NATIONAL COMPOSITES CENTRE

CATAPULT Offshore Renewable Energy

JOULE CHALLENGE

PHASE 2 SUMMARY REPORT

Project funded by Department for Energy Security & Net Zero

Executive Summary

The UK is a global leader in offshore wind and is home to the world's largest fixed-bottom and floating offshore wind farms. Offshore wind is playing a leading role in the UK's journey towards Net Zero, with over 14GW installed, and over four times that capacity in the pipeline. Volume and turbine size has led to a dramatic reduction in the cost of the technology in the last decade and given the confidence to set ambitious targets to install 50GW of offshore wind, including 5GW of floating wind, by 2030. To deliver this ambition we need strong and sustainable supply chains, which can embrace innovation as we design and deliver the next generation of offshore wind turbines.

Turbines are increasing in height and mass, which is pushing the limits on how we build them today. A new paradigm is required to continue increasing turbine size while reducing costs, creating a huge opportunity for the UK to grow manufacturing capacity and supply chain. Using our existing knowledge and skills in manufacturing light-weight composite parts for the aerospace, marine and automotive sectors, we can deliver a step change in how we design large offshore wind turbines using composite technology. This will create jobs and boost economic impact in the UK, develop expertise and support a growing local market and export opportunity worldwide.

The Joule Challenge is defining the potential for innovative design and manufacturing in composite materials to disrupt the offshore wind supply chain to the benefit of the UK economy.

Funded by the Department for Energy Security and Net Zero, the project has been made possible through the government's £1 billion Net Zero Innovation Portfolio (NZIP), which provides funding for low-carbon technologies and systems.

It has established that lightweighting through composites is feasible and explored the benefit to next generation offshore wind turbines, in particular for floating offshore wind, where weight increases would create significant challenges for traditional turbine structures.

To date the Joule Challenge has conducted concept through to detailed design of composite turbine components including blades, hub, shaft, and towers. The result of this phase showed that the greatest benefit through lightweighting is found in the tower. The design was compared against a baseline steel tower for a 20MW floating offshore wind turbine and provides several significant benefits:

- **60% mass reduction**, increasing the range of sea depths that floating offshore turbines can be installed in, which increases the number of foundation designs which could use this technology.
- **45% reduction** in global warming potential (GWP), lowering the overall environmental impact of the tower through a reduction in raw material.
- **20% reduction** in part costs making the composite tower a competitive alternative to a steel tower, creating a differentiating product that the UK can supply to turbine OEMs.
- **4% reduction** in the levelised cost of electricity (LCOE), helping to ensure that floating offshore wind can provide a competitive solution within the energy generation sector.
- **3% mass reduction** for supporting structures which helps to reduce the cost of the supporting components & overall product cost.

The next step for the Joule Challenge is for the Offshore Renewable Energy (ORE) Catapult and National Composites Centre (NCC) to work with the UK supply chain to continue to develop and de-risk the 'Composite Wind Turbine Tower' – as well as understanding the full range of wind turbine products which can utilise this technology. This will support and develop UK-based supply chain capability to address domestic and international market opportunities.

Contents

Introduction

Net Zero by 2050 is both an exciting and challenging target to achieve for the UK, and opens up a wealth of new opportunities which must be unlocked. Accelerating the transition from fossil fuels depends critically on how quickly the existing renewables market can be developed and upscaled.

Offshore wind plays a critical role in the current and future net zero energy generation landscape worldwide. As an island nation with vast wind resources, the UK is ideally placed to be a lead actor in the development of technologies that unlock low cost and net zero offshore wind energy generation. Key to the UK's success will be to exploit deep water offshore wind, which will be achieved through floating offshore wind (FOW).

By investing in new technology development today to unlock this growth, the UK can become a leader in offshore wind development, and in particular floating offshore wind development. When this technology is expanded into the global market for offshore wind the size of this opportunity becomes truly significant.

Funded by the Department for Energy Security and Net Zero through its Net Zero Innovation Portfolio (NZIP), the Joule Challenge project brings together UK government, industry and academia to stimulate a step-change in technology and manufacturing processes to make the turbines of the future today's reality.

