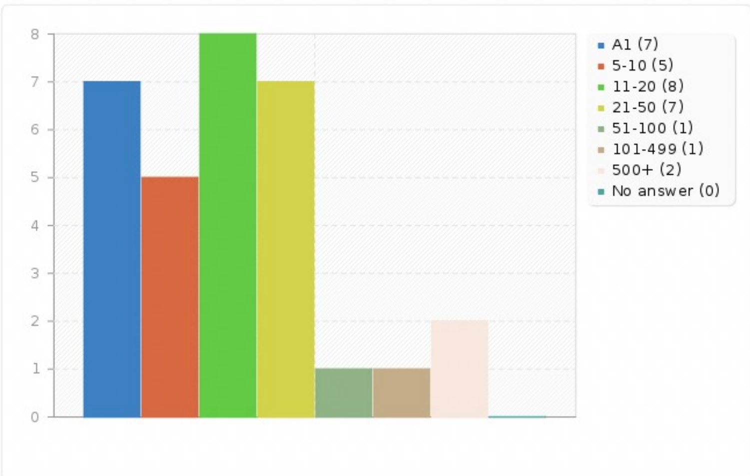
Appendix C State of the Industry Interview Response and Analysis

C.1 Survey respondents

31 individuals from different companies and organisations were interviewed. These covered a range of organisation types as shown below:



The categories that respondents selected affected the questions asked. Respondents could for example be both a technology developer and a project developer. The individuals and companies who were interviewed for this survey have been kept confidential. The range of organisation sizes is shown below:



C.2 Developer Questions

The concept of TRLs is generally well understood amongst wave and tidal developers and has been used to try and categorise support by funding agencies. Commercial Readiness Level (CRL) is less well known but is a similar concept to address the issue that technologies may be technically ready but not commercially or market ready.

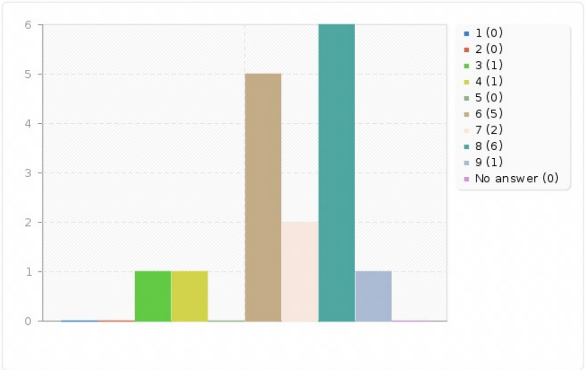
C.2.1 Technical and Commercial readiness

Developers were asked to define their technology readiness level and commercial readiness level against the following scales:

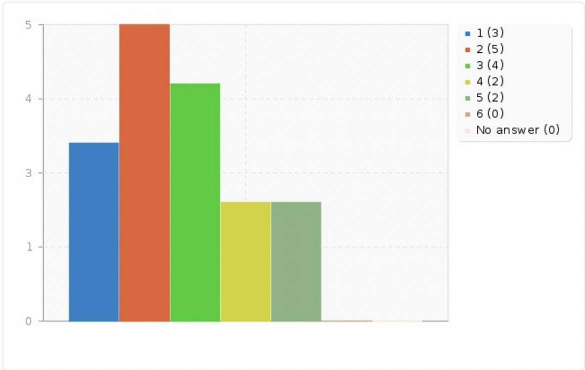
TRL	1-3	4	5-6	7-8	9
Wave	Concept validation. Prove the basic concept from wave flume tests in small scale	Design validation. Subsystem testing at intermediate scale, Scale Flume tests 1:10, Survivability; CFD; FEA Dynamic Analysis; Eng. Design (Prototype); feasibility and costing	Testing operational scaled models at sea + subsystem testing at large scale	Full-scale prototype tested at sea	Economic validation; several units of pre-commercial machines tested at sea for an extended period of time.
Tidal	Tidal-current energy conversion concept formulated	Intermediate scale subsystem testing, CFD, FEA, Dynamic Analysis	Subsystem testing at large scale	Full-scale prototype tested at sea	Commercial demonstrator tested at sea for an extended period.

Source: EMEC/OES-IA Document nº T02-0.0

CRL	1	2	3	4	5	6
	Hypothetical commercial proposition	**Commercial trial, small scale**	**Commercial scale up**	**Multiple Commercial applications**	**Market competition driving widespread develop-ment**	**Bankable Asset Class**



TRL self determined



CRL self determined

None of the developers interviewed categorised their technology as TRL1 or 2 or 9. Interestingly despite the commercial sale of tidal or wave power energy convertors or electricity generation being relatively scarce the developers' view of commercial readiness level was more optimistic than expected with more than 50% rating their level as 'commercial scale up' and greater; this may in part be due to unfamiliarity with the CRL concept.

C.2.2 Electricity generation

Those who had identified themselves as technology developers (past or present) were then asked about whether they already had machines generating electricity, or if not when they expected this to be:

	Currently generating electricity (in last 6 months)*	If not, expecting to be generating within 6-12 months	If not, expecting to be generating within 1-2 years	If not, expecting to be generating within 2-5 years	Previously had a machine generating electricity but no plans to do so at present	Machine under development but no clear idea on timescale to generate
Tidal (12)	7	3	1		1	
Wave (5)	1	1		1		2

*NB 'currently generating' may be taken to mean that a machine may have been generating within the last 6 months even if not at the time of the survey.

This limited sample appears to show that tidal sector is more advanced as a sector, albeit the quantity of developers at different stages should not necessarily be the only metric used in making this assessment.

C.2.3 Funding

Developers were asked about the size of public and private investment made to date in their technologies:

Sector	Respondent	Private funding	Public funding (investment/ grants/ debt)
tidal	1	£20m to £50m	£20m to £50m
tidal	2	£20m to £50m	£2m to £5m
tidal	3	£10m to £20m	£10m to £20m
tidal	4	£20m to £50m	£10m to £20m
tidal	5		
tidal	6	£100k to £250k	
tidal	7	£5m to £10m	£1m to £2m
tidal	8	£10m to £20m	£1m to £2m
tidal	9	£5m to £10m	£2m to £5m
tidal	10	£1m to £2m	£1m to £2m
tidal	11	£500k to £1m	£100k to £250k
tidal	12	£500k to £1m	£1m to £2m
wave	1	£10m to £20m	£2m to £5m
wave	2	£5m to £10m	£2m to £5m
wave	3	£1m to £2m	£2m to £5m
wave	4		£1m to £2m

Generally public funding for the tidal sector is equal to, or at lower level than private funding, in some cases much lower. For wave, for two of the earlier stage developers this is reversed, with more public funding than private. This may in part be due to the Wave Energy Scotland programme which can 100% fund projects.

