

An insights report by the
Energy Technologies Institute

Offshore Wind

Floating Wind Technology



Contents

Introduction	04
Project findings	05
Floating offshore wind	06
The Floating Platform System Project	14
Key outcomes	22



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Key headlines

- » With technology and supply chain development there is a clear and credible trajectory to delivering commercial offshore wind farms
 - » Floating Wind has the potential to be a cost-effective, secure and safe low-carbon energy source which could deliver a levelised cost of energy of less than £85/MWh from the mid-2020s
 - » To deliver improved costs, offshore wind needs access to good quality wind resource close enough to shore and the onshore grid system so that transmission costs are minimised and operations/maintenance costs reduced
 - » Floating technology can provide access to high quality wind resources relatively close to the UK shoreline and in the proximity of population centres
 - » In water depths less than 30m fixed foundations will be the prime solution, in water depths over 50m floating foundations provide the lowest cost solution – a mix of these technologies is likely to offer the lowest cost pathway to deliver large scale deployment in the UK
 - » UK wind resources are abundant and exploitable – and already supplied 9.4% of the UK's electricity needs in 2014
 - » The UK has the world's highest offshore wind capacity with over 4GW installed, from over 1100 turbines, average power rating 3.4MW. A further 1.4GW is in construction, 4.8GW has planning permission and the world's largest in-service offshore wind farm is in the outer Thames Estuary
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Introduction

There is an abundance of wind energy resource in the UK, both onshore and offshore. The UK's offshore wind resources are already being exploited significantly with government support, but with technology and supply chain development there is a clear and credible trajectory to delivering commercial offshore wind farms. The learning from the Energy Technology Institute's (ETI's) Offshore Wind Programme highlights the potential for floating offshore wind turbines. We conclude that floating wind has the potential to be a cost-effective, secure and safe low-carbon energy source that is well positioned to make a significant long-term contribution to the UK's low carbon energy system.

The ETI's work suggests that offshore wind has the potential to deliver levelised cost of energy (LCoE) that will compete amongst the lowest cost forms of low carbon generation from the mid 2020s.

Project findings

- » Offshore wind has the potential to be a significant part of an economic and low carbon UK energy system
 - » Floating offshore wind technology can provide access to high quality wind resources relatively close to the UK shoreline and in the proximity of population centres, which are currently inaccessible due to limitations in the depth to which fixed foundations can be deployed
 - » Appropriate floating foundation technology (such as Tension Leg Platform support structures) in suitable sites, coupled with ongoing technology and supply chain innovation in other areas, could deliver LCoE of less than £85/MWh from the mid-2020s, with the potential for further non-trivial LCoE cost reduction beyond that
 - » Encouraging the development and deployment of floating offshore wind platforms is a key strategic issue for the UK
 - » Full scale technology demonstration and implementation needs major investment and the availability of suitable test sites
 - » There is insufficient revenue from power generation alone to encourage new step-out offshore technologies to be demonstrated at full scale. Financial support for innovation will continue to be required
 - » For floating wind to start deployment at scale from the mid 2020s, demonstration projects need to be implemented before 2020
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Floating offshore wind

To deliver an improving and competitive LCoE, Offshore Wind needs

1. Access to good quality wind resource
2. To be close enough to shore and power users so that transmission costs (capital and losses) to users are minimised and operations and maintenance costs reduced
3. Reduced capital costs by ongoing innovation and improvements

To achieve this the UK needs a range of foundation types to cover water depths up to 100m. The UK's position on the continental shelf means that, apart from a few spots, there is very little water deeper than 100m sufficiently close to shore for offshore wind exploitation. Fixed foundations (which will include gravity base and jackets as well as monopiles) will be the prime solution in water depths less than 30m, with floating foundations providing the lowest cost solution in water depths over ~50m. Between 30m and 50m a mix of floating and fixed bottom solutions is likely, depending on site conditions. With a range of technologies covering both fixed bottom and floating foundations, the UK will be well equipped to harvest offshore wind with the best LCoE potential.

If the UK is to capitalise on its offshore wind resource then it will be important to open up more of the marine estate for potential offshore wind farms. Constraints from other stakeholders, as well as site conditions, are likely to limit the shallower water sites that are suitable for fixed foundations.

