Energy Innovation Needs Assessment

Sub-theme report: Tidal stream

Commissioned by the Department for Business, Energy & Industrial Strategy

October 2019

Lead:

vivideconomics
putting economics to good use

Partners:

CARBON TRUST

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Imperial College London

FRAZER-NASH CONSULTANCY

Modelling support by:

CATAPULT Energy Systems

Contents

The views expressed in this report are the authors' and do not necessarily reflect those of the Department for Business, Energy and Industrial Strategy.

Acronyms and abbreviations

Table 1. **Key acronyms and abbreviations**

Acronym/abbreviation	Definition
BEIS	Department for Business, Energy & Industrial Strategy
CAPEX	Capital Expenditure
EINA	Energy Innovation Needs Assessment
ESC	Energy Systems Catapult
ESME	Energy System Modelling Environment
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GRP	Glass-Reinforced Plastics
GVA	Gross Value Added
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
IEA	International Energy Agency
IP	Intellectual Property
LCOE	Levelised Cost of Energy
O&M	Operations and Maintenance
OEM	Original Equipment Manufacturer
OPEX	Operating Expenditure
PTO	Power Take-Off
RCA	Revealed Comparative Advantage
ROV	Remotely Operated Underwater Vehicle
RoW	Rest of World
RD&D	Research, Development and Demonstration
TINA	Technology Innovation Needs Assessment
SDS	Sustainable Development Scenario
TIPA	Tidal Turbine Power Take-Off Accelerator
TRL	Technology Readiness Level
TWh	Terawatt hours

Glossary

Table 2. **Key terms used throughout this report**

Term	Definition
Learning by doing	Improvements such as reduced cost and/or improved performance. These are driven by knowledge gained from actual manufacturing, scale of production, and use. Other factors, such as the impact of standards, which tend to increase in direct proportion to capacity increases.
Learning by research, development and demonstration	Improvements such as proof of concept or viability, reduced costs, or improved performance driven by research, development and demonstration (RD&D); increases with spend in RD&D and tends to precede growth in capacity.
Sub-theme	Groups of technology families that perform similar services which allow users to, at least partially, substitute between the technologies. For example, a variety of technology families (heat pumps, district heating, hydrogen heating) have overlapping abilities to provide low-carbon thermal regulation services and can provide flexibility to the power system.
System value and Innovation value	Estimates of change in total system cost (measured in £ GBP, and reported in this document as cumulative to 2050, discounted at 3.5%) as a result of cost reduction and performance improvements in selected technologies. This is the key output of the EINAs and the parameter by which improvements in different technologies is compared. System benefits result from increasing deployment of a technology which helps the energy system deliver energy services more efficiently while meeting greenhouse gas targets. Energy system modelling is a vital tool in order to balance the variety of interactions determining the total system costs. Innovation value is the component of system value that results from research and development (rather than from ‘learning by doing’).
Technology family	The level at which technologies have sufficiently similar innovation characteristics. For example, heat pumps are a technology family, as air-source, ground-source and water-source heat pumps all involve similar technological components (compressors and refrigerants). Electric vehicles are also a technology family, given that the battery is a common component across plug-in hybrids and battery electric vehicles.
Gross Value Add	Gross Value Add (GVA) measures the generated value of an activity in an industry. It is equal to the difference between the value of the outputs and the cost of intermediate inputs.

Introduction

Box 1. **Background to the Energy Innovation Needs Assessment**

The Energy Innovation Needs Assessment (EINA) aims to identify the key innovation needs across the UK's energy system, to inform the prioritisation of public sector investment in low-carbon innovation. Using an analytical methodology developed by the Department for Business, Energy & Industrial Strategy (BEIS), the EINA takes a system-level approach, and values innovations in a technology in terms of the system-level benefits a technology innovation provides.[1] This whole system modelling in line with BEIS's EINA methodology was delivered by the Energy Systems Catapult (ESC) using the Energy System Modelling Environment (ESME) as the primary modelling tool.

To support the overall prioritisation of innovation activity, the EINA process analyses key technologies in more detail. These technologies are grouped together into sub-themes, according to the primary role they fulfil in the energy system. For key technologies within a sub-theme, innovations and business opportunities are identified. The main findings, at the technology level, are summarised in sub-theme reports. An overview report will combine the findings from each sub-theme to provide a broad system-level perspective and prioritisation.

This EINA analysis is based on a combination of desk research by a consortium of economic and engineering consultants, and stakeholder engagement. The prioritisation of innovation and business opportunities presented is informed by a workshop organised for each sub-theme, assembling key stakeholders from the academic community, industry, and government.

This report was commissioned prior to advice being received from the CCC on meeting a net zero target and reflects priorities to meet the previous 80% target in 2050. The newly legislated net zero target is not expected to change the set of innovation priorities, rather it will make them all more valuable overall. Further work is required to assess detailed implications.

[1] The system-level value of a technology innovation is defined in the EINA methodology as the reduction in energy system transition cost that arises from the inclusion of an innovation compared to the energy system transition cost without that innovation.

The tidal stream[2] sub-theme report

The report has four sections:

- **Tidal stream and the energy system:** Describes the potential role of tidal stream in the energy system.
- **Innovation opportunities:** Provides lists of the key innovations available within tidal stream, and their approximate impact on costs.
- **Business opportunities:** Summarises the export opportunities for tidal stream, GVA and jobs supported by these opportunities, and how innovation helps the UK capture the opportunity.
- **Market barriers to innovation:** Highlights areas of innovation where market barriers are high and energy system cost reductions and business opportunities significant.

[2] Tidal barrage and lagoon are out of scope as their innovation potential is relatively low compared to other EINA technologies.

Key findings

Innovation areas in tidal stream

The main innovations for tidal stream are identified below. The list is not a substitute for a detailed cost-reduction study. Rather, it is a guide for policymakers on key areas to be considered in any future innovation programme design.

The innovation priorities below select individual or groups of the top scoring innovations. Table 3 maps the top scoring innovations to individual technology components, and Table 6 sets out the full list of innovations and their scores.

- **Structure and Prime Mover:** There is potential for innovations around the use of materials (using concrete and polymers) and the design of improved blades for turbines. Different classes of tidal stream device may prove to be more suited to different resource environments, therefore there is also potential for novel structure design.
- **Power Take-Off and Control (PTO):** Potential innovations in PTO technology include permanent magnets and control of turbines to minimise turbulence, increase yield, and reduce fatigue and improved pitch and yaw technology
- **Foundations and Mooring:** Innovations to replace gravity bases are required to make foundations for fixed tidal devices more efficient. Advanced mooring development and demonstration is particularly relevant for floating tidal devices. Technology transfer is possible from the offshore wind sector.
- **Operations and Maintenance:** Innovations in physical maintenance procedures such as reducing time spent at sea and the need to use divers are relevant for fixed tidal devices. This could be using remotely operated underwater vehicles (ROVs) and other novel condition monitoring techniques.
- **Yield:** Innovations in tidal resource modelling allows for greater understanding of the tidal energy resource, enabling yield optimisation and reducing the LCOE.

Business opportunities for the UK

Innovation provides a business opportunity to grow tidal stream-related exports, contributing up to £540 million of gross value added (GVA) per annum in 2050. This level of export could directly support around 5,000 jobs per annum. In the business opportunities section below, GVA and jobs results are set out by component (Table 7).

- The UK's large domestic market and high industry profile provides a strong platform to capture market share of the European and global markets.
- However, the global market size for tidal stream is expected to be relatively small, hence the low export opportunities compared to other sub-themes.
- The UK is at the forefront of tidal stream development and could continue to lead this with enough investment in innovation to capture market share through first-mover advantage.
- Maintaining competitiveness in current strengths such as innovative development, proven demonstration capabilities, blade manufacture, cabling, and testing facilities.
- The many different design possibilities, and the need for innovation, lend themselves to a market requiring a highly skilled workforce and technical manufacturing, ensuring greater opportunities in international exports.

Market barriers to innovation in the UK

Opportunities for HMG support exist when market barriers are significant and cannot be overcome by the private sector or international partners. In the market barriers section below, the barriers are set out by component, where possible (Table 8). The main market barriers identified by industry relate to:

- **Low level of maturity of tidal stream compared to other low-carbon technologies:** Despite opportunity for substantial future savings, tidal stream is less cost effective than other technologies. Investment is focussed on these more mature technologies, reducing opportunities for tidal stream technology to be deployed and to demonstrate progress in innovation and cost-effectiveness.
- **A lack of visibility over a sufficiently sized future market for tidal stream:** Tidal stream energy is currently not cost-competitive and relies on HMG support. Demand is therefore highly policy-dependent, and an uncertain policy position results in an unclear route to market and unpredictable future revenues, which discourage investment in the sector.
- **Costly, complex, and uncertain process required for site planning and approval:** Assessments are often costly and technically challenging in proportion to the size of the project and the environmental risk involved.

Key findings by component

Government support is justified when system benefits and business opportunities are high, and government is needed to overcome barriers.