Developers were then asked: "How much further investment in your company do you think will be required before your company is profitable (ie a margin is made on equipment sales)?" With the answer broken down into the funding needed for technology development, project development, project build and operation and 'other':

Sector	Respondent	Technology development	Project development	Project build and operation	Other
tidal	1	£5m to £10m	£2m to £5m	£10m to £20m	
tidal	2	£5m to £10m			
tidal	3	£1m to £2m	£2m to £5m		
tidal	4	£10m to £20m	£2m to £5m	£100m+	£2m to £5m
tidal	5				
tidal	6	£1m to £2m	£1m to £2m	£1m to £2m	
tidal	7	£250k to £500k	£1m to £2m	£5m to £10m	£250k to £500k
tidal	8	£5m to £10m			
tidal	9	£500k to £1m			
tidal	10	£2m to £5m			
tidal	11	£2m to £5m	£2m to £5m	£2m to £5m	
tidal	12	£500k to £1m	£250k to £500k	£2m to £5m	£500k to £1m
wave	1	£2m to £5m	£500k to £1m	£500k to £1m	
wave	2	£5m to £10m	£2m to £5m		
wave	3	£10m to £20m	£50m-£100m	£2m to £5m	£250k to £500k
wave	4	£5m to £10m			

The answers reflect the business models of the technology developers. Some consider it necessary to raise funding for project development, build and operation whereas others maybe focussed only on technology development (and implicitly not undertaking project development and project ownership). Some may consider a middle way of BOOT 'Build Own Operate and Transfer' projects. There is not necessarily a 'right' or a 'wrong' answer, self-development and self-build of projects can be a quicker route to market but clearly is more capital intensive and requires a greater breadth of skills.

An interesting point is that if *all* the above developers interviewed succeed, the estimated midpoint capital investment required for profitable sales will be:

Technology development	Project development	Project build and operation	Other
£83m	£97m	£135m	£5m

Whilst it is likely that not all developers will succeed it should also be noted that only a limited number have been interviewed.

The next question asked was about timescale to achieve this point – ie '**When** do you expect your company to be profitable? (eg electricity or generators sold with a profit)?'

Sector	Respondent	When do you expect your company to be profitable? (eg electricity or generators sold with a profit)
tidal	1	Longer than 5 years
tidal	2	3-5 years
tidal	3	Within 1-3 years
tidal	4	

tidal	5	
tidal	6	Within 1-3 years
tidal	7	3-5 years
tidal	8	Within 1-3 years
tidal	9	Within 1-3 years
tidal	10	Within 1-3 years
tidal	11	Within 1-3 years
tidal	12	Within 1-3 years
wave	1	Within 1-3 years
wave	2	3-5 years
wave	3	3-5 years
wave	4	3-5 years

Of the respondents, none are currently profitable, 50% expect to be selling electricity or generators with a profit within 1-3 years, 31% in 3-5 years, 6% in >5 years and 12% gave no answer.

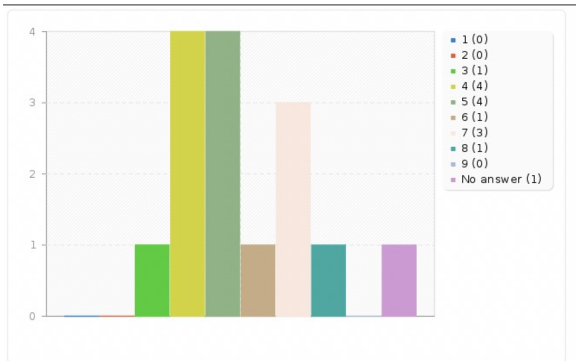
Developers were then asked "Can you state how much electricity has been generated by your marine energy technology to date?" Of the five respondents able or willing to answer (8 have generated within the past six months and 1 prior to this) the results were:

Electricity generated to date	Number of developers
<1MWh	1 x wave
1-10MWh	
10-50MWh	
100-500MWh	1 x tidal
500MWh-1GWh	1 x tidal
1-10GWh	1 x tidal
10-50GWh	1 x tidal
50-100GWh	
100GWh+	

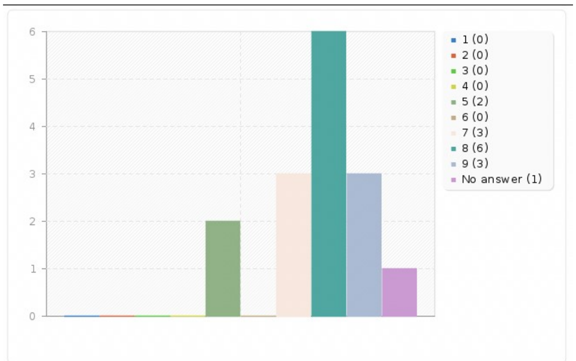
C.3 Project Developer Questions

Those respondents that identified themselves as project developers were asked what their perception was of the leading technology developers' TRL and CRL in each sector:

TRL – wave

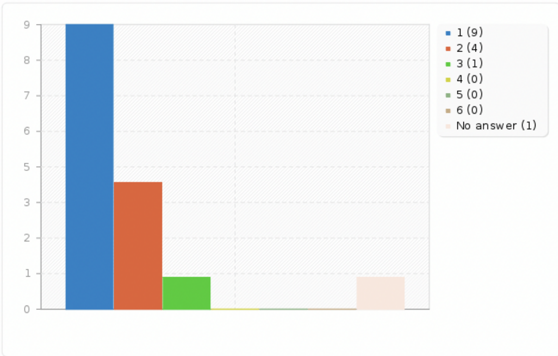


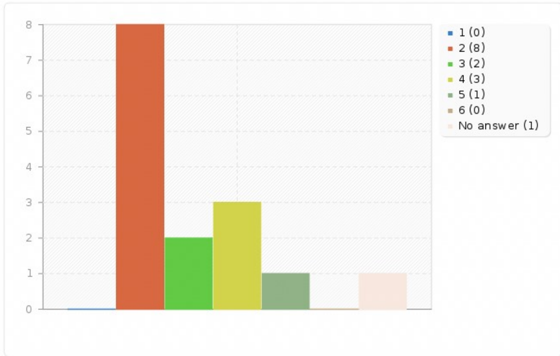
TRL - tidal



CRL – wave

CRL - tidal





The perception amongst most project developers is that the leading technology developer in each sector was at TRL 8 for tidal and TRL4-5 for wave. In terms of commercial readiness tidal is seen as more advanced although there is quite a variance in the perception of where this sits.

Project Developers were also asked how many project sites they had under development, what capacity they represented and when they expected to gain full consents (assuming a route to market):

	Project sites under development		Capacity in MW of projects either developed or under development			Project Developer target date for:	
Develop-er ID	Wave	Tidal	Early stage development (preliminary investigations and scoping)	Medium stage development (legal agreements in place to use site or grid and/or tariff secured)	Fully developed (all consents in place)	Consent, grid connection and all conditions precedent to allow investment in build of a project (subject to tariff)	Project operation post build
1		6-10	200MW-1000MW	200MW-1000MW	50-100MW	Currently in place	Currently in place
2		6-10	50-100MW	10-50MW	5-10MW	Currently in place	Currently in place
3		3	50-100MW				
4		3-5		10-50MW		Currently in place	Longer than 5 years
5		1				Within 1-3 years	Within 1-3 years
6		2	5-10MW	1-5MW		Within 1-3 years	3-5 years
7	3-5		50-100MW			Within 1-3 years	3-5 years

C.4 Supply chain questions

Companies that identified themselves as part of the supply chain (service - eg consultancy, vessel provision, components etc) were asked the following questions:

		What scale of investment would your company consider if the wave and tidal sector were to develop		
Supply chain ID	**Considering the wave and tidal sector, what scale of investment has your company made in this area to date?**	**a) with current route to market**	**b) with more favourable predictable market conditions**	**Do you consider your company to be a 'leader' or a 'follower' when it comes to the marine renewables sector?**
1	£1m to £2m		£100m+	Yes
2				Yes

3				Yes
4				Yes
5				Yes
6				Yes
7	£10m to £20m	£1m to £2m	£2m to £5m	Yes
8	£5m to £10m	£250k to £500k	£5m to £10m	Yes

Whilst the response is limited it is interesting to note the increase in investment that could result with a more favourable route to market (in this context the ability to obtain a tariff at a level commensurate with the current costs of marine renewables).

