An insights report by the
Energy Technologies Institute

Wave Energy
Insights from the Energy Technologies Institute

Key findings

- The UK has some of the world's best available tidal and wave resources
- Even with aggressive cost reduction and innovation activities current attenuator wave energy technologies are unlikely to make a significant contribution to the UK energy system in the coming decades
- Radical new wave energy extraction and conversion system approaches are needed to reduce cost and increase energy extraction and reliability. This will provide a trajectory towards lower cost solutions in the long term

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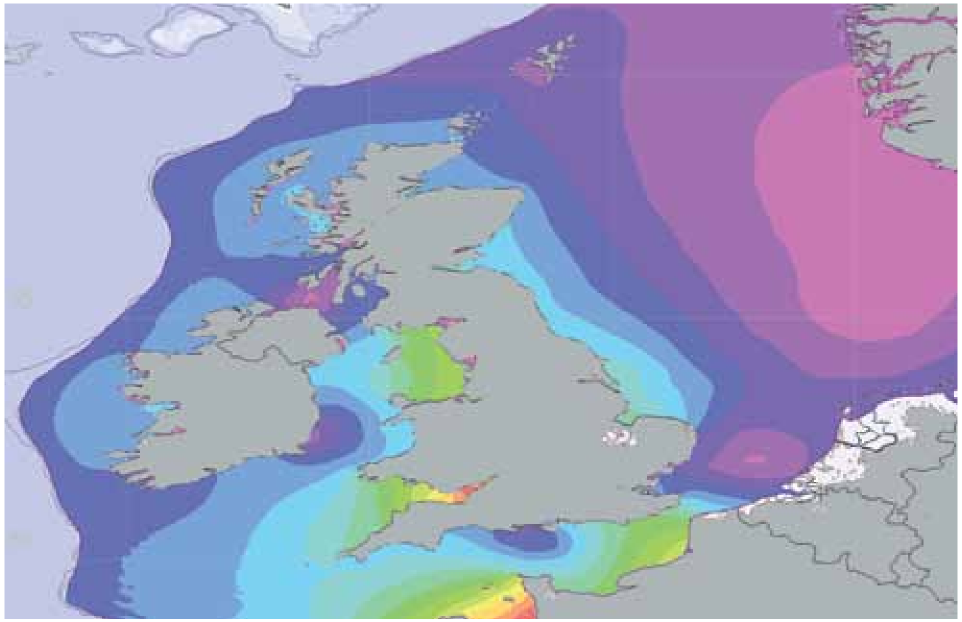
The marine environment can supply energy in three main forms – tidal stream, wave and tidal range/barrage. These have significant potential, since the UK has some of the world's best available tidal and wave resources in its waters. This paper examines the potential for exploiting wave energy in the UK and concludes that:

- Even with aggressive cost reduction and innovation activities, current attenuator wave energy technologies are highly unlikely to meet the ETI/UKERC marine energy roadmap targets[1], and are therefore unlikely to make a significant contribution to the UK energy system in the coming decades
- Radical new wave energy extraction and conversion system approaches are needed to reduce cost and increase energy extraction and reliability. This will provide a trajectory towards lower cost solutions in the long term.



[1] http://www.eti.co.uk/marine-roadmap/

A high reward energy source with significant challenges

- Wave energy could be capable of supplying 10-50TWh of the 350TWh of the UK's annual electricity demand
- Wave energy needs to achieve a 2020 levilised cost of energy in the range of 10-20p/kWh
- ETI's work suggests the sector will not achieve these targets until 2030

Wave energy is extracted from a highly energetic environment, and could be capable of supplying 10-50TWh of the 350TWh of the UK's annual electricity demand[2]. The global opportunity is much larger, and could be 50 to 100 times that of the UK. The sea surface environment in which wave devices operate is extremely challenging, therefore assurance of long-term robustness, reliability and safety is paramount.

Using the ETI's Energy Systems Modelling Environment (ESME[3]) tool – an internationally peer-reviewed national energy system design and planning capability – we have examined cost-optimised UK energy delivery pathways to 2050.