Table 3. **Cost and performance in tidal stream (see key to colouring below)**

Overall statistics for tidal stream: System value = £1.8 billion (range: £1.2-1.9 billion), 2050 export opportunity (GVA) = £540 million, 2050 potential direct jobs supported = 5,000				
Component	**Example innovation**	**Business opportunity**	**Market barriers**	**Strategic assessment**
Structure & prime mover	Advanced manufacturing and design for existing blades	Turbines (Incl. Structure & prime mover and Power take-off & control)	Moderate	Advanced manufacturing techniques may achieve large improvements in the yield and the reliability of the tidal blades. Due to the specialised nature, tidal developers manufacture most parts. Many turbine developers are UK firms, based in the UK. Business opportunities are relatively lower compared to other technologies because the size of the future tidal stream market is smaller, though the UK is likely to have a large share of this market. Some specialised parts come from other industries. In part due to the high cost involved, without government intervention, innovation in structure and prime mover will occur due to a well-functioning industry but at a lower scale and speed, due to the high cost involved.
Power take-off (PTO) & control	Early stage research for disruptive PTO technologies		Moderate	Innovation in early stage disruptive power take-off technologies offers opportunities for significant cost reduction. As above, tidal developers manufacture most parts and are based in the UK. A smaller overall market results in a smaller business opportunity compared to other sub-themes. Without government intervention, innovation in power take-off and control will occur due to a well-functioning industry but at a smaller scale and speed.
Foundations & moorings	Advanced foundations and mooring development & demonstration	Low	Moderate	Innovations to replace gravity bases (load-resistant bodies) are required to make foundations for fixed tidal devices more efficient. Some parts, including large steel components, are not high value add typically not manufactured in the UK. Without government intervention, innovation in foundations and moorings will occur at a lower scale and speed.
Connection	Cable stability, reparability, and survivability	Low	Moderate	Innovation in cables offers opportunities for cost reduction in connection. Cables are manufactured in the UK. The UK is a European leader and accustomed to offshore wind requirements. However, offshore wind and

Overall statistics for tidal stream: System value = £1.8 billion (range: £1.2-1.9 billion), 2050 export opportunity (GVA) = £540 million, 2050 potential direct jobs supported = 5,000					
Component		**Example innovation**	**Business opportunity**	**Market barriers**	**Strategic assessment**
					other technologies are relatively larger markets and so tidal stream represents a smaller sized business opportunity. Other cable manufacturers exist but are not currently specialised in renewable energy or marine. Without government intervention, innovation in connection will occur at a lower scale and speed.
Installation		Improve current installation techniques and develop novel ones	Low	Severe	Improvement in existing installation techniques and development of new ones offers opportunities for cost reduction. Turbine developers undertake installation, with the potential for a greater shift to locally trained workforces in the future. This move to a local workforce reduces the business opportunities. Without government intervention, innovation in installation is significantly constrained.
O&M		Design and demonstration of improved physical maintenance procedures	Medium-low	Severe	Demonstration of improved maintenance procedures offers opportunities to reduce O&M costs. Turbine developers largely undertake O&M, with the potential for a greater shift to a locally trained workforce in the future. This move to a local workforce reduces the business opportunities. Without government intervention, innovation in O&M is significantly constrained.
Other non-component	**Yield**	Tidal resource modelling	N/A	N/A	Yield optimisation through tidal resource modelling has potential to reduce the Levelised Cost of Energy (LCOE). Yield has not been assessed in the business opportunities and market barriers analyses, as these are component focussed.
	System balancing	Leveraging the well-known parameters – understanding the grid-level benefits	N/A	N/A	Greater understanding of grid benefits helps achieve improved efficiency in energy delivery. System balancing has not been assessed in the business opportunities and market barriers analyses, as these are component focussed.
	Decommissioning	Design for decommissioning	N/A	N/A	Integrating decommissioning early in the design can support de-risking cost reduction. Decommissioning has not been assessed in the business opportunities and market barriers analyses, as these are component focussed.

Source: *Vivid Economics, Carbon Trust*

Note: *The main innovations per component are the innovations that score highest in the innovation inventory. This table only includes component-specific market barriers. Cross-cutting barriers are included in the market barriers section below.*

Table 4. **Key to colouring in the key findings per component**

Business opportunities	Market barriers
High: more than £1 billion annual GVA from exports by 2050	**Critical:** Without government intervention, innovation, investment and deployment will not occur in the UK.
Medium-High: £600-£1,000 million annual GVA from exports by 2050	**Severe:** Without government intervention, innovation, investment and deployment are significantly constrained and will only occur in certain market segments / have to be adjusted for the UK market.
Medium-Low: £200-£600 million annual GVA from exports by 2050	**Moderate**: Without government intervention, innovation, investment and deployment will occur due to well-functioning industry and international partners, but at a lower scale and speed.
Low: £0-200 million annual GVA from exports by 2050	**Low:** Without government intervention, innovation, investment and deployment will continue at the same levels, driven by a well-functioning industry and international partners.

Source: Vivid Economics, Carbon Trust

Box 2. **Industry workshop**

Tidal stream industry, academic community, and research agencies attended the workshop. Key aspects of the EINA analysis were subjected to scrutiny, including innovation opportunity assessment, and business and policy opportunities assessment. Several views and new evidence were suggested which were used to update these assessments.

The views of the attendees were included in the innovation assessment. However, several more contextual issues were raised at the workshop:

- There is a role for government in providing public support to develop a market for tidal stream and for resolution of grid-connection issues, around which the industry could catalyse investment.
- Deployment at scale, characterised by arrays of 100MW minimum, was viewed as a key enabler of cost reduction independently of technical innovation. The lack of scale projects prevents investment in the technology.
- Costs can be decreased further through a reduction in the cost of capital. This is expected as private sector confidence increases with deployment and perceived risks are reduced.
- Other low carbon technologies are much more mature and in comparison, tidal stream appears less cost effective. The tidal stream sector has not been able to demonstrate potential cost savings that could be achieved and would make it competitive with other low carbon technologies in the future. Competing with more mature technologies for funding and support creates barriers to investment and innovation.

These overarching messages, while not fitting within the focus of the EINA framework on an assessment of innovation potential, are important considerations in setting innovation policy.

Tidal stream and the whole energy system

Current situation

Operational tidal stream capacity is 10MW in the UK, there is 2MW under construction, and a further 1,000MW sites are leased.[3] There are currently 22 device developers in the UK. In 2010, the Crown Estate awarded a major lease agreement to Atlantis MeyGen for 398MW. The development is currently the largest planned tidal stream project in the world.[4] Other major projects are Nova Innovation's Shetland Tidal Array, Orbital Marine's Flotec turbine, and Minesto's Holyhead Deep project.

There is divergence in tidal stream technological solutions. The first tranche of devices were all fixed solutions, involving three-bladed, horizontal axis turbines mounted to the seabed.[5] More recently, the market has seen the emergence of floating devices. Questions also remain on the choice of platform / structure, foundations, installation, connections, and operation and maintenance methods.

Future deployment scenarios

The UK has around 50% of Europe's tidal energy resource.[6] For tidal stream, some studies show that a total of 20.6 TWh per year could be extracted from 30 key tidal stream sites in the UK.[7] ESME assumes an upper constraint on tidal stream resources in the UK of 52 TWh; and that this could all be exploited by 2050 if tidal stream technology was rolled out and scaled up early enough. (See Box 3 below).

Sub-theme system integration: benefits, challenges, and enablers

Tidal stream is a clean source of energy that could displace some of the coal and gas generation in the grid. It has advantages over other energy generation

[3] ORE Catapult (2018), Tidal Stream and Wave energy cost reduction and industrial benefit.
[4] See Simec Atlantis at https://simecatlantis.com/projects/meygen/
[5] Energy Technologies Institute (2015) Tidal Energy: Insights from the Energy Technologies Institute. https://www.eti.co.uk/insights/insights-into-tidal-energy
[6] For both wave and tidal stream. BEIS (2013) Wave and Tidal energy: part of the UK's energy mix https://www.gov.uk/guidance/wave-and-tidal-energy-part-of-the-uks-energy-mix
[7] Carbon Trust, Black & Veatch (2011) UK Tidal resource and Economics Study https://www.carbontrust.com/media/77264/ctc799_uk_tidal_current_resource_and_economics.pdf

technologies, such as wind or wave energy, in that the resource, despite variability, is perfectly predictable and located close to the coastline. However, because the time at which peak tidal stream power occurs varies, it does not normally correspond with peak demand. Therefore, energy storage and/or other forms of system flexibility will be needed to ensure efficient grid integration.

Box 3. **System modelling: Tidal stream in the UK energy system**

Following the BEIS EINA Methodology, whole energy system modelling was conducted using the Energy System Modelling Environment (ESME^{TM}) Version 4.4 to estimate where innovation investments could provide most value to support UK energy system development.

ESME[8] is a peer-reviewed whole energy system model (covering the electricity, heat & transport sectors, and energy infrastructure) that derives cost-optimal energy system pathways to 2050. It does so while meeting user-defined constraints, e.g. 80% greenhouse gas (GHG) emissions reduction. The model can choose from a database of over 400 technologies which are each characterised in cost, performance and other terms (e.g. maximum build rates) out to 2050. The ESME assumption set has been developed over more than 10 years and is published.[9] ESME is intended for use as a strategic planning tool and has enough spatial and temporal resolution for system engineering design.

Like any whole system model, ESME is not a complete characterisation of the real world but is able to provide guidance on the overall value of different technologies, and the relative value of innovation in those technologies.

The EINA Methodology prescribes the approach to be taken to assess the system-level value of technology innovation. This involves creating a baseline energy system transition without innovation (from which a baseline energy system transition cost is derived), and on a technology-by-technology basis assessing the energy system transition cost impact of “innovating” that technology. Innovation in a technology is modelled as an agreed improvement in cost and performance out to 2050.

For the EINA analysis, the technology cost and performance assumptions were derived from the standard ESME dataset as follows:

- In the baseline energy system transition, the cost and performance of all technologies is assumed to be frozen at their 2020 levels from 2020 out to 2050.
- The “innovated” technology cost and performance for all technologies are assumed to follow the standard ESME dataset improvement trajectories out to 2050 (these are considered techno-optimistic).
- In the case of tidal stream technology, the assumed “innovated” capital cost reduction is around 40% between 2020 and 2050 values, with a corresponding capacity factor improvement of 9 percentage points in the same timeframe (from 30% to 39%).

Whole system analysis using the BEIS EINA Methodology described above shows that there is value to the UK in continued (and accelerated) innovation in tidal stream technology:

- The **cumulative[10] system benefit** of innovation in tidal stream is **£1.8 billion to 2050 (discounted at 3.5%).** ESME modelling determines this system benefit assuming a high-innovation scenario.
- **The modelled high-innovation scenario results in a tidal stream deployment of 16GW by 2050,** although most of this would occur beyond 2040. This is primarily a consequence of the carbon budget tightening towards 2050 and there being other lower-cost options available in earlier years when the budget is less constrained. It also assumes this is dependent on innovation delivering cost-reduction and performance-improvement trajectories which will be highly reliant on the technology's deployment curve.

Further work is required to estimate the value of innovations in tidal stream, or how these estimates may change in the case of different energy system scenarios.

[8] More details of the capabilities and structure of the ESME model can be found at eti.co.uk/programmes/strategy/esme. This includes a file containing the standard input data assumptions used within the model.
[9] The ESME assumption set has been developed is published with data sources at https://www.eti.co.uk/programmes/strategy/esme
[10] Discounted at the social discount rate of 3.5%.

