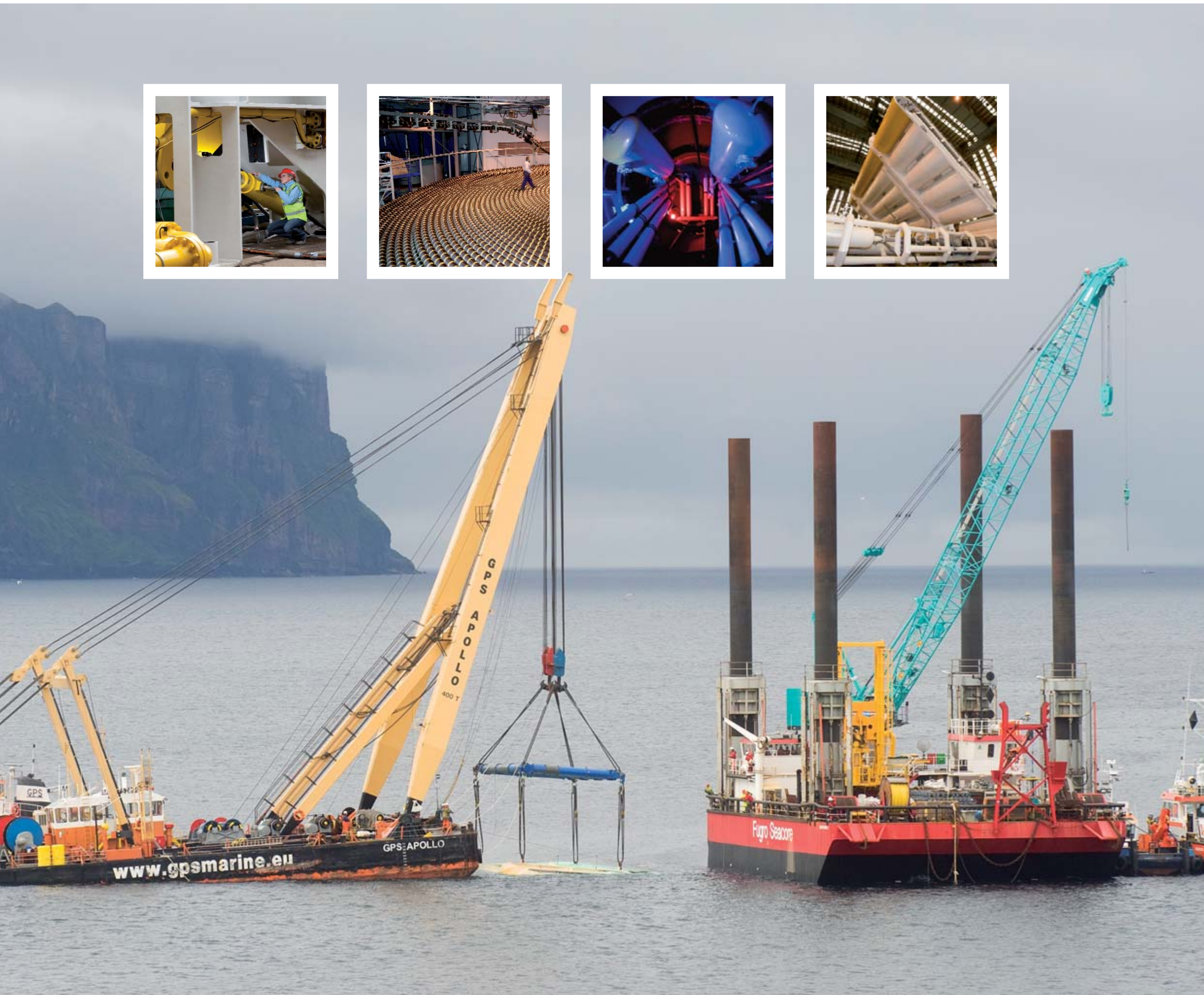
THE CROWN ESTATE



Wave and tidal energy in the Pentland Firth and Orkney waters: How the projects could be built

A report commissioned by The Crown Estate and prepared by BVG Associates

May 2011

1 Executive Summary

- During 2010, The Crown Estate announced that it had awarded development rights to a number of companies for eleven wave and tidal stream energy projects in the Pentland Firth and Orkney waters, with a total potential capacity of 1,600 MW. This followed a leasing round that The Crown Estate ran between 2008 and 2010, which received considerable interest from industry. The Pentland Firth and Orkney waters area is the first to be made available for commercial scale development of wave and tidal energy in Scotland and indeed the whole of the UK. The projects are believed to represent the largest planned development of wave and tidal stream energy worldwide.

- Working with the developers, The Crown Estate has commissioned this report to provide information about how and when the projects could be built. The report describes the expected timing of development of the eleven projects; the stages of development that each project is expected to undergo; the products and services involved at each stage and their approximate monetary values.

- We hope that stakeholders find the report of help in planning activities for the coming years, especially in identifying ways they can work with the developers to support the projects towards construction and beyond.

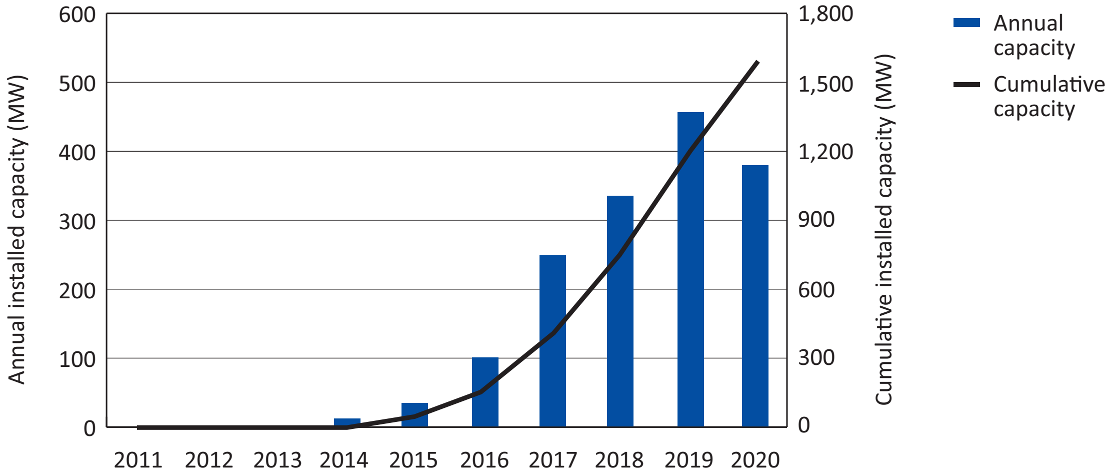


Figure i: Aggregate installation plan for the Pentland Firth and Orkney waters projects

- The expected timing of development and construction is summarised in Figure i.

- Work to develop the projects has now been underway in earnest for over a year. The initial focus is on making preparations for statutory consents applications.

- Delivery of the projects to schedule depends on a range of factors, many of which will be tackled directly by the project development companies. A range of challenging technological, environmental, planning and economic factors may have to be overcome. In addition, successful development depends crucially on support from other organisations, including technology providers, infrastructure providers (to develop additional grid capacity) and government (in consenting and financial support).

- If statutory consents are granted by Marine Scotland, and other necessary conditions are met so that investment in the project capital costs is secured, the projects can be expected to progress through installation and commissioning stages. Initial levels of device deployment will be relatively low as technologies, installation methods and operations techniques are demonstrated. If this is successful, the level of activity and the associated expenditure on project development may be expected to increase in the second half of the decade.

- These activities require a very broad range of services, equipment and infrastructure.

  - Total expenditure of approximately £100 million is anticipated on the development and consenting activities, the majority of which is expected to be incurred by the middle of the decade.

  - Manufacturing of devices and the associated foundations or moorings, subsea cabling and offshore substations is expected to entail expenditure of approximately £4 billion and the cost of installation is projected to be in the region of £2 billion.

  - The total capital expenditure on development of the full potential capacity is projected to be in excess of £6 billion, with a large part of this occurring towards the end of the decade.

- Once projects have been commissioned, there will be a requirement for ongoing operation and maintenance activities over the projects' anticipated operational lives of 25 years. Operation and maintenance will be at a relatively low level during the initial phases of deployment, but by the time the Pentland Firth and Orkney waters projects are nearing completion, there could be around 1600 devices operating, with an annual expenditure on operation and maintenance activities in the region of £100 million.

- The pattern of expenditure is summarised in Figure ii.

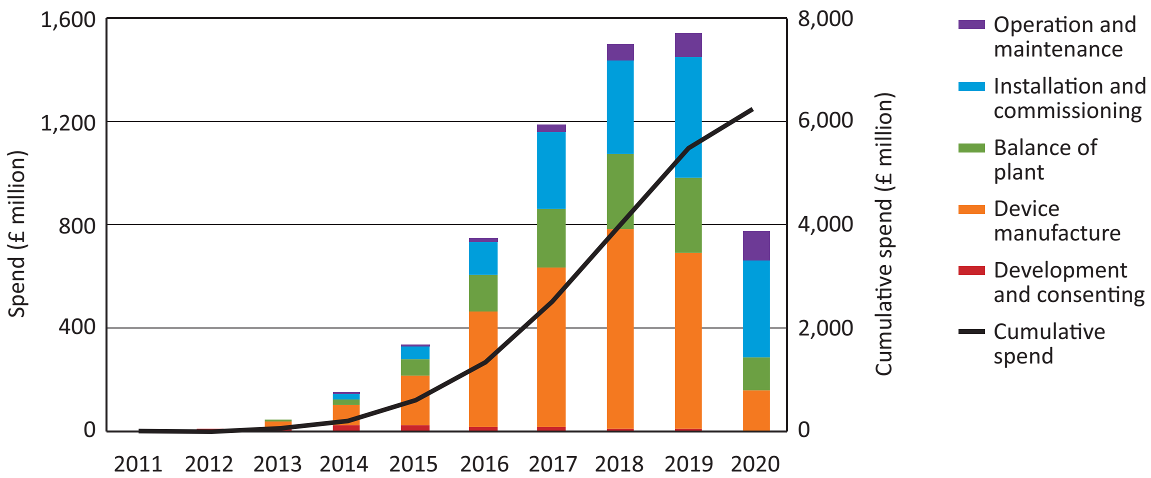


Figure ii: Forecast expenditure on Pentland Firth and Orkney waters projects

- Expenditure on development of wave and tidal energy technologies, the necessary investment in the electricity grid and other infrastructure for the Pentland Firth and Orkney waters projects are not included in Figure ii. such costs will be in addition to the £6 billion detailed in this report.

- Development of the Pentland Firth and Orkney waters projects offers the possibility of significant investment in technologies, services and infrastructure during this decade. The profile of these investments may be expected to ramp up during the course of the decade, with a relatively low level of activity in the early years. The investment is in large part conditional on the successful completion of each stage in the project development process, so at this point it is not certain that it will be made. There are opportunities for potential providers of the required technologies, services and infrastructure to engage with the developing industry. At this stage in the project development process, the manner in which the supply chain will develop is also uncertain. There are, however, significant opportunities for those who can rise to the challenges posed by the delivery of the Pentland Firth and Orkney waters projects.

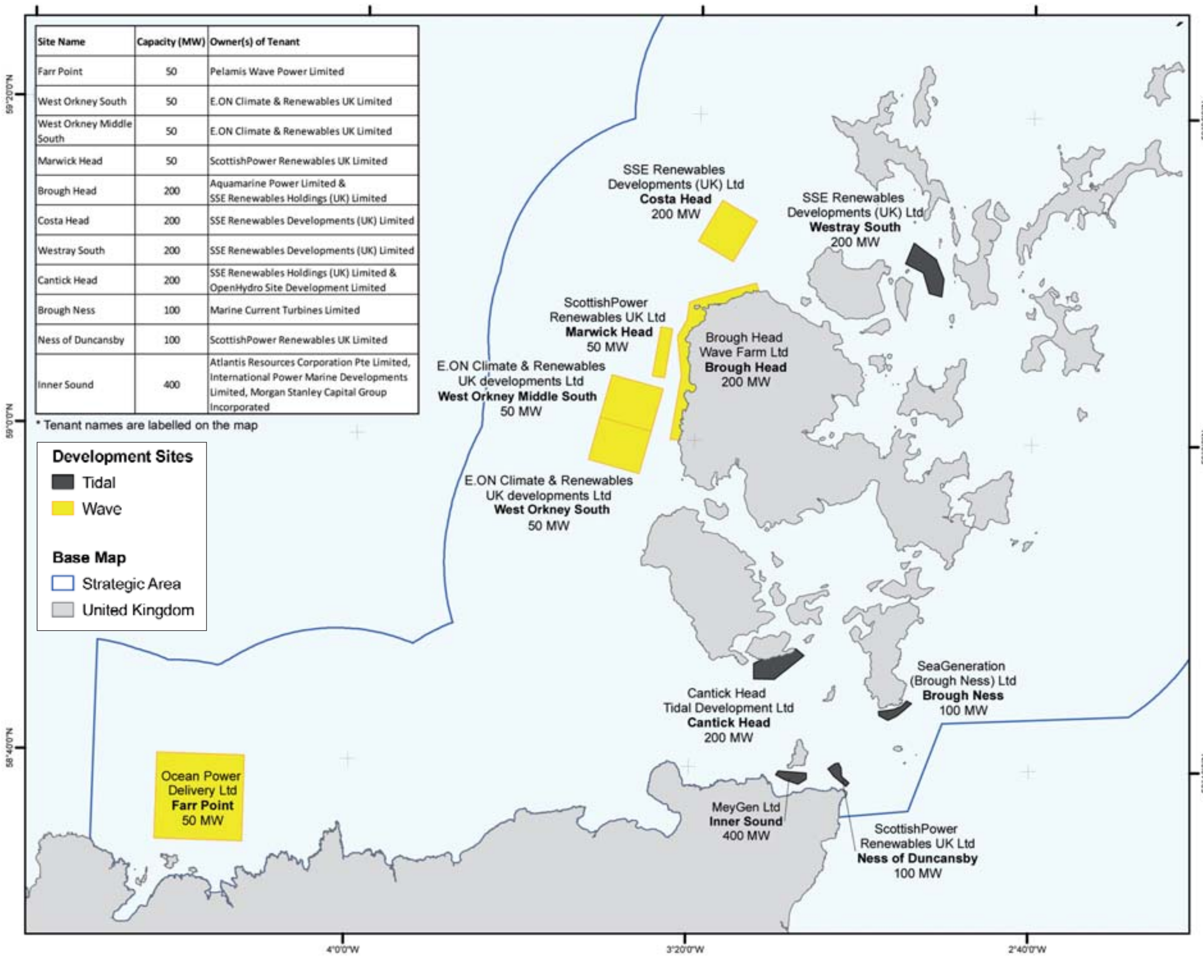
Contents

Glossary

ADCP	-	Acoustic Doppler Current Profiler
CAPEX	-	Capital expenditure
DP	-	Dynamic Positioning
EIA	-	Environmental Impact Assessment
EMEC	-	European Marine Energy Centre
FEED	-	Front-end Engineering Design
FTE	-	Full time employee
GW	-	Gigawatt (=1 thousand megawatts)
MW	-	Megawatt
OPEX	-	Operating Expenditure
REA	-	Regional Environmental Assessment
ROV	-	Remote Operated Vehicle
SEA	-	Strategic Environmental Assessment
TEC	-	Tidal Energy Converter
WEC	-	Wave Energy Converter

3 Introduction

During 2010, The Crown Estate announced that a number of energy project development companies had plans to develop a set of eleven wave and tidal stream energy projects in the Pentland Firth and Orkney waters, with a total potential capacity of 1,600 MW. This followed a leasing round which The Crown Estate ran from 2008 onwards, which received considerable interest from industry. The development sites are shown in Figure 3.1.



Site Name	Capacity (MW)	Owner(s) of Tenant
Farr Point	50	Pelamis Wave Power Limited
West Orkney South	50	E.ON Climate & Renewables UK Limited
West Orkney Middle South	50	E.ON Climate & Renewables UK Limited
Marwick Head	50	ScottishPower Renewables UK Limited
Brough Head	200	Aquamarine Power Limited & SSE Renewables Holdings (UK) Limited
Costa Head	200	SSE Renewables Developments (UK) Limited
Westray South	200	SSE Renewables Developments (UK) Limited
Cantick Head	200	SSE Renewables Holdings (UK) Limited & OpenHydro Site Development Limited
Brough Ness	100	Marine Current Turbines Limited
Ness of Duncansby	100	ScottishPower Renewables UK Limited
Inner Sound	400	Atlantis Resources Corporation Pte Limited, International Power Marine Developments Limited, Morgan Stanley Capital Group Incorporated

Figure 3.1: Pentland Firth and Orkney waters Round 1 Development Sites

Today, in May 2011, the development companies have been working for over a year on detailed plans for the projects, with a view to constructing and operating them later this decade. The entire capacity is expected to be installed and operating by 2020.