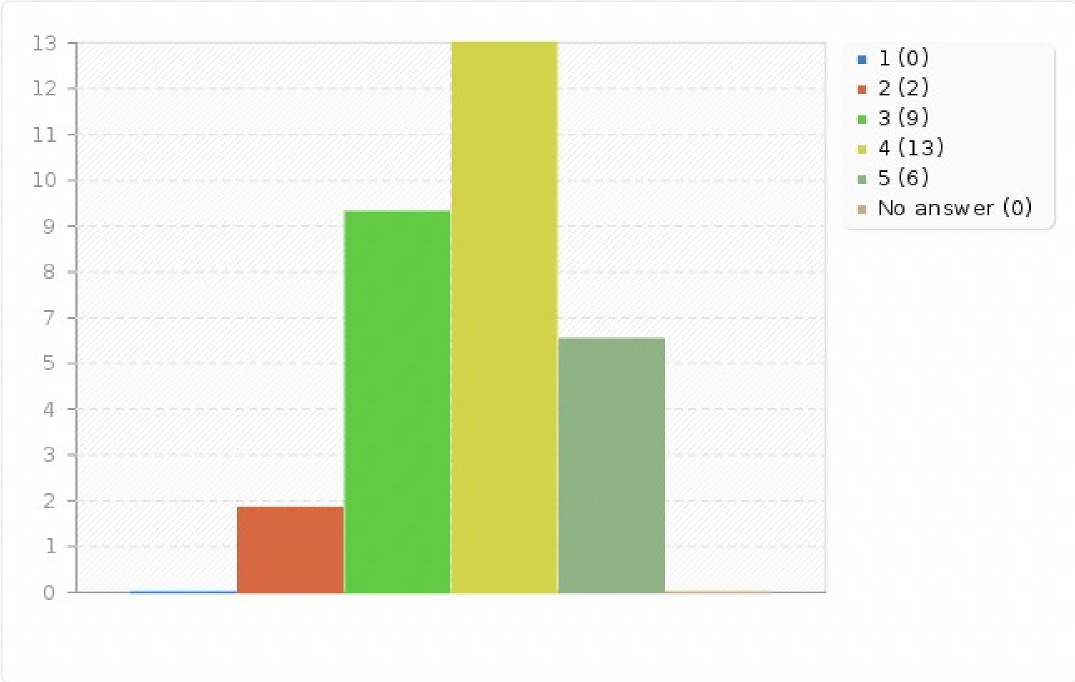
C.5 Academia questions

As well as other questions, academic respondents were specifically asked about the level of interest in wave and tidal energy a) amongst undergraduates and b) in conducting research in their department:

Acad-emia ID	Department/area of expertise	What level of interest is there in the wave and tidal sector amongst undergraduate students compared to other sectors? (1= low, 5= high)	What level of interest is there in conducting research in this area in your department? (1=low, 5= high) []
1	Marine planning	4	5
2	engineering systems, Mechanical and fluid mechanics	5	4

C.6 Public Sector questions (all respondents)

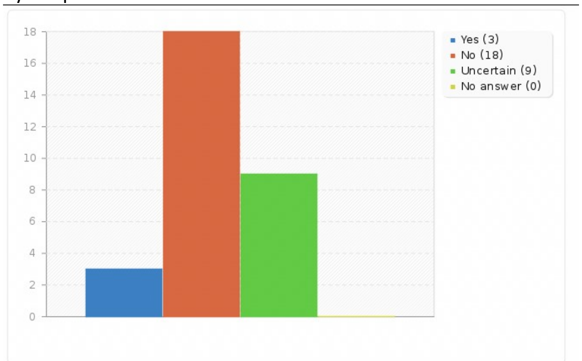
All respondents were asked “In your opinion how supportive are the general public in funding research and development in the wave and tidal sector? (1=low; 5=high)”. Answers are given below. Obviously it should be noted that these results are from respondents involved in marine renewables, nonetheless the perception is that the attitude of the general public towards funding R&D in wave and tidal is favourable.



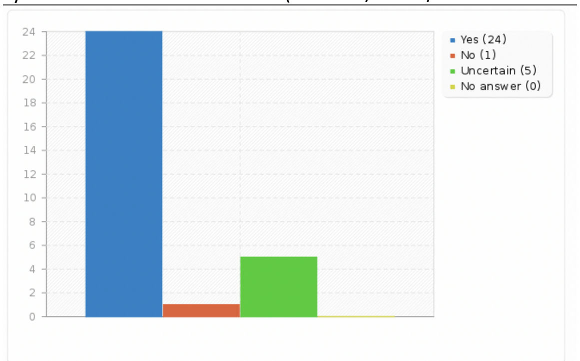
The next question considered whether the ‘investment proposition’ for wave and tidal energy was understood by different audiences, in other words that you might have to pay more for energy (or R&D) to get a ‘return’ of cheaper energy in the future and/or other economic benefits. The ‘investment proposition’ is whether investing in the sector will produce a return on investment and whether this investment is better than in other areas.

Is the investment proposition for wave and tidal energy understood? -

By the public?

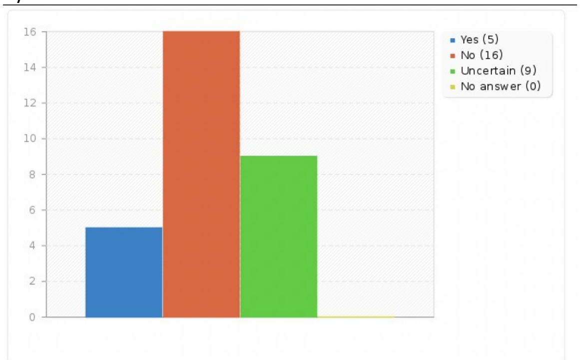


By the devolved administrations (Scotland/Wales/Northern Ireland)?

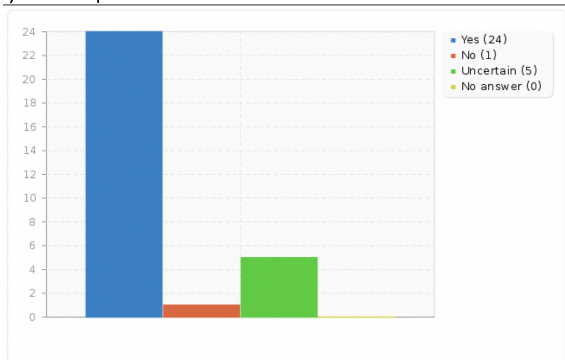


Is the investment proposition for wave and tidal energy understood? –

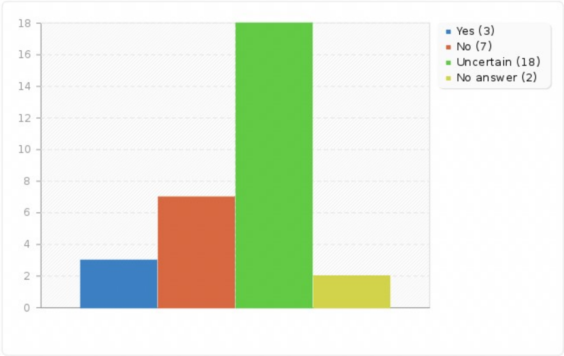
By the UK Government?