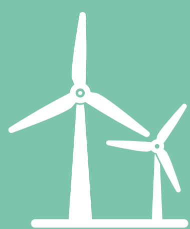
90,000 UK Jobs

By 2030

30,000 UK Offshore Wind Jobs Today

50GW Offshore Wind

By 2030



14GW UK Offshore Wind Today

450GW Offshore Wind

By 2050

60GW European Offshore Wind Today

Overview of Joule Challenge & Phase 2

The vision of the Joule Challenge is to transform the UK supply chain for Offshore Wind by harnessing the full impact of composite materials. It aims to:

- Deliver transformational innovation in the high value manufacturing supply chain.
- Create innovative and sustainable designs for the next generation of turbines.
- Position the UK as a global centre of excellence for composites in offshore wind.

Joule Challenge Phase 2 commenced in November 2021 and concluded in June 2023. The aim of this phase was to assess and compare a vast range of design concepts for composite turbine components to understand those that have the most potential. To support this, Phase 2 had the following objectives:

1) For each turbine component, generate a suite of concepts that might/could decrease the LCoE and/or mass of the turbine;

2) Taking into account CAPEX, LCoE, mass and global warming potential (GWP), downselect the concepts and components to contribute the most to system level benefits;

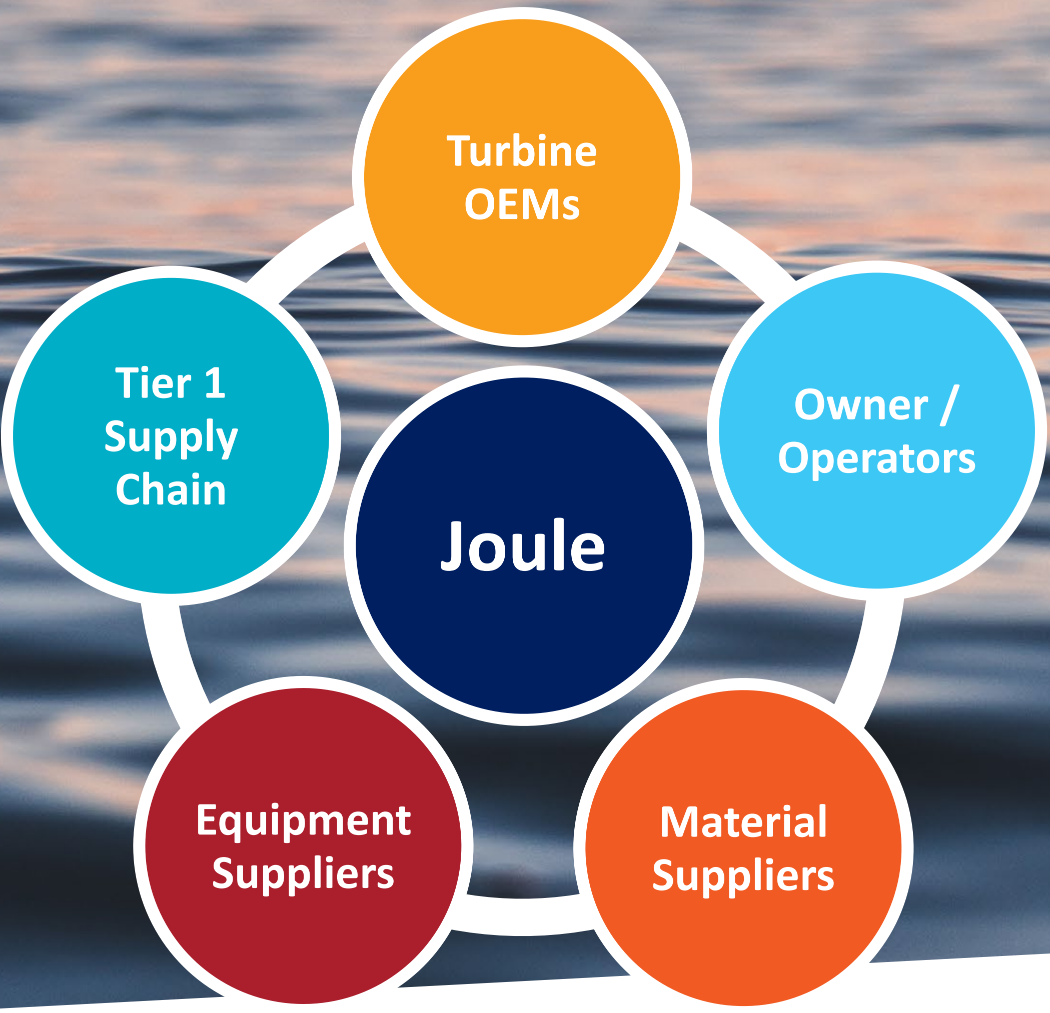
3) Engage the wind industry to align the working practices and project outcomes.

