TIDAL STREAM: OPPORTUNITES FOR COLLABORATIVE ACTION

WAVE & TIDAL

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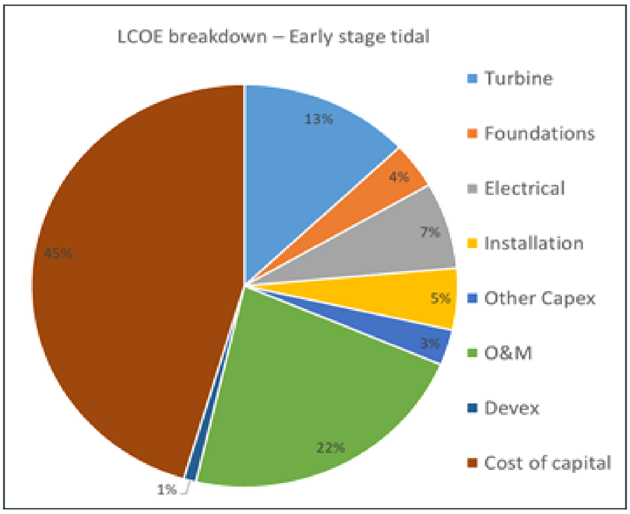
Contents

1 Background for this report

This report is being prepared to frame how the UK tidal stream industry can work collaboratively in a way which adds valuable capacity to the UK energy mix at an affordable cost and create long term export opportunities for a UK supply chain. It builds on previous work published by ORE Catapult in May 2018[1] to identify areas where some key players in the industry can work together on cost reduction actions which can be pursued in the near term to put the industry in the best possible position to achieve its full potential when further revenue support is made available in the UK, and how marine energy can benefit the UK energy mix in a way that other resources are unable to.

The leading UK tidal stream projects have been developed using a variety of collaborative mechanisms, including supply chain partnering, academic/research input and public funding. The priorities set out in this report cover a range of challenges that need to be resolved through a combination of individual developer and common industry effort to achieve a commercial industry. The collaborative areas identified, and all actions proposed in this report will respect participants' intellectual property rights (IPR), with the focus being building a strong tidal stream industry, and not the erosion of any competitive advantage. This report does not focus on the export potential for tidal stream products and services, which is set out in the earlier report.

Based on cost data that was used as an input into the Cost Reduction and Industrial Benefit report, Figure 1 shows the breakdown of Levelised Cost of Energy (LCOE) by component for an average pre-commercial tidal array on a 'per MWh' basis. It is important to note that, while it cannot be shown in this chart, the single biggest driver of LCOE is energy yield. Cost breakdown does vary by device, dependent on device rating and platform design, as does the absolute value of LCOE, however cost of capital is the biggest cost area across the board. Although it is dependent on capital expenditure (capex), there are steps that can be taken to manage risk and make the technology an attractive investment for financial institutions, lowering the cost of project financing.



Priorities based on share of LCOE:

1. Cost of capital
2. O&M
3. Turbine
4. Electrical
5. Installation
6. Foundations/Moorings
7. Devex and Other capex

Figure 1: Cost breakdown of an average pre-commercial tidal project

[1] https://s3-eu-west-1.amazonaws.com/media.newore.catapult/app/uploads/2018/11/19142426/Tidal-Stream-and-Wave-Energy-Cost-Reduction-and-Industrial-Benefit.pdf

Operations and Maintenance (O&M) cost is the next largest cost area and is an area in which there are many opportunities to learn from having devices in the water and continue to reduce costs and maximise power output. Insurance accounts for 10 – 40% of cost during the operating life of assets. There is a focus on proving the safety and reliability of devices to bring down insurance costs alongside operating costs. The wide range can be attributed to the level of cover that different insurers provide, for example property damage and professional indemnity. Other operating cost elements vary according to maintenance strategy, device design and underlying capex. Many interventions applied to O&M costs will have an additional positive benefit to installation costs.

Figure 2 shows the breakdown of capex for a generic tidal device deployed today (though there can be considerable variation between devices and projects). Opportunities for cost reduction in capex are presented in the following sections. As well as standardised components and manufacturing processes adapted from related industries such as offshore wind and oil and gas, technology developers are also continuing to optimise bespoke designs for many components, such as bearing and seal units.