Offshore wind turbines are increasing in size, with turbines in excess of 10MW (and blade diameters over 200m) being developed for deployment in the 2020s. Floating technology offers a credible path to economically exploit these larger turbines, as well as a 3-7% reduction in the LCoE for smaller turbines.

Floating foundations are still some way from large scale deployment. Given the decision making horizons associated with new wind farms, technology that is demonstrated by 2020 has the potential to be deployed at farm scale no earlier than 2025.

The offshore wind industry is currently focused on delivering the 'Round 3' sites. These will be delivered without floating technology. At this stage there is little, if any, market pull for floating solutions and technology push will be needed until deeper water sites are provided; possibly in later Crown Estate licensing rounds. Policy needs to encourage the development of floating technology suitable for UK waters if it is to be available from the mid 2020s.

Offshore Wind in the UK

Wind energy resources are abundant and exploitable¹, and supplied 9.4% of the UK's electricity needs in 2014². Offshore wind is generally much more energetic than onshore (average onshore wind speeds in the UK are around 4m/s, but offshore are over 9m/s)¹, meaning that much greater energy yields can be achieved for a given size of turbine in an offshore environment than onshore.

Offshore wind farms are also not subject to the same planning constraints as onshore farms and, if sited sufficiently far offshore, have a lower visual impact. However, the marine estate has many stakeholders and permitting for offshore wind farms is challenging.

Energy Systems Modelling

Using the ETI's Energy Systems Modelling Environment (ESME) tool – an internationally peer-reviewed national energy system design and planning capability - we have examined cost-optimised UK energy delivery pathways to 2050³. This analysis shows that affordable low-carbon energy systems will need a mix of nuclear, carbon capture and storage, and renewable energy sources. The analysis also suggests that between 18 and 56GW of offshore wind power could be required by 2050⁴.

Integrating a large variable-output energy source like offshore wind needs careful implementation to avoid unnecessary costs⁵. This process will need to consider both source and demand flexibility across a wide range of technologies.

“ Offshore wind farms are also not subject to the same planning constraints as onshore farms and, if sited sufficiently far offshore, have a lower visual impact ”

¹ LCCG Offshore Wind TINA <http://www.lowcarboninnovation.co.uk/document.php?o=8>

² DECC – Digest of UK Energy Statistics, March 2015

³ <http://www.eti.co.uk/project/esme/>

⁴ <http://www.eti.co.uk/options-choices-actions-uk-scenarios-for-a-low-carbon-energy-system/>

⁵ https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48553/5767-understanding-the-balancing-challenge.pdf

Floating offshore wind

Continued »

Offshore Wind Current Status and Costs

Offshore wind technology is relatively mature and well-understood, and is already significantly deployed at water depths less than 40m. The development of sites in more challenging environments (such as deeper water) requires resource investigation, technology development and improvements in operations and maintenance methods.

As part of Electricity Market Reform, the UK Government has used contracts for difference (CfD) to set out a “strike” price for various energy sources. The intention is to give greater certainty and stability of revenues to electricity generators by reducing their

exposure to volatile wholesale prices, whilst protecting consumers from paying for higher support costs when electricity prices are high.

Cost reduction strategies to support a lower cost of energy in these sites are illustrated in The Crown Estates “Pathways” paper⁷. Previous ETI projects such as ‘Helm Wind’ and ‘Deep Water’ (see Table 2 on pages 12/13) informed us of the potential advantages of larger power turbines situated offshore. Our intent in studying floating wind was to explore even lower cost solutions exploiting better wind resources in deeper water, and to investigate the range of technologies that could make significant improvements in LCoE.

TABLE 1

Results of Round One CfDs for Intermittent Renewables

Strike prices, £/MWh ⁶	Low	High
Onshore Wind	79.23	82.50
Offshore Wind	114.39	119.89
Large Scale Solar	50.00	79.23

⁶ <https://www.gov.uk/government/statistics/contracts-for-difference-cfd-allocation-round-one-outcome>

⁷ The Crown Estates “Pathways to Cost-Reduction in Offshore Wind” 2013 <http://www.thecrownestate.co.uk/media/5493/ei-offshore-wind-cost-reduction-pathways-study.pdf>

FIGURE 1

UK Offshore Wind Sites



Floating offshore wind

Continued »

The Value of Offshore Wind to the UK Economy

The UK has the world's highest offshore wind capacity, with over 4GW installed⁸. This is from over 1100 turbines, with an average power rating of around 3.4MW. A further 1.4GW is in construction, and 4.8GW has planning approved⁹. The world's largest in-service offshore wind farm, the 630MW London Array, is situated in the outer Thames Estuary.