Box 4. **Learning by doing and learning by research**

The total system value follows from two types of technology learning:

- **Learning by doing:** Improvements such as reduced cost and/or improved performance. These are driven by knowledge gained from actual manufacturing, scale of production, and use. Other factors, such as the impact of standards, which tend to increase in direct proportion to capacity increases.
- **Learning by research:** Improvements such as proof of concept or viability, reduced costs, or improved performance driven by research, development, and demonstration (RD&D). It increases with spend in RD&D and tends to precede growth in capacity.

The EINAs are primarily interested in learning by RD&D, as this is the value that the government can unlock as a result of innovation policy. Emerging technologies will require a greater degree of learning by RD&D than mature technologies. Academic work suggests that for emerging technologies around two-thirds of the learning is due to RD&D, and for mature technologies around one-third is due to RD&D.[11]

To reach a quantitative estimate of the system value attributable to RD&D, these ratios are applied to the system value. This implies that, as an emerging technology, around £1.2 billion of the £1.8 billion system value for new tidal stream follows from RD&D efforts. Note, this is an illustrative estimate, with the following caveats:

- The learning-type splits are intended to apply to cost reductions. However, in this study, they are applied to the system value. As system value is not linearly related to cost reduction, this method is imperfect.
- In practice, learning by research and learning by doing are not completely separable. It is important to deploy in order to crowd-in investment to more RD&D, and RD&D is important to unlock deployment.

These estimates are used in the EINA Overview Report to develop a total system value that results from innovation programmes across the energy system.

[11] Jamasb, Tooraj (2007) Technical Change Theory and Learning Curves, The Energy Journal 28(3).

Innovation opportunities within tidal stream

Introduction

Box 5. **Objective of the innovation opportunity analysis**

The primary objective is to identify the most promising innovation opportunities within tidal stream and highlight how these innovations may be realised and contribute to achieving the system benefit potential described above. This section provides:

- A breakdown of the costs within tidal stream across key components and activities.
- A list of identified innovation opportunities, and an assessment of their importance to reducing costs and deployment barriers.

Tidal stream device designs have not fully converged, however development to date has focussed on horizontal axis turbines with two alternative mounting mechanisms:

- **Bottom-fixed:** Turbines are mounted directly to the seabed or attached to a pole penetrating the ocean floor. Bottom-mounted devices are underwater, hidden away from the view of local populations, and through careful design and environmental impact planning could have negligible effects upon the marine environment. Most fixed tidal developers seemed to have grouped under the horizontal axis turbine design.

- **Floating:** Turbines are mounted to a floating platform. Floating devices eliminate most of the high-risk underwater operations and reduce the need for high cost vessels for installation and maintenance. Devices vary in the way they are fixed, this includes flexible mooring, rigid mooring, and floating structure. Devices installed to date are also of a horizontal axis turbine design.

Divergence in design also includes other alternatives that are in different stages of developing and testing, such as vertical axis turbine, Oscillating Hydrofoil, Enclosed Tips (Venturi), Archimedes Screw, and Tidal Kite.[12]

[12] The European Marine Energy Centre (2019) Tidal Devices http://www.emec.org.uk/marine-energy/tidal-devices/

Cost breakdown

The LCOE of fixed tidal stream is estimated at £300/MWh at present, with potential to reducing to £150/MWh at 100 MW deployment. Studies suggest that further cost reductions are possible through deployment at scale: an LCOE of £90/MWh could be reached at 1GW deployment, and £80/MWh at 2GW deployment.[13] The ability of the technology to reach such price points at scale is unproven and would be contingent on deployment picking up quickly and sustaining rapid growth.

For floating tidal stream, industry estimates £200/MWh LCOE for devices currently being built.[14]

Six key cost components are identified for tidal stream:[15]

- **Structure and prime mover:** The fluid mechanical process by which the device captures energy from the ocean. Can be through oscillation or rotation.
- **Power PTO and Control:** Technology by which kinetic energy is converted to electrical energy. Can be directly to electricity, via a rotary electric generator or a linear electric generator, or via a hydraulic system.
- **Foundations and Moorings:** Way the device is held in place. Can be a moored, floating structure (moorings can be flexible or rigid) or a sea-bed structure, e.g. gravity-based or pile-driven foundations.
- **Connection:** Method by which energy is transferred to shore. Can be an electrical connection (HVAC or HVDC) or, in some cases, a hydraulic connection.
- **Installation:** Process by which the device is installed. Will be influenced by the device location (e.g. near shore, or offshore) and foundation and mooring method.
- **Operation and Maintenance:** Increasingly integrated in the design of devices. Will be influenced by the location of the device, and its foundation/mooring or nacelle attachment configuration.

Variations in the breakdown of costs occur if a device is fixed to the seabed or floating. This is largely because the different foundation types entail different operation and installation costs.

[13] LCOE assumption ORE Catapult (2018) Tidal Stream and Wave energy cost reduction and industrial benefit https://ore.catapult.org.uk/?orecatapultreports=tidal-stream-and-wave-energy-cost-reduction-and-industrial-benefit
[14] According to Orbital Marine's estimations on their 2MW device under construction. The LCOE is calculated over a 10MW site deploying 5 x Orbital O2 2MW floating turbines.
[15] Based on SI Ocean 2014 data taken to industry consultation and thereafter amended, Carbon Trust.

Operations and maintenance is the largest cost component for fixed turbines, accounting for 43% of total cost. This is due to the nature of the seabed attachment requiring risky and expensive underwater procedures and surveillance. This cost is followed by structure and prime mover and PTO and control, with 25% given the importance of turbines. Together they represent 68% of total costs. The rest is integrated by connection, foundations and mooring, and installation.

The key cost components for floating tidal technologies are the structure and prime mover, and PTO and control, which when combined account for 51% of total costs. Given that floating devices are easier to access than fixed ones, operation and maintenance accounts for 17% of costs, radically less than the share for fixed solutions. Foundation and moorings represent 19% and the rest is composed of connection and installation.

Table 5. **Cost Model of tidal stream**

<table>
<tr><th>Cost Element</th><th>Fixed tidal stream</th><th>Floating tidal stream (*)</th></tr>
<tr><td>Structure & prime mover</td><td rowspan="2">25%</td><td>27%</td></tr>
<tr><td>PTO & Control</td><td>24%</td></tr>
<tr><td>Foundations & Moorings</td><td>8%</td><td>19%</td></tr>
<tr><td>Connection</td><td>14%</td><td>6%</td></tr>
<tr><td>Installation</td><td>10%</td><td>6%</td></tr>
<tr><td>Operation & Maintenance</td><td>43%</td><td>17%</td></tr>
</table>

Note: (*) May not add due to rounding

Source: ORE Catapult, Orbital Marine, and Carbon Trust analysis

Inventory of innovation opportunities

Tidal stream device designs have not fully converged, however development to date has focussed on horizontal axis turbines with two alternative mounting mechanisms: bottom fixed and floating. Devices are at different stages of technology development and have been installed over diverse site types. Floating solutions have been developed more recently and device types are more limited. This variety makes it difficult to identify specific technical innovation opportunities that are equally significant to all devices. Future device design could benefit from innovations in:

- **Yield:** Tidal resource modelling – its impact on blades and PTO – particularly reliability (as well as operations and maintenance and components) including turbulence intensity.
- **Design for decommissioning:** Incorporating decommissioning considerations into the design allow for de-risking and cost reduction.

Fixed solutions present their biggest cost-reducing potential in:

- **Operations and maintenance:** Design and demonstration of improved physical maintenance procedures.
- **Structure and prime mover:** Advanced manufacturing and design for existing blades.
- **Connection:** Investigation on cable stability, reparability and survivability.

Floating solutions have biggest cost-reduction opportunities in:

- **Structure and prime mover:** Advanced manufacturing and design for existing blades.
- **PTO and control:** Improved pitch and yaw technology investigation and demonstration, and early stage research for disruptive PTO technologies.
- **Moorings:** Advanced mooring development and demonstration.

Table 6 contains examples of technical innovation opportunities in the tidal sector. It groups technical innovations by broad category, describing which technology it applies to and the approximate timeframe for deployment. It was first developed by the Carbon Trust through desktop research and expert consultation as a proposal of innovations mapping for tidal stream. It is indicative and not exhaustive.

The attendees of the workshop discussed the contents of the table and offered feedback. The table was updated, integrating industry experts' views.

Prioritisation of cost reduction and barrier deployment was first elaborated by the Carbon Trust and presented to the industry experts. The table was then updated to reflect the importance of some innovations in the workshop interaction and circulated to participants with the opportunity to provide further comments. Participants highlighted main innovations in the updated table, which were reflected in the prioritisation**.** The magnitude of the contribution to cost reduction and reducing deployment barriers are described in qualitative terms relative to other innovation opportunities:

- Significantly above average = 5
- Above average = 4
- Average = 3
- Below average = 2
- Significantly below average = 1

An indicative timeframe for each innovation is provided. The timeframe given relates to the year the technology is deployed commercially at scale (gaining 10-20% market share).