If wave energy technology achieves the ETI/UKERC roadmap targets, then it could economically supply between 100 and 300MW of power capacity by 2020, thus demonstrating a path to being cost competitive and delivering 10GW of electricity by 2050. For this to happen, wave energy needs to achieve a 2020 levelised cost of energy (LCoE) in the range of 10 to 20p/kWh. However, the ETI's work suggests that the sector will not achieve these targets until 2030. This is likely to prevent investment over the next 10-15 years, further limiting its ability to deliver the cost reduction performance improvements and meaning that wave energy will not be meaningfully deployed.

10-50 TWh

Wave energy could be capable of supplying 10-50TWh of the 350TWh of the UK's annual electricity demand

[2] LCICG Marine Energy TINA

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

Current status and future needs

- Marine energy technology is still in the early stages of development
- ETI analysis and project insights suggests that delivering a challenging cost reduction trajectory for wave is not feasible
- The industry needs to create fresh innovative solutions rather than focus on incremental cost reduction

Marine energy technology is still in the early stages of development, with the LCoE for today's early wave energy converters estimated to be in the range £350-400/MWh[4], compared to existing renewable sources shown in Figure 1 below.

The ETI's analysis indicates that delivering cost reduction and performance improvements in line with the targets detailed in the ETI / UKERC Marine Energy Roadmap will make wave energy competitive and potentially a material part of the future UK energy system. Our recent analysis and project insights suggests that delivering this challenging cost reduction trajectory is not feasible, even if focused on innovation investment and includes supply chain development.

Future device developments will need to come to market quickly, displaying high-yield, robust and cost-effective characteristics. We need to create fresh, innovative solutions to the challenges set out in the ETI/UKERC marine roadmap rather than focus on incremental cost reduction through deployment of the current family of technologies.

FIGURE 1

Table of levelised cost of energy estimates for projects commissioning in 2014

Levelised Cost of Energy[5]	Low	High
Onshore wind	83	129
Offshore wind	129	166
Large scale solar	146	170

[4] LCICG Marine Energy TINA, P1 Key Findings

[5] DECC Cost of Electricity, December 2013, table 6, projects commissioning in 2014

Industry investment

- » UK leads the world in the development of Wave Energy Convertor devices
- » Generating power from waves is feasible and technically sound
- » Compared to tidal, wave energy cannot be predicted in the long term

The UK leads the world in the development of Wave Energy Converter (WEC) devices, with full-scale demonstrators from Pelamis and Aquamarine. These innovative devices show that generating power from waves is feasible and technically viable, and that they can be integrated into the wider electrical grid.

This early industrial implementation has significant advantages to the UK, especially in the generation of jobs and wealth.

ETI/UKERC marine energy roadmap

Cost of Energy

- » The 2020 target is an LCoE of 10-20p/kWh with availability of 90%
- » Capital cost needs to halve between each datum, and operating costs continue to reduce

Techno-economic modelling using the ETI's ESME modelling has been used to provide insights into the improvements in performance and cost that marine energy will need to demonstrate compliance in order to deliver material levels of technology deployment in the UK by 2050 on a pure economic basis.

The 2020 target is an LCoE of 10-20p/kWh with availability of 90% (Figure 2).

In the timeline shown overleaf, capital cost (CAPEX), needs to halve between each datum, and operating costs continue to reduce. This will result in a strong LCoE reduction by 2050 to 5-8p/kWh and potentially enabling 10-20GW of deployment capacity.

Compared to tidal stream which is predictable centuries in advance, wave energy is less predictable and suffers from intermittency like wind energy. It has wider geographical spread, rather than being concentrated in certain hotspots around headlands and straits.

Wave energy has benefits such as low visual impact, local economic stimulus and contribution to UK GDP. The potential disadvantages are impacts on wildlife and sea navigation and poor base-load power provision.