The developers' plans are of interest to a range of stakeholders, including potential suppliers of goods and services to the projects, government bodies and other organisations. Working with the developers, The Crown Estate has commissioned this report to provide information to such stakeholders, in order to share understanding of how and when the projects are expected to be built. We hope that stakeholders find it of help in planning activities for the coming years, especially in identifying ways they can work with the developers to support the projects towards construction and beyond.

The Pentland Firth and Orkney waters is the first area to be made available for commercial scale development of wave and tidal energy in Scotland and indeed the whole of the UK. The projects are believed to represent the largest planned development of wave and tidal stream energy worldwide. The Pentland Firth and Orkney waters leasing round received the award of Landmark Renewable Deal of the Year at the Ernst & Young Global Renewable Energy Awards, September 2010.

3.1 About The Crown Estate

The Crown Estate is the organisation, established by Parliament, to manage the hereditary estates of the Crown on behalf of the nation.

Our responsibilities are to maintain and enhance the value of the estates and their income over the long term and to do this having regard to good management. The profit earned by The Crown Estate is paid to the Treasury for the benefit of the nation. Over the last ten years, the capital value of The Crown Estate has increased by £2.6 billion and The Crown Estate has paid a total of £1.9 billion to the Treasury.

The Crown Estate comprises a diverse portfolio which includes urban, rural and marine property and land holdings. The marine estate comprises over half the foreshore and almost all the seabed around the UK. In offshore energy, we are best known for our work in offshore wind, in which we have made agreements with development companies to build up to nearly 50 GW of wind farms. These agreements were made through several leasing rounds last decade.

We work constructively with the grain of government at every level. In wave and tidal energy, we have been working particularly closely with the Scottish Government, noting the Government's objectives to grow the emerging wave and tidal industry in Scotland, through initiatives such as the Saltire Prize. For the Pentland Firth and Orkney waters projects, we are also in close cooperation with the Highland Council, Orkney Islands Council and Highlands and Islands Enterprise.

For more information about The Crown Estate and our work in wave and tidal energy, see: www.thecrownestate.co.uk/wave-tidal.

3.2 About the development companies

The companies developing the Pentland Firth and Orkney waters projects, which are expected to become tenants of The Crown Estate for the areas of seabed the projects occupy, comprise a mixture of companies, some working individually and others in joint ventures. Figure 3.2 gives a list of the company names and the types, names and sizes of their projects.

The Crown Estate awarded agreements for lease – contracts which give the developers exclusive rights over the seabed areas for site investigations and other development purposes – as the main outcome of the leasing round. Should the projects receive statutory consents, from government bodies such as Marine Scotland (part of the Scottish Government), these contracts will be converted to leases, which allow the companies to construct and operate the projects. The typical duration of agreements for lease is four to five years, which indicates that construction could begin in 2014-15.

Developer (Technology)	Site	Capacity
Wave		
SSE Renewables Developments Ltd	Costa Head	200 MW
Aquamarine Power Ltd & SSE Renewables Developments Ltd (Oyster)	Brough Head	200 MW
Scottish Power Renewables UK Ltd	Marwick Head	50 MW
E.ON Climate and Renewables UK Developments Ltd	West Orkney South	50 MW
E.ON Climate and Renewables UK Developments Ltd	West Orkney Middle South	50 MW
Pelamis Wave Power Ltd (Pelamis)	Farr Point	50 MW
Tidal		
SSE Renewables Developments Ltd	Westray South	200 MW
SSE Renewables Holdings (UK) Ltd & OpenHydro Site Development Ltd (OpenHydro)	Cantick Head	200 MW
Marine Current Turbines Ltd	Brough Ness	100 MW
MeyGen Ltd	Inner Sound	400MW
Scottish Power Renewables UK Ltd	Ness of Duncansby	100 MW

Figure 3.2: Pentland Firth and Orkney waters Round 1 Projects

3.3 About this report

Building the 1,600 MW of projects by 2020 will require several billion pounds of investment in the electricity generation equipment, balance of plant and supporting infrastructure (such as electricity networks, ports and harbours). The prospect therefore raises significant commercial opportunities for businesses, as well as economic development potential for Scotland, the regions surrounding the projects and local communities.

This report describes the following:

- The expected timing of development of the eleven wave and tidal stream energy projects planned in the Pentland Firth and Orkney waters; and
- The stages of development that each project is expected to undergo, the products and services involved at each stage and their approximate monetary values.

Also discussed are the approaches which the developers expect to take to procuring goods and services, since this is likely to help companies seeking to become suppliers.

For the most part, the report focuses on work likely to be undertaken in the coming five years. This is because:

- These activities are currently planned in most detail by the developers; and
- The activities are most likely to translate into short term sales opportunities for potential suppliers.

The report also focuses primarily on development of the Pentland Firth and Orkney waters projects, as distinct to development of the electricity generation technologies that form a part of them. Other opportunities are associated with development of these technologies in their own right, as the technologies undergo design, testing and demonstration activities.

3.3.1 How the report was prepared

The report was compiled by BVG Associates Ltd, a consultancy company which provides advice to the renewable energy industry, government and other organisations. For more information, see: www.bvgassociates.co.uk.

The report is based on information provided by the development companies, in some cases forming parts of development plans presented to The Crown Estate, and in other cases prepared specially for this project.

The project is one of the first activities to be supported through the Pentland Firth and Orkney waters Enabling Actions fund, through which The Crown Estate has committed to invest £5.7m to accelerate and de-risk development of the projects.

3.3.2 Report limitations and disclaimers

Wave and tidal stream energy projects and technologies are currently at early stages of development. While the Pentland Firth and Orkney waters schemes are very promising, no one has yet developed, constructed and operated a commercial wave or tidal stream project (of multiple devices, operated over several years) and the industry is currently learning how to do this.

The Crown Estate is publishing this report to help stakeholders in the projects understand more about them. The information presented is based on the best evidence available to The Crown Estate and the development companies. However, the projects are currently at early stages of development, and it is possible that the developers' plans could change over time. The information should be regarded as providing a good indication of developers' plans today, with costs expressed in 2011 terms, but readers should note that it may become out of date. The Crown Estate is considering publishing updates to the report in future. In case of any uncertainty, readers are encouraged to contact the developers directly (contact details are provided in Section 12).

While The Crown Estate and other organisations contributing to this report have taken reasonable steps to ensure that the information is correct, they give no warranty and make no representation as to its accuracy and accept no liability for any errors or omissions. Neither The Crown Estate nor other organisations are providing investment advice in this report and readers must take their own view on the merits of, and the risks attached to, any investment decision they undertake. Readers may wish to obtain professional advice. Nothing in this publication is intended to be, or should be interpreted as, an endorsement of or recommendation for any supplier, service or product.

4 Timescale for development

This part of the report describes the development schedule of the eleven wave and tidal stream energy projects planned in the Pentland Firth and Orkney waters.

The installation plan shown in Figure 4.1.1 is based on lease milestones proposed by project developers to The Crown Estate as part of the leasing round.

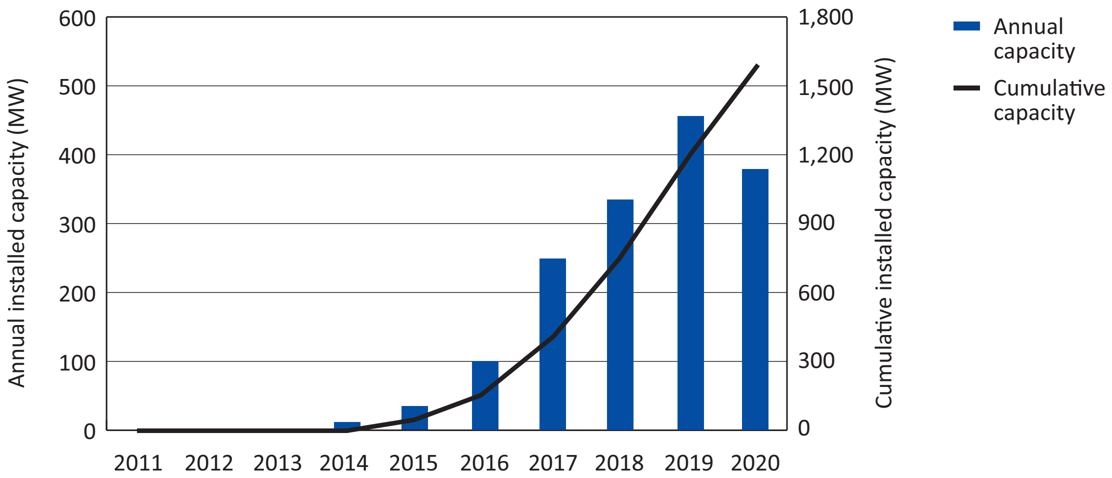


Figure 4.1.1: Aggregate installation plan for the Pentland Firth and Orkney waters projects

In practice, delivery of the projects to schedule depends on a range of factors, many of which will be tackled directly by the project development companies. The remainder of this report sets these out as it describes each stage in the project development process. A range of challenging technological, environmental, planning and economic factors may have to be overcome in order that the process may be completed successfully.

In addition to the activities undertaken by the project development companies, the successful development of the projects also depends crucially on others who are in a position to contribute to the development process, including technology providers, infrastructure providers and government.

In order for the projects to be built, it will be necessary for wave and tidal generation technologies to be developed to a point where they are suitable for commercial deployment at the levels necessary for the Pentland Firth and Orkney waters projects. Their technical capabilities must be confirmed: they must be shown to operate well, with predictable levels of generation performance, reliability and availability, and with acceptable environmental impacts. In addition to that, the demonstration of these achievements must be accepted by project investors. Today, in May 2011, there is not yet an established supply chain for wave or tidal technologies which is capable of providing tens or hundreds of devices per year for commercial deployment. To enable project development schedules to be met, a substantial acceleration in technology research, development and demonstration activities is required.

The Pentland Firth and Orkney waters wave and tidal projects require electricity grid infrastructure to convey their output. There is presently very little available grid capacity near to the project sites – existing capacity is understood to be the order of tens of megawatts capacity, versus the projects' total potential of over 1000 MW capacity. Consequently, it is clear that additional transmission and distribution infrastructure will be required for the projects to be fully built. Provision of this will be a significant undertaking, itself requiring consents, investment and other steps similar to those set out in this report for the wave and tidal generation projects. Investment in the wave and tidal projects is crucially dependent on appropriate and timely delivery of the grid infrastructure.

The Scottish Government is giving strong support for development of the Pentland Firth and Orkney waters projects, and given the magnitude of challenges in development, continuation of this support will be essential for development to be successful. Support will be necessary on a range of issues, including project consenting and finance. Marine Scotland is leading initiatives to facilitate environmental impact assessment and provision of consents, and financial support measures for wave and tidal projects are currently being considered in context of the UK government Renewables Obligation Banding Review, Electricity Market Reform consultation and the Green Investment Bank. The outcome of these policy developments could have a very material impact on the rate and scale of development.

As part of The Crown Estate's support for project development, we are planning to invest £5.7 million in Enabling Actions activities to accelerate and de-risk the process, working closely with the development companies to tackle issues that affect the projects. This report was commissioned as part of our Enabling Actions work and we plan to publish a range of other outputs from the Enabling Actions activities in future. Furthermore, The Crown Estate is continuing to work closely with the Scottish Government, Highlands and Islands Enterprise, the Highlands Council and Orkney Islands Council to coordinate our respective activities in support of the Pentland Firth and Orkney waters projects.

Development and installation of capacity at the rate implied by the milestones will require significant expenditure in a range of areas. The breakdown of lifetime costs shown in Figure 4.1.2 is based on estimates for example wave and tidal projects of a size greater than 50MW. Both the capital costs and operational costs of the projects have been taken into account and a 25 year operating life has been assumed.

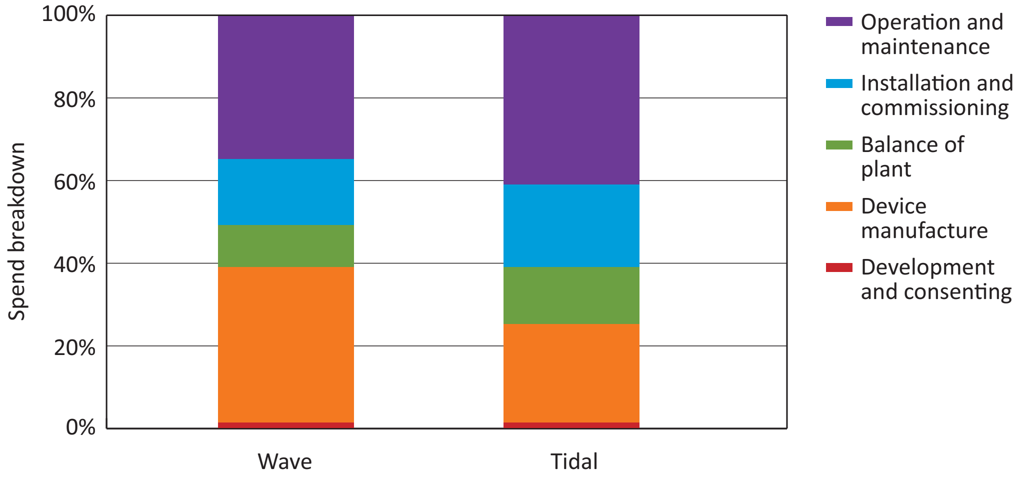


Figure 4.1.2: Undiscounted cost breakdown for Pentland Firth and Orkney waters projects

In order to derive an approximate forecast of potential expenditure between 2011 and 2020, the installation plan is combined with the cost breakdown and a forecast of changing CAPEX and OPEX per megawatt installed each year. Finally, the timing of expenditure is offset relative to the year of installation according to the following assumptions:

- Development and consents: This is anticipated to be spread over five years before the first year of installation, assuming that consents are granted at least one year before the start of site works;
- Device manufacturing: This is expected to occur over two years with 25% of spend in the year of installation and 75% in the year before installation;
- Balance of plant manufacturing: Costs are spread over two years with 50% of expenditure in the year of installation and 50% in the year before installation.
- Installation: All expenditure is in the year of installation; and
- Operation and maintenance: Associated costs are spread over 25 years of operation from the year of installation, with a reducing cost profile due to the industry learning how to carry out activities efficiently and as equipment becomes more reliable.

All costs in this report are expressed in 2011 money values. CAPEX costs over the next decade are anticipated to improve as the industry matures and experience is gained through installation and operation of devices. Initial costs assumed in this report are in line with the results of other work such as the Carbon Trust's Marine Energy Accelerator programme and the report Channelling the Energy[1] published by the trade association RenewableUK. Assumed cost improvements, also expressed in 2011 money values although relating to future expenditure, are based on predicted learning rates and global installation of devices and again have been benchmarked against the Carbon Trust's analysis[2] and other industry views. In view of the forward-looking nature of these assumptions they should be regarded as approximate indications.

The estimated expenditure across the five project stages is presented in Figure 4.1.3.

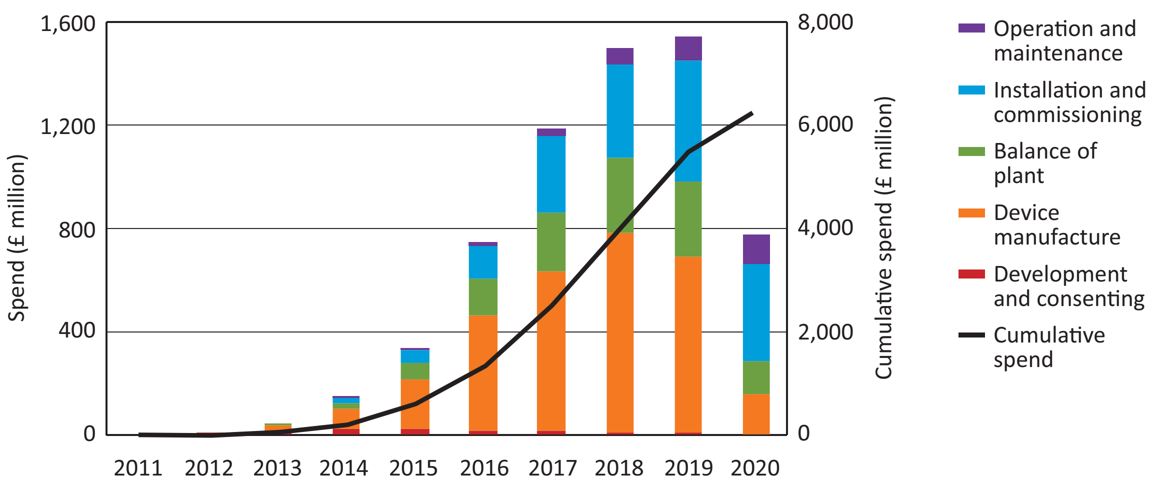


Figure 4.1.3: Forecast expenditure on Pentland Firth and Orkney waters projects

[1] Channelling the Energy, A Way Forward for the UK Wave & Tidal Industry Towards 2020, Renewable UK, October 2010

[2] Marine Renewables Green Growth Paper, Carbon Trust, May 2011

5 Activities in Development

This report section briefly outlines the development stages which each project is expected to undergo; the products and services involved at each stage and their approximate monetary values. Sections 6 to 10 provide greater detail on each of the development stages.

