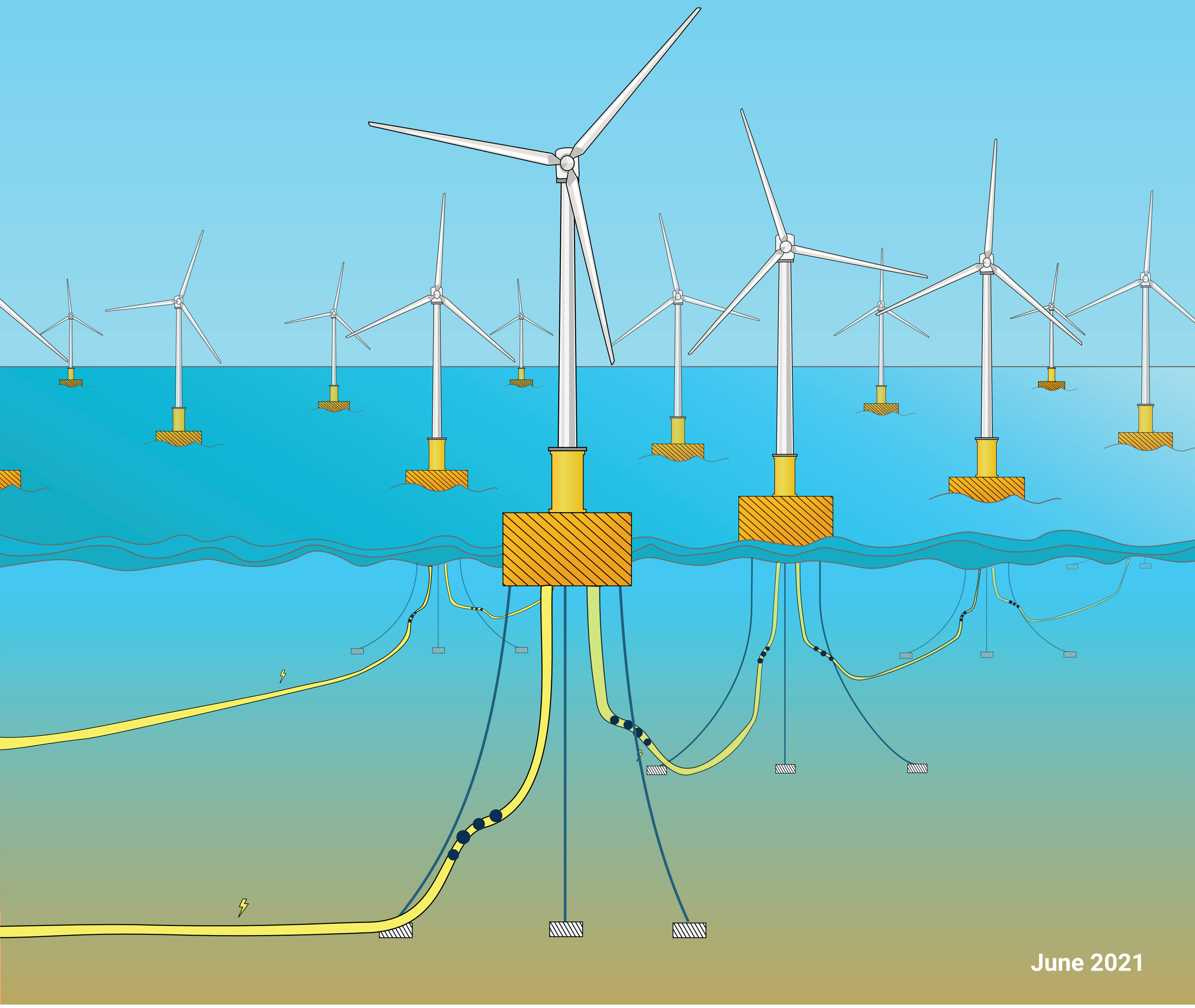
Floating Wind Technology Acceleration Competition

Summary of project achievements



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Acknowledgments

The Floating Wind Technology Acceleration Competition (FLW TAC) was funded by the Scottish Government and managed through the Carbon Trust's Floating Wind Joint Industry Project (FLW JIP).

FLW JIP, formed in 2016, is a collaborative research and development initiative between the Carbon Trust, and fifteen leading international offshore wind developers: EDF Renouvelables, EnBW, Equinor, Kyuden Mirai Energy, Ocean Winds (OW), Ørsted, Parkwind, RWE, ScottishPower Renewables, Shell, SSE Renewables, TEPCO, TotalEnergies, Vattenfall, and Wpd.

