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Marine

Marine Energy Technology Roadmap 2014

by the Energy Technologies Institute (ETI) and the UK Energy Research Center (UKERC)

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Technology roadmaps are tools that provide a framework for stimulating innovation in specific technology areas in order to achieve a long term vision, target or goal

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Introduction and Purpose

Technology roadmaps are tools that provide a framework for stimulating innovation in specific technology areas in order to achieve a long term vision, target or goal. The aim of this roadmap is to facilitate the establishment of a commercially viable marine energy[1] sector in the UK, supported by an extensive supply chain, thereby building the skills and capacity necessary to enable the sector to make a material and cost-effective contribution to the delivery of the UK's energy and climate change goals.

This Marine Energy Technology Roadmap, jointly developed by the Energy Technologies Institute (ETI) and the UK Energy Research Centre (UKERC) represents a major update to the ETI/UKERC 2010 Marine Energy Technology Roadmap, a document created to identify and prioritise the key technology and deployment issues faced by the marine renewable energy sector in the UK. This update has primarily been created to reflect the changes and advancements within the marine energy sector that have taken place since 2010, but it also recognises the engineering challenges that remain and that must be overcome to enable the industry to progress rapidly to early array deployments.

This document is complementary to, and should be read in conjunction, with the Marine Energy Technology Innovation Needs Assessment[2] (TINA) published by the Low Carbon Innovation Coordination Group (LCICG)[3] in August 2012.

Introduction and Purpose continued:

"Prioritise potential technology development"

It has three specific purposes:

- To provide forward-looking marine energy technology cost and performance targets that can be used to benchmark industry progress in the future (section 2). These are generic targets for both the wave and tidal stream sectors.

- To identify the specific technology development and demonstration activities required to progress the marine energy sector (section 3). These develop the high-level innovation support needs identified in the Marine Energy TINA and include cross-cutting industry requirements along with specific activities for the wave and tidal stream sectors.

- To prioritise potential technology development and demonstration interventions in the context of the specific role and remit of the ETI (section 4).

The most significant updates within this document relate to the technology development themes and the prioritisation of activities, in particular the increased focus on the engineering & operational issues associated with device and array deployments (as opposed to fundamental design challenges). The cost and performance targets shown in Figure 1 have also been revised, primarily to reflect a better understanding of operational costs derived from ongoing device deployments, but also the impact of some minor changes to modelling assumptions. The underlying levelised cost reduction challenge, however, remains largely unchanged from the 2010 version of this document.

1.In this document "marine energy" relates to wave and tidal stream energy technologies only
2. The Marine Energy TINA identifies at a high level the critical public sector innovation support needs for the marine energy sector and summarises (at the sub-system level) those areas with the largest potential for improvement. It can be It can be downloaded from http://www.lowcarboninnovation.co.uk/working_together/technology_focus_areas/marine/.
3.See http://www.lowcarboninnovation.co.uk/

1. About the Authors

The ETI is a public-private partnership between six global energy and engineering companies and the UK Government. It carries out modelling and strategic analysis of the UK energy system to identify the key challenges and potential solutions to meeting the UK's 2020 and 2050 targets at the lowest cost to the UK and invests in major engineering and technology demonstration projects which address these challenges.

The ETI's mission is to accelerate the development, demonstration and eventual commercial deployment of a focused portfolio of energy technologies which will increase energy efficiency, reduce greenhouse gas emissions and help achieve energy and climate change goals.

The UK Energy Research Centre (UKERC) carries out world-class research into sustainable future energy systems. It is the hub of UK energy research and the gateway between the UK and the international energy research communities. The UKERC's interdisciplinary, whole systems research informs UK policy development and research strategy.

UKERC roadmaps provide an independent and coherent strategy for energy stakeholders. Published UKERC roadmaps include the UKERC/UKCCSC Carbon Capture and Storage, Nuclear Fission, and Marine Energy Roadmaps.

About the authors continued:

"UKERC roadmaps provide an independent and coherent strategy for energy stakeholders"

The collaboration between the ETI and the UKERC has enabled the strengths of both research and industrial organisations to be brought together, allowing an efficient and effective vehicle for the commercial sector to engage with and build upon the underpinning work performed by UKERC and the research and development sector.

The ETI, in conjunction with UKERC, has defined the assessment criteria used within this document and has assessed and prioritised the specific technology development and demonstration activities. The ETI has also assessed additional criteria relevant to its specific interests within the sector. The independence and impartiality of UKERC places it uniquely to provide this service to the ETI and many other technology development organisations.