To assess the size of benefit for each of these concepts the Joule Challenge created a reference 20MW Floating Offshore Wind Turbine using traditional manufacturing methods and materials, as seen in Offshore Wind today.

SPECIFICATION	JOULE STEEL BASELINE	
Power Rating	20	MW
Turbine Class	IEC Class 1C	-
Rotor Diameter	270.4	m
Blade Length	132	m
Tower Height	160	m
Total Rotor Mass	580	t
Blade Mass	92	t
Tower Mass	2216	t
Floater Mass	4977	t

Key Outcomes of Phase 2 & Industrial Engagement

New Technology	Lightweight Design	Reduced Cost	Lower Environmental Impact
up to 25	**up to 60%**	**up to 4%**	**up to 45%**
UK Patentable Concepts	Mass Reduction	LCOE Reduction	Lower GWP

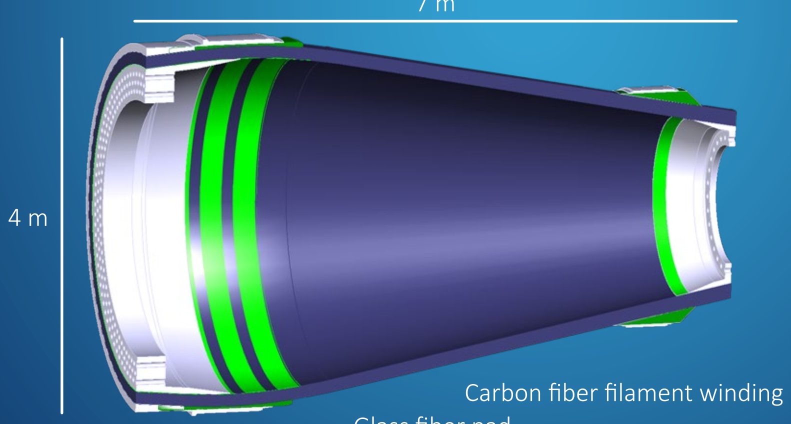


Unlocking our existing UK Supply Chain

Component Design Summary

SHAFT DESIGN

Carbon fibre wound section with integrated steel attachment inserts and bearing seats



