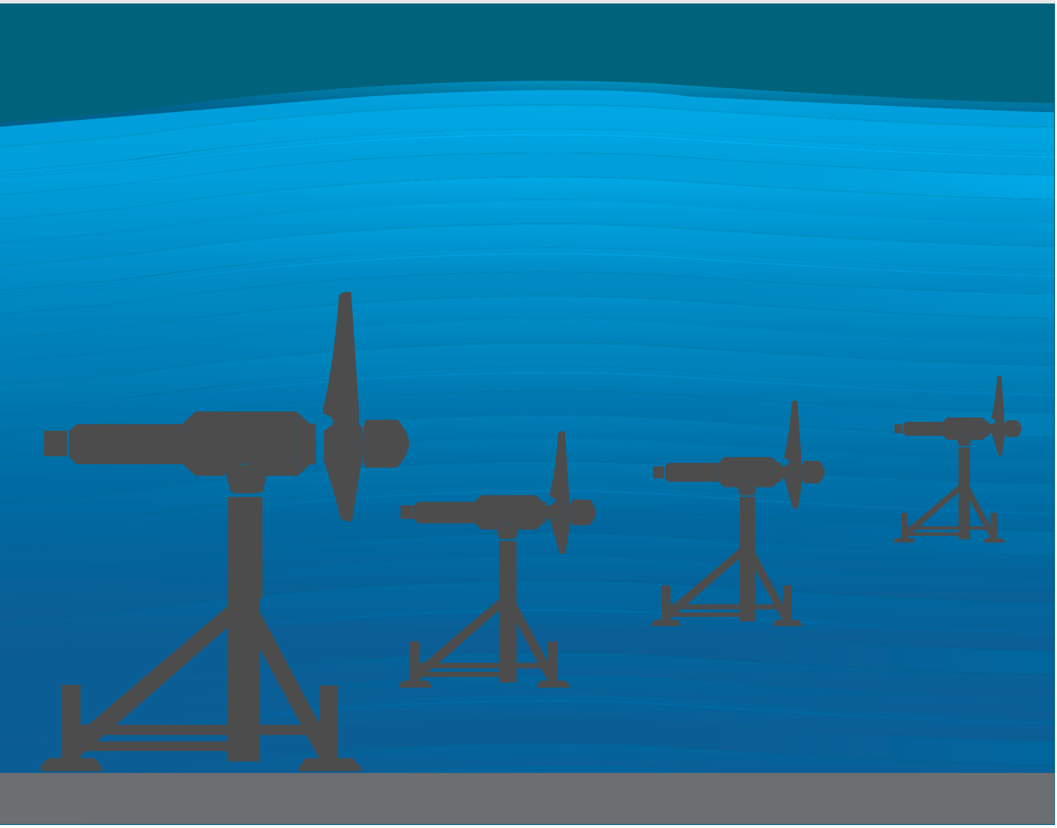
An insights report by the Energy Technologies Institute

Tidal Energy

Insights into Tidal Stream energy



Offshore Renewables

Our Marine technology programme aims to help accelerate the development of the UK's most promising marine technologies

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Key headlines

- There is a demonstrable route to making tidal stream energy competitive with other low carbon technologies; tidal stream has the potential to be a material part of the future UK energy system
- Tidal energy is capable of supplying 20-100TWh of the 350TWh of the UK's annual electricity demand
- Potential impact of the tidal industry on UK GDP is estimated to be in the range of £1.4 - 4.3billion
- The cost of energy from tidal stream arrays can compete with other low-carbon sources
- The sector has transitioned in recent years from small-scale prototype devices, through to full-scale demonstration and early commercial arrays are now in development
- The UK leads the rest of the world in the development of tidal devices
- Significant cost reduction will require coordinated investment in supply chain innovation, processes and people
- Array and device design integration is vital

Introduction

The marine environment can supply energy in three main forms – tidal stream, wave and tidal range/barrage. These provide significant potential since we have some of the world's best available tidal and wave resources in UK waters.