The Carbon Trust would like to thank everyone who has contributed their time and expertise throughout the course of the competition, including technical consultants LOC and representatives from the Scottish Government, FLW JIP partners and of course the FLW TAC project teams themselves.

Who we are

Established in 2001, the Carbon Trust works with businesses, governments and institutions around the world, helping them contribute to, and benefit from, a more sustainable future through carbon reduction, resource efficiency strategies, and commercialising low carbon businesses, systems and technologies.

The Carbon Trust:

- works with corporates and governments, helping them to align their strategies with climate science and meet the goals of the Paris Agreement;
- provides expert advice and assurance, giving investors and financial institutions the confidence that green finance will have genuinely green outcomes; and
- supports the development of low carbon technologies and solutions, building the foundations for the energy system of the future.

Headquartered in London, the Carbon Trust has a global team of over 200 staff, representing over 30 nationalities, based across five continents.

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Introduction

The Carbon Trust has over a decade of experience working with the global offshore wind industry, during which time we have developed cross-industry research, development and demonstration (RD&D) programmes to accelerate the development of new offshore wind and unlock cost reductions, and provided expert advice to governments and companies to support their ambitions in this sector.

The Floating Wind Joint Industry Project (Floating Wind JIP) is one of our key RD&D programmes and aims to investigate the challenges and opportunities for the deployment of large-scale commercial floating wind farms. It was established in 2016 and is a collaboration between Carbon Trust and 15 offshore wind developers: EDF Renouvelables, EnBW, Equinor, Kyuden Mirai Energy, Ørsted, Ocean Winds (OW), Parkwind, RWE, ScottishPower Renewables, Shell, SSE Renewables, TEPCO, TotalEnergies, Vattenfall, and Wpd.

In 2019, with funding from the Scottish Government, the Floating Wind JIP launched the £1 million Floating Wind Technology Acceleration Competition (FLW TAC) to support innovations with the potential to overcome barriers to the commercial deployment of floating offshore wind.

This document summarises the competition's objectives and the achievements of the eight projects supported. Summaries of each of the eight projects are available on the Carbon Trust website[1].

Floating Wind in Scotland

Scotland is already a leading market for floating offshore wind, notably home to the 30MW Hywind Scotland project - the world's first floating wind pilot park - and soon to host the world's largest floating offshore wind farm – the 50MW Kincardine project, currently under construction off the coast of Aberdeenshire.

The Scottish Government estimates that between 8 and 11 GW of offshore wind, both fixed and floating, could be deployed in Scottish Waters by 2030[2]. The Sectoral Marine Plan[3], published by Marine Scotland in October 2020, identifies 15 new sites for offshore wind in Scottish waters, several of which contain areas with a water depth of greater than 60 metres – generally considered as too deep for bottom-fixed wind turbines. Projects for these sites, most of which are expected to

[1] Carbon Trust (2021). Floating Wind Technology Acceleration Competition - Project Summaries

[2] Scottish Government (2020). Offshore Wind Policy Statement

[3] Marine Scotland (2020). Sectoral Marine Plan for offshore wind energy

be developed over the next 10 years, are currently being identified through Crown Estate Scotland's ScotWind leasing process[4]. In addition to commercial scale deployment, Scotland is likely to continue to be an important location to test innovations in floating wind, with floating wind demonstration projects under development, including the Pentland Floating Offshore Wind Farm[5], and the Salamander project[6], each of which could be up to 100MW.

The deployment of floating offshore wind will not only help Scotland in meeting its emissions reduction targets, but also presents an opportunity to strengthen Scotland's supply chain. Scotland's experience in the oil and gas sector means many supply chain companies have relevant skills and capabilities which could be transferred to the floating wind industry, for example by manufacturing specialised components for moorings, chains and anchors[7]. The Just Transition Commission, set up by the Scottish Government to make recommendations on how social justice can be embedded into the transition to a net zero economy, has recommended that Scotland should strive to achieve increased local content in Scottish offshore wind projects and support local businesses to diversify into low carbon markets[8].

Floating Wind Technology Acceleration Competition

To stay at the forefront of floating offshore wind innovation, the Scottish Government decided to invest £1 million to support innovations that would overcome key technology challenges, in particular those identified by the Floating Wind JIP which found electrical systems, mooring systems, infrastructure and logistics to be areas with significant technological challenges[9].