Steel Shaft Challenges

Assembly challenges

Load driver for floating structure

Composite Design Opportunities

Composite-led design

Part count reduction

Reduction in Top head mass

Manufacturing Opportunities

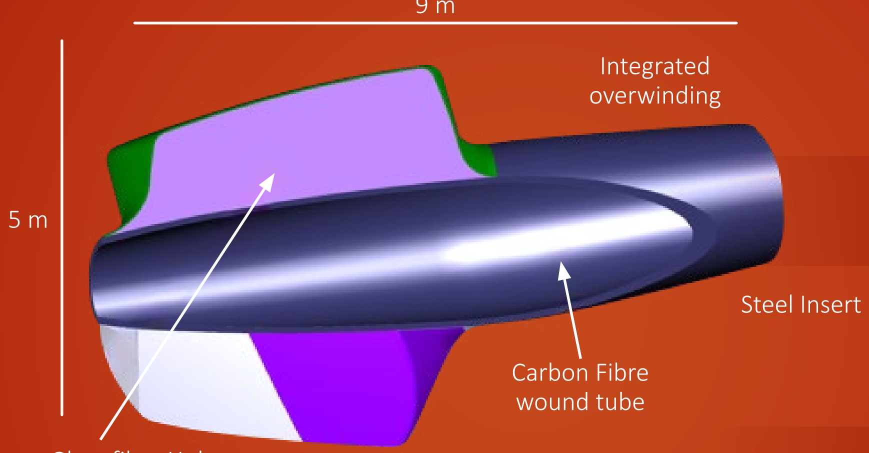
Large structure filament winding

High levels of automation

170 tonnes (Steel Baseline) → 68 tonnes (Composite)

INTEGRATED HUB/SHAFT DESIGN

Carbon fibre wound tube section and Glass fibre hub.
Overwound integration to generate a single loaded structure.



Steel Hub/Shaft Challenges

Challenges

Bolt sizing & space constraints

Component assembly

Load driver for floating structure

Manufacturing Opportunities

Large structure filament winding

Integrated one shot infusion

High levels of automation

Composite design opportunities

Composite-led design

Bolt reduction

Part count reduction

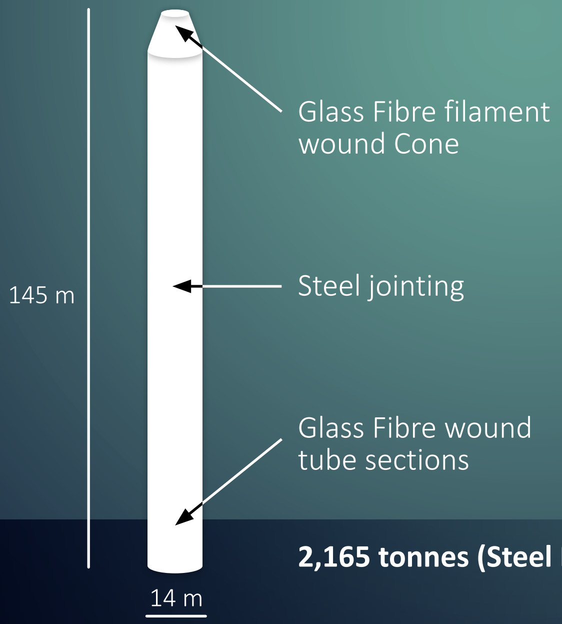
Reduction in Top head mass

312 tonnes (Steel Baseline) → 187 tonnes (Composite)

Component Design Summary

TOWER DESIGN

Filament wound glass tube section with integrated load transmission steel jointed inserts



Steel Tower Challenges

Fatigue & Strength driven
High frequency: beyond 3P
Overweight
Limiting of steel rolling capability

Composite design drivers

Frequency
Material strength (different directions)
Buckling
Joint reduction
Optimised for floating structure