This insights report examines the potential for exploiting tidal stream energy in the UK, building on the learnings derived from ETI Marine technology development projects and in-house ETI system-level analysis.

It concludes that there is a demonstrable route to making tidal stream energy competitive with other low carbon technologies and that tidal stream has the potential to be a material part of the future UK energy system.

A reliable energy source

There is sufficient energy resource in UK waters[1] (if it can be economically exploited) to make a material contribution to future UK energy supply needs

Tidal stream energy is a reliable and predictable low-carbon energy source. There is sufficient energy resource in UK waters[1] (if it can be economically exploited) to make a material contribution to future UK energy supply needs. Tidal stream energy has additional benefits such as low visual impact, economic activity and stimulus in remote areas of the UK. Some potential disadvantages are the environmental impact on wildlife and disruption to shipping navigation and other marine economic activities.

Using the ETI's internationally peer-reviewed Energy Systems Modelling Environment (ESME) tool – a national energy system design and planning capability - we have examined cost-optimised UK energy delivery pathways to 2050. This analysis confirms that tidal energy could compete successfully with alternative low-carbon energy sources[2], provided significant cost reduction and performance improvements are delivered.

ESME
Energy System
Modelling Environment

[1]Recent resource estimates vary between 20 TWh per year to 100 TWh per year; current UK electricity demand is in the order or 350 TWh per year

[2]http://www.eti.co.uk/project/esme/

Current status and future needs

- Marine energy technology is still in the early stages of development
- The sector has transitioned in recent years from small-scale prototype devices, through to full-scale demonstration and early commercial arrays are now in development
- ETI's ReDAPT project has shown that the challenges of operating in high-flow tidal streams have been underestimated

Marine energy technology is still in the early stages of development, with the levelised cost of energy (LCoE) for today's tidal energy converters estimated to be in the range £200-300/MWh[3], compared to existing renewable sources shown in Figure One.

Figure One: DECC cost of electricity, December 2013[4]

Levelised cost of energy[4]	Low	High
Onshore Wind £/MWh	83	129
Offshore Wind £/MWh	129	166
Large Scale Solar £/MWh	146	170

[3]LCICG Marine Energy TINA

[4](Figure One) DECC Cost of Electricity, December 2013, table 6, projects commissioning in 2014

The ETI's analysis indicates that delivering cost reduction and performance improvements in line with the targets detailed in the 2014 ETI / UKERC Marine Energy Roadmap (Figure Two) will make tidal stream energy competitive and (potentially) a material part of any future low-carbon UK energy system.

Our analysis and project insights suggests that delivering this challenging trajectory is feasible given focused innovation investment.

The nascent tidal industry will need sustained financial and political support to encourage investment, innovation and maturity to deliver potential substantial economic benefits to the UK.

The sector has transitioned in recent years from small-scale prototype devices, through to full-scale demonstration, and early commercial arrays are now in development.

UK based test devices have provided information on design, economics, environmental impact and security, all of which are informing design and operation improvements for future systems.

In particular, the Reliable Data Acquisition Platform for Tidal (ReDAPT[5]) project, supported by the ETI and delivered by Alstom Tidal Generation has provided valuable experience of installing, operating and maintaining a tidal stream device. ReDAPT has shown that the challenges of operating in high-flow tidal streams have been under-estimated, and that device operation reliability in such harsh conditions is paramount.

“The nascent tidal industry will need sustained financial and political support to encourage investment, innovation and maturity”

[5] http://www.eti.co.uk/project/redapt/

Industry Investment

- The UK leads the rest of the world in the development of tidal stream energy converters
- Potential impact of the tidal stream energy industry on UK GDP is estimated to be in the range of £1.4-4.3 billion
- Significant cost reduction will require coordinated investment in supply chain innovation processes and people

The UK leads the rest of the world in the development of tidal devices. Many multinational corporations such as Alstom, Andritz and Atlantis are investing in UK based manufacturing operations, engineering and research. The potential impact of this industry on UK GDP is estimated to be in the range of £1.4 to 4.3 billion, if a 15% share of the global marine energy market is captured[6].