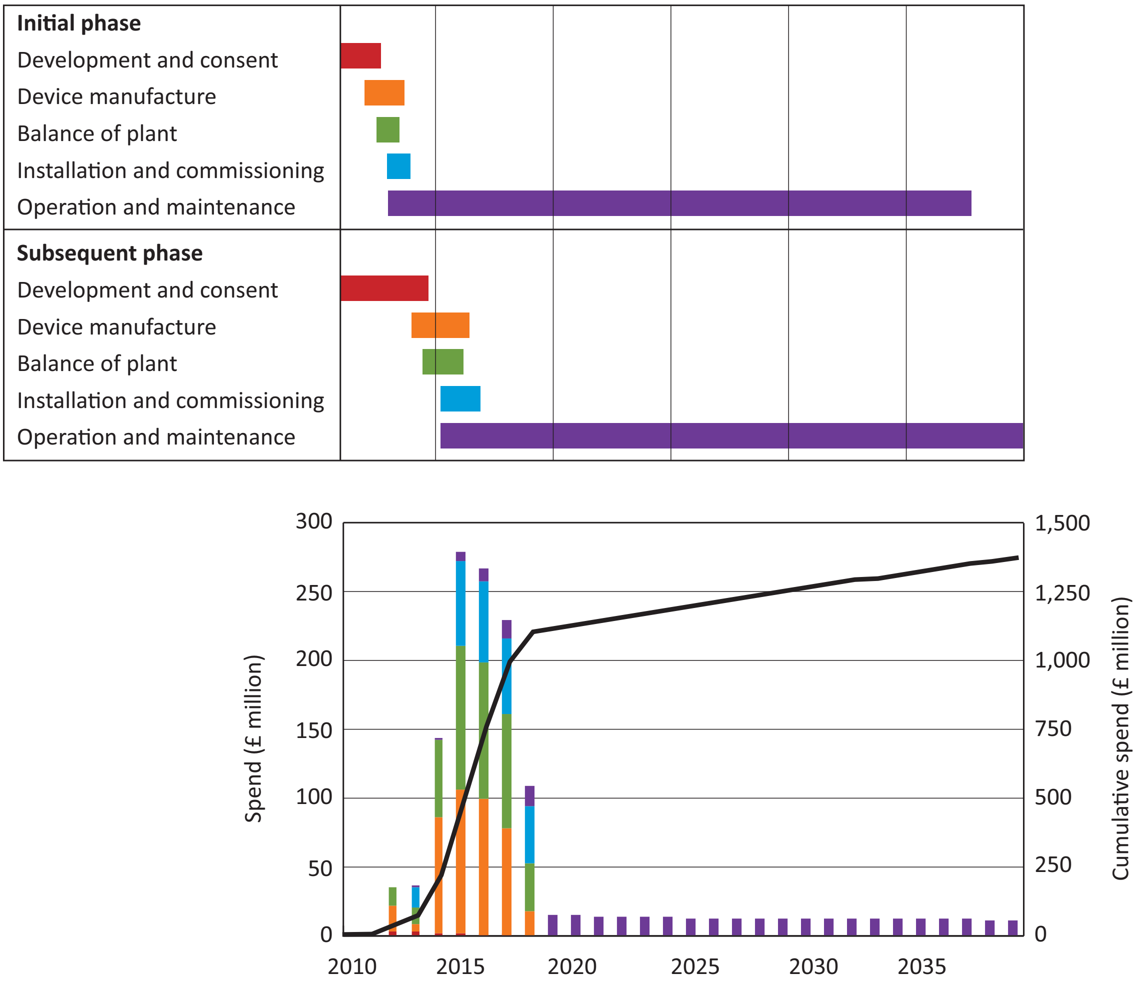


Figure 5.1: Programme of expenditure for idealised 200MW project

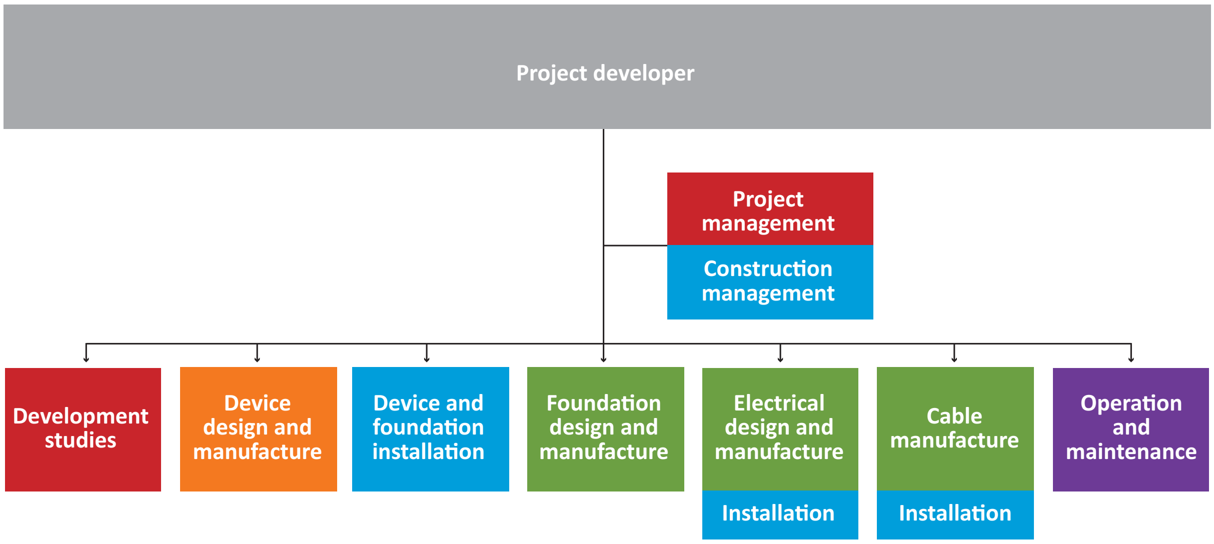


Figure 5.2: Potential multi-contract structure for wave and tidal projects

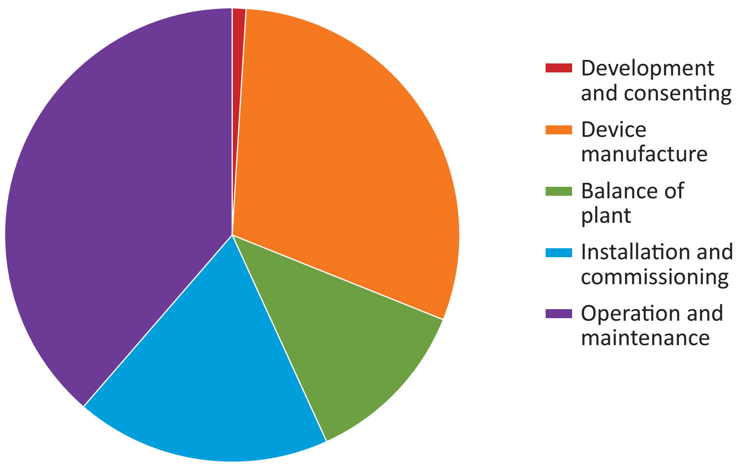


Figure 5.3: Undiscounted cost breakdown wave and tidal project

6 Development and consenting

The development and consent stage covers all activities up to the point where contracts for devices, balance of plant and installation services are placed. It incorporates significant activities related to project feasibility including environmental and human impact, surveying of site characteristics, application for electrical grid connection and planning consent and project-specific front-end engineering design.

The result of these activities is a project with all permissions to construct in place, and with financial approval to proceed based on a confirmed project design, time plan and supply contracts.

6.1 Overview

Development and consenting activities dominate expenditure during the early years of the Pentland Firth and Orkney Waters projects. The process began in earnest during 2010, and based on the developers' schedules, it is generally expected to be up to five years before installation takes place (although for some projects work is planned in shorter timescales). An indicative programme of activities for a single initial project phase is given in Figure 6.1.1.

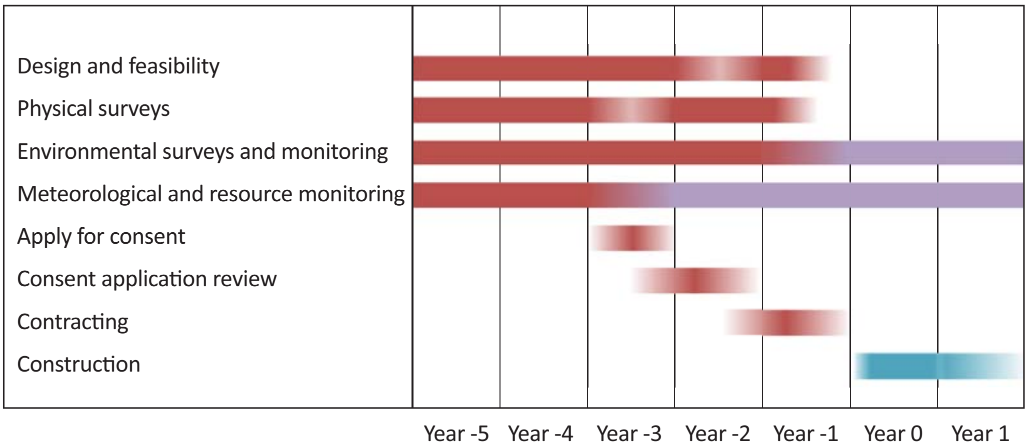


Figure 6.1.1: Indicative programme of development and consent activities

For each project, initial surveys and investigations are used to define the project outline design. These activities are undertaken several years prior to revenue generation and with a risk that the project will not be granted planning consents. As a result expenditure levels are kept to a minimum with additional more detailed worked carried out once planning consents are granted.

Although of key importance to the success of a project, relatively little investment is required during this project stage compared to that in the manufacturing, installation and operation stages. Overall investment for each project of up to £10 million is expected to be spread over the years preceding construction of each project phase. Smaller projects are likely to require a proportionally higher spend on development and consenting as many costs do not change significantly in relation to the total capacity installed.

A forecast of expenditure is presented in Figure 6.1.2, splitting the development and consenting stage into five key activities. Each activity is then discussed in more detail.

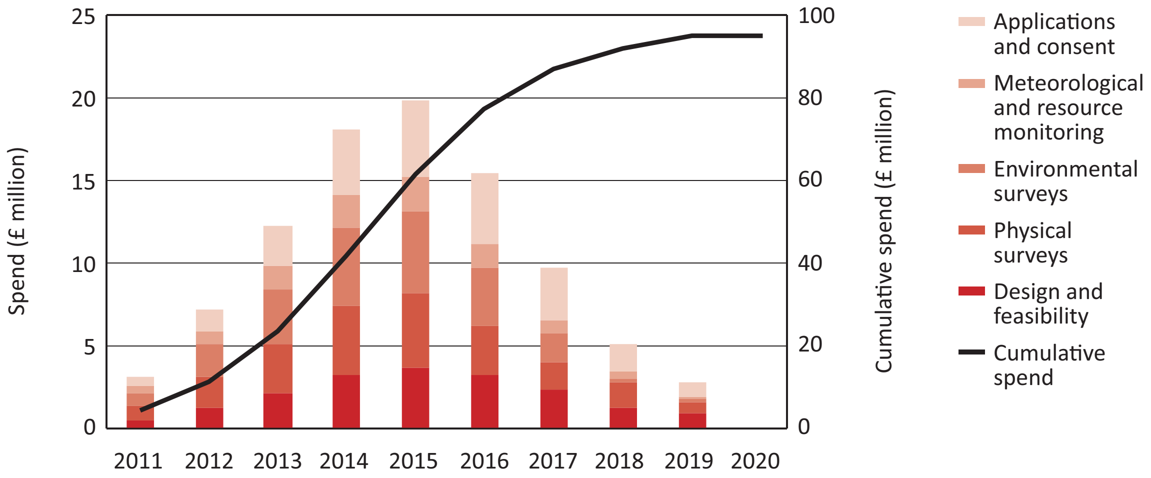


Figure 6.1.2: Forecast expenditure on development and consent activities

For all projects, initial development and consenting activities are now well underway. Significant expenditure on these activities is expected to have been committed by the end of 2013, and if work proceeds on track in accordance with the developers' milestones then most activities will have been completed by the end of 2016.

In order for the projects to proceed as scheduled, consents for the initial phase of the early projects will be required in 2013; with consents for all initial phases required by the end of 2016 as shown in Figure 6.1.3.

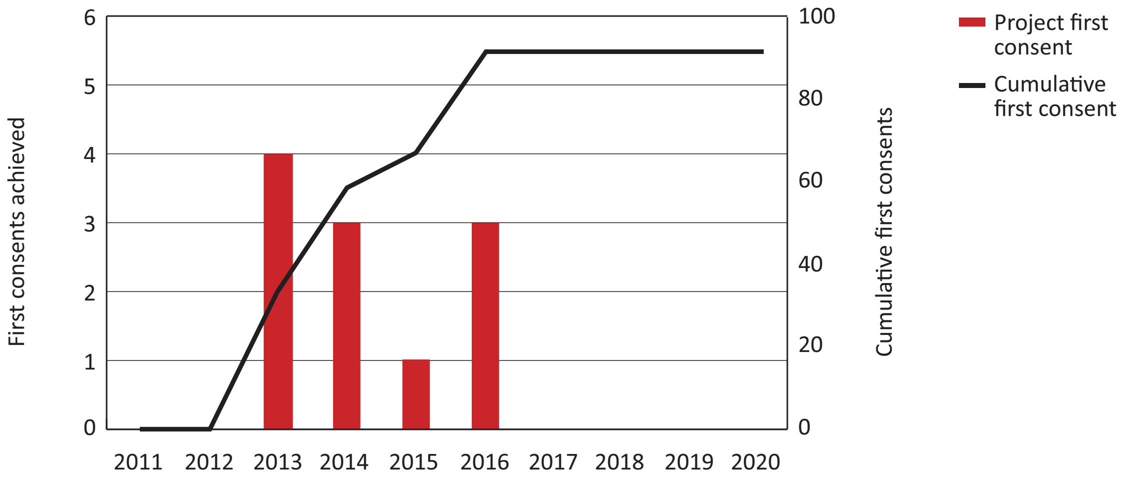


Figure 6.1.3: Timing of consents for initial phases of projects

Project developers are expected to procure most activities in this stage of project delivery directly. In some cases, they may contract first tier suppliers to deliver a broad scope of work, with specialist activities subcontracted further as required. There will be variations between the scopes of contract awarded for each project due to the specific needs of individual project developers.

Utility project developers are establishing small project teams to manage subcontract activities, but activities related to financial evaluation and technology selection are likely to be delivered by in-house resources, calling on subcontractors only for specific tasks. Other project developers anticipate outsourcing these services to a greater extent.

The key services and skills to be externally procured are highlighted in the relevant sections below. Section 12 of this report provides contact details for each of the project developers. Where first tier suppliers are involved, details should be sought from the project developer.

6.2 Activity Breakdown

A cost breakdown of key activities that will generally form parts of the development of each Pentland Firth project is presented in Figure 6.2.1. There are variations in this breakdown between different projects due to unique characteristics of each project.

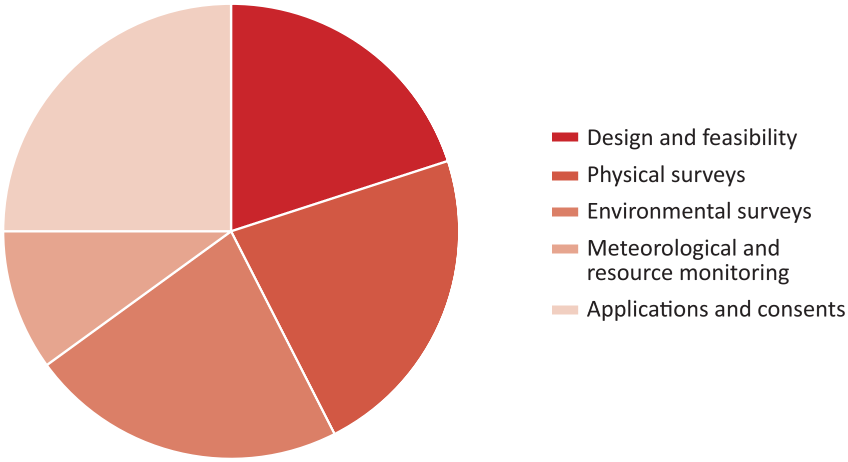


Figure 6.2.1: Typical cost breakdown for the development and consent activities

6.2.1 Design and feasibility

Feasibility and front-end engineering design (FEED) studies address areas of technical uncertainty and develop the outline and then detailed design of the project in advance of contracting. Design activities begin early in this stage and continue up to finalisation of contracts for supply of key items.