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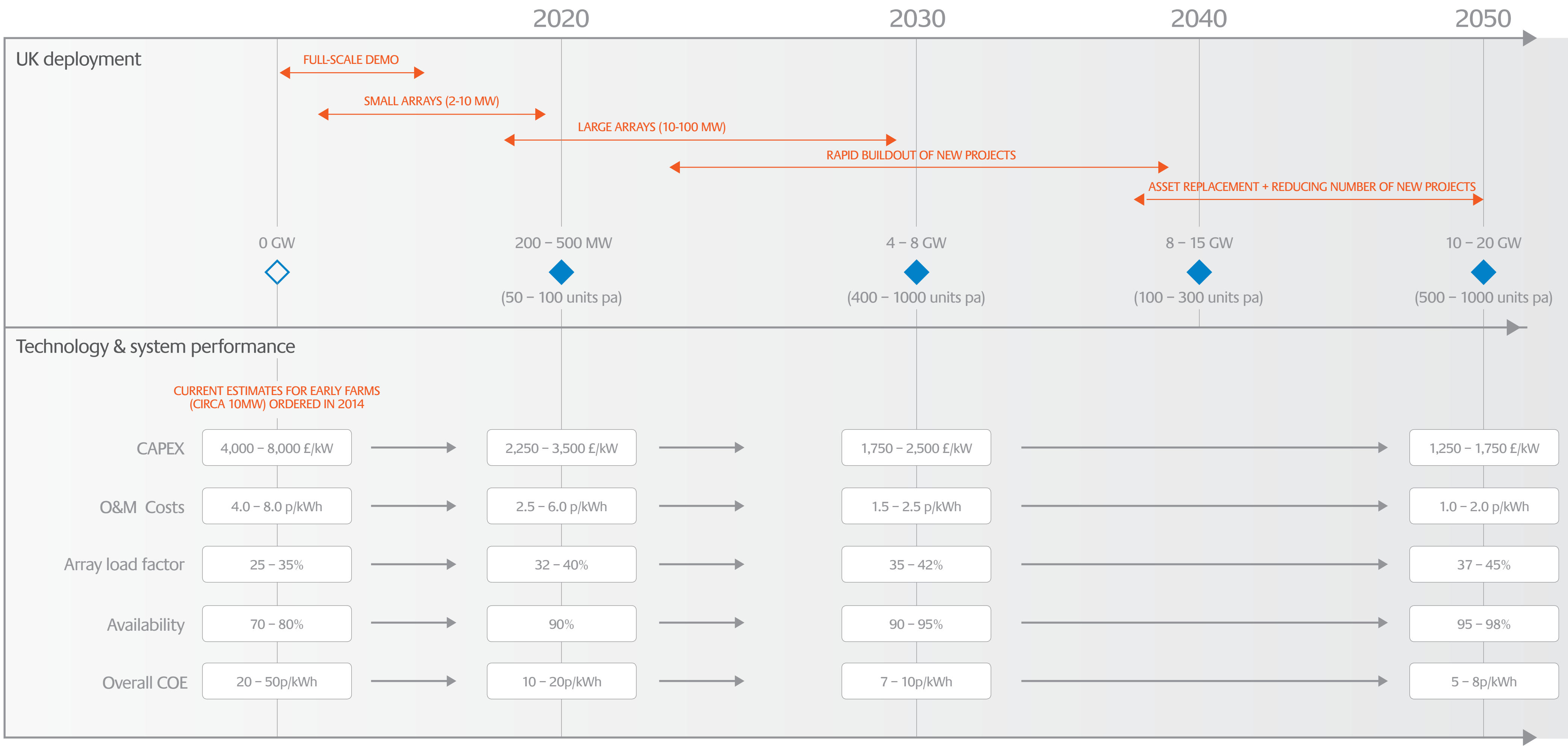
ETI / UKERC marine energy roadmap

Continued »

FIGURE 2

Table of UK deployment of marine energy and technology & system performance



Marine energy commercial impact

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

- Enable site and array developers to choose and understand their investments
- Allow utilities and device manufacturers to optimise:
  - Their mechanical and electrical systems
  - Their integration and to develop effective means of transmission and distribution

“ETI’s investment has resulted in the development of six commercial products, brought to market, and encouraging investment and exploitation”

Insights from recent ETI projects

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

- Accelerating the development and demonstration of leading device 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

PerAWaT

- Developed and validated engineering software for assessing wave and tidal energy arrays

This project developed and validated engineering software for assessing wave and tidal energy arrays. The purpose was to improve array economics and create investment confidence.

The project created the WaveDyn, WaveFarmer and TidalFarmer software suites; all available from DNV GL.