As well as technology innovation any significant cost reduction will also require coordinated investment in supply chain innovation, processes and people. Currently, the amount of UK value in these devices and systems is significant at circa 70%, but will almost certainly reduce if global supply chains offer better value.

£4.3bn

Potential impact of the tidal industry on UK GDP is estimated to be £1.4-4.3 billion

[6] LCICG: Marine Energy Technology & Innovation Needs Assessment, P1, see http://www.lowcarboninnovation.co.uk/document.php?o=7

ETI / UKERC 2014 Marine Energy Technology Roadmap

Recent techno-economic modelling using ESME has provided insights into the improvements in performance and cost that Tidal Stream Energy would need to demonstrate in order for it to deliver material levels of deployment in the UK by 2050 on a purely economic basis.

The 2020 target is to have (LCoE) of between 10 and 20p/kWh with availability of 90%, see Figure Two (page 11).

Marine Energy Technology Roadmap 2014 - a joint report by the Energy Technologies Institute (ETI) and the UK Energy Research Centre (UKERC)

The full report can be found at:
www.eti.co.uk
www.ukerc.ac.uk

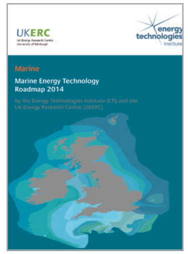
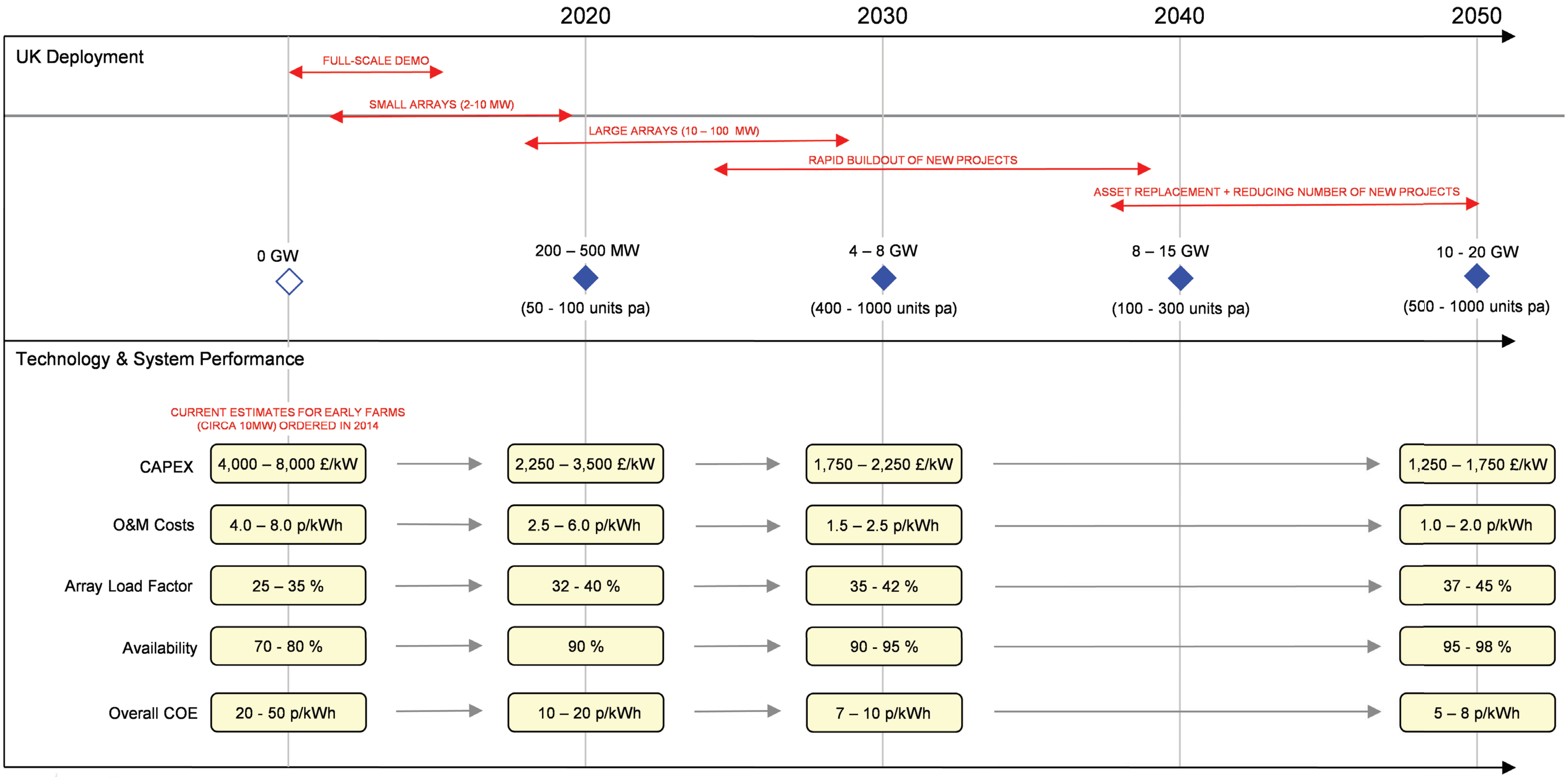