The Carbon Trust, in collaboration with the offshore wind developers in the Floating Wind JIP, designed the Floating Wind Technology Acceleration Competition (FLW TAC) to identify, assess and support technologies with the greatest potential to support floating wind development in the following four areas:

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[4] Crown Estate Scotland (2020). Scotwind Leasing

[5] Marine Scotland (2020). Pentland Floating Offshore Wind Farm – Project Applications and Supporting Documentation

[6] OffshoreWind.biz (2021). Simply Blue Energy and Subsea 7 to Develop Floating Wind Project in Scotland

[7] Scottish Government (2020). Offshore Wind Policy Statement

[8] Just Transition Commission (2021). A National Mission for a fairer, greener Scotland.

[9] Carbon Trust (2018). Floating Wind Joint Industry Project – Phase 1 Summary Report

- Challenge 1: Exchanging large turbine components on moving floating foundation structures
- Challenge 2: Disconnection and re-connection of foundation structures, when they are towed to and from ports for maintenance
- Challenge 3: Monitoring and inspection of mooring lines, cables and foundation structures
- Challenge 4: Manufacturing, installation and maintenance of mooring lines and anchors

The competition was open to technologies between Technology Readiness Level (TRL) 3 and 7, and projects could be delivered by organisations of any size and in any location. Applicants could apply for up to £250,000 of grant funding.

The competition was launched on Wednesday 11th September 2019 on the Carbon Trust website. The eight projects selected started in early 2020 and ran until March 2021.

The projects

Eight projects were awarded a share of the £1 million grant funding. Including contributions from the project participants, the projects had a combined total value of £1.5 million.

As well as funding the development of their technical solutions, a key benefit of the competition has been the opportunity to engage directly with offshore wind developers in the Floating Wind JIP, to understand their technology needs and the evidence they require to make decisions on the innovations to include in future projects. However, it should be noted that the publication of this report does not mean that each or any of the developers in the Floating Wind JIP endorse the technologies supported through the competition, nor the companies behind them.

Table 1 provides an overview of the eight projects supported through FLW TAC followed by a short summary of each project's achievements. Executive Summaries for each project are published alongside this report.

Overall, FLW TAC has enabled these projects to further develop designs and, in some cases, manufacture and test prototype products. The projects started with a range of Technology Readiness Levels (TRL) and all made substantial progress over the course of their projects. At the end of FLW TAC, one technology is now a commercial product (Vryhof's Stevadjuster®), whilst others have secured additional funding for larger scale demonstration (Intelligent Moorings and University of Exeter's Mooring Line Dampener) or are actively pursuing opportunities for commercial scale demonstration.

Table 1: Overview of FLW TAC projects

Project Lead(s)	Project Name
Challenge 1: Exchanging large turbine components on moving floating foundation structures	
Conbit	Modular lifting solution
Challenge 2: Disconnection and re-connection of foundation structures, when they are towed to and from ports for maintenance	
Aker Solutions	Splice Box
Challenge 3: Monitoring and inspection of mooring lines, cables and foundation structures	
Fugro, AS Mosley and the University of Strathclyde	Condition monitoring of floating wind mooring lines
Tfl Marine and CSignum	Autonomous mooring line fatigue monitoring
Challenge 4: Manufacturing, installation and maintenance of mooring lines and anchors	
Dublin Offshore	Load Reduction Device
Intelligent Moorings and University of Exeter	Mooring line dampener – Intelligent Mooring System (IMS)
Floating Wind Technology Company (FWTC) and RCAM Technologies	3D-printed concrete suction anchor (3DSA)
Vryhof	Stevadjuster®

Modular lifting solution

Conbit

Conbit's Modular Lifting Solution is a temporary crane which is attached to the nacelle to allow for the exchange of components such as blades or gearboxes.

It addresses the challenges of carrying out heavy maintenance offshore. By attaching the crane to the nacelle, it removes the relative motions between the crane and turbine, enabling safe exchange of components.

Project Summary

FLW TAC funding supported the development of the design of the modular lifting solution and an evaluation of different component exchange methodologies. Throughout the project, Conbit engaged with developers and wind turbine manufacturers to understand the industry's needs and the implication of the design of the Modular Lifting Solution on the design of the wind turbine.