2. Deployment Strategy & Technology Development Targets

"A global market for marine renewable energy is starting to emerge"

It is clear that the future energy system within the UK will require the deployment of significant quantities of low-carbon power generation plant if the UK government is to meet its legally binding 2050 carbon reduction targets under the Climate Change Act. It is also likely that a balanced portfolio of low-carbon technologies will be required to deliver the capacity and security of supply required out to 2050 and beyond.

Looking further afield, a global market for marine renewable energy is starting to emerge, and a global marine energy deployment target has been set out in the International Energy Agency (IEA) Implementing Agreement for Ocean Energy Systems vision document – An International Vision for Ocean Energy[4]. In order for the UK (and global) deployment strategy to succeed, marine energy must be able to reach cost competitiveness with other forms of power generation.

Recent techno-economic modelling using the ETI's Energy System Modelling Environment (ESME)[5] has been used to provide insights into the improvements in performance and cost that the marine energy sector would need to demonstrate in order for it to deliver material[6] levels of technology deployment in the UK by 2050 on a pure economic basis.

These insights are shown in Figure 1.

[4] Huckerby, J., Jeffrey, H., Sedgwick, J., Jay, B. and Finlay, L., 2012. An International Vision for Ocean Energy – Version II. Published by Ocean Energy Systems Implementing Agreement; www.ocean-energy-systems.org.

2. Deployment Strategy & Technology Development Targets Continued:

The ESME analysis that informed Figure 1 assumed that the UK's 2050 greenhouse gas (GHG) emissions targets are delivered. Furthermore, ESME analysis is performed on the basis that fiscal incentives are not applied to any of the technology options available to the optimisation process. Hence the cost and performance improvement targets shown in Figure 1 can be considered to be:

- Those that would be needed to deliver material levels of marine energy deployment in 2050 as part of the lowest-cost UK energy system solution out to 2050;
- With marine energy having competed like-for-like on an economic basis against all other technology options within the wider UK energy system, recognising the constraints and challenges associated with infrastructure development and installation;
- In a world where the UK meets its 2050 GHG emissions targets and at the same time delivers acceptable levels of security of supply;
- Without fiscal incentives being applied to ANY technology at any point in time in the future.

[5] Energy System Modelling Environment (ESME). ESME is a probabilistic engineering tool that delivers lowest-cost energy system design blueprints out to 2050. It considers the full UK energy system (i.e. power, heat, transport and infrastructure), the interactions between these different sectors, and practical challenges associated delivering major asset and infrastructure installations (e.g. supply chain constraints and build-out rate constraints).

> "Meeting the cost and performance improvements shown in Figure 1 will be challenging"

The starting point (2014) assumptions shown in Figure 1 have been derived from cost estimates contained in the Marine Energy TINA[7] (August 2012), the SI Ocean project report "Ocean Energy: Cost of Energy and Cost Reduction Opportunities"[8] (May 2013), and from ETI analysis.

Meeting the cost and performance improvements shown in Figure 1 will be challenging. To help identify key improvement opportunities, a detailed analysis of the technology development options has been performed for both wave and tidal stream technologies. These are discussed in detail in Section 3 of this document.

[6] Material in this context means achieving deployment levels of 10-20 GW in the UK by 2050, thereby delivering around 5-10% of the UK's electricity demand requirement in 2050

[7] http://www.lowcarboninnovation.co.uk/working_together/technology_focus_areas/marine/

[8] http://www.si-ocean.eu/en/Technology-Assessment/Cost-of-Energy-Assessment/

3. Technology Development and Demonstration Priorities

"A summary of technology development, demonstration activities, and ETI prioritisation of research activities"

This section summarises the technology development and demonstration activities, and the ETI prioritisation of the research activities, which could contribute to the delivery of the required performance and cost improvements shown in Figure 1.

The analysis detailed in this document, carried out in 2013 by the ETI and UKERC, was a two-stage process that considered:

a) A review and an update of the 2010 technology development activities identified as critical to the delivery of a commercial marine energy sector, both in the UK and on a global scale. This review identified the activities which have seen significant development and have already generated solutions. The review also identified new activities that need to develop in order to accelerate the commercialisation of the marine energy industry in the UK, taking into consideration the global progression of the industry.

b) Re-prioritisation of the research and development activities from the perspective of both the marine energy sector and the ETI, taking into account the purpose, skills, capabilities of the ETI Membership, and the operating model of the ETI.

The development activities identified under part (a) have been categorised into the following four themes and are shown for completion in Table 1.