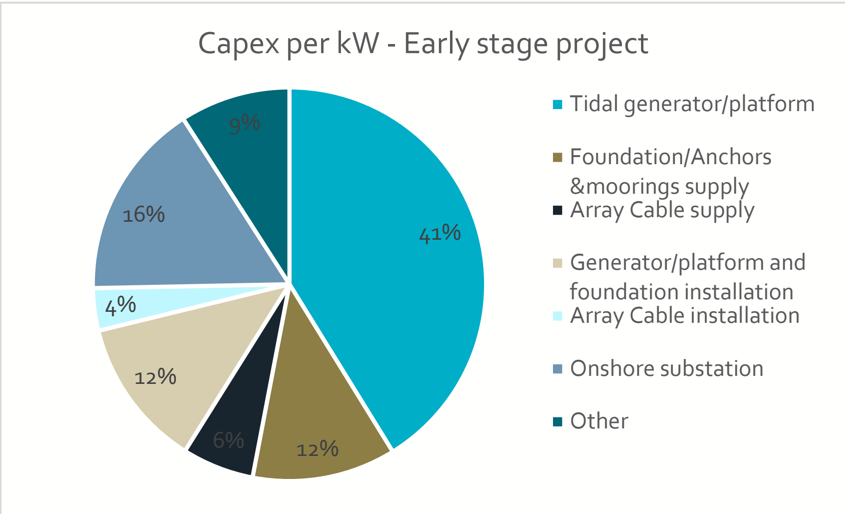


Figure 2: Capex breakdown (£/kW) for an early stage project

2 Developer Pathways

2.1 Recent Deployments

Three developers with devices in Scottish waters have informed this report, using experience of deployment to date to share priorities for reducing cost in future projects: Simec Atlantis, Nova Innovation and Orbital Marine Power. Table 1 shows their most recently installed projects. Meygen Phase 1A and Nova Shetland remain the only operational offshore tidal stream arrays in the world.

Project Name	Location	Installation Date	Device Capacity (MW)	Project Description
Meygen 1A	Stroma	2016	1.5 MW	4 gravity based, 3 bladed turbines
Nova Shetland	Bluemull Sound	2016	100kW	3 gravity based, 2 bladed turbines, integrated energy storage
Orbital SR2000 EMEC	EMEC	2016	2MW	Single floating device with two rotors

Table 1: Current projects

2.2 Next projects

A number of technology advances have been made by developers since first devices entered the water. The next set of deployments will feature next generation turbine technology, larger capacity turbines and a greater focus on array layouts. These steps will enable substantial future cost reduction and satisfy investors requirements for de-risked systems. Table 2 shows each of the next projects for the developers.

Project Name	Location	Installation Date	Device Capacity (MW)	Project Description
Meygen Project Stroma	Stroma	2019 - 20	1.5 MW/2MW	6 gravity based, 3 bladed turbines and trialling of subsea hub
Nova EnFAIT	Bluemull Sound	2019 - 20	100kW	6 gravity based, 2 bladed turbines, direct drive technology and integrated energy storage
Orbital O2 EMEC	EMEC	2020	2MW	Single floating device with two rotors, longer blades and uprated shaft power rating

Table 2: Upcoming projects

These projects are in turn supported by public, collaborative programmes:

- Meygen Project Stroma is supported by the EU's NER300 programme
- NOVA EnFAIT is supported by the H2020 EnFAIT project[2]

[2] www.enfait.eu

- Orbital O2 EMEC is supported by the H2020 FLOTEC project[3]

2.3 Activities currently underway to deliver LCOE reductions in next deployments

Validating engineering and operational performance has been crucial in advancing tidal turbine technology. Lessons learned from in-sea operation have informed the next generation of turbine designs. In general, developers are open to sharing learnings on sector-wide challenges for their next deployments through appropriate future collaboration, which can further accelerate their individual learning and get the most out of assets in the water to cement Scotland's global lead in tidal energy.

Close co-operation between individual technology developers and their supply chains is driving current innovation activities to reduce lifetime costs and increase certainty. Each developer has their own priorities for innovations which will be implemented in the next series of projects included in Table 2.

Simec Atlantis

Simec Atlantis will make use of €1m of European Executive Agency for Small and Medium-sized Enterprises (EASME) funding and €16.8m of EU NER300 funding to trial new technologies at the existing MeyGen project:

- Add two new 2MW turbines developed from the original Meygen machines to the existing array of 1.5MW MeyGen turbines
- Deploy and test a subsea hub, which will transmit power from three of the turbines to shore via a single cable. The simple junction box used to test the technology in this array will cost in the order of £1million. More advanced hubs which incorporate a more significant level of electrical equipment may cost in the order of £5million.

Proving the new turbines and the subsea hub in the field is critical for de-risking the technology and enabling them to be deployed in future deployments at a lower cost.