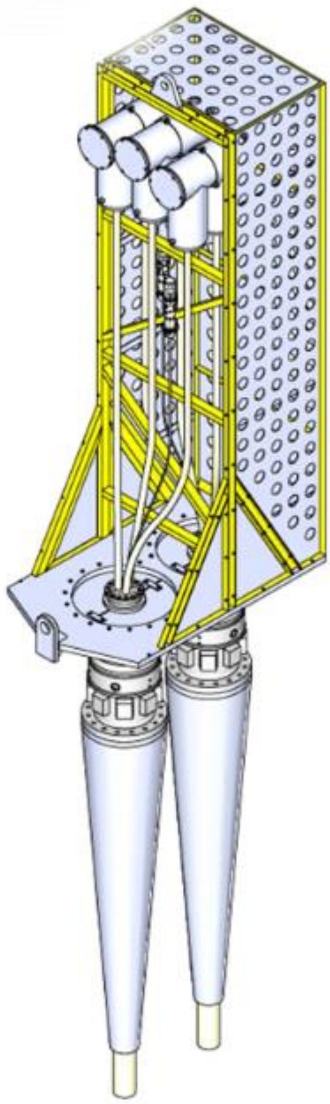
Whilst the design requires further refinement through component and prototype testing, the analysis to date indicates that the Modular Lifting Solution could be a technically feasible solution for floating wind farms.

What did the FLW TAC competition enable the project team to achieve?

"With this award we were able to set up a project team focused on the challenges related to the replacement of major components on future offshore floating wind turbines. It enabled us to develop default models for motion analysis and actually design a feasible methodology to execute major component replacement on future floating offshore wind turbines". **Joop de Fouw, Technical Director, Conbit b.v.**

Splice Box

Aker Solutions



When a floating wind turbine is towed to port for maintenance, the array cables connected to the turbine must be disconnected and protected for the duration of the maintenance. The Splice Box technology developed by Aker Solutions, protects array cables and joins them together to ensure that other turbines connected to the same array cable string can continue to export power generated.

Once disconnected from the floating platform, the two cable ends are joined together in the Splice Box above the water line using a temporary over-the-side work platform (balcony) attached to a light or medium construction vessel. Once spliced, the Splice Box (pictured) would be lowered to the seabed for the duration of the maintenance.

Project Summary

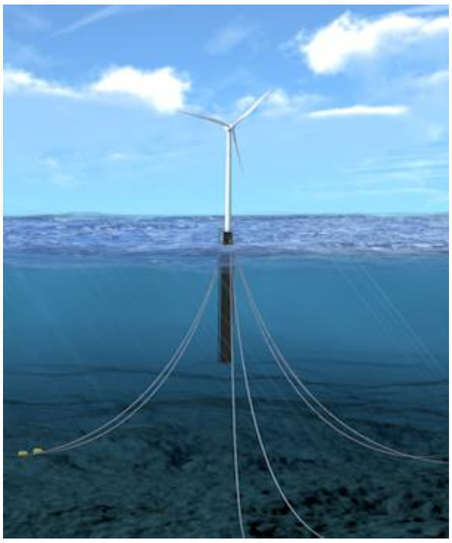
The FLW TAC project supported the development of the Splice Box design, installation procedures and testing of Splice Box components which successfully verified that a watertight seal could be formed between the outer sheathing of the array cable and the surrounding cap, which would be part of the splice box.

What did the FLW TAC competition enable the project team to achieve?

"The FLW TAC competition has provided Aker Solutions with a much broader understanding of the challenges related to floating offshore wind. For the specific project related to the tow to port for maintenance the main enablers have been to utilise existing technology and knowledge, identify gaps and further propose how to close the gaps. Even though there are several more challenges to overcome, the project has been inspiring both with respect to receiving feedback from the FLW JIP team as well to see successful physical testing" **Christian Moe, Study Manager, Aker Solutions**

Condition monitoring of floating wind mooring lines

Fugro, AS Mosley and the University of Strathclyde



Physical inspection of mooring lines requires divers or remote operated vehicles (ROV). With at least three mooring lines per floating platform, this can be a costly, and potentially dangerous, exercise. To reduce the requirement for physical inspections, the project team developed and verified a remote monitoring approach for a floating offshore wind turbine which can track mooring line fatigue. To ensure the solution is cost-effective, the software developed only requires data inputs from readily available sensors which could be fitted on or within the floating platform, namely: accelerometers, gyroscopes and satellite positioning.

The software uses peridynamic fatigue analysis to determine the fatigue life of mooring lines under typical load cycles and how fractures would progress. Peridynamics is a relatively new approach to modelling the response of materials to external forces. The perceived advantage of peridynamics over other modelling approaches is that it can model discontinuities in materials, such as cracks, and estimate how the material will respond over time.