Table 6. **Innovation mapping for tidal stream**

Component	Innovation opportunity	Cost reduction (fixed/floating)	Deployment barrier reduction	Impact on other energy technology families	Timeframe
Structure & Prime Mover	Advanced manufacturing and design for existing blades	5	4		2020-2025
	Investigation of novel reaction system technology	3	2		2030+
	Turbulence intensity and wake effects investigation	4	3		2020-2025
	New and improved blade technology investigation	5	2		2025-2030
	Testing novel reaction system designs at part-scale	3	2		2030+
	Novel materials to reduce biofouling, corrosion, and extend lifetimes.	4	3	Offshore Wind, Wave	2025-2030
Power Take Off & Control	Demonstration and improvement of current PTO technology e.g. control systems, gearbox, direct drive	3	2		2020-2025
	Early stage research for disruptive PTO technologies	5	2		2030+
	Improved pitch and yaw technology investigation & demonstration	5	2		2025-2030
Foundations & Moorings	Advanced foundation development & demonstration	4	3	Offshore Wind	2025-2030
	Advanced mooring development & demonstration	4	2	Offshore Wind, Oil and Gas, Wave	2025-2030
Connection	Standardised electrical architecture & connections	1	4	Offshore Wind, Wave	2025-2030
	Dynamic umbilical connection	3	2	Offshore Wind, Wave	2025-2030

Component	Innovation opportunity	Cost reduction (fixed/ floating)	Deployment barrier reduction	Impact on other energy technology families	Timeframe
Connection	Standardised subsea hubs	3/0	1	Wave	2030+
	Investigation on cable stability, reparability and survivability	4	3	Offshore Wind	2020-2025
	HV subsea hub	2	3		2020-2025
	Installation of cables in different seabed conditions	2	3	Offshore Wind	2020-2025
	Array design, impact on cable layout and avoided hub cost	3	3		2025-2030
Installation	Improve current and develop novel installation techniques [e.g. cabling, drilling, anchoring, mooring for floating] – arrays, sea conditions	3	3	Offshore Wind	2020-2025
	Build and test support vessel	2	2	Offshore Wind	2025-2030
	Geo-technical surveys	3	4	Offshore Wind	2020-2025
Operations & Maintenance	Design and optimisation of systems to ease design for maintenance	4/2	3		2025-2030
	Conditions monitoring of devices and predictive maintenance techniques	4/2	3		2025-2030
	Design and demonstration of improved physical maintenance procedures	5/2	3	Offshore Wind	2025-2030

Non-Component-Specific		Innovation opportunity	Cost reduction (fixed/ floating)	Deployment barrier reduction	Impact on other energy technology families	Timeframe
Other	**Yield**	Tidal resource modelling – its impact on blades and PTO – particularly reliability (as well as O&M and components) including turbulence intensity	5	3		2020-2025
		Array planning & modelling	4	3		2020-2025
	System Balancing	Leveraging the well-known parameters – understanding the grid-level benefits	3	3		2020-2025
	Decommissioning	Design for decommissioning	3/2	3		2020-2025

Source: Industry consultation and Carbon Trust analysis

Innovation opportunity deep dives

We identify five important innovations that illustrate cost reduction and deployment barrier opportunities across tidal stream technologies.

Innovation in Structure and Prime Mover

The structure and a prime mover offer a great number of opportunities for innovation. Firstly, there are the opportunities relating to the use of materials other than steel; for example, the use of reinforced concrete polymers such as glass-reinforced plastics (GRP). The use of both concrete and polymers also offers the innovative opportunities associated with novel manufacturing techniques such as rotational mouldings.

A further innovation opportunity arises with the design and manufacture of improved blades for tidal turbines. Advanced manufacturing techniques may achieve large improvements in both the yield and the reliability of the tidal blades. Away from the horizontal axis three-bladed turbines, there may still be further opportunities for innovation. Different designs of tidal stream device may prove to be more suited to different resource environments – therefore investigation and investment into novel design-types of technologies could also be considered.

Innovation in Power Take-Off and Control[16]

There are several potential innovations with respect to PTOs which warrant further investigation – for example the use of permanent magnets. As the tidal stream energy sector nears maturity the PTO will require optimisation to bring down the cost of energy.

Yield optimisation of control software and the novel use of blade pitch and turbine yawing will present multiple innovation opportunities. Control of the turbines will become more of a challenge as the sector matures. As tidal stream moves from single devices to small arrays and through to commercial-scale arrays, the way in which turbines interact with one another will become more apparent. By analogy with wind – much work is required to understand and minimise the wake effects on downstream turbines. Minimising the turbulence on downstream turbines has a twofold effect; it optimises the potential yield from the resource and reduces the loads on the turbines – thus reducing fatigue. This remains an active area of research in wind and will continue to be a challenge for the tidal stream sector. Control innovations are needed for the development of active pitch and yaw technologies and independent blade pitch control.

[16] PTO refers to the way in which kinetic energy (for example of the rotation of the turbine blades) is transferred to electrical energy.

Innovation in Operations and Maintenance (for fixed)

Increasingly, the design of devices is taking aspects of installation and maintenance into account – an important aspect of design innovation. Further innovation relates to reducing both time spent at sea and the need for divers. This could be using ROVs and through other novel condition monitoring techniques.

In terms of installation, floating devices are fundamentally cheaper and easier to deploy than fixed turbines as they can simply be towed to location. Bespoke vessels could be designed and utilised to install large numbers of fixed seabed-mounted tidal turbines as the sector grows and the need for large-scale installation increases.

Innovation in yield and resource

In order to make tidal stream energy competitive, the LCOE needs to be reduced and one of the fundamental ways to see this reduction is through the optimisation of the yield. Better methods to understand the tidal energy resource at a greater level of granularity are needed, as well as the development of methods of measurement and the modelling of the resource.

Innovation in Foundations and Mooring

To date, fixed tidal turbine installations, be they single devices or small-scale arrays, have generally used gravity bases where large amounts of steel are employed to resist the forces. They use vast quantities of material as ballast to ensure that the devices will not move within the harsh environments of tidal flows. While this is a solution that works well for the early stages of a technology’s development, it is inelegant and not sustainable for large scale deployment due to wastefulness of material.

A new approach to seabed (fixed) turbines requires investigation. There are many possible solutions and much technology transfer that is possible from the offshore wind sector, such as novel piling techniques, the use of monopoles, suction buckets, and noise mitigation strategies.

Floating tidal devices require innovation in moorings rather than foundations and these represent a different set of engineering challenges – for example, novel rock anchors and pin piles. In addition to the methods of station keeping, there are another class of foundation related innovations – mounting multiple turbines on a single foundation. This has been explored as a technical solution before and represents further innovation potential.

Business opportunities within tidal stream

Introduction

Box 6. **Objective of the business opportunities analysis**

The primary objective is to provide a sense of the relative business opportunities against other energy technologies. To do so, the analysis uses a consistent methodology across technologies to quantify the 'opportunity'; in other words, what *could* be achieved by the UK. The analysis assumes high levels of innovation but remains agnostic about whether this is private or public. This distinction is made in the final section of the report. Two key outputs provide:

- A quantitative estimate of the gross value adds, and jobs supported associated with hydrogen and fuel cell technology exports, based on a consistent methodology across technologies analysed in the EINA
- A qualitative assessment of the importance of innovation in ensuring UK competitiveness and realising the identified business opportunities. Note, the quantitative estimates for GVA and jobs supported cannot be fully attributed to innovation.

Appendix 2 provides further background to the methodology used.

The commercial tidal industry is starting to form, providing an opportunity to get in and capture large market shares while it starts to rapidly grow. There are relatively few established, multinational companies operating in the turbine space. Unlike more established industries such as offshore wind, there are no large-scale incumbents in the tidal market. The ecosystem is largely formed of specialised turbine development companies with support along other parts of the supply chain. Existing players include specialised original equipment manufacturers (OEMs) and larger firms that are transitioning their skills and manufacturing base to tidal stream. Manufacturers are supported by testing facilities before expanding to a test site.

The UK is the fastest growing deployment market and has an opportunity to develop expertise and reduce costs supplying the domestic market, to

subsequently export.[17] The UK's relatively larger tidal potential, around 50% of Europe's tidal energy resource,[18] is likely to attract testing and manufacturing facilities to the UK. The UK could build on and leverage to not only supply its domestic market, but export globally. In the last few years, the UK has begun the world's first tidal array and the first large-scale tidal array. These are being delivered by UK companies and from substantial UK content,[19] due to the specialised nature of the parts.

Box 7. **The UK's current tidal industry**

- UK strengths in relevant fields include: Cabling and substations, turbine blades, O&M provision, costal and offshore engineering skills from large existing sectors, such as the oil and gas industry and offshore wind. Some of these strengths are more easily exported, such as cabling and blades, while others, such as O&M provision, are not as readily traded.

- Notable UK producers include: SIMEC Atlantis Energy, the turbine producer and energy company delivering the MeyGen project (Phase 1: 105MW, permitting expansion to 398MW);[20] EMEC, the leading tidal energy test centre; and Nova innovation, tidal energy specialists who delivered the world's first offshore tidal array.[21]

- Key competitors include France in Europe and Japan and Canada in the rest of the world.

Given the UK's strong skill base, continued expected growth, and existing turbine developers and manufacturers, tidal exports are a potential business opportunity for the UK. Tidal potential has been established for quite some time as technically possible but is in the early phases of commercial deployment. The tidal industry has the potential to grow rapidly beyond current levels, providing a regular and predictable quantity of energy, if the price can be brought down relatively quickly. Exponential growth is forecast, from current demonstration levels to over 50GW globally by 2050 and the development of a global industry. The UK has an established comparative advantage in marine energy.[22] Related expertise areas are offshore engineering (oil and gas), O&M and manufacture of offshore drilling

[17] Based on number and size of projects deployed globally
[18] BEIS (2013) Wave and tidal energy: part of the UK's energy mix https://www.gov.uk/guidance/wave-and-tidal-energy-part-of-the-uks-energy-mix#wave-and-tidal-stream-potential
[19] 43% of project expenditure is in Scotand. Simec Atlantis (2019) Tidal stream projects https://simecatlantis.com/projects/meygen/
[20] MeyGen Ltd. (2011) MeyGen Phase 1 EIA scoping document http://marine.gov.scot/datafiles/lot/Meygen/MeyGen_Offshore_Tidal_Array_SoS_Scoping_Opinion_Report.pdf
[21] Nova Innovation (2019) Bluemull Sound, Shetland https://www.novainnovation.com/bluemull-sound
[22] LSE (2018) Sustainable growth in the UK http://www.lse.ac.uk/GranthamInstitute/publication/sustainablegrowth/

platforms, cabling and substations, and development of offshore sites. However, as a less established energy technology, timely innovation is key for the UK to protect and grow its market share.

Market overview

The North Sea and surrounding waters are key markets for the UK, both domestically and for exports to other European countries. The UK is one of the world's largest market opportunities, given the naturally occurring favourable tidal conditions. Sites and manufacturers are establishing themselves across the UK with demonstration projects, testing facilities, and test sites. The tidal supply chain is not yet well established, due to the relative novelty of the technology in comparison to other electricity sources. UK deployment, and the establishment of UK supply chains, are essential factors in being able to export goods globally.