Figure Two: UK Marine (Wave & Tidal) Energy Deployment Strategy and Technology Development Targets



energy technologies institute
UKERC UK Energy Research Centre

In the timeline shown capital cost needs to halve between each datum point, and operating costs carry on reducing. This will result in a continuous reduction in LCoE, such that by 2050 there is the potential for 10-20GW of resource to be economically competitive, and still more to progress.

Commercial Impact

The ETI has supported the development of marine energy in the UK with a series of initiatives that developed engineering and economic tools to:

- enable site and array developers to select and understand their investments
- allow utilities and device manufacturers to optimise:
  1. their mechanical and electrical systems.
  2. their integration into arrays and within device topologies.
  3. development of effective means of transmission and distribution.

ETI's investments in Marine projects has resulted in the development of commercial products brought to market, and encouraging investment and exploitation.

ETI Tidal Projects

Project Name	Aims	Outcomes
Performance Assessment of Wave and Tidal Array Systems (PerAWaT)	Create numerical models to predict the hydrodynamic performance of Wave (WEC) and Tidal Energy Convertors (TEC) arrays	Validated engineering tools created to give greater investor confidence by reducing commercial risk. These tools are commercially available
Tidal Modelling	To develop a model of the UK's Continental Shelf, 100 times more accurate than existing models	Demonstrated the effects of the roll out of tidal current and tidal range developments. Allows optimisation of the tidal resource around the UK and ensures there is no detrimental impact to other tidal sites and the environment. Commercially available as SMARTtide
Reliable Data Acquisition Platform for Tidal (ReDAPT)	The project demonstrated the performance of a new tidal generator. Its aim was to increase confidence in tidal turbine technologies by providing a wide range of environmental impact and performance information	The project has delivered valuable data to industry, academic partners, and proven that marine operations to deploy and retrieve devices in high velocity tidal streams is reliable and safe

Insights from ETI projects

The tidal energy projects supported by the ETI have focussed on:

- Accelerating the development and demonstration of leading tidal turbine and sub-system technologies;
- De-risking project investment through the development of array performance analysis tools; and
- Identifying array design and technology development pathways that can inform innovation investments and lead to commercial roll-out

Project Partners:

E.ON, ALSTOM, EDF Energy, DNV·GL, PML Plymouth Marine Laboratory, EMEC Orkney, The University of Edinburgh, University of Oxford, The University of Manchester, Queen's University Belfast, Black & Veatch, HR Wallingford, Atlantis Resources, Lockheed Martin

Reliable Data Acquisition Platform (ReDAPT)

- Over 1GWh of electricity has been exported to the grid
- Marine operations to deploy and retrieve devices in high-flow tidal conditions are feasible and predictable

The Alstom led ReDAPT project has provided the following support to the Tidal Energy Industry:

- Demonstrated installation of a commercial scale horizontal flow turbine
- Contributed to the development of analytical and environmental assessments
- Created improved confidence in tidal turbine technologies
- Contributed to the Classification Society guidelines
- Accelerated the development of the tidal energy industry

Over 1GWh has been exported to the grid[7], and operational experience gained in a wide range of environmental conditions. It has proved that marine operations to deploy and retrieve devices in high-flow tidal conditions are feasible and predictable. ReDAPT also gave insights into the impact of reliability in remote and demanding locations.