Nova Innovation

Nova Innovation are leading the EnFAIT project, a Horizon 2020 flagship €20m project to advance tidal energy. EnFAIT is a collaboration between eight leading European industrial and academic partners including Nova Innovation, ORE Catapult, the University of Edinburgh and Wood[4]. The project will demonstrate the development, operation and decommissioning of the world's largest tidal array (six turbines) in Shetland over a five-year period to prove a cost reduction pathway for tidal energy and that it can be cost competitive with other forms of renewable energy. Within the project, a number of innovations will be tested:

- Adapting the proven Nova M100 turbine design and improve the manufacture, assembly, installation and performance of tidal turbines whilst reducing lifetime costs. Key innovations include: the move to a direct drive power take-off (see below); development of a robust subsea connector solution; and

[3] orbitalmarine.com/flotec
[4] www.enfait.eu

development of bespoke tools to reduce the time and cost of offshore operations. The project will include instrumenting turbine blades to improve understanding of turbine loads, turbulent flow and behavioural response.

- Integrate the expanded array with the existing Tidal Energy Storage System (TESS) operating at the site. TESS used funding from the Scottish Government's Low Carbon Infrastructure Transition Programme (LCITP) to add Tesla battery storage to the Shetland Tidal Array. Incorporating storage adds to system value as discussed in detail in Section 4.1 and enables the array to command a revenue premium by matching electricity supply with periods of high demand.

- The Tidal Turbine Power Take-off Accelerator (TIPA) Project is a collaborative H2020 project between 7 leading European partners, including Nova Innovation, the University of Edinburgh and Wood[5], which will demonstrate and validate a direct drive power take-off (PTO) solution for tidal turbines. By replacing the gearbox and conventional generator in the turbine with a PTO featuring a high-efficiency, low-maintenance direct drive generator, the technology could reduce the lifetime cost of tidal power by 20% and provide long-term system reliability. Recent developments in offshore wind may provide transferable lessons learned to tidal stream.

Orbital Marine

The collaborative Floating Tidal Energy Commercialisation (FloTEC) project at EMEC has received funding from the European Union's Horizon 2020 research and innovation programme to demonstrate how floating tidal systems can provide low-cost, high-value energy to the European grid mix. This will include:

- Larger, 10m composite blades on the Orbital O2 2MW demonstrator to enable 50% greater energy capture compared with the SR2000 unit, with a peak power rating of 2.3MW at 2.5m/s current speeds

- Optimised platform configuration to offer a simplified manufacturing process whilst resolving low cost maintenance capabilities for all major systems and components

- Compatibility with local supply chain and infrastructure including de-risking all construction and maintenance activities for small vessels. All major components and systems on the Orbital O2 can be safely accessed whilst the turbine remains in the water (potentially even on site) without the need for anything more than a multi-cat vessel which will save significant vessel cost and revenue loss in the case of a major repair.

- Mooring load dampers to reduce fatigue effects throughout the power take-off system and main turbine structure in parallel with reducing peak mooring loads

Alongside FloTEC, the TOPFLOTE project, also at EMEC, will deliver a pitch controller for floating tidal turbine blades allowing pitch angle to be varied in real time to manage dynamic loadings and optimise power performance, similar to those seen in wind power. The TOPFLOTE project, supported by the

[5] www.tipa-h2020.eu

European Ocean Energy ERA-NET Cofund, could enable up to a 50% increase in yield from the Orbital O2 being installed in 2020.

2.4 Further action required to enable further LCOE reduction for next planned deployments

The developers noted several valuable areas for collaborative innovation, listed here. These are areas where the cost of initiatives could be reduced, and learning could be significantly accelerated through collaborative action. These are not presented in order of priority; differences in technology development pathway mean that different areas are of immediate focus to different developers.

Turbine blades

There is similarity in blades across devices in terms of materials used (glass reinforced plastic and carbon fibre) and tooling used to produce them (moulds, ovens, painting facilities). Given the individual flow characteristics associated with tidal stream resource at site, blade shapes are optimised for each project to enhance yield thus making this part of the supply chain more valuable than the same sector for wind turbines.

Differences include blade scale – Nova blades are 4m in length compared to 10-12m for Orbital and Atlantis. Blade design is also unique to each developer – for example, Nova blades are symmetric, designed for bidirectional, fixed-pitch operation. The scale of different turbines also leads to different blade manufacturing and testing requirements.