The market for tidal stream technology is immature, and therefore the UK's competitive position is not yet established. France, Canada, and Japan currently pose the greatest competition to the UK and have companies undertaking the design and manufacture of tidal turbines. Given the immature nature of the market and low levels of current trade, robust market shares are not yet established. Analysis included trade data for parts, including various types of marine turbines, drive train parts, and a range of goods like those required for tidal stream. This indicated a UK market share in Europe of roughly only 1.0% and a 1.4% market share in the rest of the world.[23] This indicates that, overall, the manufacture of these goods is not well established in the UK, though some individual parts have a higher share.

Global sales in tidal stream energy outside of the UK are expected to increase to over £20 billion annually by 2050.[24] Substitution will drive demand away from carbon-intensive electricity technologies (such as coal), an overall increase in energy demand globally, and the relative benefits of tidal over other renewable energies. The International Energy Agency (IEA) forecasts around 150GW[25] of capacity in ocean technologies, with around 50GW likely to come from tidal stream by 2050.[26] International sales and trade are in the early phases with some UK firms in discussions with other countries,[27] as well as a European cross-border consortium called Tidal turbine Power take-off Accelerator (TIPA).[28] Trade is expected to grow

[23] Based on Comtrade data for HS codes: 252390, 841011, 841012, 841013, 841090, 850239, 850423, 850434, and 854460.
[24] Vivid Economics calculations based on IEA Energy Transitions Program (2017) 2-degree deployment scenario.
[25] Deployment based on IEA Energy Transitions Program (2017) 2-degree deployment scenario.
[26] 30% share comes from ORE Catapult (2018). Tidal stream and wave energy cost reduction and industrial benefit.
[27] Simec Atlantis Energy (n.d.) Tidal stream projects https://simecatlantis.com/projects/
[28] Nova Innovation (2017) TIPA Press release https://www.tipa-h2020.eu/pan-european-consortium-secures-funding-for-tidal-turbine-subsystem-development/

as costs are reduced across each of the components through innovation. We assume some larger items, such as foundations and moorings or some services, are likely to be only regionally traded once the technology is well established. Wider implementation of this technology implies a potential tradeable market accessible to the UK of almost £13 billion annually by 2050.

Figure 1 **The current and future tidal stream market**

Current market for tidal stream

- *Production:* Global turbine deployment is largely for demonstration projects with the first large-scale tidal array, MeyGen, currently being commissioned.
- *Trade:* Most UK production is currently for internal test sites, as there is significant tidal potential in the UK.
- *Markets:* The UK is a large potential market, as well as other North sea locations and Canada.

Tradability of market

- *Goods:* Tidal will be deployed from the country with the supply chain capabilities while the technology is relatively new and still in the testing phases. This will decrease as the specialised manufacturing skills spread globally longer term.
- *Services:* Majority of service GVA and jobs supported in O&M activities.
- *Trends:* International trade is expected to increase sharply once costs decrease and demand increases.

Trends in deployment

- *Global:* Tidal deployment is expected to grow exponentially once proven to 50GW by 2050.
- *Growth pattern:* Growth is driven by global deployment. The UK has a significant proportion of European tidal potential.
- *Uncertainty:* Global deployment is highly variable for a technology that is not yet at market stage.

Global and regional market size to 2050

- *Growth trend:* Near exponential growth forecast out to 2050 to meet SDS targets. Sales growth will slightly exceed deployment growth given replacement needs.
- *Key markets:* EU is expected to make up around half of global deployment until post 2030, 3GW out of the total 7GW deployed globally. Expected to grow to around a £20 bn industry globally by 2050.

Source: Vivid Economics

UK's competitive position

UK-based companies are leading, and have a comparative advantage, in demonstrating tidal technology as commercially viable.[29] This is demonstrated by UK-based company, which has successfully delivered the world's first offshore tidal array in the Shetland Islands.[30] Another UK-based company has deployed the world's first large-scale tidal array, MeyGen.[31] Experts in the workshop noted that the

[29] LSE (2018) Sustainable growth in the UK. http://www.lse.ac.uk/GranthamInstitute/publication/sustainablegrowth/

[30] Severin Carrell (2016) World first for Shetlands in tidal power breakthrough.

https://www.theguardian.com/environment/2016/aug/29/world-first-for-shetlands-in-tidal-power-breakthrough

[31] The Guardian (2016) World's first large-scale tidal energy farm launches in Scotland

https://www.theguardian.com/uk-news/2016/sep/12/worlds-first-large-scale-tidal-energy-farm-launches-scotland

UK had a strength in technical skills and knowledge, which is well recognised in the industry.

The UK does not have an established manufacturing base across the parts needed in tidal stream energy. At a more aggregated level, current UK tidal exports are less than £3 million annually, and the RCA is 0.55.[32] This suggests that exports of tidal stream related goods are not a relative strength of the UK. However, it is likely that this is somewhat obscured by the relative newness of the industry in relation to the use of components and manufacturing sites for other goods. Other compounding factors could be the specialised knowledge and small production of such a specific product. Regionally, the UK must compete with France who represent approximately 1.4% of global exports and 4.2% of the European market,[33] a similar share to the UK's. Experts noted Japan and Canada as the biggest competitors outside of Europe; however, the data indicated they have even smaller market shares than both the UK and France.[34] These low market shares for tidal related goods indicate that the countries who were seen by industry as major competitors also did not have a significant existing manufacturing base in the related goods.

The UK is already a key innovator and is one of the few countries demonstrating competency in delivering commercial-scale projects. New tidal turbines are increasingly being developed around the world and are being tested in UK facilities. Companies are choosing to locate in the UK to take advantage of the momentum, opportunities, and tidal potential available. Blades and cable manufacture and design are areas that are relatively developed in the UK, building on the existing expertise in the telecoms and oil and gas industries and innovations coming through from offshore wind. These factors help to provide a potential comparative advantage for the UK. Due to the relative cost of blades, and their association with other integral parts, if developed, they could provide a large injection of GVA and jobs to the UK economy in the future. However, as cables are a proportionally smaller part of costs, the GVA or jobs supported is smaller than other elements. Expanding this knowledge to full arrays and innovative new power storage on land could rapidly increase the value of this component.

International competition and potential markets in tidal are geographically dispersed, with Canada and Japan providing the greatest international competition, and more countries expected to join. Tidal is served by a few players experienced in renewable energies, as well as smaller, newer firms that only

[32] Vivid Economics analysis based on Comtrade data for HS codes: 252390, 841011, 841012, 841013, 841090, 850239, 850423, 850434, and 854460.
[33] Ibid.
[34] near 0% market shares in the broader goods sectors

develop tidal and other marine technologies. In comparison, offshore wind has been established longer and requires similar technology and innovations, suggesting that lessons learnt, and strategies used in that sector could apply to tidal. If tidal developed in a similar manner to offshore wind, then a few big players may be likely to emerge in line with the growth in deployment.

For the UK to grow its current market share, continued innovation is required as well as leveraging its established base in large UK projects. The forecast rapid expansion of tidal globally presents an opportunity to capture market share and become the key player in Europe and internationally. As the UK is unlikely to compete on low-cost, high-volume production, the UK will need to continue to innovate to ensure it can maintain its competitiveness in relatively specialised versions of the technology. Within Europe, the UK is geographically well placed at the centre of much of the tidal potential, located in the North Sea,[35] and could service this directly from UK ports. Figure 2 shows the UK's competitive position in comparison to European and other international competitors.

[35] Energy BC (2016) Tidal power http://www.energybc.ca/tidal.html

Figure 2 **The UK's competitive position in trade in tidal goods**

Current UK competitiveness

- *Strengths:* Many sites and interest in the UK. Established in cables, blades and a complementary skill market of offshore gas. Has many good testing facilities.
- *Weaknesses:* No established base in other areas of turbine supply.

Key EU competitor - France

- *Strengths*: Has the only long established tidal plant in operation; however this is of a different type, barrage.
- *Weaknesses:* Relatively low price of electricity that leaves a bigger gap between market price and the price needed to ensure investment in tidal stream technologies.

Global competitor – Japan

- *Strengths*: Established turbine suppliers with technical manufacturing capabilities. High population density reduces grid connection costs.
- *Weaknesses:* Currently relying on foreign exports and knowledge to develop tidal stream in Japan.

Global competitor – Canada

- *Strengths: Increased policy support and focus on growth of tidal stream technology.*
- *Weaknesses: Tidal stream energy is clustered in more remote locations where grid connection costs significantly increase overall project costs. Canadian projects still rely on at least some foreign technology.*

Source: Vivid Economics

Box 8. **Industry workshop feedback regarding business opportunities**

- The removal of the 'minima' funding, which guaranteed a certain level of marine and tidal deployment, meant that tidal had to compete against more developed renewable technologies like offshore wind. This resulted in a significant reduction in foreign investment in the UK and saw some developers and manufactures look at moving to other countries.
- Prior to 2017, the UK was clearly the strongest player. However, since this time countries such as Canada and France have indicated significant support for tidal stream and are likely to attract firms or manufacturing.
- The UK provides a good opportunity to learn about and develop tidal stream turbines and show their commercial viability, to subsequently export.
- There is technical expertise and intellectual property (IP) in the design, manufacture, and O&M of turbines, leading to a high level of exportability and business opportunities globally.

Table 7. **2050 outlook: UK Market shares and innovation impact**

Component	Tradeable market 2050	2050 outlook *with* strong learning by research			
		Market share	Captured turnover (£m)	Captured GVA from exports (£m)	Rationale for the impact of innovation
Turbines (incl. structure & prime mover and power take-off & control)	**EU: £200 m** RoW: £3.4 b	**EU: 20%** RoW: 20%	**EU: 30** RoW: 700	**World: 200**	High-value component with strong research potential for lower costs and higher yields to solve market gap associated with blades. Accelerated innovation provides a competitive edge in an industry with rapid product cycles. Innovation could give the UK a significant first-mover advantage and higher market shares.
Foundations and moorings	**EU: £40 m** RoW: £1.1 b	**EU: 10%** RoW: 10%	**EU:4** RoW: 100	**World: 40**	Significant opportunity to be the first mover supplying tidal and becoming a world player.
Connection	**EU: £100 m** RoW: £1.9 b	**EU: 13%** RoW: 13%	**EU: 10** RoW: 240	**World: 50**	Innovation solves technological grid connection barriers to allow for wider implementation and large global market shares.
Installation	**EU: £50 m** RoW: £920 m	**EU: 10%** RoW: 10%	**EU: 5** RoW: 100	**World: 50**	Can leverage large domestic market to lead in installation across western Europe directly from UK ports; continued innovation in techniques is key to being competitive.
O&M	**EU: £800 m** RoW: £4.3 b	**EU: 6%** RoW: 6%	**EU: 50** RoW: 250	**World: 200**	Solidified UK strength in O&M service vessels, becoming large EU player. Innovation in remote operation will be key to providing low-cost O&M services.