There is significant industrial investment with job creation in manufacturing and the supply chain, offshore services, operations and maintenance and decommissioning. RenewableUK has estimated that over 6,800 jobs were associated with wind energy in the UK in 2014¹⁰, and that the industry could contribute £0.58 to £1.15bn to UK GDP by 2020¹¹.

Current Foundation Technologies

Proven fixed foundation offshore wind turbines are already operating in water depths of up to 40m and within 40km of the UK shore line. The most common foundation structures for these shallower depths are monopiles and jackets.

Monopile foundations are single, large piles driven into the seabed, connected to a transition piece and fixed with grout. The transition piece upper part provides the interface to the wind turbine tower. These are the most common foundations for water depths less than 25m.

Jacket foundations are fabricated structures, having three or four legs connected to driven piles, similar to monopiles. The jacket transition piece has a wide stance to provide excellent stability, while the smaller water-plane area reduces wave loadings compared to monopiles. Jacket structures are most appropriate for water depths between 20 and 50m.

Other foundation technologies, such as gravity based foundations and suction caissons are in development, and will be used in shallow waters, similar to other fixed foundations.

Accessing Deeper Water

The UK has many high-energy offshore wind sites within 70 to 100km of the shoreline, but which sit at water depths in the range of 50-100m, beyond the depth at which existing foundation technologies are commercially viable. Cost competitive foundation

⁸ RenewableUK Wind Energy database May 2015 (<http://www.renewableuk.com/en/renewable-energy/wind-energy/uk-wind-energy-database/>)

⁹ RenewableUK Offshore Wind website 2015 <http://www.renewableuk.com/en/renewable-energy/wind-energy/offshore-wind/>

¹⁰ RenewablesUK website 2015 <http://www.renewableuk.com/en/renewable-energy/wind-energy/offshore-wind/index.cfm>

¹¹ Renewable UK report on the Wider Economic impacts of Wind power <http://www.renewableuk.com/en/publications/reports.cfm/onshore-wind-economic-benefits-summary>

technology suitable for these deeper waters would enable the UK to make the most of the favourable (but currently unexploitable) wind energy resources around our coastline.

Cost of Energy Targets

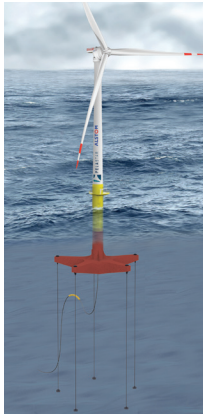
The ETI's ESME modelling outputs have been used to define the improvements in performance and cost that offshore wind energy would need to demonstrate to deliver material levels of technology deployment in the UK by 2050 on a pure economic basis. If offshore wind can deliver a LCoE of around £100/MWh by 2020, in line with targets set by the industry¹², then it is on track to play a major role in the delivery of an affordable low-carbon energy system to 2050.

ETI Projects

The ETI has supported the development of UK offshore wind energy with a series of initiatives as summarised in Table 2. These have developed engineering designs and economic tools to select optimum device and drivetrain configurations, and reduce operating costs.



Semi-Submersible



Tension Leg Platform



Floater



Spar

These technologies are described in Table 4

¹² The Crown Estates "Pathways to Cost-Reduction in Offshore Wind" 2013 <http://www.thecrownestate.co.uk/media/5493/ei-offshore-wind-cost-reduction-pathways-study.pdf>

Floating offshore wind

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TABLE 2

ETI Offshore Wind Projects



Aims

An optimised design horizontal axis wind turbine in up to 40m water depths, up to 100 km from shore

Outcomes

The optimal system solution is a wind turbine with nominal rating of 9-10MW, downwind 3-blades, and direct drive generator



Aims

A novel, floating, tension-leg platform (TLP) system design for use in water depths of 30-300m, and a two-blade teeter-bearing wind turbine