1 GWh

Exported

Over 1GWh has been exported to the grid

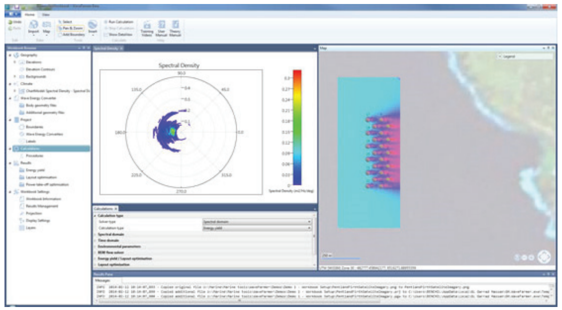
[7] December 2014

Performance Assesment of Wave and Tidal Array Systems (PerAWaT)

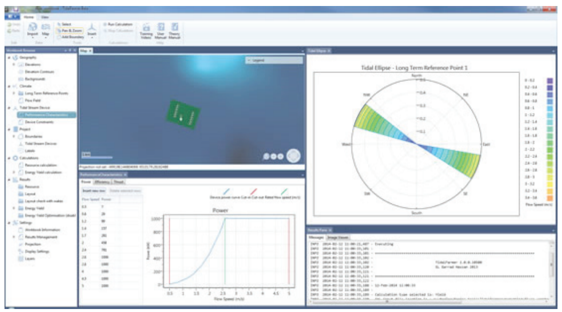
▸ The project created the WaveDyn, WaveFarmer and TidalFarmer software suites – all commercially available from project partner DNV GL

The PerAWaT project developed and validated engineering software for use in assessing wave and tidal energy arrays. The purpose of the project was to improve array economics and create investment confidence.

The project created the WaveDyn, WaveFarmer and TidalFarmer software suites; all commercially available from project partner DNV GL[8].



“ Developed and validated engineering software for use in assessing wave and tidal energy arrays ”



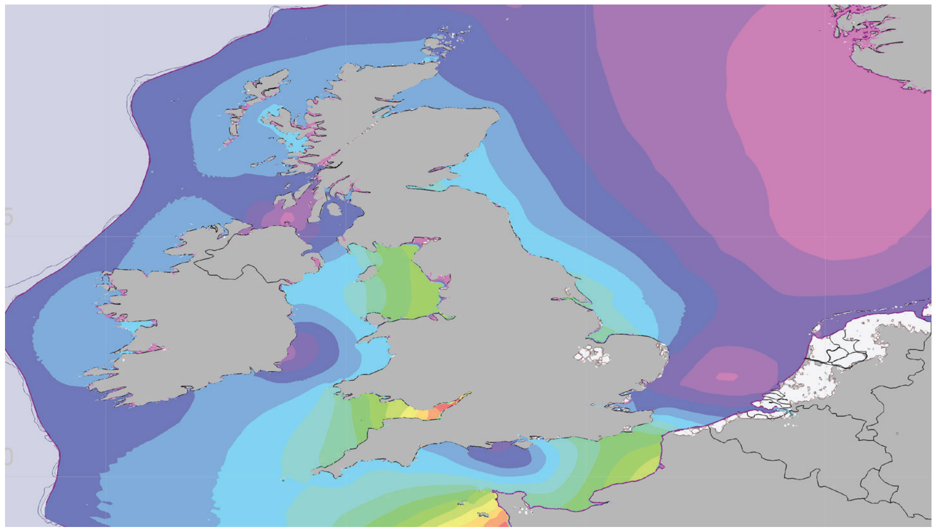
[8] http://www.dnvgl.com/news-events/news/wavefarmer-tidalfarmer-software.aspx