- Device and System Deployment
- Sub-Systems
- Design and Optimisation Tool Development
- Arrays

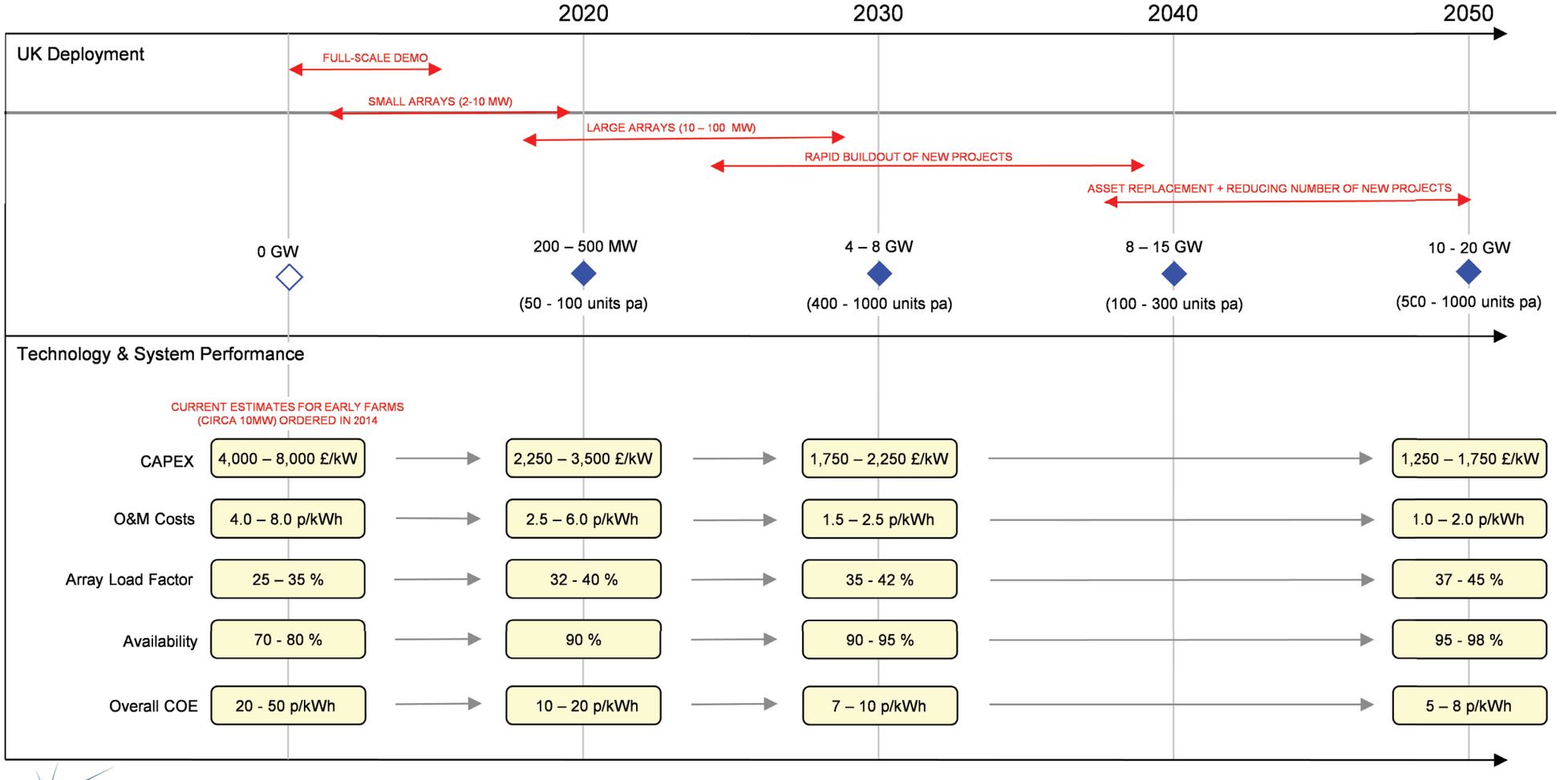
To deliver the prioritisation identified in part (b) above, the activities within each theme were ranked in terms of the needs of the UK marine energy sector generically, and their alignment with the objectives and purpose of the ETI. A separate assessment was carried out for both wave and tidal systems. Further details of the assessment methodology are provided in Section 4. The results of this prioritisation are reproduced and illustrated in Table 3 and Table 4 (see page 12)

Table 1: Development Themes and Activities

Device & System Deployment	Sub-Systems
• Performance Data Collection • Knowledge Transfer & Dissemination • Economic Installation Methods • Economic Recovery Methods • Connection / Disconnection Techniques • Pre-commercial Device Sea Trial • Pre-commercial Array Sea Trial • Design For Maintenance • Novel System Concepts • Sub-sea Preparation Work • Vessels • Reliability Demonstration (Device & Sub-Component)	• Control Systems • Intelligent Predictive Maintenance Systems • Power Take Off • Power Electronics • Device Structure • Hydraulic Systems • Cooling Systems • Bearings • Foundations & Moorings