Note: *Future market shares are not a forecast, but what UK business opportunities could be. The possible market share of the UK, and rationale for the impact of innovation, are based on ESC Catapult modelling informed by industry experts and cross-checked against current UK capabilities in industries with similar technology, such as offshore wind and ship propellers. These numbers are slightly higher around 2030, where the UK* *captures more of the market, then drop by 2050 as more competitors enter the market. They represent a blend of both EU and RoW, with the mix somewhat uncertain at this preliminary stage of tidal energy.*

Source: *Vivid Economics*

UK business from exports

Box 9. **Interpretation of business opportunity estimates**
The GVA and jobs estimates presented below are *not* forecasts, but instead represent estimates of the potential benefits of the UK capturing available business opportunities. The presented estimates represent an unbiased attempt to quantify opportunities and are based on credible deployment forecasts, data on current trade flows, and expert opinion, but are necessarily partly assumption-driven. The quantified estimates are intended as plausible, but optimistic. They assume global climate action towards a 2 degree world and reflect a UK market share in a scenario with significant UK innovation activity.[36] More information on the methodology, including a worked example, is provided in Appendix 2, and a high level uncertainty assessment across the EINA subthemes is provided in Appendix 3.

Growth of UK tidal stream exports could add over £540 million GVA and nearly 5,000 jobs per annum by 2050. This growth is largely driven by a substantial increase in deployment as a result of continued innovation to drive down the LCOE. It relies on the assumption that the UK can gain a solid market share of around 15%, in line with ORE Catapult modelling.[37] Figure 3 shows the increase in GVA by component as well as the corresponding increase in jobs supported, Figure 4. The jobs supported by the industry are expected to be dispersed around the country and particularly in coastal towns[38] that have higher than average unemployment figures and are more in need of an economic boost. This ensures an available workforce and a greater impact on job creation. While tidal opportunities may be smaller than for other sub-themes, the wider knowledge spillovers could be quite large.[39] O&M services, as the larger component of LCOE, will be the largest source with over £200 million GVA per annum, and builds on its requirement for highly technical and specialised skill sets. Turbines will be the second-largest source of GVA and could also deliver around £200 million per annum by 2050. It is likely that, at least in the

[36] Note, other IEA climate scenarios were also used as a sensitivity. Where the level of global climate action has a meaningful impact on market size, this is highlighted in the market overview section. Full results are available in the supplied Excel calculator.
[37] ORE Catapult undertook the estimation of these figures in consultation with a wide range of developers on how they expected cost and UK content to change over the periods 2020/2025/2030. It was a combination of data from devices in the water, contracted prices, and developer expectation and cross-checked against potential in existing UK markets in other comparable industries.
[38] ORE Catapult (2018) Tidal stream and wave energy cost reduction and industrial benefit https://ore.catapult.org.uk/?orecatapultreports=tidal-stream-and-wave-energy-cost-reduction-and-industrial-benefit
[39] LSE (2018) Sustainable growth in the UK http://www.lse.ac.uk/GranthamInstitute/publication/sustainablegrowth/

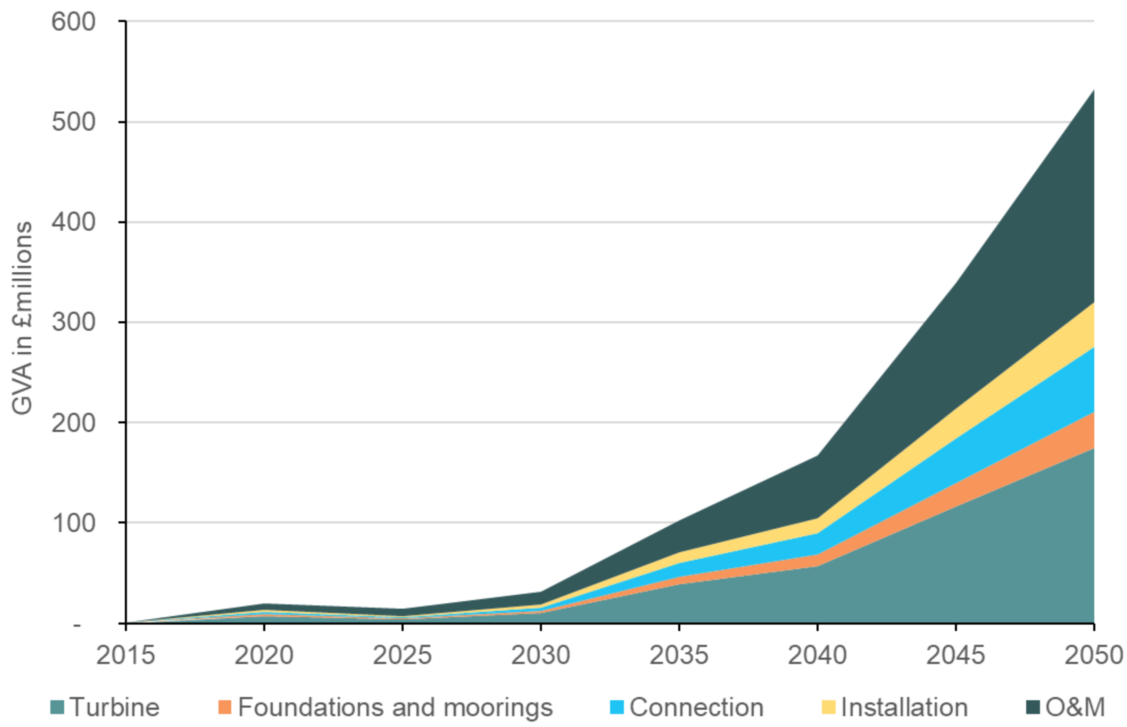
initial years, these two activities will be highly linked. A turbine developer will also likely be required to organise, perform, or train specialists to undertake, O&M services. Turbines and O&M are covered in further detail in the business opportunities deep dives.

UK connections exports could build on existing expertise in cables and other technologies to contribute almost £50 million GVA to the UK economy per annum by 2050. Collection and transmission of power to national grids is a key opportunity for innovation and builds on existing strengths. Collection and transmission are crucial in making tidal energy grid-accessible and to meet flexibility requirements. The UK could leverage skills and knowledge from its existing base in cables, the offshore wind and gas industry and UK telecommunications, to further innovate and grow market shares. Flexible and well-connected systems are essential for variable technologies like tidal; significant innovation is required in this area to develop the required connection systems. This innovation could be developed in conjunction with that of offshore wind or could provide additional GVA and jobs through use with that technology. JDR Cables is an established producer in the UK and is expanding in the European market, but cables are generally a small part of connections and overall costs.

Installation of tidal arrays requires technical skills that are highly linked to the technology being deployed, increasing the opportunity to export these services beyond Europe. This could represent around £50 million GVA per annum by 2050. The skills build on an established UK base in marine engineering services, plus substantial expected growth resulting from delivering innovative new models. Fixed tidal turbines need to overcome significant challenges from installing in marine environments and under water. Due to the high skill level, this will initially involve a skilled workforce that could be supplied from the UK. However, by 2050 a greater share of this is likely to be undertaken by a locally trained skilled workforce. Newer arrays will therefore provide a greater business opportunity to the UK workforce.

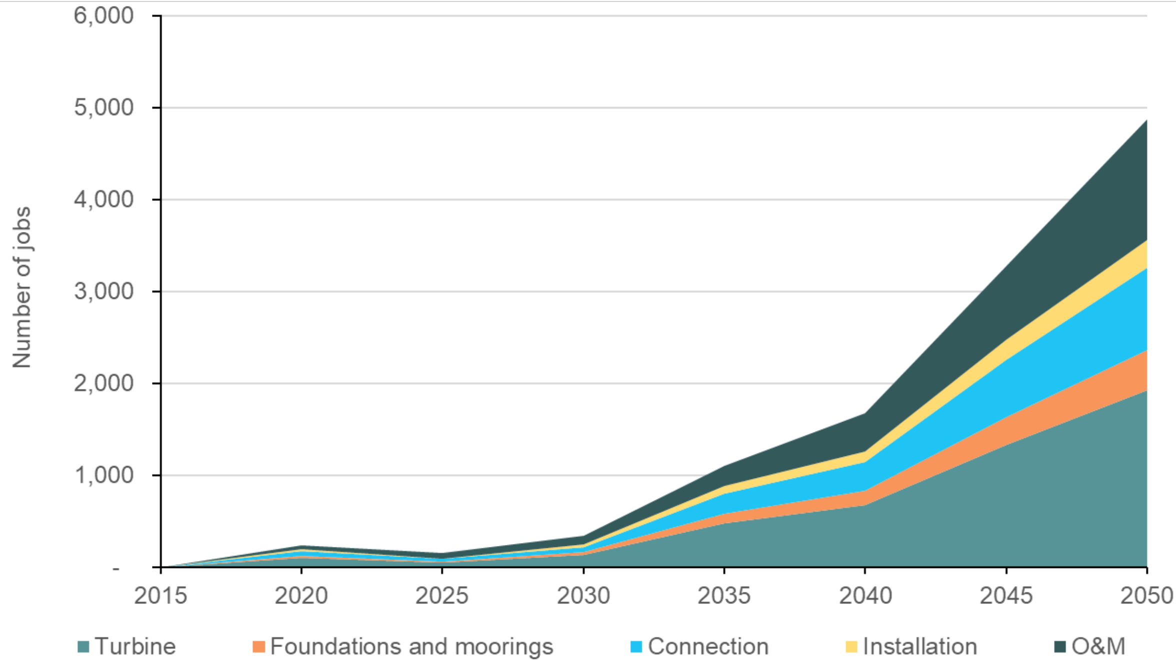
Different types of tidal foundations are continuing to emerge, with substantial expected growth resulting from delivering the required innovations. Floating platforms and novel foundations are important to reducing overall costs as they also impact on other cost aspects such as installation and O&M. The innovations include radical innovation over incremental change, presenting a big opportunity for first-mover advantage. While the technology is still relatively new it requires more technical expertise. Even sites in distant locations could be served directly from UK-manufactured platforms, reducing as the technology becomes more utilised and local or cheaper manufacturing is undertaken.