Feasibility and FEED studies are likely to run for four years, with detailed work carried out after physical and environmental survey data become available. Around £1.5m is likely to be spent over the course of an individual project, with a third of this being in the first two years on feasibility tasks and the remainder on more detailed design activities. Some of the activities are likely to be delivered by the project developer's internal team. Engineering and maritime consultancies and academic organisations could deliver contracted tasks.

> "We have already undergone a lengthy and detailed process of both desk based studies and site specific work to identify a site we consider viable from perspectives of consenting, the ability to install devices and its potential resource."
> **SSE**

Examples of activities include:

- Development of device arrangements and routing of subsea array cables using data gathered from surveying and resource monitoring;
- Grid connection feasibility and integration with national network;

- Engineering design of balance of plant systems and components, broadly covering mechanical, electrical and structural engineering disciplines;
- Marine logistics studies to optimise installation methods, vessel and port requirements;
- Development of contracting strategies for all services throughout the project's life cycle; and
- Techno-economic analysis to determine the expected costs and revenues arising from the project to facilitate eventual financial investment decisions.

Organisations with a track record in the marine environment, perhaps gained from industries such as oil and gas or offshore wind, fishing, marine aggregates extraction or similar, may be well placed to undertake this work. Competencies and services relevant to these activities include:

- Knowledge of the site-specific conditions in and around the projects; gained through operation of vessels or offshore construction in and around the Pentland Firth and Orkney waters. This includes occurrences of extreme waves and irregular tidal flows throughout the lunar cycle as well as knowledge of seasonal sea state patterns.
- Relevant technical knowledge in marine renewables or parallel sectors, including pressurised vessels, marine equipment and aquaculture.
- Understanding of subsea electrical equipment with consideration of access for maintenance and comparison of cost of increased redundancy or reliability compared to more maintenance.
- Experience in construction planning and methods suitable for short access windows due to tidal flow or high wave environments.
- Health and safety culture and processes including designing out the need for diving operations wherever possible and considering the failure modes of key components.

6.2.2 Physical surveys

Coastal process surveys and seabed surveys are used to examine the subsea environment and the potential impact of the wave or tidal energy project, particularly on sedimentation and erosion.

Coastal process surveys are of relevance when considering potential subsea cable routes and land-fall sites for cables. Surveys are often augmented by computer modelling, and in some cases scaled physical modelling.

Sea bed surveys normally consist of two elements:

- Geophysical surveys of sea bed features and bathymetry (shape of the sea bed). These characterise the seabed in terms of depth, sediment cover and the uppermost rock strata.
- Geotechnical surveys of the sea bed characteristics. These consist of sampling from boreholes and the use of cone penetration tests once the critical areas for sea bed analysis have been established and characterise soil conditions at varying depths at the site and determine load bearing capacity at that site.

The results of these surveys provide an understanding of the seabed in terms of stability, geology, physical attributes and risks of geohazards such as subsea valleys, buried boulders or unstable regions. For instance the typical feature of tidal sites is a completely scoured area of ridged rock; this landscape requires detailed knowledge of cable routing requirements and very site specific analysis of potential device positioning. The surveys typically use a mix of desktop studies and on-site investigations to complete.

The survey results are interpreted and used as an input to the design of subsea components such as foundations and moorings. Skills and services relevant to these activities include:

- The supply of specialised vessels for both geophysical and geotechnical work. It is possible to carry out some tasks using lower specification vessels but this is likely to impact the quality of results. Competition for specialised vessels with other industries including offshore wind may affect costs and influence decisions on alternative installation methods. This could include using gravity foundations in place of piled foundations to enable float-out-and-sink operations.
- Knowledge of sediment transfer, which is particularly important at wave energy sites. Findings will influence device positions and geographical areas of survey.
- Geotechnical engineering and the ability to understand and interpret results. Typically this is provided by specialist consultancy organisations.

Figure 6.2.2.1 illustrates how vessels may be used for physical surveying. Vessels included are specialist vessels (jack-ups and DP vessels), modified vessels (where non-surveying craft have been upgraded with specialist equipment) and support vessels (used for personnel transfer and monitoring lifting activities). The chart shows that more surveys are carried out on initial phases of projects in order to map the key areas of the project. It is anticipated that surveys for subsequent phases will be focussed on specific areas of concern. Uncertainty exists around these estimates as timings and levels of deployment depend heavily on when consents are granted for each phase of the project, which is likely to trigger additional expenditure on surveys. The chart shows a peak in 2013/14, with a change in focus towards more specialist geotechnical surveys in the latter years.

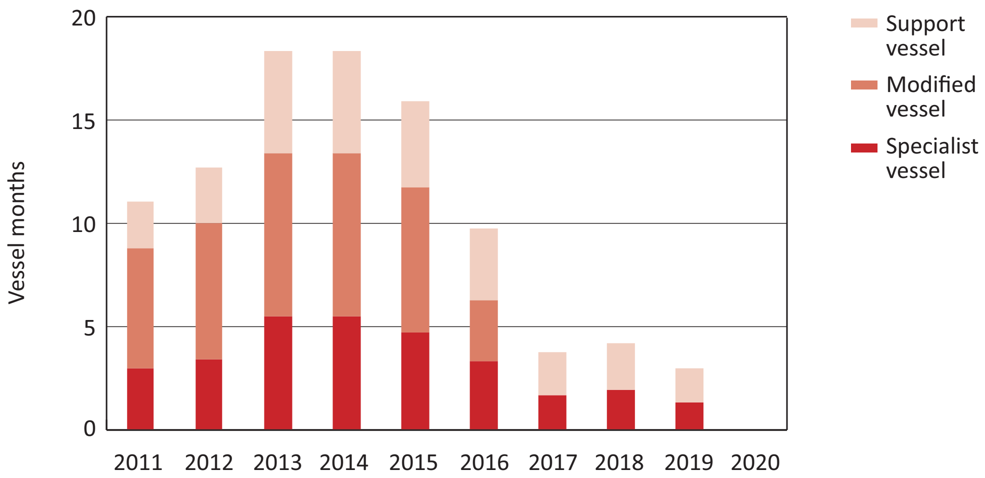


Figure 6.2.2.1: Forecast vessel use for physical surveys in each year

6.2.3 Environmental surveys

Environmental surveys are used to assess any impact that a project could have on species that live in, use or frequent the offshore environment, both in the sea and in the air. They are likely to be started early in the development process. Standard practice has yet to develop, so this report assumes that surveys begin five years before construction and are largely completed in advance of applications for consents. The actual lead times and durations may be different, depending on the specifics of each technology type and project location. Environmental monitoring continues through to decommissioning at the end of the project lifecycle. Some surveys require data collection over two consecutive years in order to sufficiently understand local populations of flora, fauna and marine species. Environmental surveys provide key input data for Environmental Impact Assessments (EIA) required in the design and in the planning consents applications.

The following surveys can be expected to be carried out:

- **Benthic surveys:** These consider species that live on the seabed and in sediment. They involve visual analysis and collecting physical samples from representative areas of seabed. Surveys can often be carried out using locally based fishing vessels onto which survey equipment is installed. Of particular interest are unique tidal channel habitats.
- **Fish (pelagic) surveys:** These establish what open sea species are present, most notably fish populations. These are often carried out by trawling, again using local fishing vessels and knowledge. Seasonal spawning grounds are of interest due to the potential electromagnetic and thermal impact of underwater cables and subsea electrical equipment on suitable spawning conditions for specific species.
- **Marine mammal surveys:** These analyse the location and behaviour of sea mammals. Aerial and boat-based surveys are used, combined in some cases with tagging of mammals to track movements in and around project areas. Observation is likely to be required during the installation stage of projects, especially during any invasive activities such as piling. The acoustic impacts of devices on sea mammals are of special interest.
- **Bird (ornithological) surveys:** These are necessary if the project may affect bird populations. Physical observations are carried out using vessels but also can be completed from the air using high resolution cameras and video imaging.
- **Onshore surveys:** These are carried out at the location of onshore equipment and cable laying routes. Knowledge of local ecological issues is likely to be valuable.

There is the potential for flexibility in the logistics of delivering environmental surveys and a range of different vessels can be used.

"During project development there is a need to procure specialist design services, environmental survey work, geosurveys and navigational risk studies."
Aquamarine Power

Some tasks are undertaken alongside physical surveys whilst others use simple vessels crewed by wildlife observers, typically marine biologists or ecologists. Regular visits are likely to be required over the survey period and a single vessel may be fully utilised across several projects taking into account weather delays. It is also likely that over the first six months up to five vessels will be needed for short periods at any one time to carry out necessary baseline surveying. The forecast average cost for environmental surveys on a complete project up to construction is around £2m. Environmental surveying is contracted by the project developer to external companies.

Skills and services relevant to these activities include:

- Supply of a range of vessels including local fishing craft, 30m long vessels and specialist physical surveying vessels for environmental surveying.
- Local knowledge from fisherman, marine biologists and ecologists who operate and have experience and knowledge of prevalent species in the survey areas.
- Supply of specialist surveying, trawling and imaging equipment for deployment on vessels and ability to tag marine mammals for monitoring.
- Aerial surveying where coverage of larger areas is required.
- Knowledge of local species from qualified ecologists, biologists and environmental scientists.

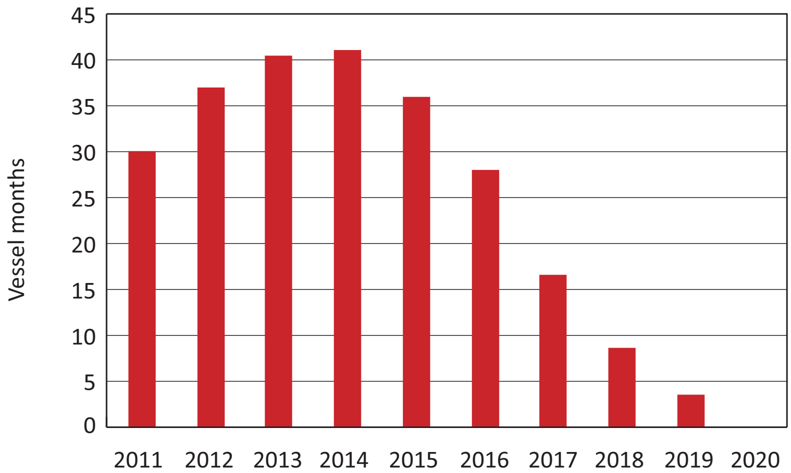


Figure 6.2.3.1: Forecast vessel use for environmental surveys in each year

Figure 6.2.3.1 shows forecasted vessel activity levels required on a year by year basis to deliver environmental surveying requirements during the development and consenting phase of projects. It shows that three or four vessels could meet the peak annual requirement if work could be spread out over the whole of the year but it is likely that multiple project developers will require surveying at the same time each year. This could equate to around six to eight vessels used on a shorter charter basis. The ongoing requirement for environmental monitoring during the construction and operational stages of projects is covered in Section 10.

The forecast assumes a need for vessels to begin surveying three years prior to applications for consents. Project developers indicated that the majority of surveying for lease areas would be carried out during development of the initial phases of projects. The chart shows a gradual increase in demand to 2014 and that by the end of 2016 most environmental surveys are assumed to be complete.

6.2.4 Meteorological and resource monitoring

ADCP unit during installation, Marine Current Turbines Ltd

At an early stage in the development process, sensors are deployed to measure meteorological and metocean conditions. This enables detailed modelling of the wave and tidal resource characteristics (wave heights, wave periods, tidal speeds and directions of both waves and tides).

The data collected are used alongside historical and modelled outputs to inform the project design, particularly to estimate energy yields and predict the mechanical loading that equipment will experience. The data can be used to enable optimisation of the wave or tidal device itself as well as the layout of devices on the farm.

Tidal sites may require the deployment of six or more acoustic doppler current profilers (ADCP, pictured above left) on to the seabed to collect sufficient data over a site area. Remotely operated vehicles (ROVs) and divers may be used for safe installation of ADCPs, and with the likelihood of safe working periods of less than one hour in each tidal cycle, this may take two days per unit. Long-term resource characteristics may be possible to estimate using data from a monitoring period of just one month (lunar cycle). This is due to the predictability and consistency of the tidal resource and the fact it does not vary seasonally or inter-annually.

Wave sites are likely to require deployment of two or more wave rider buoys. These can be towed to site or lowered and anchored very simply and may take just a few hours to install. In contrast to ADCPs, the buoys may need to stay in place for several years to fully characterise the wave climate at the site, owing to its temporal variability.

Each Pentland Firth and Orkney waters project may use up to four instruments early in development and further instruments in subsequent phases. Deploying ADCPs at tidal sites may take two weeks using dynamic positioning (DP) vessels while installing wave rider buoys at wave sites may take just one week with standard vessels. In total for each complete project an estimated £1m may be spent on resource monitoring and modelling.

Skills and services relevant to these activities include:

- Supply of meteorological instruments and packaged measurement units ready for deployment;
- Operation of vessels for the installation and management of wave rider buoys and subsea ADCPs;
- Technical consultancy services to interpret data through modelling and advise on impacts on wider project development issues; and
- Services related to planning and permitting the deployment of the instruments, (arising, for instance, due to environmental impacts of the instruments being deployed in their own right).

The forecast shown in figure 6.2.4.1 represents the number of new sensor stations that may be installed across all projects each year. After 2015 it is likely that while sensors are required, they will be moved from other locations. Some developers may rely entirely on resource modelling of their sites and data from existing stations that are already in place.

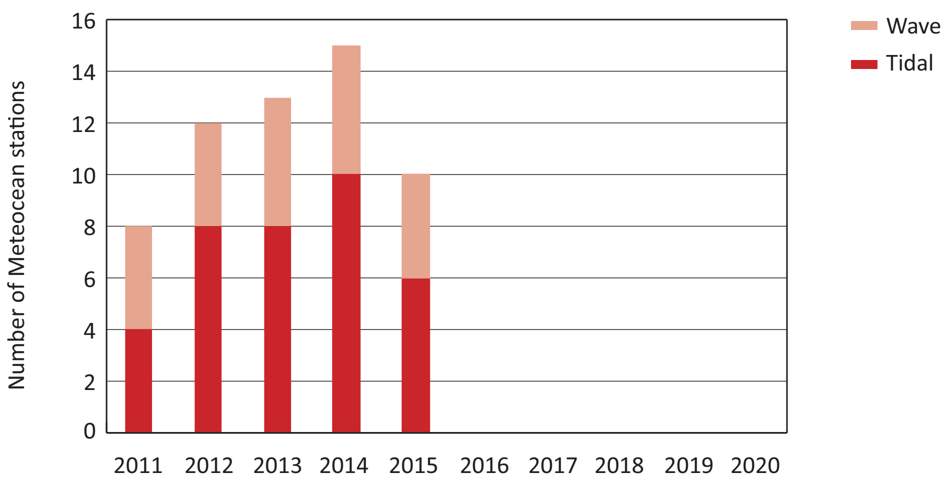


Figure 6.2.4.1: Forecast of new metocean stations installed in each year

6.2.5 Application, consents and other activities

In addition to gathering data, various formal statutory processes need to be followed during this stage of the project, including:

- Completion and submission of the environmental statement which presents key findings of the EIA.
- Application for and negotiation of electrical grid connection conditions including modelling of device and array power quality output.
- Supporting activities such as stakeholder engagement and wider public relations activities.

Formal applications for consents may be submitted two to three years before construction. Preparation of consents applications may involve specialist consultants with existing EIA and related specialist experience, and per project could cost up to £2m. The services are likely to be contracted directly by the project developers.

Skills and services relevant to these activities include:

- Detailed experience in the consenting of projects within the marine environment, normally residing with environmental consultancies or the project developers;
- Knowledge and experience of electrical power systems at a transmission and distribution level, with grid modelling capability and design experience to ensure compliance with all relevant grid codes and regulations; and
- Knowledge of key local stakeholders and their relative interests in a project. This may be provided by local consultancies.

7 Wave and tidal energy device manufacturing

Wave and tidal stream energy devices generally consist of a prime-mover element coupled to a power take-off arrangement, a reaction system and a control system. A range of different device technologies are currently under development and several full-scale prototype devices are now being tested. The next step is to demonstrate small arrays of devices, either as an initial phase of the Pentland Firth and Orkney waters projects or elsewhere in the UK or overseas.

A significant amount of work in design, physical testing and prototyping is required before devices will be ready for serial production and commercial deployment. The focus of research and development is likely to evolve from proving device concepts to demonstrating reliability, understanding the operation of multiple devices within arrays and achieving lifetime cost savings through design for production. Providing sufficient investment is made in these activities, significant improvements in device design and operation could be made in the next few years.

It is likely that most device manufacturers will specify and purchase main components and assemble them into finished devices. The balance between in-house manufacturing (and associated facilities) and outsourcing is likely to evolve as demand for generation devices increases.