The process of producing the associated patterns and moulds is a reasonably high value process itself. Turbine blades can account for up to 30% of turbine capex (depending on the developer) and as well as being a potential area for cost reduction, blades have great potential for export given their relatively small dimensions compared to wind turbine blades and their weights. The maximum length is expected to be circa 10-12m, which makes them easily transportable in standard cargo containers. This is seen as a significant opportunity for Scottish design and manufacturing companies to capture global market share.

The manufacturing processes to produce tidal blades are not hugely different from wind turbine blades. It is a relatively labour-intensive process that is currently being done by wind turbine blade manufacturers or composite boutiques at low volumes. Current Scottish manufacturing facilities active in this market include Shetland Composites, who have supplied blades to Nova Innovation. However, there are no established suppliers in Scotland for larger blades and suppliers will need a project pipeline to attract the capital investment required to build a global supply chain.

Key blades issues:

- Tidal turbine blades can currently cost 3-4 times as much per kg as a wind turbine blade due to bespoke tooling and moulds at current project scale (Using moulds once/twice)
- Blades needs to be proven for long-term durability in a marine environment in order to provide comfort to developers, financers and insurers. An initial blade life of approximately ten years is

needed. The lifetime strategy may incorporate a blade replacement strategy mid-life, which is viable for tidal stream projects as blades can be more accessible than offshore wind turbine blades.

- Blade manufacturing processes are currently very labour intensive which increases time and cost

Collaborative actions:

- Instrument existing turbine blades already in operation and those on next turbines to be deployed in order to better understand performance of the current state of the art and feed this in to design of next generation blades
- Identify existing composites manufacturing facilities and conduct feasibility study into expanding or converting to tidal blade-specific manufacturing facilities
- Identify specific InnovateUK and European funding opportunities for monitoring, testing and manufacturing programmes
- Design a blade testing programme including qualification of fatigue life, in conjunction with University of Edinburgh's FASTBLADE structural composites research facility, planned to be constructed in 2021

Pitch Control

Pitch control systems have been individually designed for each device (except for fixed pitch devices, like the Nova M100 turbine). The pitch control systems used in wind turbines are not suitable for tidal turbines, making this a key area for development. Given the definition of resource characteristics at a site and the difference in loading challenges coming from turbulence intensity in tide as opposed to wind, likely control strategies will need to vary from those used to date on wind turbines.

The pitch control system allows the required oscillation to control the loads and power of the turbine and brings the blades to the desired position by adapting the blade angle in relation to the tidal flow to maximise power generation, as well as being used for braking for the turbine system. Optimal control strategies may differ between fixed bottom and floating devices. Optimised hardware will maximise swept area for a minimal nacelle mass, which is key in enabling larger turbines which generate larger forces on the nacelle. There is potential for gross capacity factor to reach 50% at good sites. A 1% increase in net capacity factor results in approximately 1% decrease in LCOE, so optimising the pitch control system to maximise power output reliably is key to bringing down costs of pitch-controlled devices.

The Orbital O2 device is fabricated in the UK with components sourced from across Europe. The Project Stroma 2MW device uses pitch control systems manufactured almost entirely in Scotland and there is an opportunity for Scotland to take a global lead in developing pitch systems, and in particular assembling full pitch systems which requires significant value adding assembly labour.

The Nova M100 is a fixed pitch device. Although this reduces energy capture compared to a well-functioning pitch control system, it has a benefit of reducing capex, operating costs and downtime as it removes a component that is expensive and, according to experience from wind turbine operation, prone to failure. Nova have no immediate plans to introduce pitch control but are open to using it in the future when reliability improves and costs fall.

Key pitch control issues:

- For pitch-controlled turbines, pitch system reliability is a major area of concern – it is critical to power output performance and a major driver of bankability and insurability. Current pitch control designs require maintenance and major failures of the component require expensive replacements and have a long lead time.
- There is still a lack of deep understanding of the appropriate safety factors for pitch control design.
- Blade and pitch control systems are currently designed on a site by site basis – there is no suitable off-the-shelf design available – this drives up costs and results in a lack of standards.