Figure 3 **Gross value added in tidal by component**



Source: Vivid Economics

Figure 4 **Jobs in the tidal stream industry by component**



Source: Vivid Economics

Business opportunity deep dive: O&M

O&M services for tidal arrays require technical skills that are highly linked to the technology being deployed, increasing the opportunity to export these services internationally. O&M makes up 43% of LCOE for fixed tidal stream energy. As the largest lifetime cost component, it provides a significant market opportunity. Innovation is required to lower costs by reducing both time spent at sea and the need to use divers to drive LCOE costs down. The skills build on an established UK base in marine O&M and engineering services, plus substantial expected growth resulting from delivering innovative designs. Newer types of arrays will provide a greater business opportunity to the UK workforce, as the specialised nature of the work may need experts from the UK to fly to even distant locations, as well as the training of local teams. However, by 2050 it is less likely that services will be as readily traded in RoW as 2030. At this time the technology will likely be more established, including more global competitors and an increase in the locally trained workforce.

UK exports of O&M services could add over £200 million of GVA annually to the UK economy by 2050. Developing a significant UK market share is likely to come from either innovation in O&M or through the supply of turbines that need servicing. As with many components in tidal stream energy, further development of existing innovation opportunities in complementary sectors, such as offshore wind or the ship-building industry could increase total GVA to the UK. It is estimated that tidal stream alone could support over 1,300 jobs per annum by 2050.

Business opportunity deep dive: Turbines

Turbines require significant innovation, providing an opportunity for the UK to gain a first-mover advantage in this high value area. Turbines are the largest CAPEX component, 44% of CAPEX costs, and provide the largest market opportunity. Global sales for turbines are expected to increase to almost £5 billion annually by 2050. The trend is towards both lower costs and higher yields, to drive LCOE costs down, thus requiring significant innovation. Improved blade design is seen as key to increasing yields and could be aligned with the two UK facilities currently producing blades for wind turbines. Additionally, the UK is a significant supplier of converters and gearboxes, within the drive train, to the offshore wind industry, with the potential to transfer learnings from this sector to tidal. Further innovation is required to increase reliability and reduce downtime.

Many types of turbine designs have been identified, providing more innovation opportunities and greater potential to continue the need for specialised, rather than cheap, manufacture. Specialised manufacture is better suited to increasing

GVA to the UK economy. EMEC lists 6 fundamental types of tidal designs,[40] though there are many variations possible on the list or new designs to suit new conditions. They are relatively labour-intensive to produce and assemble, requiring very technical expertise, and could support nearly 3,000 jobs. Due to their tradability and high specialisation they can be exported to both Europe and to more distant locations in the rest of the world.

The UK could plausibly ramp up turbine exports over the next 15 years to capture 20% of the market, comparable to Denmark's market share in offshore wind. This market share in exports could be worth over £700 million per annum by 2050 and contribute approximately £200 million of GVA per annum to the UK economy by 2050. Increasing the UK's market share could come through various channels:

- Existing innovation opportunities, such as further development of blades, converters, and gearboxes, which could provide the UK with a significant competitive advantage and likely increase the UK's market share of value associated with turbines.
- Producing turbines encourages manufactures of the parts to locate themselves within proximity of the key producer, to create hubs.
- Crossovers with other technology sectors that help to bring down tidal costs or that add extra GVA due to increased manufacture for a comparable sector.

The tidal market is in the process of forming with a greater than usual potential for capture of market share, representing significant, but feasible, growth.

[40] EMEC (2019) Tidal Devices http://www.emec.org.uk/marine-energy/tidal-devices/

Market barriers to innovation within tidal stream

Introduction

Box 10. **Objective of the market barrier analysis**

Market barriers prevent firms from innovating in areas that could have significant UK system benefits or unlock large business opportunities. Market barriers can either increase the private cost of innovation to levels that prevent innovation or limit the ability of private sector players to capture the benefits of their innovation, reducing the incentive to innovate.

Government support is needed when market barriers are significant, and they cannot be overcome by the private sector or international partners. The main market barriers identified by industry are listed in Table 8, along with an assessment of whether HMG needs to intervene.

Market barriers for tidal stream

Over the last ten years, innovation in tidal stream has been significant. Tidal energy devices are employed, and their likely performance can be confidently estimated. First array projects have been funded from public and private sector sources.[41] In the UK, there are currently 22 tidal stream technology developers.[42] Tidal stream energy is currently not cost-competitive due to its low level of maturity and relies on HMG support. Demand is therefore highly policy-dependent, and HMG plays an important role in providing a route to market. The UK is in a global leadership position for innovation in tidal energy, limiting opportunities for adopting innovations developed elsewhere.

Table 8 lists the main market barriers in tidal, along with an assessment of whether HMG needs to intervene. For each identified market barrier, an assessment of the need for government intervention is provided. The assessment categories are low, moderate, severe, and critical, where:

[41] Offshore Renewable Energy Catapult (2018) Tidal stream and wave energy cost reduction and industrial benefit https://www.marineenergywales.co.uk/wp-content/uploads/2018/05/ORE-Catapult-Tidal-Stream-and-Wave-Energy-Cost-Reduction-and-Ind-Benefit-FINAL-v03.02.pdf
[42] EMEC (n.d.) Tidal Developers http://www.emec.org.uk/marine-energy/tidal-developers/

- **Low** implies that without government intervention, innovation, investment, and deployment will continue at the same levels, driven by a well-functioning industry and international partners.
- **Moderate** implies that without government intervention, innovation, investment, and deployment will occur due to well-functioning industry and international partners, but at a lower scale and at lower speed.
- **Severe** implies that without government intervention, innovation, investment, and deployment are significantly constrained and will only occur in certain market segments or must be adjusted for UK market.
- **Critical** implies that without government intervention, innovation, investment, and deployment will not occur in the UK.

Table 8. **Market barriers**

Market barriers in tidal stream	Need for public support
Uncertain HMG policy position, resulting in unclear route to market and uncertain future revenues	Critical
Complex site planning and approval processes, involving costly and technically challenging assessments in proportion to project size and environmental risk	Severe
High support infrastructure costs, particularly relevant for small companies	Moderate
Significant **common grid infrastructure requirements**, including connection, capacity, and availability; more severe for remote locations	Moderate
Lack of financial innovation and appropriate project insurance schemes, limited data availability to demonstrate de-risking	Moderate
Limited coordination and knowledge sharing, due to concerns about competitiveness, reduces innovation; challenges to retaining IP benefits from R&D	Low

Source: Vivid Economics analysis and stakeholder input

Box 11. **Industry workshop feedback**

Industry experts raised several areas that require HMG support:

- **A lack of visibility over a sufficiently sized future market for tidal stream was identified as the main barrier to innovation.** Tidal stream energy is currently not cost-competitive and relies on HMG support. Demand is therefore highly policy-dependent and an uncertain policy position results in an unclear route to market and unpredictable future revenues, which discourage innovation. Removing the 'minima' criteria in the contract for difference scheme was considered a major obstacle for innovation in tidal stream. This is because it requires increased direct competition with more mature technologies with substantially lower cost of electricity generation, such as offshore wind. This barrier affects all areas of the supply chain and resolving it would reduce the impact of the other barriers.

- **A severe barrier to deployment and innovation is the costly and complex process required for site planning and approval.** Assessments are often costly and technically challenging in proportion to the size of the project and the environmental risk involved. While reducing environmental impact is an area of innovation, prohibitively costly processes for assessment and unclear data requirements reduce incentives to innovate in tidal stream technology significantly. This barrier is particularly relevant in the planning and build stages and for smaller businesses with fewer opportunities to cross-subsidise.

- **Tidal stream infrastructure is very costly, and HMG support could reduce costs and increase the appetite of industry for investment and innovation.** High infrastructure costs are more problematic due to uncertain demand and no clear policy for decommissioning. Small companies are more affected. Cost uncertainty has been reduced significantly in recent years as the technology has matured.

- **Insufficient common grid infrastructure for connection to the grid, for upgrades and new build, and for feeding into the grid, including availability times and capacity, presents a moderate barrier for innovation.** Other infrastructure requirements, such as harbours and ports, are no longer a significant barrier. The severity of this barrier is closely linked to location, with remote installations being at a disadvantage.

- **The lack of financial innovation and appropriate project insurance schemes limits investment and innovation.** Due to limited deployment, insufficient data exists to demonstrate de-risking to investors.
- **The low level of maturity of tidal stream technology presents a barrier.** Other low-carbon technologies are much more mature, and, in comparison, tidal stream appears less cost-effective despite opportunity for substantial future savings.

International opportunities for collaboration

International data sharing and analysis can support streamlining site planning and approval processes and defining common standards for tidal stream. Common and proportionate requirements would facilitate processes and allow an assessment of required costs and effort, informing investment and innovation decisions.