7.1 Overview

The wave or tidal stream energy generation device is at the heart of a generation project. All other planning activity and development of supporting infrastructure is focussed on enabling the device to extract energy from the environment safely, reliably and at the right cost over a design life of around 25 years. A number of first-generation prototypes have been tested over the last decade and by 2011 it is estimated that more than ten such devices will be undergoing full testing programmes around the world. A significant proportion of this testing is being carried out at EMEC in Orkney.

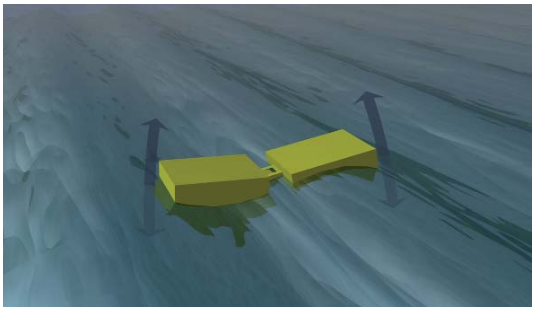
A range of generic wave and tidal stream device concepts is described below. For each device, the hydrodynamic system is considered to be that which interacts with the water to extract energy from the natural resource (kinetic energy of water moving due to waves or tides). The power take-off system converts the energy extracted to electrical energy. The reaction system holds the device in position and the control system provides both supervisory and closed-loop control and also incorporates auxiliary systems.

Wave energy devices

Waves are created by the action of wind on the surface of the sea. Initially acting on small perturbations of the surface, continued wind action grows these small disturbances into fully developed waves. The propagation of waves in terms of their size and energy content depends on the duration and speed of the wind and the distance over which the wind acts (the fetch). Wave characteristics are strongly affected by water depth, sea-bed bathymetry and diffraction effects around obstacles.

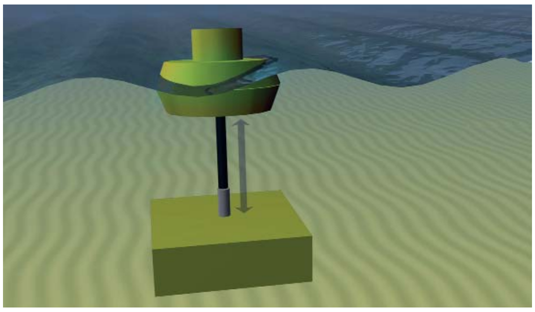
Table 7.1.1: Summary of wave energy device concepts (images courtesy of EMEC)

Attenuator



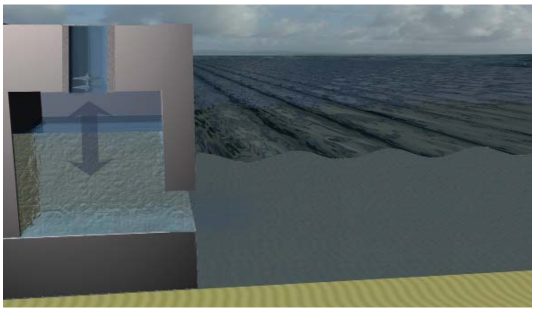
The motion of waves causes the elements of the device to move relative to each other. This oscillating movement is used to generate electricity.

Point absorber



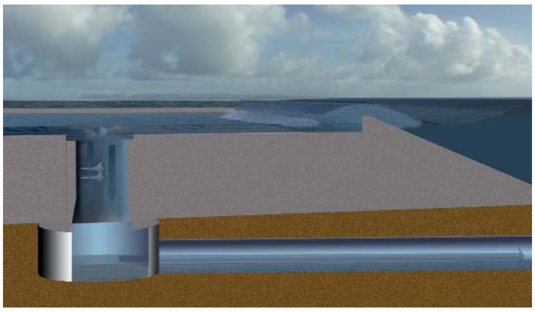
The motion of waves causes the floating element to move relative to the anchor point. This linear oscillating movement is used to generate electricity.

Oscillating water column device



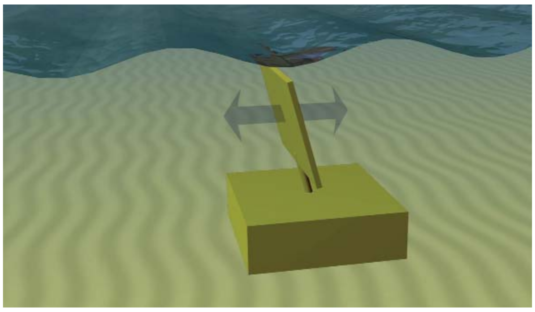
A water column is formed using a partially submerged, hollow structure. The motion of the waves causes the water level to rise and fall and this movement is used to compress and force air through a turbine. The rotation of the turbine is used to generate electricity.

Overtopping device



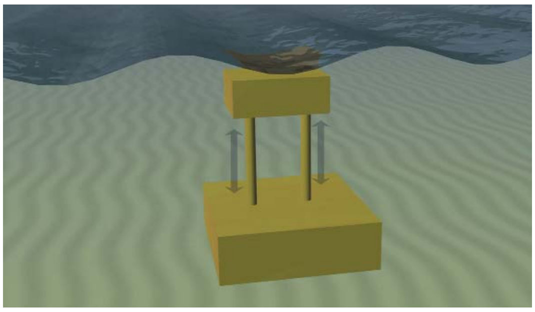
By positioning of guides interacting with waves, water is forced upwards and into a reservoir before returning back down to the sea via a low head turbine. The rotation of the turbine is used to generate electricity.

Oscillating wave surge converter



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

Pressure differential device



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

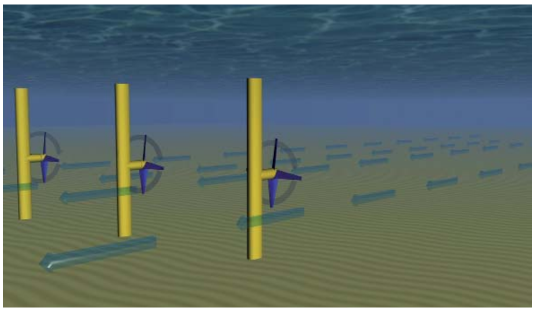
Pelamis P2 sea trials, Pelamis Wave Power

Tidal energy devices

The gravitational forces of the earth, moon and sun cause the natural rise and fall of sea levels and the consequential flow of significant amounts of water back and forth each tide in coastal areas. Tidal stream energy devices capture energy from this flow in a similar way to the manner in which wind turbines capture energy from the flow of air, the amount of energy captured being a function of the flow speed and intercepted area. However, due water being much denser than air, a smaller machine is needed for an equivalent energy capture.

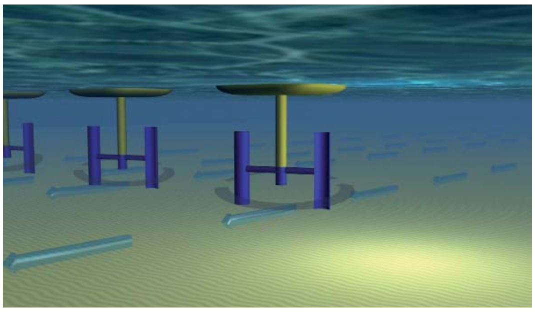
Table 7.1.2: Summary of tidal energy device concepts (images courtesy of EMEC)

Horizontal axis turbine



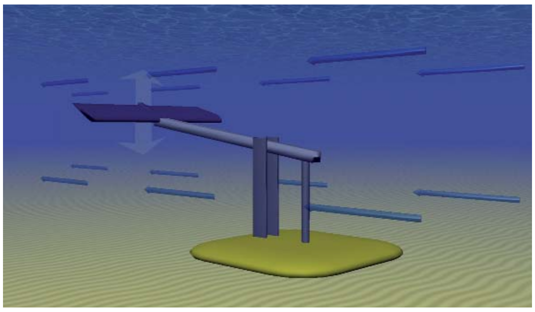
The flow of water turns the rotor by generating lift due to the flow around the blades. This rotational movement is used to generate electricity. The device can be housed within a duct to accelerate the flow through the rotor, thus increasing energy capture.

Vertical axis turbine



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

Oscillating hydrofoil



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

In all cases, the device converts movement of water into movement of an element of the device. This movement is either an oscillation or a rotation. There are a number of power take-off arrangements for converting this movement into electricity.

Deployment of OpenHydro turbine, OpenHydro

Considering all the Pentland Firth and Orkney waters projects, the estimated expenditure on generation devices necessary to meet the planned capacity targets over the coming years is presented in Figure 7.1.1. Due to the variety of devices in development, the cost breakdown reflects average estimates rather than representing any particular device type.

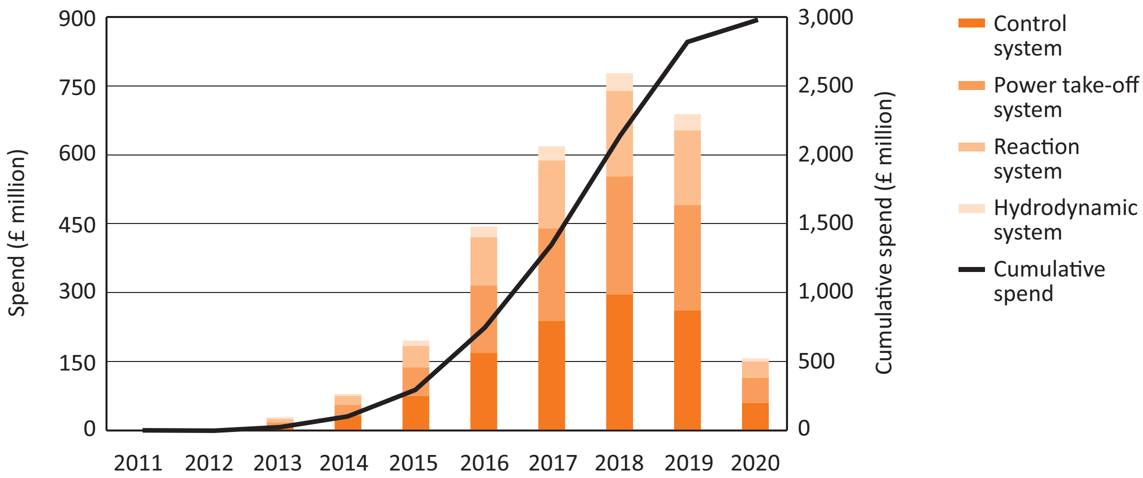


Figure 7.1.1: Forecast expenditure on device manufacture

Procurement

Device manufacturers are likely to assemble their devices from bought-in components. Some are assembling prototype devices at present and a number of manufacturers each envisage batch production of around 20-50 devices per year by the middle of the decade.

> "We will tender the manufacture of our devices. As an Edinburgh-based company we would prefer Scottish delivery of the work, although some components may come from the Continent or beyond"
> **Aquamarine Power**

The number and type of components required varies with the type of device. In most cases however, components include low-value off-the-shelf items, higher-value catalogue items manufactured to order and both small and large items manufactured to drawing and/or specification.

Section 12 of this report gives contact details for each of the device manufacturers already linked to specific Pentland Firth and Orkney waters projects.

> "OpenHydro has been operating at EMEC since 2006. During this period the company has spent in excess of £10 million on Scottish operations,"
> **OpenHydro**

Technology Development

Research and development of wave and tidal stream energy technologies has been underway for several decades. The installation of increasing number of devices at EMEC in the near future indicates a continued commitment to technology development. Both gradual evolution and step changes in generation technologies may be anticipated over the years ahead. Although much of the focus today is on development specifically for Pentland Firth and Orkney waters projects, there are of course many other opportunities for installation of devices elsewhere in the world, with potential for a global market.

Generation devices are likely to account for 20% to 40% of total project costs, so technology development will be a significant area of focus for value engineering. When moving from prototype testing to commercial array deployment, effort is also likely to be put into refining device designs and control methods to improve reliability and energy generation efficiency.

The skills necessary to undertake device development are wide-ranging and ongoing activity offers opportunities for a range of suppliers to engage, especially as the sector matures. Relevant services include:

- Loads analysis and stress modelling of sub-system and component specification, sourcing and verification;
- System integration, design management and procurement expertise;
- Knowledge of design features for the marine environment from industries such as oil and gas or aquaculture; and
- Scale workshop and tank testing.

Figure 7.1.2 indicates the rate at which, once manufactured, devices may be installed to form the Pentland Firth and Orkney waters projects.

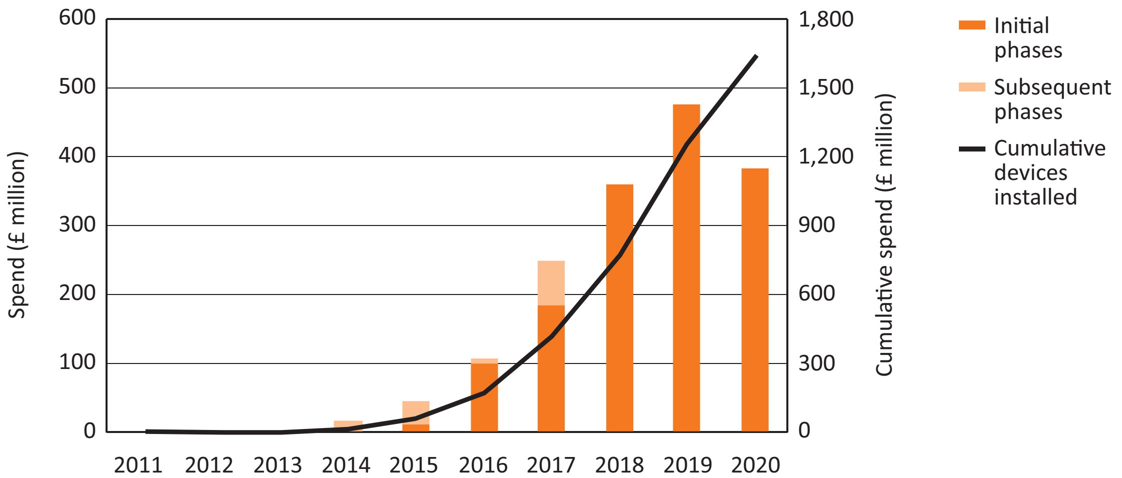


Figure 7.1.2: Anticipated device deployment split for initial and subsequent phases

7.2 Manufacturing activity breakdown

A breakdown of typical capital costs of the main sub-systems of devices is given in Figure 7.2.1 for each of wave and tidal stream. This is an aggregated view; in individual cases the relative cost of elements can vary considerably dependent on design. Assembly and other generic costs are spread across components.

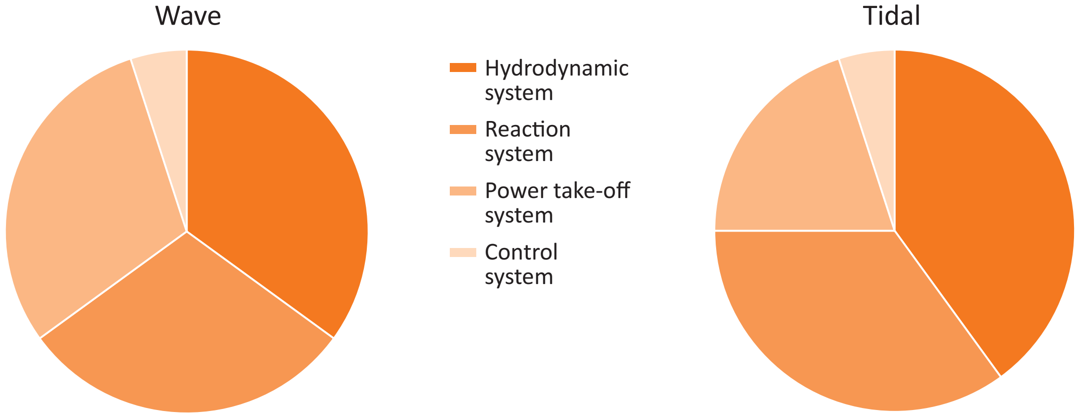


Figure 7.2.1: Cost breakdown of wave and tidal devices

A significant proportion of components are likely to be made from steel. Figure 7.3.1 shows the likely requirement for steel in manufacturing devices including support structures, based on an average steel content per device derived from discussions with a range of device manufacturers. Exact quantities will depend on device and foundation type and specific ground conditions. While steel is likely to remain the dominant structural material for the foreseeable future, other structural materials such as concrete could be used in due course. This may affect these estimates, particularly in later years.