The WEC project

- Route towards significant capital and operating cost reductions by adoption of innovative materials and design features was created

The WEC System Demonstration Project was commissioned by the ETI with the objectives of:

- Accelerating the development and commercialisation of WEC systems and their transition to arrays
- Seeking to develop cost competiveness with other generation forms
- Focused on design and economic analysis and implementing step-change innovative technical solutions at the array scale

This £1.4m investment was made with Pelamis Wave Power (PWP) as lead contractor in February 2013.

The project identified a range of innovation opportunities both at the device and array scale, and quantified the potential impact of these innovation on cost and performance. This information was used to develop detailed designs and costs for the system mapped onto a timeline out to 2030. This included control system options, array architectures, operations and maintenance approaches, installation methods and electrical system integration. A route towards significant capital and operating cost reductions by adoption of innovative materials and design features was created. It specifically considered array designs of greater than 10MW and up to 200MW in suitable UK waters.

Optimisation and innovation

- WEC System is comprised of a series of semi-submerged pressure hulls, hydraulic power take-off systems, power conversion, kinetic joints and mooring systems
- No industry convergence in topology
- Array and device system engineering was vital to reduce LCoE

The WEC System is comprised of a series of semi-submerged pressure hulls, hydraulic power take-off systems, power conversion, kinetic joints and mooring systems. The Pelamis WEC is an 'Attenuator' design, but there are other types of WEC's, such as 'point absorber' or 'oscillating water column'. There is no industry convergence in topology, unlike tidal stream where most designs are horizontal axis turbines.

A total of 57 innovations across the full WEC system were studied, and the impact on energy yield, capital cost and operating costs were assessed for each innovation. Additional aspects such as implementation risk and technical difficulty were also considered to develop a prioritised list of innovation options. PWP engaged over 60 of their supply chain partners to ensure compliance with design-for-manufacture targets, and further cost reduction. The evolved Pelamis design, uses the best of these innovations on the existing machine platform and successfully shows how the original concept can be modified and improved to reduce LCoE. It's energy yield could be 50% higher than the existing model. This machine could have its first year of operation in 2019.

A new design was produced and used the learning from the evolved series and greater innovation to produce the lowest possible cost of energy. The new design will produce 13% more energy than the evolved, and nearly 70% more than the existing design.

It was recognised by the development team at an early stage that array and device system engineering was vital to reduce LCoE. For example, using some of the engineering tools and learning from the ETI PeraWAT project, PWP showed that up to a 15% average energy yield improvement could be gained by optimising the array design, thus improving the LCoE by 0.8p/kWh.

FIGURE 3

Wave energy converter topology

WEC configuration	Pros	Cons	Highest TRL
Attenuator	Energy yield, robustness, array design	Complexity, transient event control, mass and footprint	7
Point absorber	Simplicity, small size, omnidirectional	Finite scaling, array sizes, control of transient events	5
Terminator	Energy yield, calm water beyond device, scaling	Requires robust structures, unidirectional	7

Cost of energy

» 2020 target for marine energy is an LCoE of 10-20p/kWh with availability of 90%

The 2020 target for marine energy is an LCoE of 10-20p/kWh with availability of 90% (Figure 4).

The LCoE has been estimated for these scenario conditions:

» 'Base' and 'high' energy sites
» No, or moderate learning
» New design deployment in the mid-2020s

The moderate learning rate is based on a yearly reduction in operations and maintenance costs of 3%, an increase in yield of 50%, and reduced insurance costs. The supply chain will need to reduce capital costs too, and this is based on a deployment rate of 60 devices per annum in 2020 and 310 devices per annum by 2030.

In 2020, the LCoE could range from 15-32 p/kWh for the base to the evolved design with high resource site and moderate learning.

In 2030 the cost could range from 16p/kWh for the base to 7.5p/kWh for the advanced new design with high resource and moderate learning.

The likelihood of this happening is low due to the relatively short time available to develop the new design, manufacturing methods and consenting in high-resource sites. This scenario would mean that the fleet size in 2030 would need to be 1600 units.

The most likely scenario is the evolved design with an LCoE of 22.5p/kWh in 2020 and 12p/kWh in 2030. This machine design and manufacturing method has significant risk, and needs significant investment in design, manufacturing and the supply chain. This scenario means that the ETI / UKERC Roadmap targets will not be met.