Outcomes

Compared to fixed foundations, the cost of energy reduction could be 15 to 40% by using floating platforms for wind turbines. Optimum architecture affected by water depth, distance offshore and significant wave height

Condition Monitoring

Aims

Detect and predict faults and component failures in turbines

Outcomes

Major fault detection on high-value components like blades generators, gearboxes, bearings is technically feasible

Floating Platform System

Aims

Detailed Front End Engineering Design (FEED) study for a full-scale floating wind system for operation in UK waters

Outcomes

Delivered a floating platform design suitable for economic deployment in most UK sites and conditions, with the potential for £85/MWh LCoE from the mid 2020s



Very Long Blade

Aims

Develop a technology platform for blades in excess of 100m

Outcomes

Expected to be the world's longest modular blades, for machines greater than 6MW nominal capacity. The project delivers a blade for validation testing at the Offshore Renewable Energy Catapult at Blyth in Winter 2015

The Floating Platform System Project

Project Overview








The project was commissioned by the ETI with the objectives of:

- » Developing a floating offshore wind foundation for water depths of greater than 50m, where wind conditions would give an average annual wind speed greater than 9m/s and a capacity factor of more than 45%
- » Creating a through-life cost model for the floating system concept covering a range of location types in UK waters
- » Deliver a front-end engineering design study for the floating system concept
- » Understand the commercial and technical risks associated with future development and commercialisation of the technology

This £4m investment was made by the ETI in 2012 with a project team led by The Glostén Associates. The principal organisations involved in the project are listed in Table 3.

TABLE 3

Floating Platform System Demonstrator project partners

 <p>Alstom Wind</p> <p>Responsibility: Wind turbine Location: Spain</p>	 <p>DNV GL</p> <p>Responsibility: System certification Location: UK / Norway</p>	 <p>Fibremax / DSM</p> <p>Responsibility: Tether system Location: Netherlands</p>	 <p>Glostén Associates</p> <p>Responsibility: Prime contractor & overall system design Location: USA</p>
 <p>KML / LDD</p> <p>Responsibility: Offshore marine operations Location: UK</p>	 <p>RES Offshore</p> <p>Responsibility: Asset management Location: UK</p>	 <p>Wave Hub Ltd.</p> <p>Responsibility: Test site Location: UK</p>	

System Design, Optimisation and Innovation

The PelaStar™ floating offshore wind system comprises a sea-anchoring system, tethers, submerged hull, transition piece, wind turbine and associated electrical infrastructure, see Figure 2.

The tethers are made from a synthetic polymer, with grouted anchor structures. The design of the buoyant hull for full-scale demonstration is a welded fabrication with five arms and tether attachment points. For the Wave Hub demonstration site, Pelastar's mass is circa 1400 tonnes¹³, and supports an Alstom Haliade 150 wind turbine of 6MW rating, upwind 150m rotor diameter, and a direct drive generator. The TLP design is sufficiently generic to enable wind turbines from other manufacturers to be deployed as well.

The mass of the PelaStar™ structure compares favourably against the material weight of a spar foundation, which typically uses 1500 tonnes of steel and 5000 tonnes of ballast for 2.3MW of installed power. The foundations for the different system design approaches have differing anchoring concepts - PelaStar™ has tensioned flexible fibre tethers, and the others having catenary tethers.¹⁴ Catenary tethers have a much larger seabed footprint, which is a disadvantage for array design and navigation. A comparison of the floating wind technology concepts is provided in Table 4 (page 18).

A TLP approach was chosen by the ETI for the project in preference to other floating foundation concepts in view of the TLP's:

- » Low mass and consequent lower cost to make, transport and install
- » Low seaway motions leading to minimal wind turbine adaption being needed to cater for loads due to movement in the water
- » Ability to be assembled on the dockside, thereby improving safety and cost-effectiveness
- » Small seabed footprint, providing greater array design flexibility and lower cost of array cabling and other ancillary equipment

The main disadvantages with TLP designs relate to the risk and cost of novel fibre tension tethers and high vertical load anchors, their installation, and the need to prove their long-term in-service robustness.