Design Optimisation & Tool Development	Arrays
• Design Optimisation Tools • Device Modelling Tools • Failure Modes & Conditioning Monitoring Techniques • Environmental Impact Assessment Tools • Site Characterisation Techniques • Resource Analysis Tools • Array Design & Modelling Tools • Techno-economic Analysis Tools	• Offshore Grid Design & Optimisation • Array Electrical System • Sub-sea Electrical System • Array Interaction Analysis • Offshore Umbilical / Wet MV Connectors • Reliability Demonstration (Array Level)

Figure 1: UK Marine (Wave & Tidal) Energy Deployment Strategy and Technology Development Targets



(Refer to section 2 for guidance on how these targets have been derived and how they should be interpreted)

4. Activity Prioritisation Approach

"Identify the activities needed to deliver marine energy industry commercial-isation"

A major focus of the development of the ETI / UKERC Roadmap was to identify the activities needed to deliver marine energy industry commercialisation, and then use the alignment of these activities with the ETI purpose in order to identify the key activities where the ETI could focus its project intervention support.

Each activity summarised in Table 1 was originally ranked using twelve high level assessment criteria. Nine of these corresponded to an assessment of industry need, the remaining three being more relevant to the ETI purpose and objectives. For each criterion, the activity was given a score of 1-3, typically corresponding to low-medium-high. As part of this roadmap update, the industry need assessment criteria was increased to nine rankings primarily to assess how development funding could contribute to a device and array level performance improvement and to assess the impact funding could have on array development.

These criteria and the resulting scores were also weighted to represent the relative importance of each criterion to the prioritisation assessment.

Table 2 shows the assessment criteria used in the revised analysis.

Table 2: Assessment Criterion, Descriptions and Scoring

Assessment Criterion	Description	1	2	3
Sector urgency	Is rapid development urgent for the Marine sector?	low	med	high
Cost reduction potential - impact on CAPEX	What is the CAPEX cost reduction potential?	low	med	high
Impact on technical risk and survivability	How much would development funding contribute to overall system risk reduction and survivability?	low	med	high
Level of adaptation required	How readily adaptable is existing technology to the Marine sector?	high	med	low
Cost reduction potential - impact on OPEX	What is the OPEX cost reduction potential?	low	med	high
Performance improvement	How much would development funding contribute to overall device & array performance improvement?	low	med	high
Array development and assessment	How much would development funding contribute to the progress of array development?	low	med	high
Cost reduction potential - installation, deployment & retrieval	How much would development funding contribute to overall cost reduction in installation, deployment and retrieval techniques?	low	med	high
Commonality	Is the development potentially available for use across a range of other technologies outside of marine renewable energy (e.g. can the development of this technology be utilised in wave & tidal & offshore wind	low	med	high
ETI Additionality	To what degree can ETI skills & capabilities add value to the development?	low	med	high
Impact of Investment (ETI)	How much impact would ETI investment have on the development?	low	med	high
Fit with ETI Objectives	How closely aligned is the technology/system with ETI objectives?	low	med	high

Assessment Criterion, Descriptions and Scoring

Using the previous approach, the following normalised measures for each activity were derived from the scores:

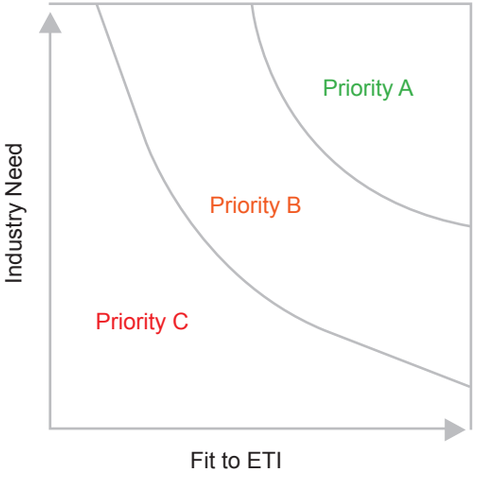
a) UK Marine energy sector industry need (0-100)

b) Alignment with the purpose and objectives of ETI (0-100)

These were then plotted on a graph, of the type indicated in Figure 2 to determine the relative priority of each activity.

It is important to note that if an activity is classified as Category C, this does not necessarily mean it is not an important industry issue. It is more likely to reflect a lack of alignment with ETI purpose.