Collaborative actions:

- Record and share data on the frequency and nature of pitch control system failures in operational and next deployment turbines in order to better understand performance and identify ways of optimising pitch control systems for reliability and performance
- Developers work with key suppliers to ensure learnings from each project are being shared in order to secure continuous improvement at an industry level and not just at a project or individual technology level

Subsea Electrical Hubs

Subsea hubs enable connection of 8-12 turbines through a seabed mounted junction box. They are essential for deployment of bottom-fixed tidal turbines in order to: step-up turbine output voltage to a level which can be efficiently exported to shore; and collect array cables from individual turbines and export to shore via a single cable. Hub sizes will vary depending on the types of turbines, but there will be sufficient commonality to provide scope for shared industry endeavour. The hubs are preferably subsea to reduce cost, navigational and visual impact – this is in contrast to offshore wind, where offshore substations are generally sufficiently far from shore to pose less of a visual or navigational impact. Subsea hubs are not critical to floating tidal turbines, which have converters in the floating hull, and which can be daisy-chained into strings, with each string connecting to shore via a single, larger cable. Grid connection supply and installation costs can currently make up around 20% of project costs[6], so successfully proving subsea hub technology in situ could have a significant cost saving impact for bottom-fixed tidal turbines.

Key subsea electrical hubs issues:

[6] 20% of project costs including share of cost of capital; 12% excluding cost of capital

- Subsea cabling is expensive to lay and prone to damage. Cables systems account for up to 10% of capex in small arrays and can account for a much larger proportion in larger arrays so minimising cabling in future projects is essential.

- Hub reliability will be critical, similar to the offshore substation and export cable for offshore windfarms.

Collaborative actions:

- Different types of subsea hubs will be deployed as part of the EnFAIT project (Nova) and MeyGen Project Stroma (Atlantis). There is an opportunity to combine the learnings from each project and accelerate development of reliable and, ultimately, optimised, technology. This must be done in a way which respects the IPR of all parties involved.

- Optimise subsea hub design to minimise material use and installation costs, whilst retaining redundancy to reduce the effect of cable outages.

Wetmate Connectors

Failure of subsea electrical connectors has been a recurring problem in the marine energy industry. In addition, appropriate subsea connectors reduce vessel time in managing cable ends and can reduce the cost of a turbine installation/retrieval by up to 65%. By improving reliability and reducing the cost of installation and maintenance operations, this could amount to a significant overall LCOE saving. Floating turbines can adequately use dry-mate connectors and therefore are not dependent on using wet-mate connectors.

Key wetmate connector issues:

- A range of wetmate connectors is available but not ideally suited to tidal arrays due to the voltage required and harsher environment

- Using wetmate connectors on subsea electrical hubs is still to be proven

Collaborative actions:

- Share learnings from current connector usage in the EnFAIT and MeyGen projects

- Collaborate with industries with experience using the technology, such as oil and gas

- Develop subsea connector solutions tailored to the tidal energy industry.

Nacelle deployment and recovery

For subsea turbines, vessel costs are a significant component of operating and deployment cost. The development of technology that would allow low-cost, locally available vessels to be used for nacelle deployment and retrieval could significantly cut the LCOE of tidal array. This would also boost the economic impact of tidal energy, by increasing opportunities for local vessels to contribute to the supply chain.

Key nacelle deployment and recovery issues:

- High vessel costs; limited operating windows (tide, weather and light); limited availability of larger vessels; limited local economic impact of large vessels.
- The lack of available technology drives the need for innovative solutions that enable low-cost, local vessels to be used for nacelle deployment and recovery operations.

Collaborative actions:

- Assess requirements for different developers for nacelle deployment and recovery technology.
- Assess the capabilities of the Scottish vessel fleet and further opportunities to share vessels across sites, particularly during the operation phase of projects. Though there is a divergence between fixed and floating devices, multi cats are used by both parties.
- Assess potential cross-over benefits of new technology to other industries, such as oil and gas and aquaculture.

2.5 Collaborative Action Plan

Based on alignment with existing innovation priorities, Table 3 shows where we have identified key collaboration initiatives. ORE Catapult intends to work with developers to define a clear set of outputs to frame how efforts will be streamlined to accelerate technology progress and cost reduction in their next set of projects and over the longer term. This would include settings milestones for when each collaboration point can be completed.

	Blades	Pitch Control	Subsea Hubs	Wetmate Connectors	Nacelle Deployment & Recovery
Simec Atlantis					
Orbital Marine Power					
Nova Innovation					

Table 3: Collaboration matrix for next planned deployments

2.6 Potential further action to enable further LCOE reduction

Testing, Validation and Demonstration

Real data on running and failure modes will accelerate optimisation of tidal devices, which will increase turbine reliability and cost reduction.

While they are distinct technology sectors, there is some overlap between tidal and wave platforms. Developers see potential to draw on work being done by Wave Energy Scotland to de-risk components such as mooring lines and electrical cables through fatigue testing and destructive testing. Critically, this would also have the benefit of reducing project insurance costs and attracting project financing which is often contingent on low risk, tested and field-proven devices.