Tidal Modelling (SMARTtide)

▸ The project was delivered by the University of Edinburgh, Black & Veatch and HR Wallingford, with the validated tool launched and developed by HR Wallingford as a commercially available resource

To improve the understanding of tidal interactions, the SMARTtide[9] dynamic modelling tool was created. The project was delivered by the University of Edinburgh, Black & Veatch and HR Wallingford, with the validated tool launched and developed by HR Wallingford as a commercially available resource.

SMARTtide provides a high-finesse map of UK tidal waters and their energy potential. The map helps developers identify potential sites and maximise energy yield with accuracy and confidence, and to understand the effects on regional and national resources.



[9] http://www.hrwallingford.com/smarttide

Tidal Energy Converter (TEC)

- Project focused on array-scale design, innovation and optimisation
- Over 40 supply chain companies contributed their knowledge and insights to the project
- Over 2400 combinations of key components studied to identify the optimum commercial and technical design topologies
- Phase 2 of the ETI's TEC project will see two Atlantis owned 1.5MW commercial tidal energy turbines installed on an innovative foundation structure designed and built as part of the project. This will take place at the MeyGen site in Scotland

The TEC System Demonstration Project[10] was commissioned by the ETI with the objective of demonstrating a clear and verifiable route to delivering the 2020 cost and performance targets set within the ETI / UKERC Marine Roadmap, In addition it outlined credible pathways to delivering the longer-term 2030/2050 targets.

The project was focussed on array-scale design, innovation and optimisation, using generic horizontal axis tidal turbines as the array building block. The project consortium was led by Atlantis Resources Corporation, with Black & Veatch acting as technical advisors, and Lockheed Martin as System Engineering integrators. Over 40 supply chain companies contributed their knowledge and insights to the project.

It specifically considered array designs of 10 MW or larger nominal-rating, with a view to investigating the impact of arrays of 200 MW and above. The study included different tidal environments, with fast and shallow, fast and deep, slower and shallow etc. and other combinations (Figure Three).

> “The project was focussed on array-scale design, innovation and optimisation, using generic horizontal axis tidal turbines as the array building block”

[10] http://www.eti.co.uk/project/tidal-energy-converter/

The optimised TEC System comprises multiple components within and outside the turbine. These include the foundation system, hydrodynamic absorber, power take-off, electrical infrastructure, marine operations vessel and other infrastructure needed to install and maintain the system through its service life. Over 2400 combinations were studied to identify the optimum commercial and technical design topologies. Selection criteria included development potential, technology maturity and risk, impact on levelised cost and supply chain maturity.

The analysis concluded that optimal tidal array designs are likely to comprise:

- Foundation structure with improved array energy yield;
- Two turbine nacelles per foundation to help reduce capital costs and marine operations;
- Variable pitch blades to provide good driveline control and energy yield;
- Three blades per hub to allow best energy yield, driveline costs, control and safety.

The optimum device in operation consists of;