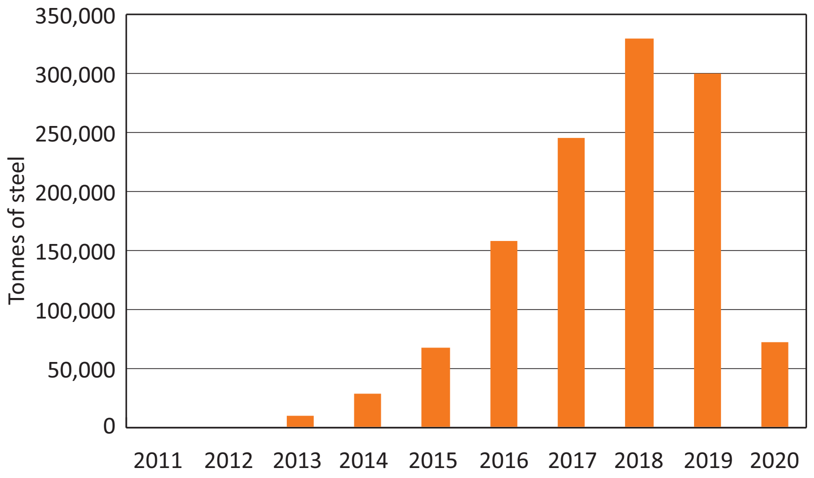


Figure 7.3.1: Forecast steel requirements for device manufacture in each year

Noted that the chart is a similar shape to that of the forecast of devices installed, but is offset as steel is required earlier for the manufacturing of key components. Based on the assumption that devices will be rated at 1 MW each, implying that 1,600 devices will be needed to meet the total potential capacity, it can be roughly estimated that over a million tonnes of steel will be required.

7.2.1 Hydrodynamic system

Oyster wave energy converter, Aquamarine Power

The hydrodynamic system moves directly under the influence of forces applied by the water and in some cases is the only significant moving part of the device. In tidal devices it is typically the blades or hydrofoils and in wave devices it is the component that reacts to the oscillating wave motion.

Components of the hydrodynamic system may be made from steel, composites, concrete or other materials and depending on device type, manufacturing may be of the scale of length five metres to 50 metres and mass of 200kg to a number of tonnes.

In producing the required hydrodynamic system components, the following skills and services are likely to be needed:

- Hydrodynamic and structural design of large structures;
- Precision fabrication of blades and hydrofoils where steel and other metals are used;
- Moulding and finishing of composite materials;
- Casting of metal structures used in providing buoyancy;
- Assembly of components with fasteners, welding or other means;
- Experience in the design and production of pressure vessels for the marine environment;
- Provision of coatings and treatments to control corrosion and marine growth; and
- Workshop testing and verification.

7.2.2 Reaction system

The reaction system keeps the device in position and provides the static reference point for oscillating devices.

The system may consist of a mooring arrangement, a gravity base foundation or a foundation fixed to the sea bed via piles, suction bucket or similar method. These components are likely to be made from steel or concrete.

In producing these components the following services are likely to be needed:

- Design of dynamic structures in the marine environment under frequent waves of height 3m and extreme waves of height over 15m;
- Procurement, fabrication and handling of large scale steel and concrete structures of up to over 1000 tonnes and length up to over 50m;
- Design, manufacturing and installation of wire ropes, chains and anchors in mooring systems;
- Expertise in corrosion and marine growth prevention where tidal velocity does not keep the structure clear; and
- Local knowledge of marine conditions.

7.2.3 Power take-off system

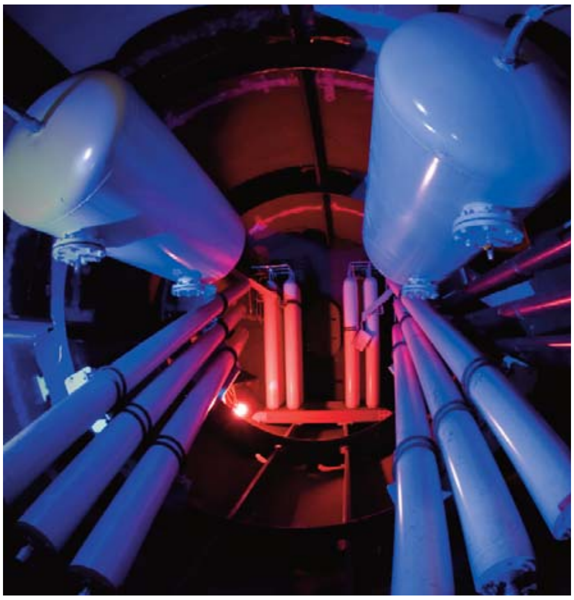
There are a number of methods for converting the motions of a device's hydrodynamic system into electrical energy, depending on the pattern of movement. For reciprocating systems, energy can be converted by resisting movement via (for example):

- Hydraulic actuators that pump oil into a pressurised reservoir from where it drives a hydraulic motor connected to an electric generator; or
- Linear electrical generators.

For rotating systems, energy can be extracted most simply by constraining movement via (for example):

- Speed-up gearboxes and electric motors; or
- Direct drive electric motors (without gearboxes).

In order to interface the generator to the local electricity grid on-device electrical protection, a transformer, switchgear, and subsea electrical connectors may be used. In addition to these core components, a range of additional elements may be required depending on the device type. These include bearings to support hydrodynamic systems as well as cooling and lubrication systems.



Pelamis hydraulic system, Pelamis Wave Power (credit Mike Roper)

In producing these components the following experience and services may be required:

- Application of electrical and hydraulic knowledge in the marine environment;
- Production of gearboxes, bearings and power transmission components in the marine environment; and
- Subsea connectors from devices to inter-array cabling with voltage rating of 11kV and above.

7.2.4 Control system

The control system provides both supervisory and closed-loop control and includes auxiliary systems such as those for:

- Yawing (turning the device to face the required orientation);
- Pitching (adjusting blade pitch angle on some horizontal axis tidal turbines);
- Braking (stopping the hydrodynamic system from moving); and
- Adjustment of hydraulic systems to optimise reaction to resource and maximise energy generation.

In producing these components, the following services and products are likely to be needed:

- Specialist sensors and data collection systems related to the marine environment to indicate pressure, movement, electrical characteristics or environmental conditions;
- Experience in design and use of SCADA systems;
- Hydraulic actuators, valves or other equipment;
- Bearings and actuation components for use in yawing or pitching; and
- Design and production for high reliability applications.

8 Balance of plant manufacture

The balance of plant for a wave or tidal stream energy project includes all components that are not part of the wave and tidal energy device but are necessary for its construction and operation. Depending on the device type, balance of plant is likely to include at least foundations or moorings, subsea cabling and substations offshore, onshore or both.

8.1 Overview

Although wave and tidal devices are at the heart of each project, balance of plant items make up a significant part of the capital cost and are required to make operation safe and reliable. Balance of plant items may be subjected to the same extreme environments as devices and it is expected that technology development will continue over the next years in order to deliver the required functionality at optimum cost. Adaptation of existing technology is likely to be required to suit specific applications and varying site conditions.

An estimate of expenditure is presented in Figure 8.1.1 assuming manufacturing a year prior to installation. Each area is then discussed in more detail.

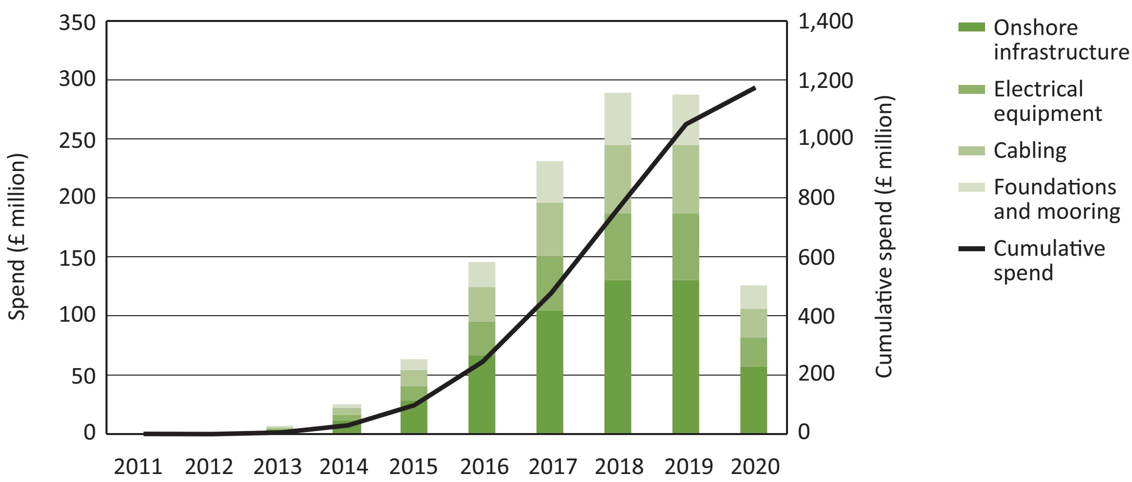


Figure 8.1.1: Forecast expenditure on balance of plant manufacture

Procurement

Given the novelty of wave and tidal stream project development, there is not yet a single pattern of procurement or supply of balance of plant items. However, it can be expected that electrical and cabling systems will be procured by the project developer with input from the device manufacturer in order to ensure proper interfacing with devices. Foundations, where they do not make-up an integral part of the device, may be designed in conjunction with the device manufacturer but procurement may again be managed by the project developer.

Procurement activities are likely to commence in the development and consenting stage, with orders being placed around one to two years before installation. For some parts such as electrical transformers and subsea cables, earlier procurement may be required due to typical component lead-times. Section 12 of this report gives details for each of the project developers and device manufacturers already linked to specific projects.

8.2 Activity breakdown

A breakdown of key activities for an example project is presented in Figure 8.2.1. This will vary by project dependent on its scale, the device being used and its location in relation to the onshore electrical infrastructure.

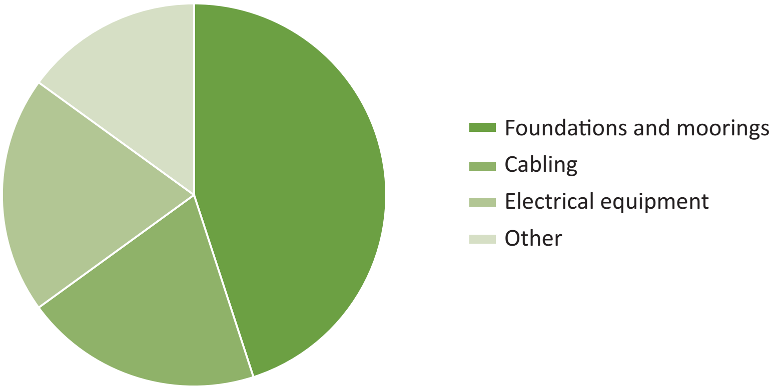


Figure 8.2.1: Cost breakdown for balance of plant supply

8.2.1 Foundations and moorings

Foundations and moorings provide the anchoring of the device to the seabed and their design depends very much on the device type. Possible arrangements include:

- Steel space frames pin-piled to the sea bed;
- Concrete gravity bases lowered into position on the sea bed; or
- Multipoint mooring systems with steel anchors inserted into the sea bed.

A single project could consist of 100 or more individual sets of foundations or moorings. In approximate terms, foundations could require 50,000 tonnes of steel in total and moorings 15km of steel cable.

Seagen foundation, Marine Current Turbines

In producing these components the following services are likely to be needed:

- Large scale concrete structure production of length in excess of 50m;
- Fabrication of steel frame structures weighing up to over 500 tonnes;
- Expertise in the design of dynamic structures for the marine environment, including consideration of fatigue loading; and
- Corrosion and marine growth prevention products.

8.2.2 Subsea cabling

To export power from multiple generating units, array cables are likely to be deployed to connect 'strings' of devices to an offshore substation. Higher- voltage export cables will connect the substation to the onshore grid connection point. In some cases due to distances and the power ratings of projects, offshore substations may not be used and in others, transfer of power to shore may be via pressurised hydraulic fluid.

Some devices require connection to a moving (floating) device, implying a dynamic umbilical, while others require cables to be located in high-flow areas where burial is not possible and placement between rock strata is required. Both of these situations impose additional considerations for cable designers and suppliers.

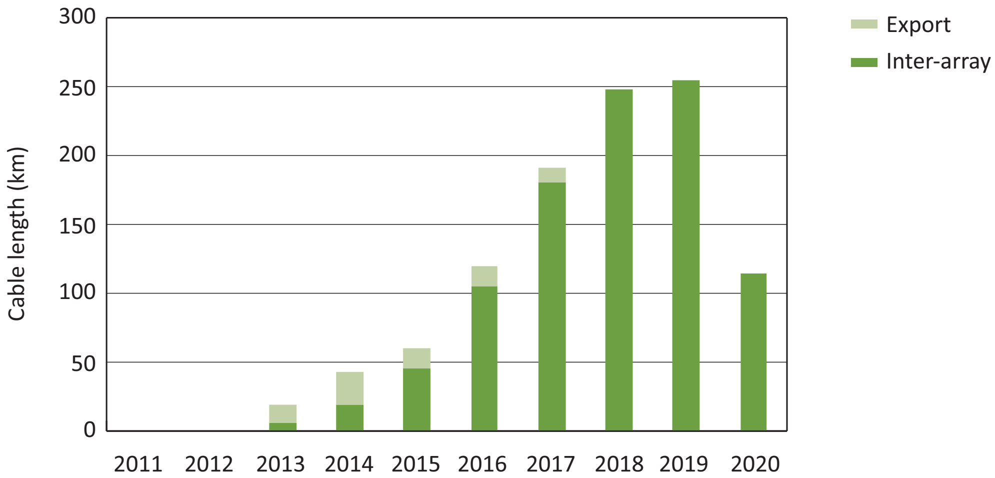


Figure 8.2.2.1: Forecast of subsea cabling requirements in each year

Figure 8.2.2.1 illustrates the lengths of subsea cable that may be required year by year. It is based on expected device spacings, farm layouts and likely distances from offshore substations to shore. The final lengths required will depend on exact site layouts and separation distances between devices as well as the method of connection between devices, which could have dedicated connections to the transformer or be chained together. The chart has the same profile as that of the number of devices installed, but offset as cables are purchased in advance of installation. Export cables installed as part of a project's initial phase may be specified with sufficient capacity to accommodate later phases as well.

At present, there is a high demand for subsea cables for offshore wind farms and other industrial sectors where application-specific designs are being developed. Although the volume required for the Pentland Firth and Orkney waters projects is relatively small in this context, the already limited supply could conceivably cause bottlenecks if cable manufacturing capacity does not increase.

Due to the proposed methods of device installation and O&M, for some devices it would be advantageous to use wet-mateable connectors. Development of such technology at sufficient electrical capacity is ongoing, including via a project funded by the Energy Technologies Institute. Wet-mateable connectors are particularly important if subsea connection hubs are to be used.

The manufacturing of subsea cabling and associated products is a specialist market serviced by existing players. The products require:

- Dedicated large scale and high precision cabling extrusion and assembly equipment;
- Expertise in the production of insulation for cables to provide thermal and electrical protection;
- Cable armouring products able to withstand extreme forces and ensure 25 year life of the conductor; and
- Detailed electrical design knowledge to influence selection of cable and mechanical engineering knowledge to specify protection requirements.

A project of 100 devices could require over 50km of inter-array cabling and export cable lengths of between two km and 20 km. The length required is highly dependent on the location and layout of the devices along with subsea conditions that influence cable laying requirements.

8.2.3 Electrical equipment

For each of the Pentland Firth and Orkney waters projects, transformers are likely to be required to step up from low array voltages (e.g. 6.9kV) to export voltages (e.g. 132kV) at the offshore substation, and again at the onshore substation to higher voltages. Associated monitoring, protection and switchgear will be required at each stage. One consideration is whether the offshore electrical equipment is surface or subsea mounted. This decision may have a significant impact on design requirements and also on capital and operational costs.

Subsea electrical equipment, JDR Cables

The transformers, switchgear and other electrical equipment are likely to be based on conventional electrical power engineering products but adapted to meet the needs of specific applications. Organisations involved should be able to demonstrate:

- A clear understanding of the design requirements of distributed generation and the impacts of the nature of both wave and tidal supply characteristics; and
- Experience in the manufacturing and development of offshore electrical solutions.

8.2.4 Onshore infrastructure

In addition to the offshore equipment there will be balance of plant items onshore, such as cabling, substation and buildings. Buildings could be used to house electrical equipment, control centres, office space and spare parts.

9 Installation and commissioning

The installation and commissioning stage starts once the device and balance of plant items are complete and ready for final assembly. It includes onshore assembly, offshore installation activities and on-site commissioning. The stage ends with hand-over to the client and the start of O&M activities.

This stage typically uses a range of vessels including specialist, modified and standard vessels. The installation methodologies used are heavily influenced by the prevailing site conditions and specific design of the device to be installed. The installation method will have been defined during the development and consent stage but will be refined during this stage.

9.1 Overview

There are a variety of challenges associated with the deployment of wave and tidal devices offshore. The most significant of these include the inherently hostile environmental conditions on site and therefore severely limited periods of safe working for installation.

The high tidal flow velocities experienced at tidal device installation sites may limit the period of safe working subsea to less than one hour in each tidal cycle. For wave devices, the wave height at the installation site may exceed the safe operating limit of standard installation vessels for a significant fraction of the time. This has the potential to introduce costly weather delays to the installation and commissioning phase. Project developers and device manufacturers are working to develop methods to minimise complex and weather-dependent operations that must be carried out offshore.