For the TLP, the wind turbine and hull assembly and commissioning can be carried out at the dockside quay, using a “float-out and fit” technique. This installation method will reduce offshore marine operations, reducing weather risk and improving safety. Dockside commissioning and testing of the complete wind turbine system allows safe access for staff, which improves the quality of assembly and provides faster turn-around.

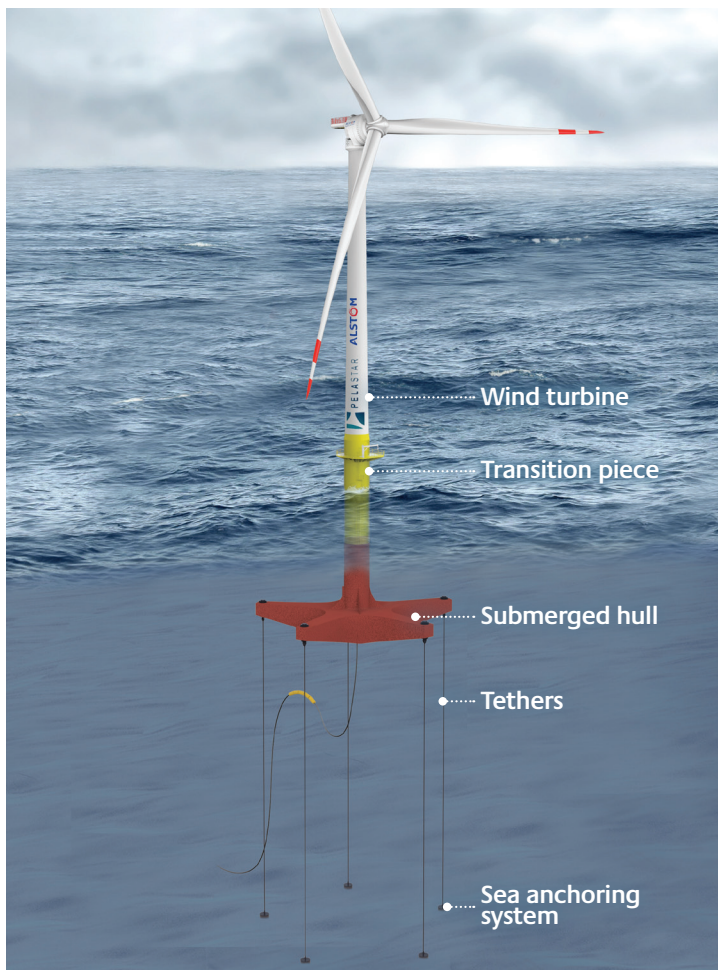
¹³ The Wave Hub test site has wave and water depth conditions that needed a larger hull mass than most UK installations require.

¹⁴ A Catenary Tether follows the shape of a chain if supported at each end, being a hyperbolic cosine. The shape is commonly seen in rope hand-rails.

The Floating Platform System Project Continued »

FIGURE 2

PelaStar™ Floating Offshore Wind System



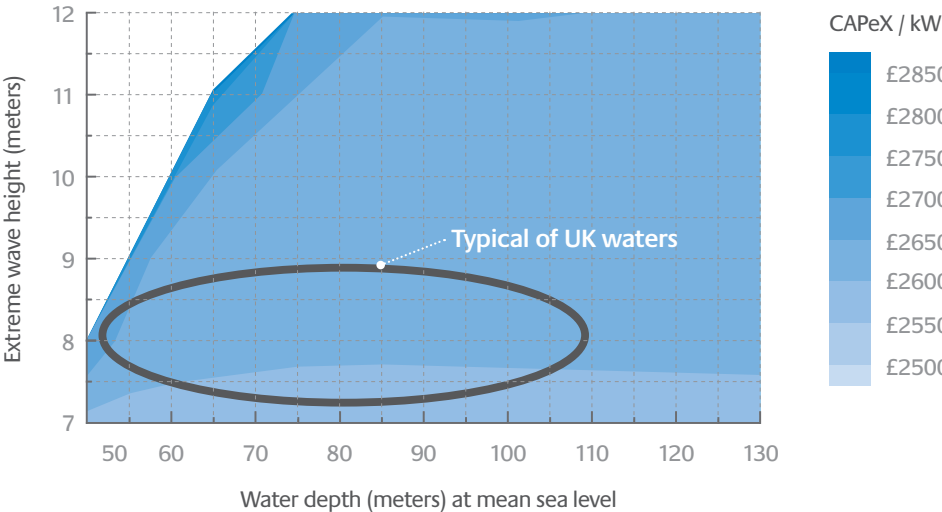
PelaStar™ belongs to the Glosten Associates of Seattle, USA