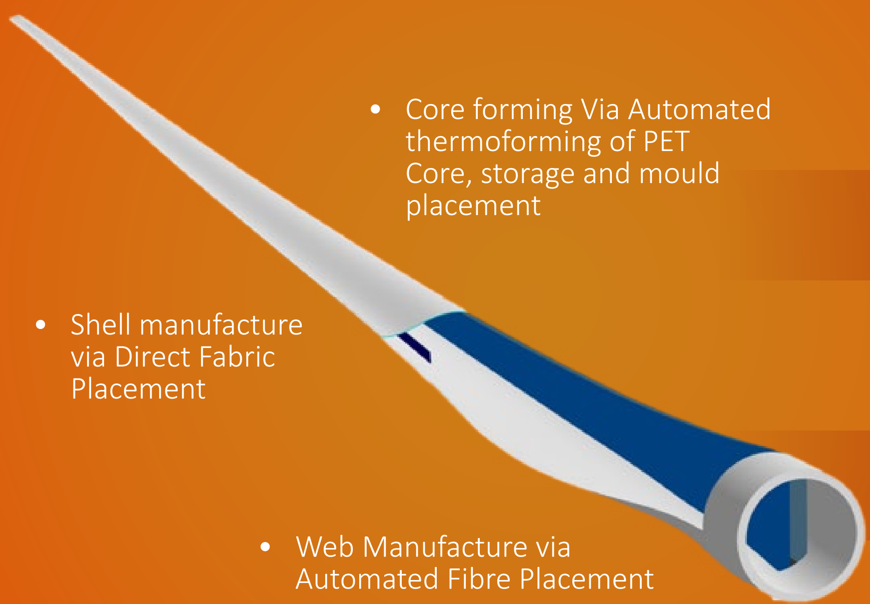
Manufacturing Opportunities

Large format wet tape winding
Large structure assembly

2,165 tonnes (Steel Baseline) → 1,285 tonnes (Composite)

BLADE AUTOMATION

Conventional composite blade construction with several composite automated processes used to replace hand lamination. Also allowing for design, weight and material optimisation.



Blade Challenges

Large length: 132m
Mass: 105t
Long cost of quality rework out of tool
Limited space in tool to 'add more operators'

Composite design opportunities

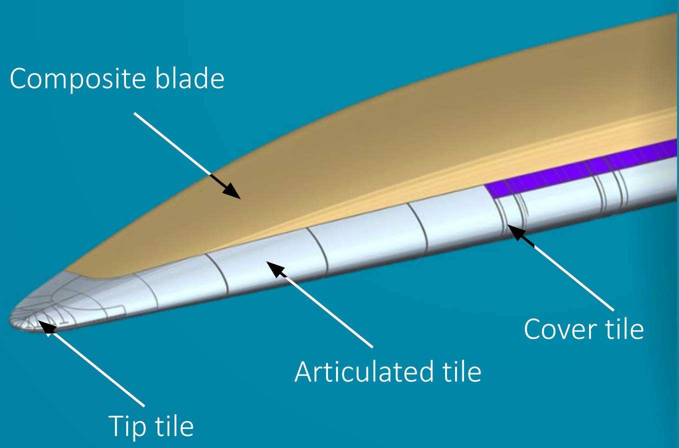
Automation tipping point Drive for 'right first time'
Reducing part to part variability

Automation Opportunities

Automating process with low levels of consistence
Flexible deposition systems to spread CAPEX

Blade Leading Edge Protection Summary

A cold-formed metallic material (Ti-6Al-4V) tile leading edge protection system that is mechanically fastened to the blade composite structure



Conventional LEP Challenges

High level of repair needed

AEP losses due to erosion

Limitation to blade tip speed due to erosion characteristics

Composite Design Opportunities

Design optimisation to reduce number of individual parts/concept CAPEX

Investigation of alternative bonding methods

Manufacturing Opportunities

Sourcing metal sheets and forming processes

3D printing of constituent parts e.g. seals, capping strips, packers

Material Demand Breakdown

From the work carried out to date, a shift from conventional steel structures for large offshore wind turbines to composites could provide a significant opportunity for UK supply chain development, with a huge demand on materials to support the UKs planned growth for offshore wind. This potential to unlock existing capability and aid job creation around the UK is a significant opportunity.

It is worth highlighting that composite components such as a tower would not replace steel towers, but add much needed extra capacity to meet the ambitious deployment targets and improve the resilience of the supply chains. The table below shows the potential demand on composite materials based on UK manufacture of 100 of Turbines per annum:

Masses in Kg.	Glass	Carbon	Carbon pultrusions	Resin	PET Foam	Gelcoat	Adhesive	Steel	Copper	Total
BLADE (A)	52,000	0	13,400	25,200	8,650	1,000	3,250	2,800	130	106,430
SHAFT	1,329	12,153	0	6,272	0	0	5	48.287	0	68.046
HUB	69,259	30,024	0	51,661	0	0	16	36,086	0	187,043
TOWER	740,022	0	0	398.473	0	TBC	0	145,618	0	1,284,113
TOTAL	684.348	42,177	40,200	532,006	25,950	3,000	9,771	238,391	390	1,858,492
TOTAL PER ANNUM (TONNES)	**68,435**	**4.218**	**4.020**	**53,201**	**2,595**	**300**	**977**	**23,839**	**39**	**185,849**