A further challenge is presented by the variation in device designs currently available. There are not yet broadly defined methods of installation that are consistent across several different device types. Installation of tidal devices may require specialist dynamic positioning (DP) vessels to overcome the tidal currents during installation and hold position between tides. Installation of wave devices may be more straightforward, for example if they can be towed to site and moored using relatively standard methods and readily available vessels.

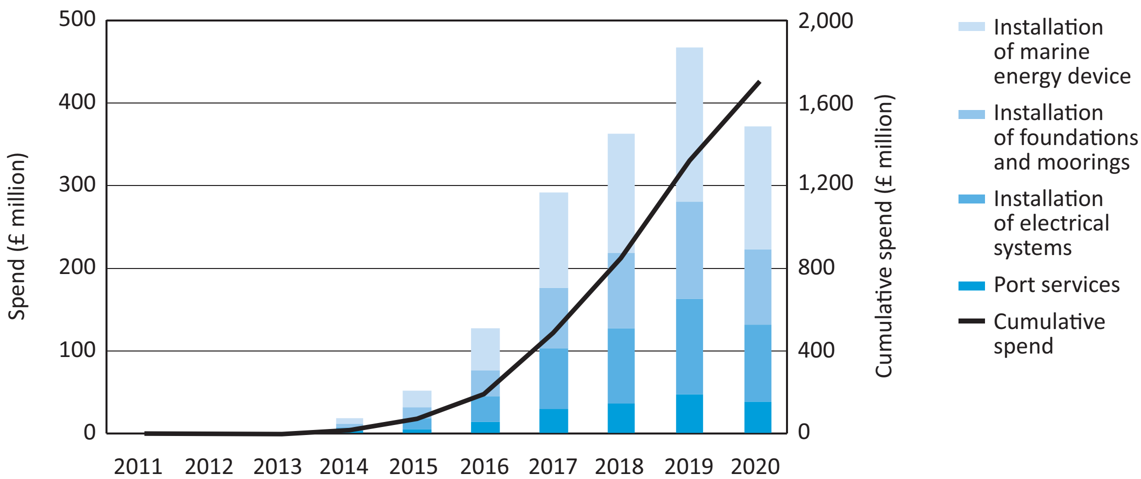


Figure 9.1.1: Forecast expenditure on installation and commissioning

The use of jack-up vessels may be required for installation of some devices but project developers and device manufacturers are seeking alternative methods - e.g. float-out-and-sink operations. Where piling is required, novel tooling may be used to enable drilling and installation in a single operation.

> "Ideally we would subcontract the entire installation and grid connection package. Our responsibility would be to supply completed and tested devices to the quayside and provide all balance of plant items with defined installation method statements, however, we appreciate that only a few companies have the capability to complete this installation."
> **Marine Current Turbines**

The number of first tier suppliers able to manage and deliver safe, timely installation of expensive and relatively delicate technology in the tough environmental conditions is presently quite limited. Complete packages of work will exceed £100 million for some projects and these are likely to be awarded to specialist organisations with a strong balance sheet.

At the same time, however, opportunities may also exist for smaller companies. Engagement may be through first tier suppliers employed to manage the delivery of the work. Local knowledge, understanding of conditions and access to labour may be key benefits offered by small suppliers.

The build-out schedule suggests there could be a significant step up from small scale installation (project phases with capacities of 10MW order) in 2013-15 to large scale installation (capacities over 100MW) from 2016 onwards. Such a step would require suppliers to move from low volume to high volume techniques, requiring more storage and assembly space as well as more efficient installation methods.

9.2 Activity Breakdown

A breakdown of key activities that might be expected for a project is presented in Figure 9.2.1. This will vary by project depending on the location and specific conditions of the site and the device being installed. The cost breakdown shows an average view of the Pentland Firth and Orkney waters projects.

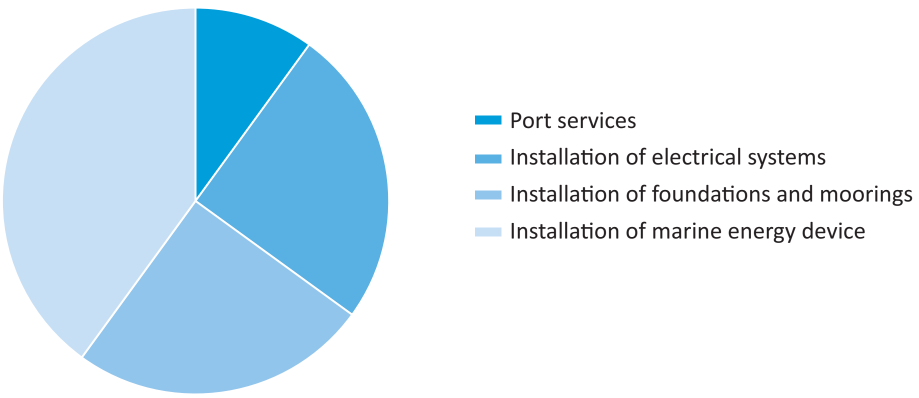


Figure 9.2.1: Typical cost breakdown for installation and commissioning activities

Considerable variation in this breakdown is anticipated between devices, in particular due to foundation and mooring arrangements and their relation to the device itself. For some devices, complex piling systems may be required whilst for others the device's reaction system may be part of a gravity-based foundation, meaning that installation of the device and foundation is carried out simultaneously.

9.2.1 Port Services

Developers aim to carry out as much activity as possible prior to departing from port as this minimises the time spent working offshore, which is costly and high risk. It can therefore be expected that final assembly and dry commissioning activities for the Pentland Firth and Orkney waters projects will be carried out at the quayside.

There are logistics challenges to transporting large components or devices to a construction port for installation. As a consequence, manufacture or final assembly of components may tend to be local to installation sites.

Pelamis module being lifted, Pelamis Wave Power

Key requirements for a construction port suitable for a range of devices include

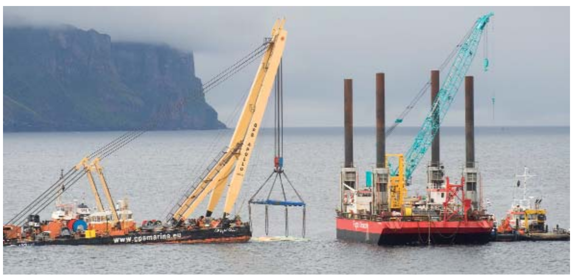
- A heavy lift capacity of up to 1000 tonnes;
- Large lay-down and storage areas of several hectares to enable assembly of components and rapid deployment of devices for larger scale developments
- Suitable space for final assembly adjacent to the quayside;
- Dry and potentially wet commissioning of electrical parts with the need for a sufficient quay length for in-water activities that could exceed 200m;
- Supply of support vessels and personnel. During installation of an individual project phase up to six vessels and several man years of support are required on site; and
- Sufficient draft and beam to facilitate movement of vessels and devices at a range of tides.

> "Assembly and test facilities local to the project with adequate quayside space and overhead cranes will be required for large scale installation"
> **Marine Current Turbines**

Key skills requirements include marine logistics, mechanical and electrical fit-out and commissioning and testing.

9.2.2 Installation of foundations and moorings

Generally speaking, the reaction systems and foundation structures for generation devices may need to be installed prior to or at the same time as the device. In some cases, it may be cost effective to complete installation prior to deploying the device as it allows disruptive, high impact or weather dependent activities such as piling to be carried out with no risk to the device.



Installation methods are largely dependent on device design. Gravity structures require minimal site preparation or post installation activities, and the focus is on accurate positioning and detailed foundation design. In comparison, methods involving piling will require several stages to deployment and the use of specialist installation tooling. In some cases mooring systems may be quickly deployed by anchor handling vessels whereas others will require further subsea operations to fully secure them.

The precise location of these structures is defined during the development and consenting stage, where physical surveys, resource assessments and energy production studies are used to optimise the farm layout.

Dependent on the device type there are requirements for:

- Specialist vessels able to carry out complex installation procedures;
- Supporting vessels locally sourced to provide construction and monitoring support; and
- Supply and operation of specialist tooling and ROVs during installation activities.

9.2.3 Installation of electrical systems

Typically, installation of both onshore and offshore substations and cabling is required. The onshore activities are conventional and so not covered in more detail in this report.

Offshore electrical installation activities may include:

- Directional drilling at the cable landing point. This requires expert geotechnical knowledge and specialist equipment;
- Draw-through and installation of several kilometres of subsea cabling to avoid geohazards;
- Cable protection and securing using rock dumping and, where appropriate, pinning and active positioning around seabed features using ROVs. Installation methods and challenges are quite different for tidal energy projects compared to wave. Particular care must be taken at tidal sites to avoid cable vibration (strum) that can severely reduce life expectancy;
- Installation and connection of the offshore substation, which may be on a piled foundation or subsea; and
- Installation and connection of array cabling between devices and the offshore substation. These are installed prior to the devices in most cases.

Cable laying makes use of specialist vessels but also requires the support of a range of other vessels to ensure navigational and operational safety. Substations and their foundations are likely to use similar installation methods to the device and its foundation. Logistical planning is likely to draw on local knowledge to ensure efficiency in installation.

9.2.4 Installation of marine energy devices

Technology developers and project developers alike appreciate the need for comprehensive and cost effective installation techniques, to enable efficient deployment of multiple devices. These techniques may be different to those used to date to deploy prototypes. One approach may be to carry out all preparation of the device at the construction port and then to float-out and install devices using general purpose vessels where possible; minimising complex activities at site.

OpenHydro installation, OpenHydro

> "Installation and maintenance of devices off-shore remains a major challenge, particularly in the tidal environment. However, there are some promising developments which, through experience in the water, should reduce the risks involved."
> **SSE Renewables**

Standard vessels can be augmented by ROV support and customised tooling for specific tasks. Several device manufacturers have or are planning to modify standard vessels or develop new designs of dedicated vessels. If maintenance activities will routinely include towing back to shore then an approach which avoids the need for specialist vessels may be beneficial, since this reduces the risk of vessel unavailability or high cost due to competing customers.

Generally speaking, a wave or tidal device may on average take one or two days for installation using methods currently envisaged. This suggests it may take around five months of installation activity to install a 100MW project (assuming good weather conditions). With a minimum of three vessels required, this equates to over a year of vessel time for each project. To illustrate the collective total demand for the Pentland Firth and Orkney waters projects, a single multi-purpose vessel with necessary support vessels and perfect weather would take nearly six years to install the entire 1,600 MW capacity if it worked 24 hours a day, seven days a week.

Commissioning activities on site may include
- Electrical energisation;
- Safety checks on all systems;
- Operational check to ensure systems are operational after installation activity, and
- Early monitoring of device to ensure normal operation.

There are a number of key supply opportunities relating to this stage of activity. These include:
- Supply, fit-out and manning of specialist installation vessels using local knowledge of port facilities and marine work environment.
- Manufacture of specialist tooling and ROVs.
- Marine logistics planning with knowledge of local conditions and constraints.

9.3 Supply chain requirements

Figure 9.3.1 represents the total number of vessel months required on a year by year basis for installation and commissioning of the Pentland Firth and Orkney waters projects. Vessels included in this estimate are specialist vessels (jack-ups or DP vessels), modified vessels (vessels tailored to the requirements of specific type of device) and support vessels.

OpenHydro installation, OpenHydro

The forecast was constructed by associating a number of vessel days for each class of vessel to each type of device, based on dialogue with device manufacturers and project developers. Generally tidal devices have a higher requirement for DP class vessels due to the difficulties in holding position at high tidal velocities. For some wave and tidal devices specially modified vessels are already being developed to increase the efficiency of installation.

According to the forecast, vessel use can be seen to increase in line with the increased device installation rate as project phases become larger during the final four years of the period. The vessel requirements of each individual project are likely to change throughout the course of the projects and this may affect the overall number of vessels required as well as the split between types.

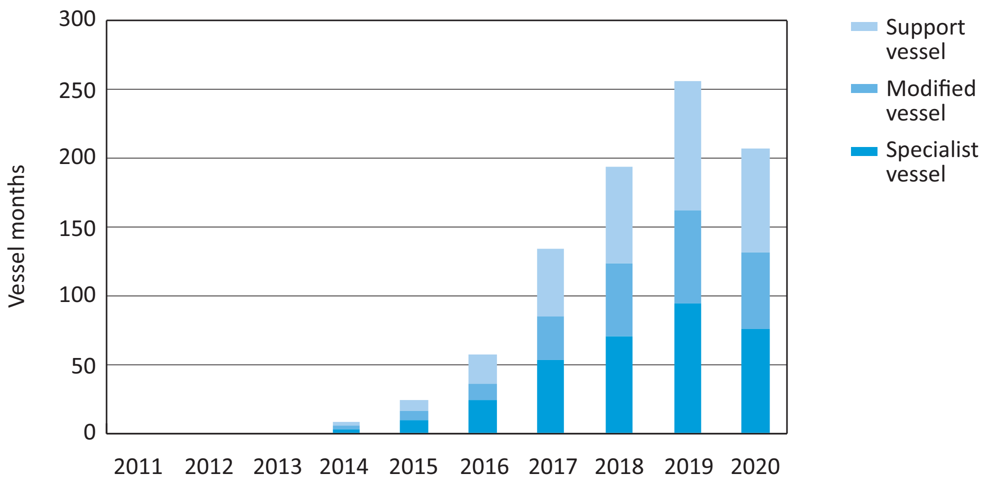


Figure 9.3.1: Forecast installation vessel requirements in each year

A key requirement for manufacturing, installation and maintenance activities is the availability of local quays and quayside facilities as devices and associated tooling are in many cases not convenient for road transport. Estimates of space requirements during construction, operation and maintenance are provided in Figure 9.3.2.

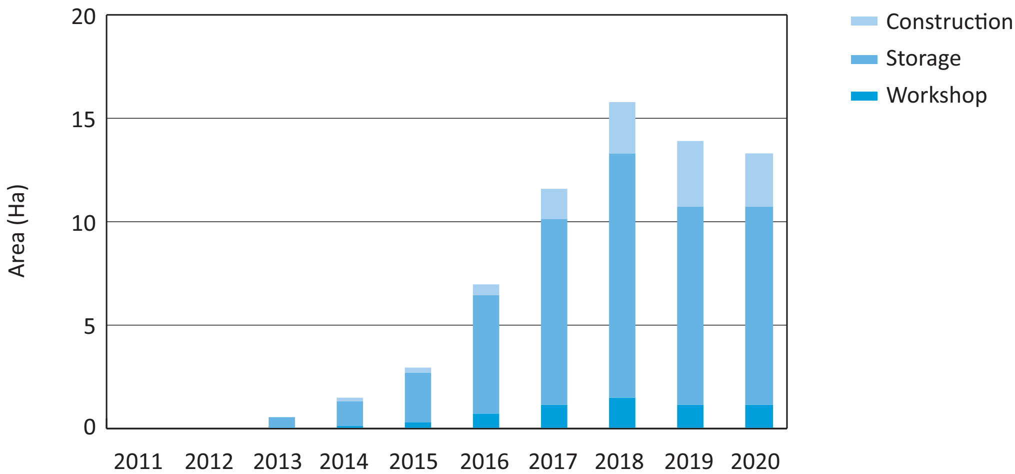


Figure 9.3.2: Estimated construction space requirements in each year

The space requirements during construction are based on an assumed scale of components being handled, the assembly activities being undertaken and the necessary additional space needed to enable safe and efficient storage before final assembly and shipment to site.

10 Operation and maintenance

The operation and maintenance (O&M) stage covers all the activities necessary to ensure ongoing generation during the project's anticipated operational life of 25 years. These activities commence once the project is 'handed over' after installation and commissioning and continue up to decommissioning. It is an area that will in time present significant opportunities for supply, including for companies local to projects.

Included in operation is monitoring of device and balance of plant condition, energy output performance and the impact of the project on the environment. Maintenance includes planned and unplanned elements.

10.1 Overview

Operation and maintenance makes up a significant fraction of lifetime cost and continuous safe and reliable operation is essential to the success of a project. Operations on multiple devices in harsh environmental conditions pose considerable challenges and further development of both tooling and processes will need to continue over the coming years in order to deliver required levels of reliability and operating costs.

A forecast of expenditure on O&M services (excluding development of new methods for O&M) and other ongoing costs up to 2020 is presented in Figure 10.1. Note that annual expenditure is expected to be sustained at around the 2020 level for the life of projects.