Key testing, validation and demonstration issues:

- Facilities to readily test devices are few and far between, and expensive to access, which can delay progress or add cost
- A lack of tried and tested standards for device components can lead to overly cautious safety factors and prevents different tests from being comparable
- Limited experience of in-sea operation and a lack of convergence in device design reduces the utility of standards in some areas.
- Testing and validation plays an important role, and is a key complement to, but not a substitute for, experience from devices operating long-term in real-world tidal arrays.

Collaborative actions:

- The RiaSoR (Reliability in a Sea of Risk) project is establishing industry best practice in reliability testing for wave and tidal devices through the development of reliability guidelines and provision of training on using the newly established methodologies.
- A tidal industry representative should sit on the International Electrotechnical Commission (IEC) committee alongside Wave Energy Scotland to ensure the needs of the tidal stream sector are addressed.
- Opportunity for technology developers, supply chain and testing organisations to define a framework for standardising testing procedures and data capture to maximise comparability
- Further opportunity for industry to collaborate to consider what key components are appropriate for certification and implementing the process efficiently.

3 Actions for further cost reduction with revenue support in place

A significant level of cost reduction will be unlocked with the growth of a continuous project pipeline that comes with a government-backed revenue support scheme A new dimension of economies of scale will be realised as the industry moves to volume production. Assembly lines and tools (e.g. blade moulds) produced for a single project/turbine can be re-used on larger arrays and across numerous sites. Full-time employees can continue to learn in their roles and developers can secure more attractive supplier contracts and attract investment.

The benefits of this growth will be realised throughout the tidal energy supply chain. Confident in future orders, suppliers can invest in R&D and boost capacity to meet growing demand. This will drive down costs, which in turn will increase demand, creating the kind of positive feedback already observed in the wind and solar energy industries.

3.1 Large-scale Projects

There is huge potential to invest in UK facilities for device assembly and manufacture. Many of the companies currently supplying the industry are SMEs with small sites close to areas of tidal stream deployment.

Key issues for large scale UK manufacturing and assembly:

- Scotland has ample sites with quayside load-out, suitable for heavy structural fabrication, painting, major assembly and load-out but these facilities are not necessarily compatible with assembly of precision machinery and bearing systems (i.e. pitch hub units, MSU's and nacelles) which require clean (and relatively warm) facilities. Large, clean assembly sheds with gantry cranes that can lift >100T and have reasonable access to quaysides are rare, almost non-existent. Building infrastructure in Scotland will anchor the industry to the region as a global export market grows.

Collaborative actions:

- Work with enterprise agencies to ensure companies have the means and financing opportunities to grow and invest in facilities to serial-manufacture components for large projects when revenue support enables a step change in project scale. This will be a combination of in-house facilities for technology developers, and supply chain specialists, such as Shetland Composites, Calder Engineering, AJS Productions LTD and Pentland Precision.

- Work with local planning authorities to assess site potential for nacelle assembly and maintenance facilities to enable Scotland to capture a large share of both domestic and global market for tidal stream manufacturing. There is potential to refurbish existing sites in Scotland for this purpose, for example portside warehouses suitable for precision manufacturing and accessible to barges.

3.2 Access to commercial debt

Projects are currently financed through a combination of grant support, revenue support and private finance. As the industry matures and is considered less risky by financial institutions, this is envisaged to move to a model where commercial debt begins to form a portion of project financing at a lower rate. With volume deployment and proof of technology at commercial scale, we expect that weighted average cost of capital (WACC) will reduce to ~8% by the time 200MW is installed, with each 1% reduction in WACC reducing LCOE by approximately 7%.

The allocation of risk between supply chain, technology developers and financers has been a difficult balance to achieve for early projects. Developers are already actively engaged with supply chain to accelerate the industry towards a more conventional contractual arrangement in which component manufacturers deliver supply with warranty.

Collaborative actions:

As the technology is proven through successful in-sea operation and long-term component testing, OEMs should move to offering fully commercial conditions with performance and schedule guarantees. Fixed-price O&M contracts provide budget certainty to project developers which results in lower cost of finance and are a key move towards giving the level of comfort and type of arrangements which are attractive to banks and investors. These arrangements are not yet universal and so there remains a great deal of scope for future cost reduction from this source.

3.3 Other areas for long-term industry action

As well as the points noted above, tidal developers already have their sights on a range of technological and industry advances they will pursue when they have visibility of a self-sustaining industry. These will all contribute to reducing LCOE and growing a domestic industry.