Based on 100 turbine systems per year

Joule Challenge – Next Steps

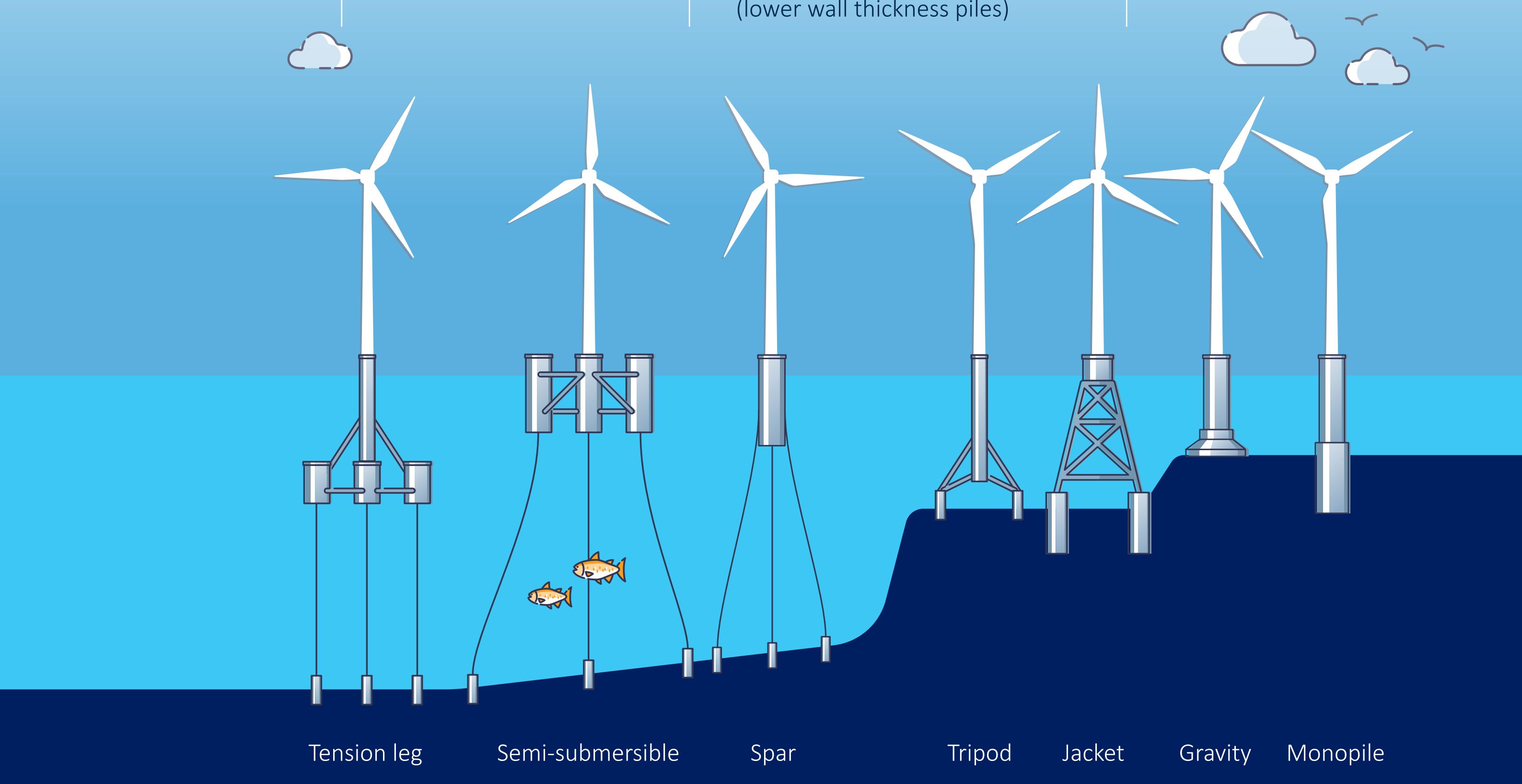
The scope of the Joule Challenge has to date targeted a 20MW floating wind turbine. For floating offshore wind scaling up linearly from current steel designs (e.g. 15MW platform) will become technologically challenging. By introducing lightweight composite materials these changes can help reduce cost and improve sustainability at the biggest/heaviest end of the scale.