By the European Commission?



Is the investment proposition for wave and tidal energy understood? -
By the Investment Community?



The results indicate that most respondents felt that the investment proposition *was not* understood by the general public or by the UK Government but that it *was* by the devolved administrations and the European Commission. Most respondents were uncertain as to whether it was understood by the investment community.

(NB one point made was that it was hard to consider the devolved administrations collectively).

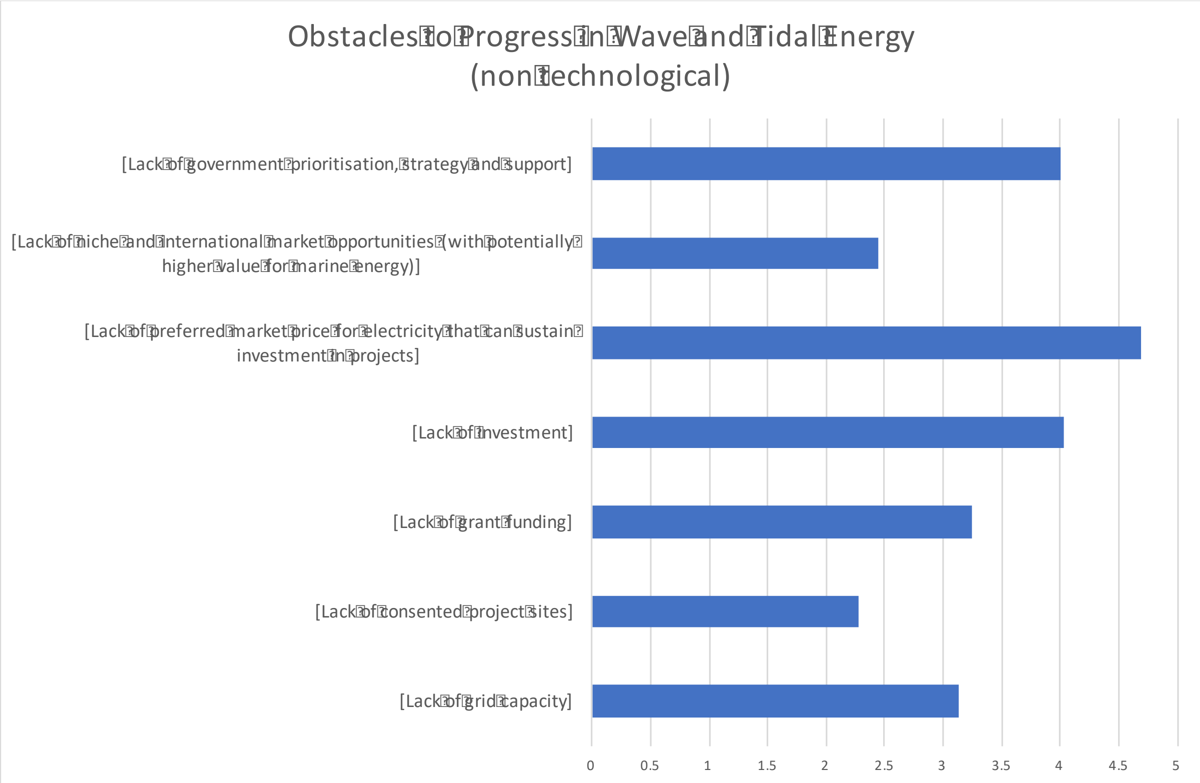
Respondents were asked to elaborate on this question, a selection of responses is given below:

Yes, the investment proposition is understood but the question is what they do with it and its prioritisation. Not a high enough priority
UK government appears anti? Scotland and devolved regions very supportive - live closer to coast and 'get it' and need industry
Sector needs support and is not at a stage yet where it can survive without this. Not unusual for technology at this stage of development. In the zone of bridging the gap between R&D and commercial. Need to drive down costs but also give investors confidence that the technology works.
Investment community - perceived risk of tidal, scale of projects, wind and solar easier to finance, mature market
My comment to government would be to highlight that the biggest cost and timescale involved in our route to success come from those factors directly in the control of legislators/government - i.e. the cost and timescales involved in completing site consenting.
Mislead by over promising and under delivering
Answers depend upon large number of factors, too many to mention!
The investment proposition is partially understood by the investment community
Lack of UK market is making the investment unattractive to private sector investors. Governments can see investment across broader returns than just financial. If the UK government accepts the responses to the Industrial Strategy Consultation then this might change.
The CfD being removed is clear indication that the investment proposition is not understood. CCS Peterhead is another example of short sightedness. (Our tech is also good for CCS).
Investment community perceives the risk well. However people like Triodos perceive wave and tidal too risky. Public failures seen for wave influence the perception for wave.