Move from gravity-based anchors

Improved understanding of at-sea performance is expected to lead to design optimisation and especially reduction in mass of main anchoring structures – reducing the mass of material by up to 90% for fixed bottom structures. However, the manufacturing process is not suited to small projects as it requires a large space and bespoke moulds and tooling. Piled or driven foundations become more economically viable when constructed in batches and will be incorporated on large fixed-bottom turbines when manufacturers can secure demand for 25 – 30 monopile per year.

A move to piled or drilled foundations for both fixed and floating structures, replacing gravity-based, in the next generation of turbines will enable fewer vessel journeys to bring foundations to site and a significant reduction in anchor mass. A number of supply chain companies, including Leask Marine, are building drill rigs to test drilled anchor solutions, bringing solutions to the market within the next five years.

Local job creation support in O&M services and vessel and equipment suppliers

Intervention rates comparable to onshore wind will mean that tidal developments will require locally based or permanently onsite ongoing monitoring and responsive maintenance teams. Investment in training and facilities will help create O&M engineering hubs in coastal regions of resource. These scalable fixed cost team or teams (a single six-man service team could maintain multiple turbine units) will create demand for equipment hire / supply and local commerce will benefit from increased industrial trade.

Industry-specific technician training

Apprenticeships would provide an ideal training opportunity for young people and other workers transferring from related industries, producing capable technicians to construct and maintain devices to a high standard, increasing uptime. On site apprenticeships attract local staff who can work on call as opposed to recruiting workers nationally who may be more expensive to attract and employ on a shift pattern. A pipeline of projects will build confidence in the industry and attract recruits to the sector.

Weather Forecasting and operations planning

Operating offshore can be very expensive, as sites are often in remote locations, installation and maintenance vessel costs are high and working windows are limited by weather and tide. Optimising site operations through more sophisticated planning tools can reduce weather downtime costs and turbine downtime.

4 How will tidal energy enhance the energy system

4.1 Reliable baseload generation

The UK energy system will behave differently in 2030 relative to today. National Grid estimate that total electricity capacity could increase from 103 GW today to between 131GW and 161GW by 2030 and between 189 GW and 268 GW by 2050[7] to incorporate a move towards electrification. A higher level of storage and interconnection will complement a system which is smarter and more responsive to fluctuations in supply.

One potential drawback for wind and solar power is the requirement to maintain a level of back-up capacity to provide power when wind is not blowing, or the sun is not shining for an extended period of time. This can be mitigated to an extent by diversifying the location of projects, however this is not always sufficient, and the capacity of batteries required to store a week's worth of wind would be cost prohibitive.

In contrast, tidal stream power is predictable and consistent seasonally. To illustrate the unique value of tidal power, we should consider the operating cycle of a battery installed on a wind farm. This will tend to fill up in a few hours on a windy day; stay full for a week (while the wind keeps blowing); then discharge quickly when the wind drops. Meanwhile, the battery on a tidal array could charge and discharge predictably about 30 times in that period, leading to a much higher utilisation of the battery. Combined with staggering of peak times around the UK coast, tidal + storage presents an excellent renewable candidate for helping displace baseload power sources like coal and nuclear.

4.2 Participate in the Capacity Market

The Capacity Market is now in its second year of full operation[8]. It is designed to deliver the required generation capacity or reduce the demand during times of system stress. Table 4 shows the year ahead auction results for the winter 2018/19, where gas makes up the vast majority of reserve capacity. This is demonstrated in Figure 3. From 2011 to 2019, the relationship between CCGT and wind generation changes drastically, with CCGT taking on a much more responsive role to the level of wind power on the system. Tidal could potentially deliver up to 15GW of capacity on the UK grid[9], providing a valuable low-carbon, reliable power source to replace fossil fuels in the Capacity Market.

Primary Fuel Type	Anticipated De-Rated Capacity (MW)
Bio-fuel	76
Biomass	33

[7] https://www.nationalgrid.com/uk/publications/future-energy-scenarios-fes

[8] At the time of writing, the market was suspended pending review from the European Court of Justice. It has been referenced to emphasise what form the majority of the UK's back up currently is and how that may change going forward.