To assess this in detail, Phase 2 developed an architecture for a baseline steel and composite 20MW platforms – this detailed system modeling allowed the benefits of cost, weight and sustainability to be directly compared between the baseline steel and composite architectures. As the Tower offers the greatest potential benefit, the next phase of the Joule Challenge, Phase 2B, will focus predominantly on tower technology innovations.

The next phase of Joule will look at the greater potential benefit to be gained for the tower. It will focus on how to unlock a larger portion of the offshore wind market by assessing the potential benefits of the composite tower at a smaller scale. It will identify the impact lightweighting may have on the 'fixed' and 'transition' zones.

This Information will help to assess the true potential size of the market, beyond just floating. Should the benefits be as promising, the investment case for the composite tower will become even more attractive. With an understanding of the true potential for this technology, Phase 2b will be able to provide a quantifiable assessment of the jobs, skills and export opportunity available for UK supply chain.

Depth	**>60m deep**	**60m - 30m medium**	**<30m shallow**
Most Suitable Tech	**Floating Foundations**	**Transition Zone – less exploitable**	**Fixed Foundations**
Technology Benefits	• 60% tower mass reduction • 4% system LCOE reduction • 45% GWP reduction (lower environmental impact) • 20% part cost reduction • 3% mass reduction for supporting structures	Lighter composite tower is a catalyst towards exploiting water depths previously considered less exploitable, because lighter top structure enables: • Shallower floating (less turning motion) • Deeper Fixed Monopiles (lower wall thickness piles)	Size of benefit to be fully understood during current phase of the program, results available Jan 2025.



This image is reference from: blog.dhigroup.com/decode-offshore-wind-engineering-challenges-at-every-stage

About Us

NATIONAL COMPOSITES CENTRE

The National Composites Centre (NCC) is the UK's world-leading research and development facility; where innovators come when they need to make things lighter, stronger, smarter and more sustainable. Its key focus areas are Composites, Digital Engineering, Hydrogen and Sustainability. With access to 'beyond' state-of-the-art technology and the best composites engineering capabilities in the world, the NCC collaborates with customers to solve the most complex engineering challenges of our time.

Part of the High Value Manufacturing Catapult, the NCC works across all manufacturing sectors and has forged strong links with aerospace, energy, defence, space, construction, infrastructure, auto, rail, marine and biomedical. It works with organisations across the board from micro enterprises through SME to disrupters, supply chain and OEMs, providing businesses with a de-risked environment to design, develop, test and scale their ideas and get them to market.

www.nccuk.com **info@nccuk.com**

CATAPULT Offshore Renewable Energy

ORE Catapult was established in 2013 by the UK Government and is part of a network of Catapults set up by Innovate UK in high growth industries. It is the UK's leading innovation centre for offshore renewable energy.

Independent and trusted, with a unique combination of world-leading test and demonstration facilities and engineering and research expertise, ORE Catapult convenes the sector and delivers applied research, accelerating technology development, reducing risk and cost and enhancing UK-wide economic growth.

Active throughout the UK, ORE Catapult has operations in Glasgow, Blyth, Levenmouth, Aberdeen, the Humber, the East of England, the South West and Wales and operates a collaborative research partnership in China.

ore.catapult.org.uk **info@ore.catapult.org.uk**

This project has been made possible through the government's £1 billion Net Zero Innovation Portfolio (NZIP), which provides funding for low-carbon technologies and systems. Decreasing the costs of decarbonisation, the Portfolio will help enable the UK to end its contribution to climate change. For more information please see: www.gov.uk/government/collections/net-zero-innovation-portfolio

Department for Energy Security & Net Zero