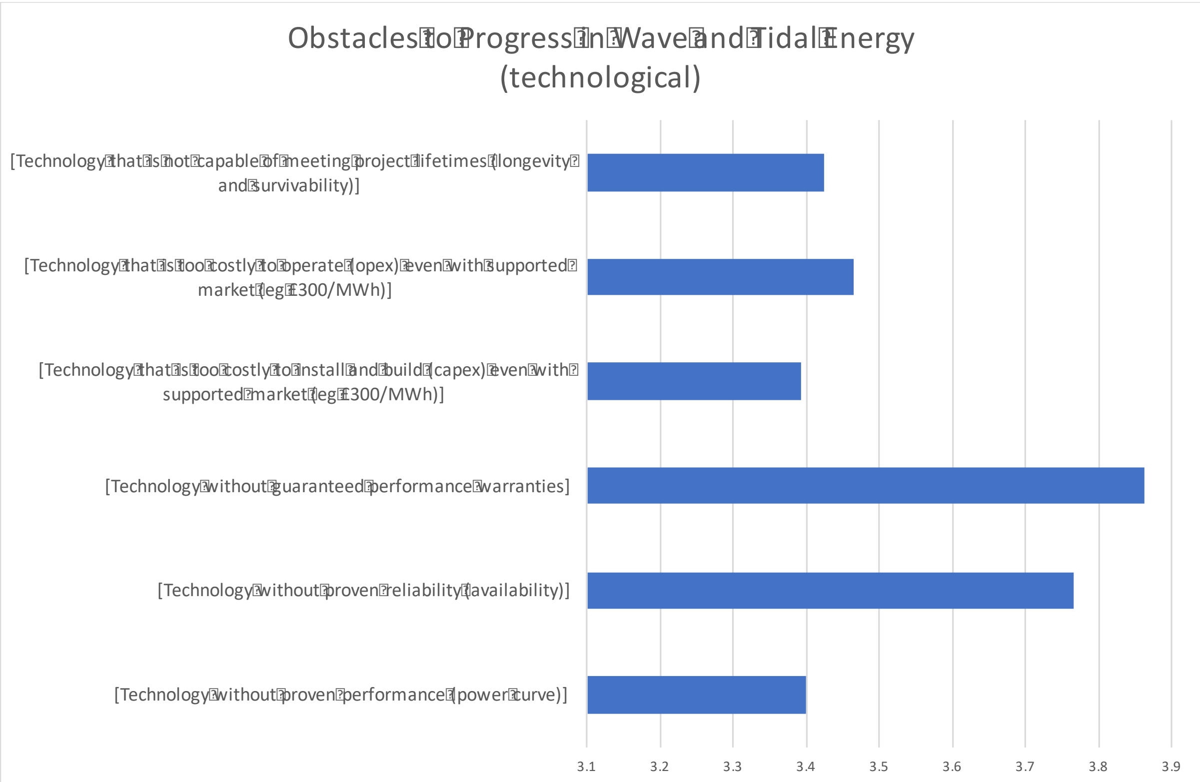
Still uncertainties about what support is available from government
Generally yes to understanding the investment proposition for renewables but not necessarily for wave and tidal. Some yes some no. UK Government understands the investment proposition for renewables but for not for wave and tidal, they think it's a Scottish issue. They think they can meet targets with wind farms - why bother with other stuff? DG MARE understand the potential in blue growth, employment for coastal communities. DG RESEARCH also putting money in as a result. EU doing a lot, Wave Energy Europe being started just as we leave.... but maybe there will be a route to staying in H2020 post BREXIT.
Scottish Government understands the investment proposition but are short of cash. Investors love it because of global opportunity/picture, they do understand the proposition but do not like things that are incentivised and open to political interference, instability. Needs long term price stability.
Innovation is not limited to technology alone. OEA is further developing industrial research on 'The Insurance-Debt Nexus' whereby InsurTech can enable smarter insurances based on real data. The relationship ('nexus') between business development insurance and project finance is already understood in more mature sectors (e.g. onshore wind). State intervention to create a space for insurance innovation can provide a contracted floor, allowing lenders to lend, sooner and on better terms. Thus leveraging limited equity with an increased internal rate of return (IRR) and enabling scale to bring down the cost of energy.
Investment community is a bit sheep like - they have limited information - make the best choice based on what other people doing - at present a lot of people left en masse so people are doing that. But in the past there was a momentum where everyone felt the need to get involved (10 years ago). So in the past the investment proposition was understood - 'we need to get in not to not miss out'. What is maybe not understood now is that technical field trials have been interpreted as failure, and that wave energy is not an investable proposition. I don't think there is a full understanding from the investment community at present. Contra investors exist - but have concerns that they may be leaving as well. Crowdfunding could be a route but concern that what is research is being marketed as development and supply of a product.
For the devolved administrations, Scotland and Wales have a good understanding and Northern Ireland less understanding.
Investment community - depends on the proposition and financial return which presents the biggest risk. Small Scottish Government more nimble and forward looking. Driven by need to replace North Sea oil and gas sector. Not as big an issue for UK government.
They public don't understand relationship between jobs and marine renewables or the power generation potential which could create a new industry

C.7 Obstacles to progress

Respondents were asked to rank a number of obstacles to progress in the wave and tidal energy sector in a) technology and b) non technological aspects. The results below are the averaged results from ranking each element from 1-5 (1=low; 5= high):



The biggest obstacle to progress in wave and tidal energy is seen as the lack of a preferred price for electricity that can sustain investment in projects.

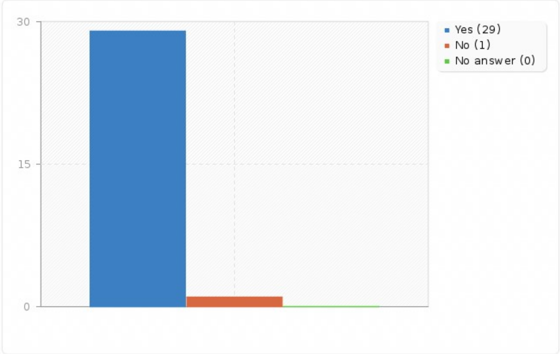


The biggest obstacles seen in terms of technology were the lack of performance warranties and technology without proven reliability.

C.8 Saltire Prize

C.8.1 Awareness

Respondents were asked if they had heard of the Saltire Prize. All but one had:



They were also asked what the prize was. 59% of respondents correctly identified the prize as being £10m.

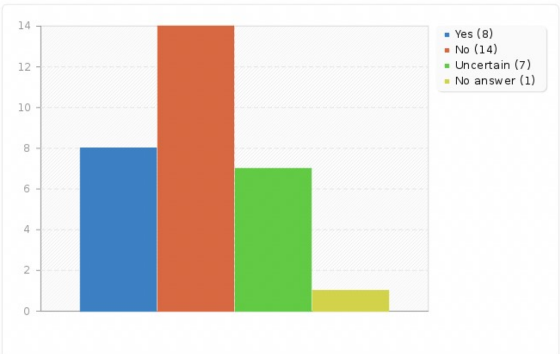
The next question was 'do you know what was required to win it?' Only three respondents were able to correctly say what was required to win the prize (the first wave or tidal project in Scotland to generate 100GWh over 2 years before 2017). Only four were able to identify the energy target of 100GWh. Responses are shown below:

Do you know what the prize was?	Do you know what was required to win it?
Yes, applied for it	max amount generated by a certain year (by 2016?) by an array - 100GWh - 10 turbines were needed
Getting first 10MW? 10MWh? 100MWh? no one has made it	as above in 2 years
£10 million	100GW/h over one year
A million pounds	certain amount of energy in a certain time by a certain date
£10m for the first whatever... installed capacity... delivered to the grid?	to be installed before a certain date which has expired
£10m for achieving 1GWh or something -I 'd rather have had a mars bar!	
£10 million	Generating over a certain amount.
£10 million	Delivering 100mwh into the grid
It was a government incentive - £10M for the first to produce above certain energy generation limits in marine energy.	not in detail - it was a fairly detailed criteria.
Original for whole sale generation of 100 GWHrs over two years	Had to have at least13 Mw of installed capacity
£10m	to meet an output in 1 yr of 10GWh/year?
£15 million	Through a competitive process of project proposals
Vaguely. I don't know figures or eligibility requirements	Think it was something to do with MWh produced by a certain point in time
Financial reward for first project to generate a given amount of power. (I forget the numbers).	Generate a given amount of power
£10m	Most power generated into the grid over a certain period of time (12 months? 2 years?)

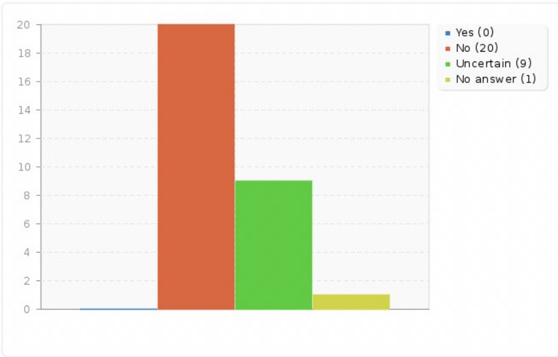
Millions	Something wholly unobtainable for the industry as it was at the time
£10m	Generation of 10GWh from tidal stream or wave, part of what drove everyone to go big straight away
No	No
£10m	First person to generate 1GWh over a 2 year period?
£10m	First company to generate over 10TWh? quite a lot of energy
£10m for the generation of 100GWh over 2 years (this is from memory although I had to look it up to check)	Roughly £100m of CAPEX
£10 million	10GW/h before 2017
£1 million (Anders) £10 million (Chris)	To produce 1GWh
£10 million	Reach 10GW/h over 12 months
£10m (I'm guessing)	First one to generate a particular threshold of energy
£10Million	Generate 100 GW hours over 2 years
£10m	10MW installed?
No	No
£10Million prize	installed capacity of 10MW? for a certain amount of time.