Figure 2: ETI Priority Level Classifications and Category Descriptions



Priority A activities have a high need and are also closely aligned with ETI purpose and additionality

Priority B activities score highly on industry need but are not closely aligned with ETI purposes and additionality, or vice versa. It also includes those that have a medium score for both industry need and ETI purpose and additionality.

Priority C activities generally score poorly on both industry need and ETI purpose and additionality. It also includes some activities that score highly on industry need but are clearly not within the ETI's remit.

Table 3: Activity Prioritisation by Theme

Device & System Deployment
ETI Priority Activity
• Performance Data Collection
• Economic Installation Methods
• Economic Recovery Methods
• Pre-commercial Device Sea Trial (Wave)
• Pre-commercial Array Sea Trial
• Design For Maintenance
• Novel System Concepts
• Vessels (Tidal)
• Reliability Demonstration (Device & Sub-Component)
ETI Priority B Activity
• Knowledge Transfer & Dissemination
• Connection / Disconnection Techniques
• Pre-commercial Device Sea Trial (Tidal)
• Vessels (Wave)
ETI Priority C Activity
• Sub-sea Preparation Work

Sub-Systems
ETI Priority Activity
• Power Take Off (Wave)
• Device Structure
• Hydraulic Systems (Wave)
ETI Priority B Activity
• Control Systems
• Intelligent Predictive Maintenance Systems
• Power Take Off (Tidal)
• Hydraulic Systems (Tidal
• Bearings (Wave)
• Foundations & Moorings
ETI Priority C Activity
• Power Electronics
• Cooling Systems
• Bearings (Tidal)

Design Optimisation & Tool Development
ETI Priority Activity
• Reliability Tools
• Array Design & Modelling Tools
• Techno-economic Analysis Tools
ETI Priority B Activity
• Design Optimisation Tools
• Device Modelling Tools
• Site Characterisation Techniques
ETI Priority C Activity
• Environmental Impact Assessment Tools
• Resource Analysis Tools

Arrays
ETI Priority Activity
• Array Electrical System
• Sub-sea Electrical System
• Offshore Umbilical / Wet MV Connectors
• Reliability Demonstration (Array Level)
ETI Priority B Activity
• Offshore Grid Design & Optimisation
• Array Interaction Analysis

Table 4: ETI Activity Prioritisation by Priority Category

ETI Priority Activity
• Performance Data Collection
• Economic Installation Methods
• Economic Recovery Methods
• Pre-commercial Device Sea Trial (Wave)
• Pre-commercial Array Sea Trial
• Design For Maintenance
• Novel System Concepts Vessels (Tidal)
• Reliability Demonstration (Device & Sub-Component)
• Power Take Off (Wave)
• Device Structure

ETI Priority Activity
• Hydraulic Systems (Wave)
• Failure Modes & Conditioning Monitoring Techniques
• Array Design & Modelling Tools
• Techno-economic Analysis Tools
• Array Electrical System
• Sub-sea Electrical System
• Offshore Umbilical / Wet MV Connectors
• Reliability Demonstration (Array Level)

ETI Priority B Activity
• Knowledge Transfer & Dissemination
• Connection / Disconnection Techniques
• Pre-commercial Device Sea Trial (Tidal)
• Vessels (Wave)
• Control Systems
• Intelligent Predictive Maintenance Systems
• Power Take Off (Tidal)
• Hydraulic Systems (Tidal)
• Bearings (Wave)
• Foundations & Moorings
• Design Optimisation Tools
• Device Modelling Tools
• Site Characterisation Techniques
• Offshore Grid Design & Optimisation
• Array Interaction Analysis

ETI Priority C Activity
• Sub-sea Preparation Work
• Power Electronics
• Cooling Systems
• Bearings (Tidal)
• Environmental Impact Assessment Tools
• Resource Analysis Tools

5. Implications for Future ETI Activities

"The prioritisation analysis in this document has been performed from the perspective of the ETI and its specific role and position"

The analysis presented in this document will be used by the ETI in its consideration of potential future project interventions, to shape existing projects, and to identify areas for collaborative interventions with other project funders.

It should be noted that the prioritisation analysis in this document has been performed from the perspective of the ETI and its specific role and position within the energy funding landscape. Other UK funding organisations will have different funding priorities based on their own strategic remit, allowing each funding organisation to target specific aspects of the overall sector development needs, preventing duplication and repetition of projects and funding. This process is managed and co-ordinated through the Low Carbon Innovation Coordination Group.

ETI Project Images

1MW Tidal Turbine

Wave Energy Convertor

11kV Wet-mate Connector

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