Appendix 1: Organisations at expert workshop

- Albatern
- EMEC
- Marine Energy Wales
- Minesto
- Nova Innovation
- Orbital Marine
- OREC
- Quoceant
- RenewableUK
- Scottish Renewables
- SIMEC ATLANTIS
- Sustainable Marine
- University of Edinburgh
- University of Plymouth

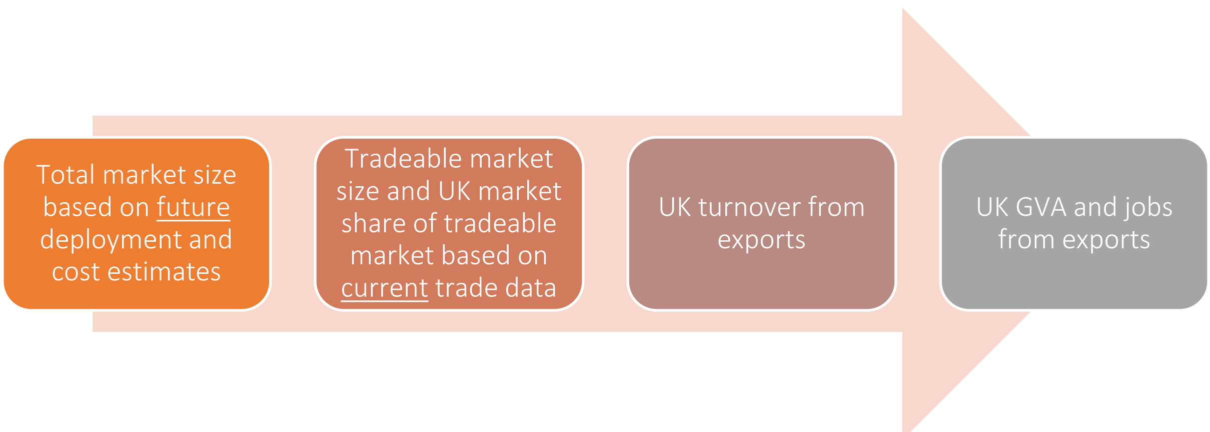
Appendix 2: Business opportunities methodology

Methodology for export business opportunity analysis

In identifying export opportunities for the UK, the EINA process uses a common methodology to ensure comparability of results:

- The **global and regional markets** to 2050 are sized based on deployment forecasts, which come from the IEA when available. For example, deployment of nuclear power is multiplied by costs to obtain annual turnover for the nuclear market.
- The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the global market is likely to be accessible to exports and gives a figure for the tradeable market.
- The UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below.
- The tradeable market is multiplied by the market shares to give an estimate for **UK-captured turnover**.
- The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by productivity figures for that sector to obtain **jobs created**.

Figure 5 **Methodology for assessing export opportunities**



Source: Vivid Economics

For all EINA sub-themes, the assessment of the UK's future competitive position is informed by the UK's existing market share of goods and services, the market share of competitors, industry trends, and workshop feedback.

Export business opportunities for goods

- Current market shares of UK goods are evaluated based on existing trade data, where available. If the technology is immature or export levels are low, UK shares are based on trade data from trade in related goods.
- Based on the importance of innovation in unlocking markets, the UK is projected to reach a market share in the EU and RoW by 2050. The potential future market share is intended as an ambitious, but realistic, scenario. It is triangulated using:
    - Market shares of competitor countries, as a benchmark for what is a realistic share if a country is 'world leading'.
    - The maturity of the existing market, which affects the likelihood of market shares changing significantly.
    - The importance of innovation in the technology.
- Market share assumptions are validated at a workshop with expert stakeholders and adjusted based on stakeholder input.

Export business opportunities for services

- The EINA focus on service exports directly associated with the technology and innovations considered within the sub-theme. For example, this could include EPCm services around the construction of an innovative CCS plant, but it will not include more generic service strengths of the UK, such as financial services.
- The EINA methodology does not quantify opportunities associated with installation and operation and maintenance as these are typically performed locally. Exceptions are made if these types of services are specialised, such as in offshore wind.
- The key services to consider are based on desk research and verified through an expert workshop.
- The services considered in the CCUS EINA export analysis are EPCm services, transport and storage services.

Appendix 3: Assessment of business opportunities uncertainty

The assessment of business opportunities in the long term, associated with new technologies is uncertain. This assessment does not attempt to forecast what *will* happen. Instead, the business opportunity assessment attempts to provide a realistic and consistent assessment, based on current information, on the business opportunities that *could* be captured by the UK. Whether these opportunities are indeed realised depends on domestic and international developments, political decisions, macro-economic conditions, and numerous other complex variables.

As this assessment is not intended as a full forecast, a formal quantitative sensitivity analysis has not been performed. the below provides a high-level qualitative assessment of the uncertainty associated with the sized opportunity. Note, this is *not* an assessment of how likely the UK is to capture the opportunity, rather it is an assessment of the uncertainty range around the size of the opportunity. The assessment is based on three key factors driving the assessment

1. *The level of future deployment of the technology*. Technologies such as offshore wind are deployed at scale across different energy system modelling scenarios and hence considered relatively certain. In contrast, there is more uncertainty for e.g. hydrogen related technologies. The export analysis is based on 3 IEA scenarios (with numbers provided for the IEA ETP 2 degree scenario). Domestic analysis is based on a single ESME run used across the EINA process.
2. *The potential domestic market share* the UK can capture. This assessment attempts to estimate a plausible market share for the UK across relevant markets. Where this can be based on longstanding trade relationships and industries, this assessment is considered more robust.
3. *Future technology costs and production techniques* are a key driver of the future turnover, gross value added and jobs associated with a technology. For immature technologies for which manufacturing techniques may, for example, become highly automated in future, future costs and jobs supported by the technology may be significantly lower than assessed.

The ratings in the table below are the judgement of Vivid analysts based on the above considerations. The analysts have worked across all sub-themes and the ratings should be considered as a judgement of the uncertainty around the size of the opportunity relative to other sub-themes. As a rough guide, we judge the uncertainty bands around the opportunity estimates as follows:

- **Green**: Size of the opportunity is clear (+/- 20%). Note, this does not imply the UK will indeed capture the opportunity.
- **Amber:** Size of the opportunity is clear, but there are significant uncertainties (+/- 50%).
- **Red:** There are large uncertainties around market structure and whether the technology will be taken up at all in major markets. The opportunity could be a factor 2-3 larger or smaller than presented.

Table 9. **Assessment of uncertainty in business opportunities across sub-themes**

Sub-theme	Uncertainty rating	Comments
Biomass and bioenergy		• **Deployment**: Moderate deployment uncertainty; BECCS can produce negative emissions that have high value to the energy system under a deep decarbonisation pathway; there is moderate uncertainty as to whether BECCS will be used for hydrogen production, as in the ESME modelling, or for power generation. • **UK market share:** Speculative market share for immature traded equipment, but majority of business opportunities associated with certain untraded services and feedstocks. • **Costs and production techniques:** Relatively certain costs with most opportunities associated with labour input rather than immature technologies.
Building fabric		• **Deployment:** Depends on levels of retrofit that greatly exceed those seen to date. • **Market share:** Speculative for traded. However, majority of market untraded, highly likely captured domestically. • **Costs and production techniques:** High share of labour costs (independent of uncertain tech cost).
CCUS		• **Deployment:** Moderate deployment uncertainty; decarbonisation scenarios anticipate rapid uptake of CCUS, though there are few large-scale facilities today. • **Market share:** Moderate market share uncertainty; the UK is likely to be competitive in the storage of CO2 and EPCm services while component market shares are less certain given numerous technology choices and lack of clear competitors. • **Costs and production techniques:** Moderate cost uncertainty; the lack of large-scale facilities today makes estimating future costs difficult.
Heating and cooling		• **Deployment**: Expected to be deployed in most UK buildings by 2050. • **Market share:** some uncertainties, immaturity in markets such as for hydrogen boilers. • **Costs and production techniques:** Relatively certain given relative maturity of boilers and heat pumps. • **Deployment of hydrogen boilers or heat pumps** lead to similar opportunities for UK businesses, while heat networks present a 50 per cent smaller opportunity per household.

Hydrogen and fuel cells		• **Deployment**: Highly uncertain future deployment with a wide-range of 2050 hydrogen demand estimates across scenarios, particularly for export markets. • **UK market share**: Speculative market share for immature traded equipment, but majority of business opportunities associated with certain untraded services. • **Costs and production techniques:** Although deep uncertainty in future hydrogen production costs, for example electrolysis, most domestic costs are associated with labour input rather than equipment.
Industry		• **Deployment**: Relative certainty in deployment as it is based on the 2050 Roadmaps • **UK market share**: Some uncertainty due to poor quality of trade data that may not be representative of technologies within scope. • **Costs and production techniques:** Some uncertainty in costs, particularly for less mature technologies.
Light duty transport		• **Deployment**: Certainty in deployment; low-carbon vehicles will be required in any deep decarbonisation scenario. • **UK market share**: Speculative market share for a relatively immature market; a small number of uncertain future FDI investment decisions generates high uncertainty in overall business opportunities. • **Costs and production techniques:** Highly uncertain future costs, with substantial falls in battery costs a key enabler of BEV uptake.
Nuclear fission		• **Deployment**: Moderate uncertainty in future deployment with some proposed nuclear plants recently cancelled • **UK market share**: Relatively certain market shares based on robust estimates of current nuclear activity; market share growth is dependent on uncertain development of UK reactor IP; however, most business opportunities are associated with untraded activity or areas where the UK has existing strength • **Costs and production techniques:** Uncertain costs for nuclear new build, with dangers of construction overrun; deep uncertainty in costs for immature nuclear technologies, for example SMRs and AMRs.
Offshore wind		• **Deployment**: Offshore wind will be required in any deep decarbonisation scenario, with clear government commitments. • **UK market share**: Expected growth in current market shares given commitments and progress to date. • **Costs and production techniques:** Costs are relatively certain, with clear pathways to 2050.
Tidal stream		• **Deployment**: Global sites for tidal stream are relatively limited, and hence the potential market size well established. • **UK market share**: Although the market is immature, the UK has a an established (and competitive) position. • **Costs and production techniques:** Costs are relatively certain, although the impact of potential scale production is hard to anticipate.
Smart systems		• **Deployment**: High deployment uncertainty given immaturity of smart system market today and evolving business models and regulatory framework. • **UK market share**: Moderate uncertainty given immaturity of the market today and scalable nature of digital smart

		technologies, though there is UK leadership in aggregation services and V2G charging. • **Costs and production techniques**: Moderate uncertainty of cost reductions of batteries and V2G and smart chargers, though costs are expected to continue to fall.

Source: Vivid Economics

Contact us if you have any enquiries about this publication, including requests for alternative formats, at:

Department for Business, Energy and Industrial Strategy
1 Victoria Street
London SW1H 0ET
Tel: 020 7215 5000

Email: enquiries@beis.gov.uk