The following questions were asked about the prize to gauge knowledge and awareness of the elements that made up the prize:

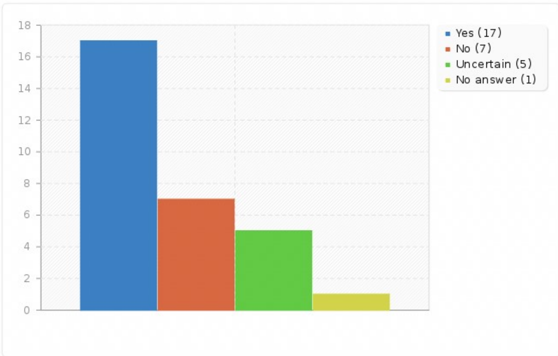
Which of these elements made up the Saltire Prize? [A prize for schoolchildren to develop a working test tank model in wave or tidal energy] – *this was part of the Saltire prize programme and considered to be quite successful by those that were involved with it in encouraging interest in science and engineering and wave energy.*



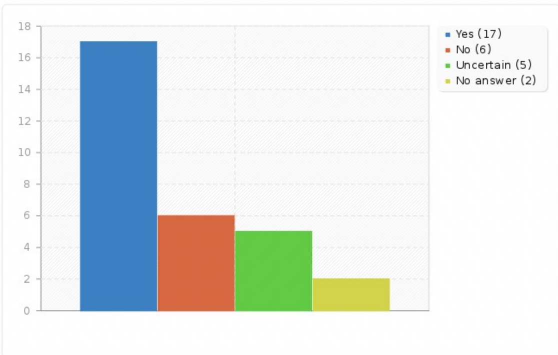
Which of these elements made up the Saltire Prize? [A prize for a concept to achieve a certain power capture performance and levelised cost of energy as demonstrated in a test tank] – *this was not part of the Saltire Prize but was in fact the US DOE Wave Energy Prize.*



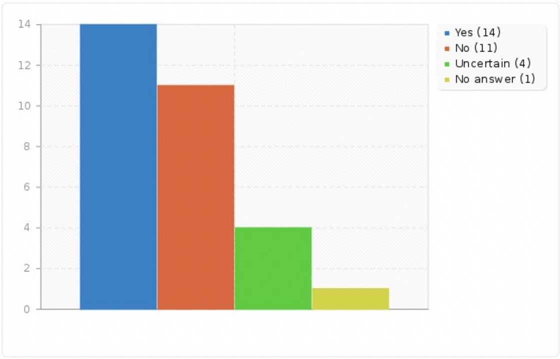
Which of these elements made up the Saltire Prize? [A prize for wave or tidal **project owners** achieving a significant milestone in terms of electricity generation] – *this question was linked with the next question to distinguish between whether it was a prize for technology developers or project owners.*



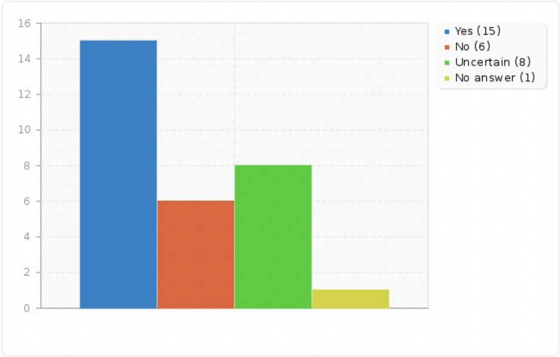
Which of these elements made up the Saltire Prize? [A prize for wave or tidal technology **developers** achieving a significant milestone] – *as above this question was linked with the previous question to distinguish between whether it was a prize for technology developers or project owners.*



Which of these elements made up the Saltire Prize? [A medal recognising achievement in the field of wave and tidal energy] – *this was part of the Saltire Prize programme, albeit this caused some confusion to a respondent who thought that 'Richard Yemm had already won the prize' whereas in fact he was a recipient of the medal.*

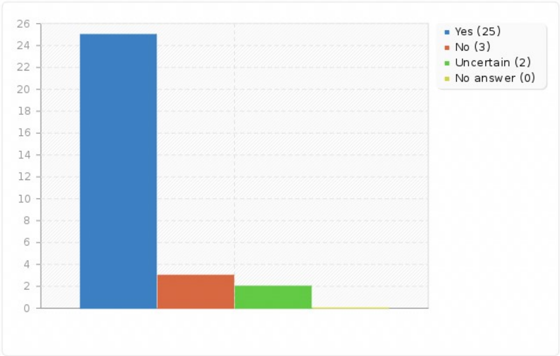


Which of these elements made up the Saltire Prize? [The first project to generate 100GWh over a two year period] – *this was of course the main criteria for the prize, which more respondents recognised when presented this as a question.*

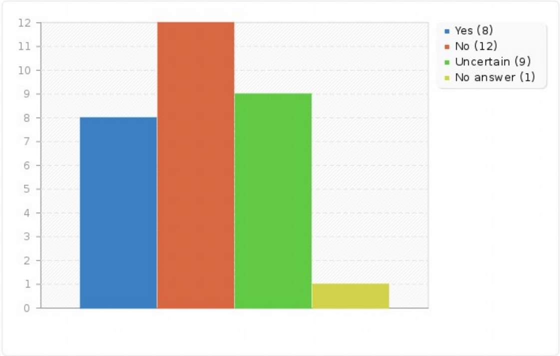


C.8.2 Saltire Prize as a stimulus

Do you think the Saltire Prize: [Was in principle a good initiative?] – *83% of respondents thought it was*

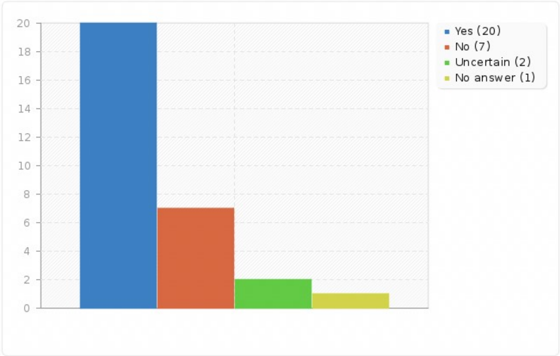


Do you think the Saltire Prize: [Was a stimulus to investment and teams within the sector?] – *70% of respondents thought it wasn't or weren't sure*

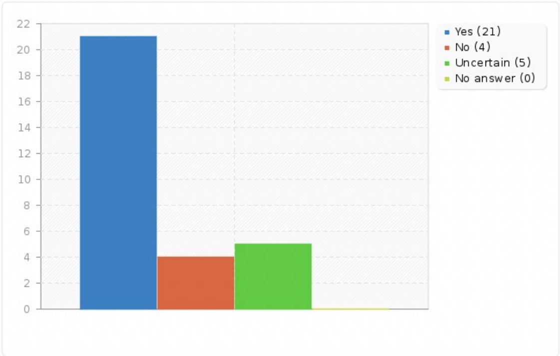


Do you think the Saltire Prize: [Created interest from the general public and media in the sector?] –