The hull, tether and anchors have been simplified and optimised, when compared to conventional oil platform designs. 150 different combinations of wave and tidal range conditions typical of UK waters were studied to assess their impacts on risk, design and subsequent costs (see Figure 3). Further work was undertaken to optimise the tethers for service life and robustness, whilst still maintaining cost and supply chain targets.

Figure 3 shows that the capital cost of the PelaStar™ system is broadly insensitive to water depth and wave height; these parameters only have a significant (negative) impact when there is a combination of a low water depth and high extreme wave heights. This is helpful as it delivers the potential for standardised hull designs and hence significantly lower production costs.

FIGURE 3

Variation of PelaStar™ capital costs with wave height and water depth. 80% of potential UK applications are within the ellipse





The Floating Platform System Project

Continued »

TABLE 4

Floating Wind Technology Comparison

	 Tension Leg Platform	 Semi-Submersible	 Spar	 Floater
General arrangement	A submersed buoyant structure held in place by tensioned tethers	Submerged ballasted structures connected to a working platform above wave height	A ballasted structure anchored by catenary tethers	A semi-mobile ballasted structure anchored by catenary tethers
Typical Mass for 6MW (tonnes)	1100	2500	11500	1900
Stability ¹⁵	*****	**	*****	***
TRL ¹⁶ (all applications)	4	7	7	4
Minimum water Depth (m)	>50	50	80	30
Comments	Anchoring system and tether complexity challenges	Active ballasting system complexity adds cost	Installation needs sheltered deep water site, which limits application in UK waters	Often feature dampers for improved stability, which help turbine reliability

¹⁵ Stability means amount of movement due to external forces. Greater stability is indicated by more stars.

¹⁶ Technology Readiness Level is a method of describing technology development maturity

Cost of Energy Uncertainty

A key part of the project was to develop a robust LCoE model for the PelaStar™ system that can be used to provide projections of LCoE variations over time under different roll-out scenarios. It was important in this analysis to include a range of external and technology-related uncertainties. External uncertainties include variations in parameters such as exchange rate, financing costs and wind speed; technology-related uncertainties include variations in parameters such as operations and maintenance requirements, fabrication costs (as a function of system design), installation method and overall system availability.

Figure 4 (overleaf) shows the results of the PelaStar™ LCoE¹⁷ analysis out to 2050, including identified uncertainty ranges.

Of the technology – related uncertainties, the top 5 were identified as:

- » Turbine maintenance
- » Turbine losses
- » Steel costs
- » Turbine availability
- » Platform transport distance

What is clear from Figure 4 is that external factors (i.e. those beyond the control of the system designer) have a very significant impact on overall uncertainty levels.

The analysis has confirmed that with early roll-out of the PelaStar™ technology and with ongoing technology innovation, its LCoE could achieve less than £85/MWh by the mid 2020s, with variations around this value being primarily a function of the location, seabed type and wind resource. These variables impact cost by distance for maintenance, capacity factor, anchoring type and installation method.

New Investments and Developments

The insights delivered by the Floating Platform System project have shown that floating offshore wind technologies are capable of accessing previously inaccessible high wind resources in deeper water (>50m depth) locations around the UK at affordable and competitive costs. It has also shown that the use of existing fixed foundation approaches in shallower water locations (circa 30m) is generally preferable to floating technologies in these situations.

Therefore, the most affordable way of achieving substantial long-term offshore wind roll-out in the UK is likely to be delivered through a mix of fixed foundation systems in shallower waters and the deployment of a variety of new floating platform technologies in higher wind, deeper water locations between 12 and 100km from shore.