[9] https://s3-eu-west-1.amazonaws.com/media.newore.catapult/app/uploads/2018/11/19142426/Tidal-Stream-and-Wave-Energy-Cost-Reduction-and-Industrial-Benefit.pdf

Coal	438
Coal mine methane	10
Diesel	95
Demand Side Response	429
Gas	4,366
Storage - Battery	112
Storage - Compressed Air	3
Waste	227
Total	5,790

Table 4:National Grid Capacity Market Register 2018/19 T-1

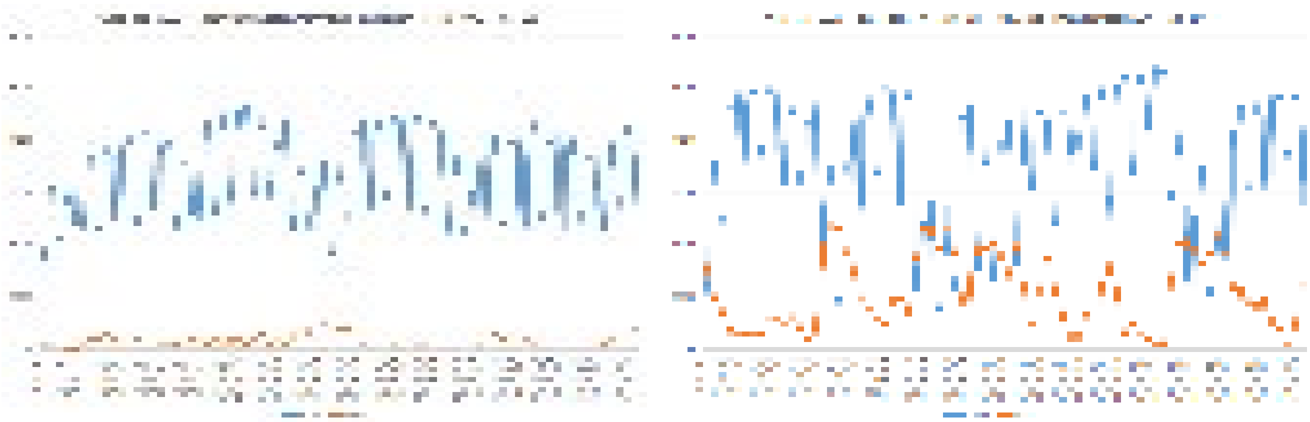


Figure 3: Change in relationship between CCGT and Wind generation from Jan 2011 to Jan 2019

4.3 Local generation to reduce expensive transmission works

Tidal stream energy could make a contribution to the decentralisation of energy distribution networks. The network operator in Scotland has raised concerns about grid strength due to aging infrastructure and exacerbated by increasing electricity demand, particularly in remote Highland and Islands areas. Tidal could provide a predictable, low carbon, local power resource that is cheaper to construct and operate, and cleaner than reverting to diesel generation.

4.4 Delay costly system-level investment decisions

Importantly, tidal projects are very modular. When compared to the strike price of new nuclear (£92.50 per MWh for 30 years), tidal can provide a low carbon means to delay investment decisions for a very capital-intensive project and potentially be available at a utility scale for a lower price by 2030, whilst supporting UK jobs and UK manufacturing.

5 Summary

The priorities set out in this report cover a range of challenges that need to be resolved through individual developer and common effort to achieve a commercial industry, specifically focusing on key actions needing to take place in the near term to begin to achieve the cost reduction trajectory expected for the industry.

Validating engineering and operational performance has been crucial in advancing tidal turbine technology. In the next generation of projects, developers have individual plans and priorities for innovation. ORE Catapult, with support from Scottish Government, will facilitate a series of quarterly workshops (precise content and format to be agreed with Scottish Goverment and leading developers) to share learnings from these projects, with the aim to further accelerate their individual learning and get the most out of assets in the water.

Areas of developer interest include:

- Turbine blades
- Pitch Control
- Subsea Electrical Hubs
- Wetmate Connectors
- Nacelle deployment and recovery

In addition, ongoing cross-industry programmes for testing, validation and demonstration will accelerate component optimisation and satisfy technology validation requirements for financial investors. Over the longer term, we expect that more significant cost reduction will come with revenue support by opening up opportunities for projects with access to commercial debt. Increased deployment will also make further technology advances economically viable, such as innovative mooring and foundation solutions and sophisticated offshore planning tools.

The predictability and seasonal consistency of tidal stream power make it beneficial to the grid. Small arrays, particularly where coupled with storage, are ideal for providing a level of base load to remote Scottish communities with weak network connections. Energy intensive industries, such as whisky distilling and ferries, operate in batches which can be aligned to power supply.

Collaborative action is key to attaining the goals set out for reducing costs and seeing an economic benefit to the UK through the marine energy industry as efficiently and quickly as possible. The sector is being driven forward by collaborative projects. ORE Catapult will continue to work with tidal developers to advance their technologies towards a competitive and successful marine energy industry in Scotland.

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