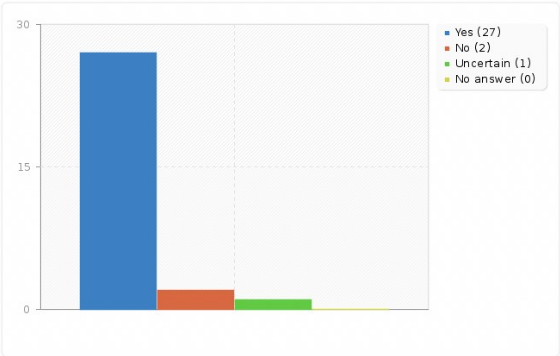
two thirds of respondents thought so



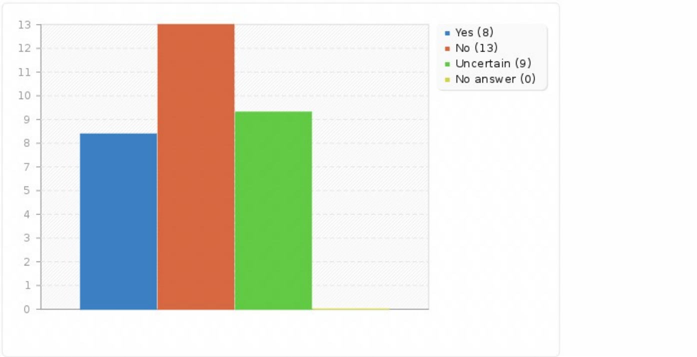
Do you think the Saltire Prize: [Was a milestone that is relevant to the sector if it is to become a commercially available energy option?] – *70% of respondents thought so*



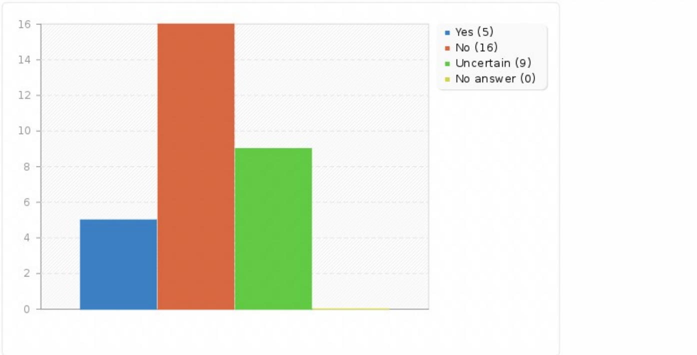
Do you think the Saltire Prize: [Was set at too ambitious a level?] ***– 90% of respondents thought so***



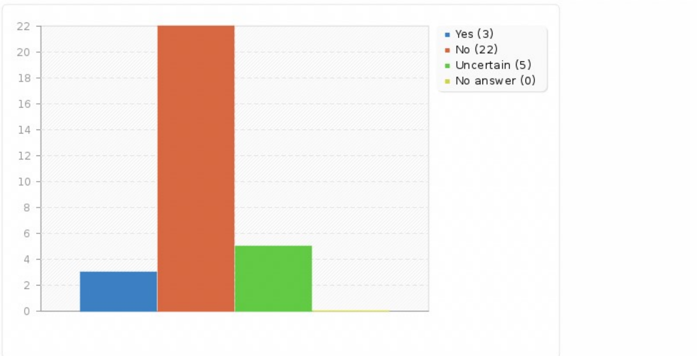
Do you think the Saltire Prize: [Was targeted at the wrong people?] – *when (if) elaborated on, this question sought to distinguish between technology developers and project owners winning the prize. As construed the prize would have been won by a project owner. This may or may not have been a technology developer, dependent upon whether they could finance the build of project. 26% of respondents agreed it was targeted at the wrong people with 43% disagreeing and 30% uncertain. This question caused some confusion as to whether it was obvious that the project owner* ***should*** *be the winner (as someone who could build such a project) or whether they* ***should*** *as the most deserving candidate.*



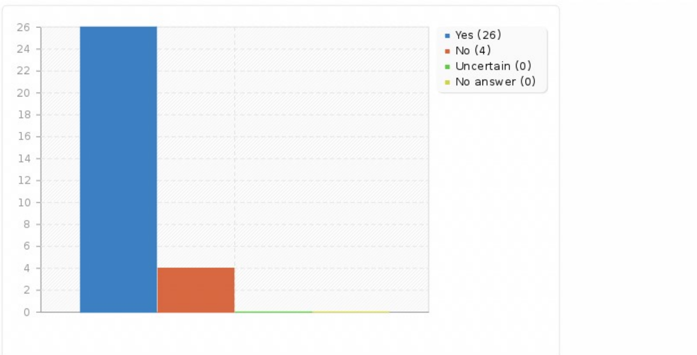
Do you think the Saltire Prize: [Was a distraction from other supportive policy initiatives? (eg provision of tariff, grants etc)] – *53% of respondents thought it wasn't*



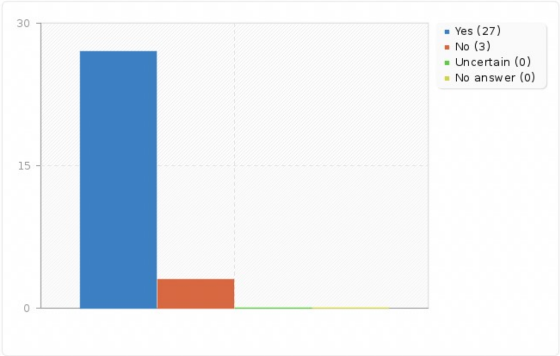
Do you think the Saltire Prize: [Should be kept in place and unchanged?] – *this question is linked to the following question below. 73% of respondents thought it shouldn't be kept in place* ***and*** *unchanged.*



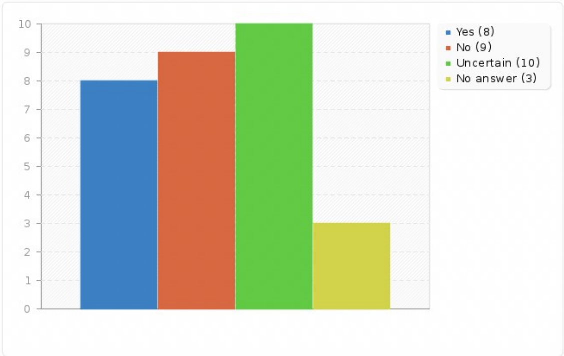
Do you think the Saltire Prize: [Should be reformed to better accelerate the development of the wave and tidal sector?] ***– 87% of respondents thought it should be reformed***



Do you think the Saltire Prize: [Should be separate for wave and tidal energy?] – *90% of respondents* *thought it should be separate*



Do you think the Saltire Prize: [Should be staged like the US DOE Wave Energy Prize?] – *the answer to this was inconclusive with 27% in favour, 30% against and 33% uncertain.*



C.8.3 Options for the Saltire Prize

Respondents were then asked for suggestions on how the Saltire Prize could be revamped to help accelerate the sector to commercial viability. Snippets from this discussion are recorded below:

Probably too late for a staged approach like the US for tidal. Tidal should be all about generating in the field. Wave could also be too late. LCOE too subjective to base something on given uncertainties in OPEX. Levels should be different. 20GWh first phase so would take 5 years with 1A. Target should be set at a level that is achievable within 2 years of operation. Has to be full scale devices. Tidal - array. Wave - half decent full scale prototype. Generation target is good because clearly tangible. Prize should be about making wave and tidal a significant part of the energy mix. Must be measureable.
Two different levels for wave and tidal - aim at developers - technology will have issues so project developers not keen. Yes to an electricity generation target. The ideal thing to do at EMEC. Be nice to see Saltire Prize brought back or something similar. Has name been besmirched by lack of winning? Call it something new. DTI did the 'gold bar wrapped in barbed wire'..... [the MRDF] At the moment the insurers want a year as a minimum requirement to demonstrate operation.
Pro generation over month. Make it a race/challenge.
US DOE structure is too closed- only people who are in it from the start will be eligible. There are many technologies developing that could miss out. Assumes that you have captured the right technology from the start. Good to have it as an open ended, tantalising objective. The idea of splitting it into wave and tidal in order to give both sectors a chance. Happy to discuss further at a later date.
Keep it as it is! Why wasn't it extended for two years? Maybe it should be 50GWh?
No - don't do like the DOE prizes because 'so called' experts would be passing judgement. Should be to a technology developer because they have the highest risk and the phase of where it

is at the moment. How do you pull supply chain, eg Mojo? example of 15 year contract for project versus 6 months for vessel.

3 prizes in different categories, has to be material (eg £5m):
1. Technology developer
2. Supply chain
3. Project developer

Project developer has least risk so should be least rewarded. Other two should be rewarded.

Have to reward innovators and entrepreneurs.

Wider picture should be for a 1.5GW plan with stages, to motivate and incentivise the supply chain.

Basic premise is sound. Needs less ambitious targets. Need to be achievable by people who have kit in the water now. Could be really positive for the sector.

Challenging to tweak to take into account the MW scale developers and the small-scale developers.

Instead of being focused on power generating, could be focused on operational hours, in terms of survivability and reliability- which would make it a more level playing field for the large and small-scale operations.

Continued to drive towards large scale too scale. Could be staged to allow other people to demonstrate other things rather than just performance. Separate wave and tide.

Don't want giant slalom race with many being discarded.
Incentivise it for values led people who believe and have shown commitment to Scottish marine energy- rather than people who move an office in based on cash incentive.
Should be a long-term proposition. Focus on social impact - most significant social impact in Scotland - eg appropriately measured by a consultancy. Training, local jobs, local energy, local supply chain. Got to have a decent product but not what you're getting the prize for. (cf Armani in Oban - triple bottom line). eg B Corp. Bill Gates - impact investment. All Directors get a company Tesla!!

It should be progressive
Bronze - for first 5 developers to achieve 1 GWhr of gen in 1 year
Silver - for 3 developers to achieve 10 GWhrs in 1 year
Gold - for 1 developer100 GWhrs in 2 years

Conversation with WES to deliver a revised staged wave prize suitable to the industry at its current stage, possibly learning from the DOE wave energy prize (we're dealing with DOE already). Prize should be wave only, tidal industry considers it is a stage beyond. time and energy are good measure points however it may be better to have a more nuanced approach. Needs to be achievable within a reasonable timeframe. Perhaps prize should be more like Masterchef - competitors come in, then WES picks a winner and funds them to build a device. Or panel of independent experts looking at evidenced data.

Submit a proposal for a prize and don't have to go through lots of rounds, should be targeted. More fairly distributed, potentially to smaller distributors. Should be spread amongst the other arts of the supply chain.

Good news from Scot renewables - the generation produced to date. 2years of continuous energy production - in timeframe >10GWh. Should be about production rather than capacity. Maybe take into account capacity factor and location.... Maybe availability is better to focus on. Maybe a LCOE focus assessment might be good....

Reward success for range of projects for power generated, focusing smaller projects that allow a range of technologies to be deployed on self-financing projects provided they are successful in generating power.

Have something that is economical - prize for market acceptance/ commerciality - get it past the cusp - something that can be sold and made money.... but difficult to do - could be fiddled? Could be a profit level reached - £1m? Paid off expenditure? Audit trail. But needs to be open and transparent. Would need established methodology. Too complicated rules could put off people. We

looked at it originally but concluded there was no chance with the route that we were taking.... Should try and avoid issues with people taking different technological/market approaches. Perhaps give £1m per year - would give real traction. Perhaps the goal is not purely the energy but the impact it has. Impact = economic, environmental, remote communities - changing their entire livelihood. Making communities CO2 neutral/negative.
Pointless to have prize and competition as if you are serious about a business proposition you'll do it anyway. Its rubbish
Has to have a fixed date with something that has to be delivered by that date. More than 2-3 years is to far if it is to have an impact. Not sure it should be a specific generation criteria, but difficult to assess otherwise. Generation clear cut. Formula Student - could be a model? Eg example of developing a man-powered submarine - Unis get together to build a human powered submarine. Aim could be trying to get engineers into renewables. Takes competitive commercial out a bit. Edinburgh involved in Formula Student. Another possibility could be a commercial milestone with an informed customer at the end... Joint work on metrics with DOE and IEA which could be utilised.
Technology developers became project developers because of the Saltire Prize which was a mistake. Initial wave developers burned a lot of money on project development. Prize still relevant - we have to start scaling. Challenge no doubt but we have to do it.
The previous questions on TRL verses CRL is relevant. Technology push alone is like pushing on a string. Focus should be on enabling market pull from a project development perspective. Innovation is not limited to technology alone, and can include financial services.
Good to have and achieve publicity. Good incentive.
Should not preclude hybrid technologies.
- guarantee 5x ROC equivalent for the next 25 years – this should be somehow part of it - have a race for a wave powered boat challenge, to get corporate sponsorship like the solar race challenge - as a follow on from the WES programme - competition like the US Wave Energy Prize, except starting from tank tests going to sheltered test sites with funding for it, with high media profile - turn the whole thing into a documentary (but would need to be done by sympathetic people, not to make us look ridiculous).
Has to give some revenue support. You could get investment in if you had the revenue support. Separate mechanism for wave and tidal to recognize different stages of development.
"Maybe they didn't want to hand out the prize...". Could be decreasing prize over time.... pot stays indefinitely. Shouldn't be like DOE wave prize (although it was a good thing) but maybe some stage funding would be good. Half the US prize went on administration ($3m). Probably only the winners thought it was a good prize. The criteria was very subjective. Nice thing about Saltire prize was that it was unambiguous. I like the electricity generation but the threshold was too high. Maybe prize for prototype stage and one for project stage? Technology developers are the face of the industry. Problems with US WEP was not a technology development programme, was too fast. Criteria was based on surface area and what it would be made out of. People that won had bottom mounting buoys and didn't take into account mooring costs in a non-arbitrary way. ie there were arbitrary criteria, although not deliberately done. Needs to go technology developers to motivate them, big guys are already motivated.
The money would be better spent supporting the various second generation wave and tidal companies that are desperate for small lumps of funding- especially Scottish businesses, or attracting other businesses into Scotland.
The same level of prize. Smaller cash prizes could be given out for achieved milestones by technology developers using certain criteria including Scottish content The prize goal (100 GWh over two years) should be retained as a target for the sector. However, the funding should be released to directly support the development of the Scottish marine energy sector, providing grant funding to one or two small-scale tidal energy projects. Additional revenue support will be required to bring these projects to fruition. The goal should be the development of a thriving marine energy sector that maximises benefits to the Scottish economy.