WEC conclusions

The project has delivered valuable insights:

» WEC arrays have the potential to significantly reduce their cost of energy

» Despite the significant potential cost reduction, existing attenuator WEC arrays are unlikely to meet the ETI / UKERC Marine Roadmap LCoE targets

» Site selection and array optimisation is essential to obtain the best LCoE like other offshore renewable energy sources

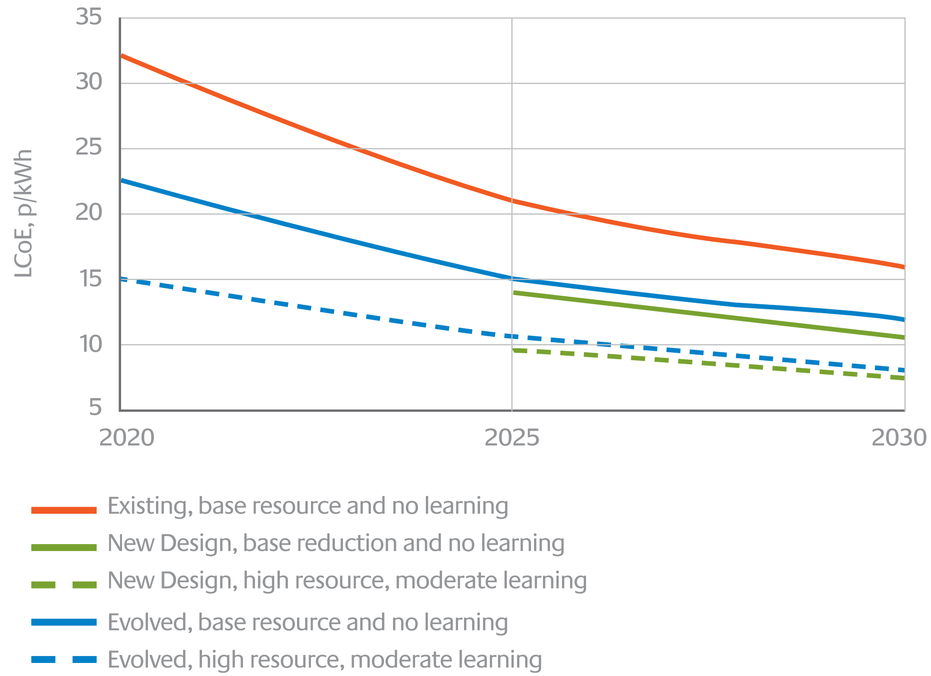
» Volume manufacturing and lessons learnt need to be rigorously exploited to help reduce the cost of energy

» Uncertainty needs to be assessed when making optimisation choices and when establishing likely energy costs. This facilitates understanding sources of variation, optimal sites and innovation opportunities

» New disruptive technology is required followed by rapid deployment to increase the likelihood of wave energy commercial development.

FIGURE 4

LCoE for Pelamis device developments



10-20p kWh

2020 target for marine energy is an LCoE of between 10-20p/kWh with availability of 90%

Conclusions

- Wave Energy is potentially attractive to the UK due to its abundance, geographical distribution, and positive impact on reduction of our greenhouse gas emissions and reducing reliance on energy imports.
- Even with aggressive cost reduction and innovation activities, current attenuator wave energy technologies are highly unlikely to meet the ETI/UKERC marine energy roadmap targets and are therefore unlikely to make a significant contribution to the UK energy system in the coming decades.
- There is now a need to reconsider some of the fundamental wave extraction and conversion system approaches to establish whether alternative methods are plausible to deliver lower cost solutions in the longer term.
- Wave energy requires radical innovative thinking rather than incremental cost reduction through deployment of the current family of technologies.

Facts and figures

Wave energy is a plentiful and accessible low-carbon energy source, capable of supplying 10-50TWh of the 350TWh of the UK's annual electricity demand[6].

Pelamis WEC technology has a high level of design flexibility, allowing the concept to be optimised for specific conditions.

[6] LCICG Marine Energy TINA

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WEC

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57

A total of 57 innovations across the full WEC system were studied, and the impact on energy yield, capital cost and operating costs were assessed for each innovation

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