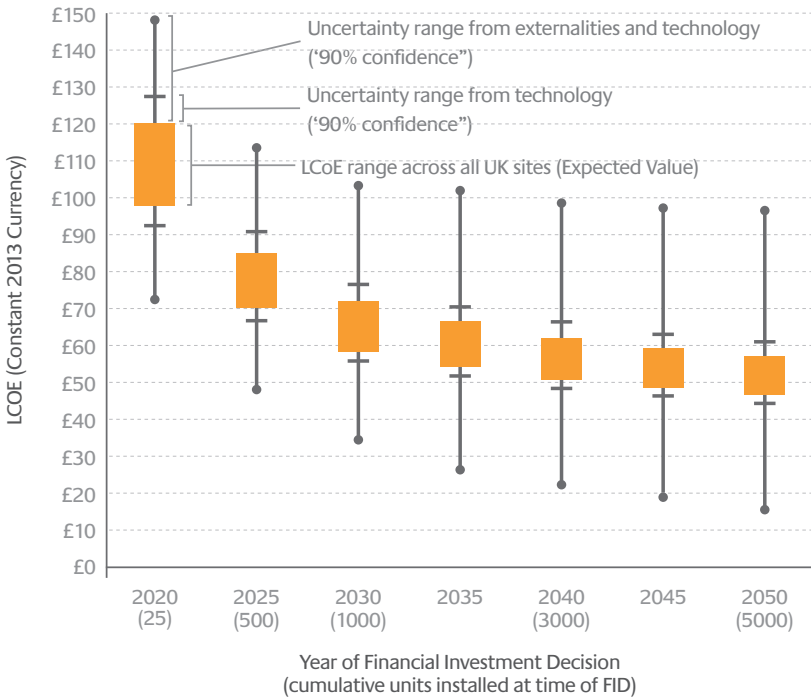
¹⁷ <http://www.eti.co.uk/wp-content/uploads/2014/03/PelaStar-LCOE-Paper-21-Jan-2014.pdf>

The Floating Platform System Project

Continued »

FIGURE 4

PelaStar™ LCoE Forecast for UK Waters out to 2050



Encouraging the development and deployment of floating offshore wind platforms is therefore a key strategic issue for the UK. Demonstration sites are required where identified locations could be used to test floating wind technologies, and then apply them in volume. This is expected to require financial support for the significant innovation investment as there is insufficient revenue from power generation alone to encourage new step-out offshore technologies to be demonstrated at full scale.

Timescales for developing wind farms are long and technology demonstration needs to be included in planning applications at an early stage. For floating wind to start deployment at scale from the mid 2020s, demonstration projects need to be implemented before 2020.

Sites suitable for floating wind can be generally characterised by

- » Having greater than 9m/s average annual wind speed to maximise energy yield
- » More than 40m mean water depth which is close to the economical limit for jackets and current technical limit for monopile foundations
- » Less than 70 - 100km from shore, thereby not requiring expensive High-Voltage DC transmission systems

Example locations that fit within these characteristics include the Irish Sea, Eastern and North Eastern Scotland, North Western Scotland and North Eastern England.

As wind turbine technology advances, and turbine sizes increase, we should see further LCoE reduction of circa 10%¹⁸.

¹⁸ The Crown Estates "Pathways to Cost-Reduction in Offshore Wind" 2013 <http://www.thecrownestate.co.uk/media/5493/ei-offshore-wind-cost-reduction-pathways-study.pdf>

Key outcomes

From Floating Platform System project

Floating offshore wind technology is capable of capturing previously inaccessible wind resources close to the UK shoreline in deeper water locations (PelaStar™ TLP for >50m depth) at affordable and competitive costs

A mix of fixed and floating foundation technologies is likely to offer the lowest cost pathway to delivering mass deployment of offshore wind in the UK in the longer-term

Early roll-out of the PelaStar™ TLP technology, coupled with ongoing technology innovation, could deliver LCoE of less than £85/MWh from mid-2020s

Encouraging the development and deployment of floating offshore wind platforms is therefore a key strategic issue for the UK

Facts and Figures for PelaStar™

£85^{/MWh}

Could be less than £85/MWh Levelised Cost of Energy from the mid 2020s – competitive with other forms of low carbon generation

150m

Based on Alstom Haliade direct-drive 6MW Wind Turbine, with a 150m Blade Diameter

>50m

Suitable for water depths from >50m to many hundreds of metres

1100t

1100 tonnes PelaStar™ mass for 80% of potential UK sites





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