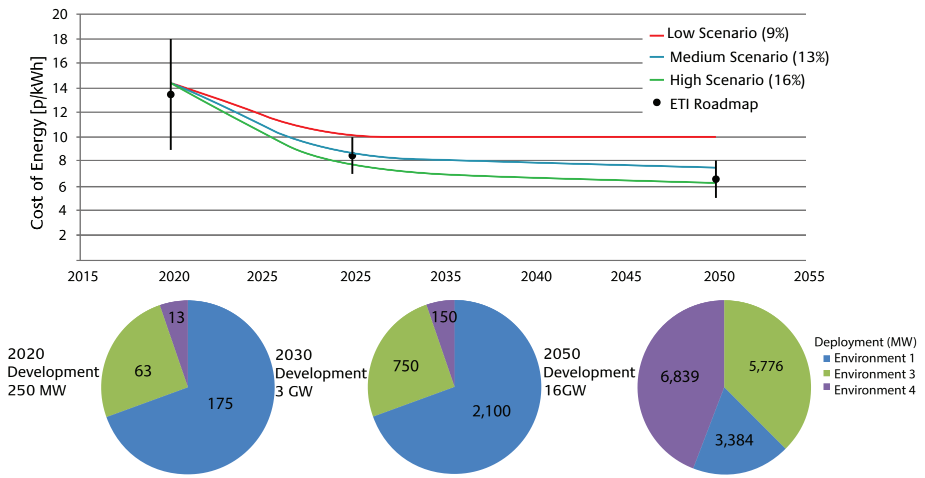
- a gear-driven medium-speed generator keeping mass, risk and costs down and good compactness and reliability;
- Sub-sea power conditioning and conversion with cables to shore grid-connection;
- Marine operations would be performed by an innovative automated dynamic-positioning intervention system (ADIS) for safe and reliable installation, recovery and maintenance.

Cost of Energy Progression - TEC

The TEC Cost of Energy modelling is based on three scenarios: low, medium and high, representing annual cost-reduction rates of -9%, -13% and - 16% and development of tidal sites in different environment types around the UK. The most likely cost reduction rate is -13%.

The applied annual cost reduction rates were attained by technical assessment of over 2400 component combinations. The projected (LCoE) costs for the tidal energy medium and high scenarios achieve the ETI/ UKERC roadmap targets (vertical black lines in the graph)

Figure Three: TEC Levelised Cost of Energy progression by year and describing the environment type implementation



The most advantageous sites in environment 1, being shallow and fast tidal streams, are exploited first. The less advantageous sites, being environment 3 (deep and fast), and 4 (shallow and medium speed), are utilised by 2050, but annual cost-reductions offset the possible negative effects on LCoE.

13%

Cost Reduction

The most likely cost reduction rate is -13%

Key Insights - TEC

- Tidal Stream arrays can meet the ETI / UKERC Marine Roadmap targets for 2020 and beyond;
- Device cost reduction cannot meet the targets in isolation, array-scale system engineering is essential;
- The level of newness to provide an optimised solution is moderate and risks can be mitigated within a short development cycle;
- The supply chain has a major role to play in delivering the potential value, and much of the required skills and capability exists, or could be developed, in the UK;
- 80% of the features and innovations required are low risk and are ready for considered implementation
- Uncertainty needs to be considered and assessed when making optimisation choices and when establishing likely energy costs.

Conclusions on Tidal Energy

Tidal range energy is a reliable and predictable low-carbon energy source, and there is sufficient energy resource in UK waters[11] to make a material contribution to future UK energy supply needs. A commercially competitive cost, meeting the ETI/UKERC marine roadmap targets, can be delivered, with targeted innovation. Achieving this would enable tidal range energy to play a material role in the UK's 2050 low carbon energy mix.

It was recognised by the ETI's project partners at an early stage that array and device design integration was vital, and that device design and supply chain cost savings could not on their own deliver the required cost levels. To achieve this, a rigorous system engineering, rather than component focussed, approach is required.

"It was recognised by the project partners at an early stage that array and device design integration was vital"

[11]Recent resource estimates vary between 20 TWh per year to 100 TWh per year; current UK electricity demand is the order or 350 TWh per year

Facts and Figures

20 -100 TWh

Tidal energy is a predictable low-carbon energy source, capable of supplying 20 to 100TWh of the 350TWh of the UK's annual electricity demand[12]

£4.3 bn

Contribution to UK GDP could be in the range of £1.4 to £4.3 billion, if a 15% share of the global marine energy market is captured[13]

2020

Tidal Stream Energy can meet the ETI / UKERC marine energy targets in 2020, 2050 and beyond

10-20 p/kWh

2020 target is to have a levelised cost of energy between 10-20p/kWh

TEC

The TEC project shows that the potential cost of energy from Tidal Streams can compete with other low-carbon sources

[12]LCICG – Marine Energy TINA P3
[13]LCICG – Marine Energy TINA P4

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