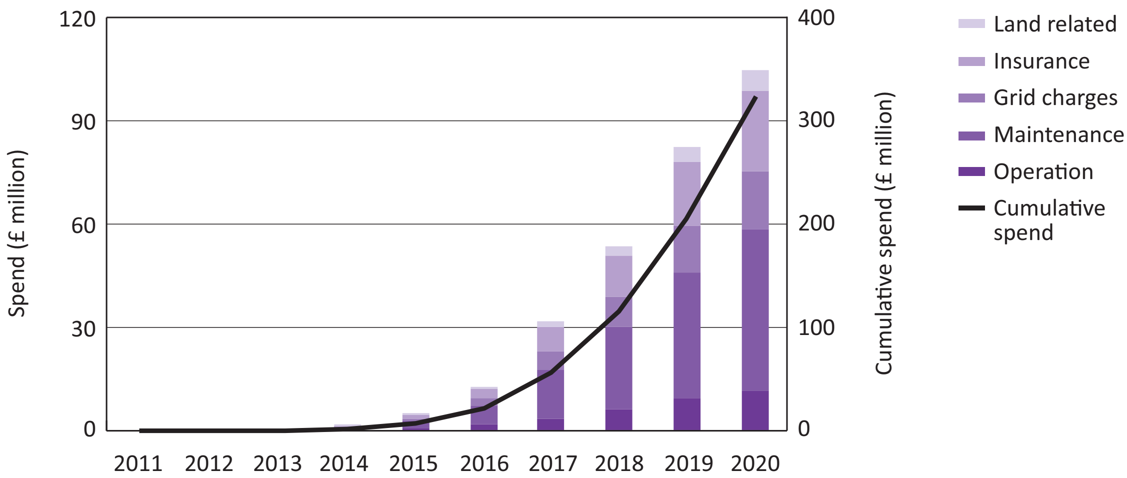


Figure 10.1: Forecast expenditure on operation and maintenance to 2020

By the time the Pentland Firth and Orkney waters projects are nearing completion, there may be around 1,600 devices operating. Some technology developers envisage that devices will be maintained at least partially in-situ, for example, where the rotors and drive trains can be lifted out of the water for repair. Others will require disconnection and towing to shore for maintenance, even for repair or replacement of low cost components. Minimising waiting time for access to devices is recognised as key in maximising uptime.

"OpenHydro's business model is to build devices local to site wherever possible along with an operations base from which the installation may be staged.

An example location of where such a base could be set up is Lyness harbour, though significant investment and facility upgrades would be required to make it suitable."
OpenHydro

Logistics costs and response times are reduced by carrying out a large proportion of maintenance activities local to each project, thus using local port facilities. If port facilities were shared between projects and able to accept complete devices for repair or refurbishment, then the scale of activity could attract a supporting supply chain with a clustering effect.

Although the procurement models for O&M services are yet to be fully developed, it is anticipated that in early years, core activities may be led by staff based locally and employed by device manufacturers. This will aid feedback of design improvements to improve next generation devices. As the industry matures, more third-party providers could be expected to enter the market. Even for early phases, it is anticipated that providers of vessels and onshore component refurbishment and repair will contract with the manufacturers of a number of different devices.

10.2 Activity Breakdown

A breakdown of key activities is presented in Figure 10.2.1. Overhead charges have been included alongside direct operations and maintenance tasks. Relative costs will depend on the device, the scale of the project and the harshness of site conditions with respect to access.

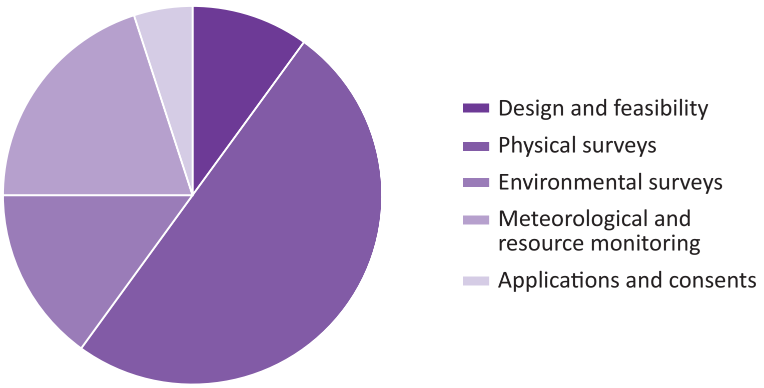


Figure 10.2.1: Cost breakdown for operation and maintenance

10.2.1 Operations

Operations include:

- Monitoring the condition and performance of devices and balance of plant.
- Planning and management of maintenance activities, including the resources required; and
- Managing and monitoring the ongoing environmental impact of the project.

SSystem monitoring is likely to be carried out remotely via telemetry and could be carried out in a project-specific control facility or a central utility facility also used for other energy generation assets. SCADA systems are used to provide data on both the instantaneous status of devices and trends in key parameters in order to be able to register changes in system health before an actual failure occurs. This allows planning of maintenance activities prior to failure. A fully functional SCADA system enables devices and plant to be stopped and started remotely and operation tuned to optimise output and reliability.

Planning and management activities ensure that the correct materials, vessels and people are available at the right time to maximise net revues from the project. Planning routine activities to coincide with weather windows and responding to unplanned events will be critical. There are also administrative activities necessary to meet customer, regulatory and legal requirements.

Ongoing environmental monitoring including some physical surveying is likely to be a requirement of the consents for a site. These activities will be conducted in a similar way to the development and consenting stage, using local ecologists, vessels and marine biologists where appropriate.

10.2.2 Maintenance

Marine energy devices and balance of plant equipment may be subject to continuous fatigue loading, together with occasional extreme loading due to rare environmental or operating events. In particular they are located in and exposed to the marine environment and sea-air interface. Devices are being considered with a 25 year design life but many contain wear-parts or consumables such as lubricants that need to be exchanged a number of times during the lifetime of the device.

> "Devices must operate for 5 years and then undergo major refurbishment. This creates a rolling programme of work. To deliver this; planning, support and infrastructure need to be in place; especially in ports and workshops."
> **Scottish Power Renewables**

Maintenance can be broken down into two key activities; planned and unplanned.

SeaGen blade transport, Marine Current Turbines

Planned maintenance includes activities scheduled in advance to replace components or carry out refurbishment. Project developers are in agreement that a 5 year rolling programme of planned maintenance is desirable for devices that are not accessible for in-situ maintenance, though for devices where in-situ inspection is possible, intervals of six months are preferred for some systems.

Unplanned or reactive maintenance is enforced by a failure to equipment that necessitates repair or other manual intervention. Depending on access to the device and the type of failure, these activities could entail anything from a short visit to returning the device to shore for a strip-down and rebuild of key components.

For any significant activity requiring return of the device to port, it will be essential to have an O&M port facility available. This will be a location to which the devices can be transported, and may be chosen for having:

- A quayside lifting capability to lift the device to shore;
- Local workshop facilities to allow strip down, refurbishment, re-assembly and testing of devices; and

- A local skills base with mechanical and electrical technicians and familiarity with devices and necessary maintenance requirements.

10.3 Supply chain requirements

Figure 10.3.1 shows the numbers of devices estimated to require towing to shore, either for unplanned repair or planned refurbishment up to 2030. The chart reflects plans by some device manufacturers to operate a five-yearly refurbishment programme.

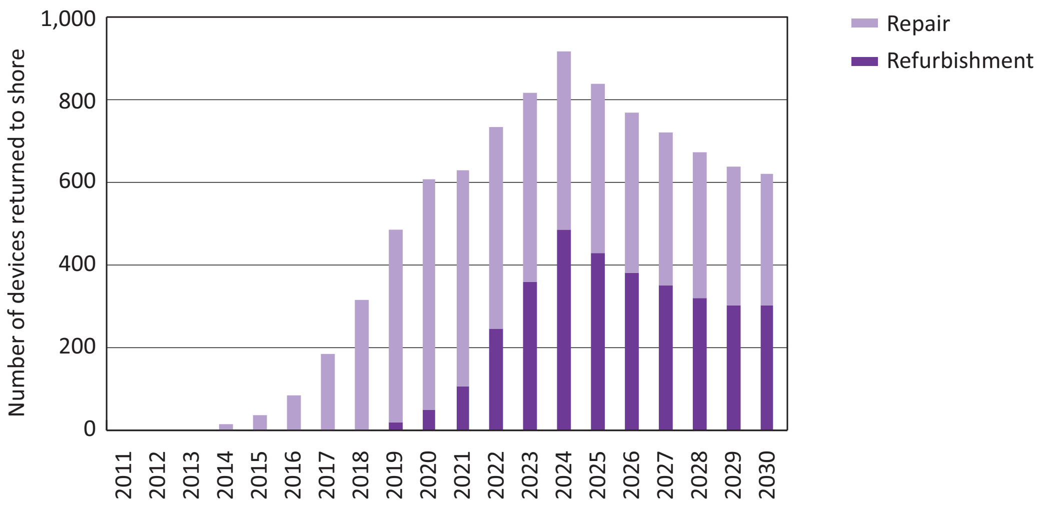


Figure 10.3.1: Estimated device maintenance requirements for all projects in each year

The estimates assume that a mean time between failures of five years is achieved by 2030 through a gradual improvement in performance from first installations, where there is a much higher chance of unplanned failure. These assumptions are based on long- term targets for the industry but there is significant uncertainty in how these devices will operate in terms of failure rates, particularly in the early years after deployment. There will be a variation in performance between devices, individual project conditions and approaches taken by the project developers.

The chart shows that repair work dominates up to beyond 2020 due to anticipated relatively short mean times between failure and a five year gap between installation and first refurbishment of devices. By 2024 refurbishment is expected to become a significant component of maintenance activity provided that the reliability of devices has improved in line with estimates.

It is anticipated that due to the amount of space required, a mix of local and more distant facilities will be used.

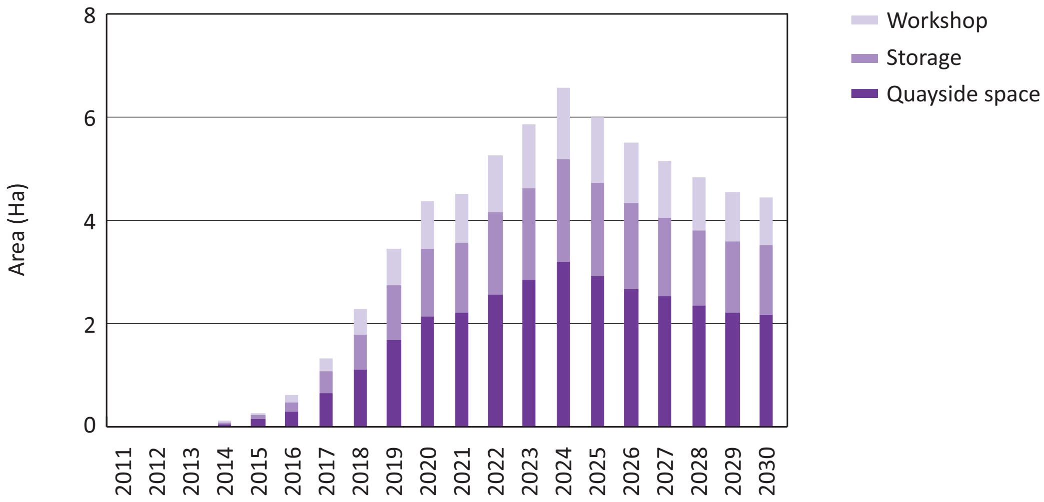


Figure 10.3.2: Estimate of operation and maintenance space requirements in each year

Using a similar basis as the one for construction activities, but based on the number of devices requiring shore-based maintenance, the forecast in Figure 10.3.2 suggests there could be a relatively stable ongoing space requirement for maintenance activities.

10.3.1 Grid charges, insurance and land related costs

Overhead costs associated with a marine energy project include:

- Grid charges to cover access and use of the electrical distribution and transmission networks
- Insurance to cover the risks related to the ongoing operation of the project
- Land-related costs for both onshore and offshore leases.

11 Supporting functions

In addition to activities that contribute directly to specific stages of the project there are a range of supporting functions required. These include:

- Professional services;
- Training;
- Academic research, and
- Enabling and supporting bodies

A wide range of services will be required to deliver wave and tidal projects, including some supporting functions. The costs of these supporting functions have been included in the expenditure forecasts set out in the other sections of this report and brief descriptions are set out in this section.

11.1 Activity Breakdown

11.1.1 Professional services

Professional services include technical, legal, financial, communications, recruitment, logistics and management support.

Support could be in the form of a turn-key management service in delivering a wave or tidal energy project, where a contractor assumes responsibility for the planning and implementation of the installation process. As more projects progress and the supply chain becomes mature, a number of organisations might offer this service to project developers.

11.1.2 Training

Training and skills development will be a crucial component in enabling delivery of the Pentland Firth and Orkney waters projects. A large part of the learning required may be obtained through carrying out the work, but this can be supported by courses, access to training facilities and other activities to encourage involvement in the sector and share knowledge.

Our discussions with project developers suggest that developers are keen to support such work and anticipate that it could be delivered through existing training organisations augmented by the new infrastructure created by the projects. Analysis of skill requirements and the timing of when skills will be needed could be important to ensure that the sector has timely access to the right personnel.

11.1.3 Academic Research

Academic research and university-level education are essential to support development of the Pentland Firth and Orkney waters projects, given the continuing novelty of wave and tidal energy and large range of associated scientific, engineering and other complex uncertainties that need to be addressed.

From an engineering perspective, support to improve understanding of physical resources (including site modelling), generation device technology development (including performance prediction and testing) are important.

11.1.4 Enabling and supporting bodies

National and local public bodies and trade associations could also play an important role in enabling growth by stimulating supply chain development and inward investment, together with raising awareness of key industry challenges and facilitating cooperation between parties to address these. Specific interventions, for example investment in ports and other infrastructure, may be championed by public bodies such as the Scottish Government, development agencies and local councils.

12 Project development company contracting strategies

The contracting approach adopted by the project development companies will depend on the stage of the project and approach of the developer. In some cases, the developer may be intending to be the long-term asset owner, whereas in others, the developer may be seeking to develop and sell on. Alongside device manufacturers, major first or second tier suppliers are likely to include organisations coordinating the delivery of large packages of work (e.g. electrical engineering) or large-scale providers of manufacturing facilities, vessels or specialist services.

During the development and consenting stage it is likely that a number of contracts will be placed to cover surveying and application processes over a number of years. These will generally be relatively low value contracts for services.

> "We see ourselves as the organisation responsible for delivering these projects and as the customer to device manufacturers."
> **E.ON**

For manufacturing and installation, project developers are likely to place a small number of contracts of relatively high value to main contractors. Key contracts will be with the device manufacturer and installation contractor. These main contractors would in turn place a number of contracts with suppliers for more specific services.

During the operation and maintenance stage, device manufacturers are likely to provide a key service in troubleshooting and carrying out a variety of tasks. Part of this service may be on a warranty basis with other tasks covered by risk allowances. Further maintenance contracts may be let on a call off basis or negotiated to cover regular tasks required over a period of five or more years. The focus on contracting here will be on increasing availability and reliability of services at lowest risk to the project. Project developers are likely to use pre-qualification to streamline final selection processes and ensure standards are met.

> "Where the required skills are available close to the project they are preferred because of the insight into local conditions and cost benefits. This model has been used in our previous work in Portugal and Orkney.
>
> The North of Scotland and Orkney have well established maritime, development and engineering capability.
> **Pelamis Wave Power**

Typical requirements of purchasing organisations will cover health, safety & environmental performance, value for money, experience, local knowledge and financial standing.

For major awards a competitive tendering process may be carried out with bidders subjected to a rigorous weighted evaluation of submissions. This is to ensure goods and services are procured from qualified suppliers with the best available quality, pricing, technical capability, HSE standards and total lifetime cost.

In general, suppliers will be expected to be aware and able to comply with the relevant provisions of:

- Relevant health and safety legislation such as Construction Design Management Regulations 2007;
- Appropriate compliance with design standards and methods of construction such as relevant marine environment DNV, BS and IE codes; and
- Management system models such as BS EN ISO 9001, 14001 and 18001 for quality, environmental and health and safety methodologies respectively.

Project developers hold overall responsibility for the delivery of individual projects. Relevant contact details are given in Table 12.1.

Table 12.1: Contact details for project development companies

Site	Address
Brough Head	Aquamarine Power 24 Elder Street Edinburgh EH1 3DX
Cantick Head **Costa Head**	SSE Renewables Airtricity House Ravenscourt Office Park Sandyford, Dublin 18
Westray South	SSE Renewables Inveralmond House 200 Dunkeld Road Perth, PH1 3AQ
Inner Sound	MeyGen Ltd King's Scholars' House, Third Floor 230 Vauxhall Bridge Rd Victoria, London SW1V 1AU
Ness of Duncansby **Marwick Heady**	Scottish Power Renewables Cathcart Business Park Spean Street Glasgow G44 4BE
Farr Point	Pelamis Wave Power Ltd. 31 Bath Rd, Leith, Edinburgh EH6 7AH
Brough Ness	Marine Current Turbines Limited The Court, The Green Stoke Gifford, Bristol BS34 8PD
West Orkney South **West Orkney Middle South**	E.ON Climate & Renewables UK Ltd Westwood Way, Westwood Business Park Coventry, CV4 8LG