Applied to mooring lines, the peridynamic software was shown to provide not just accurate predictions of the formation of fatigue cracks, but also where and how they would progress to failure. This information could be used in a digital twin system to allow wind farm operators to see when and where damage starts and how it propagates, and develop a less conservative, risk-based physical inspection regime as a result.

Project Summary

The project team developed and tested the peridynamic software solution using modelled data, successfully passing Factory Acceptance Tests (FAT) at the end of the project. The next step is to further demonstrate the validity of the model outputs using real data from floating offshore wind farms.

What did the FLW TAC competition enable the project team to achieve?

"This award enabled us to refocus our extensive experience of fatigue tracking of subsea oil & gas wells towards developing an enabler for the floating offshore wind industry. We have established a specification for a monitoring system solely within the floating unit (i.e., no subsea components) to track mooring line fatigue but which can also detect events and give early warning of failure scenarios. We are now seeking full scale validation of this technology on up-coming floating wind projects." **Stuart Killbourn, Principal Engineer, Fugro**

Autonomous mooring line fatigue monitoring

TfI Marine and CSignum

TfI Marine and CSignum, demonstrated a solution which integrates mooring load sensing, power generation and wireless subsea communications into a TfI SeaSpring to enable autonomous full life fatigue monitoring. The TfI SeaSpring acts as a dampener to reduce mooring line tension.

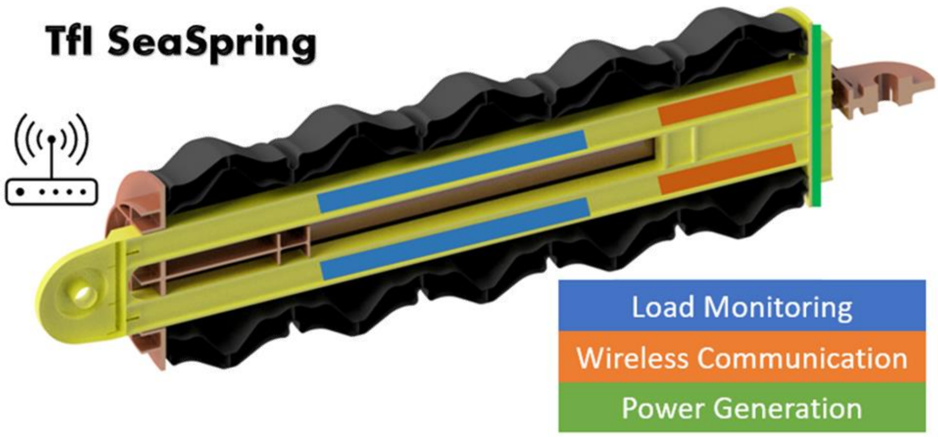
Project Summary

The first phase of the project established the feasibility of incorporating the load sensing technology in TfI's SeaSpring. In the second phase the units incorporating piezo electric power capture and strain gauge load monitoring were manufactured and integrated into a Sea Spring. CSignum provided the subsea communications utilising their HydroFi low frequency radio technology to transmit real-time data from the spring, through the air-water boundary to the topsides structure. The system was tested in the DMaC test facility in the University of Exeter and the LiR NOTF in Cork, Ireland.

What did the FLW TAC competition enable the project team to achieve?

"The funding enabled the accelerated development of the technology. We are now closer to offering this solution to the market, offering reliable long term mooring line load and fatigue monitoring, to help drive down the cost of FOWT" **Paul McEvoy, CTO, TfI Marine**

"Working with TfI on this project was invaluable as it gave CSignum a chance to test and gain valuable data on our solution for Floating Wind mooring line fatigue monitoring which will be used as we commercialise our product for future operations" **Chris Brooks, CEO, CSignum**



Load Reduction Device

Dublin Offshore

The Load Reduction Device (LRD) is a subsea component of an offshore mooring system targeted at the floating wind market. It is fully scalable and tuneable to deliver a cost and design optimised, site-specific mooring response. The LRD is manufactured using established low-cost materials such as steel and concrete which have a demonstrated track record in the marine environment. The LRD is integrated in-line with the mooring system and passively delivers controlled mooring compliance in response to the movement of the floating platform. This dampening significantly reduces mooring dynamic load, delivering cost savings largely through CAPEX reductions on the platform and mooring line systems, with additional project and supply-chain benefits.

Project Summary

The Load Reduction Device has progressed from TRL 4 to TRL 7 over the course of the FLW TAC project. Dublin Offshore first validated the technology through tank testing at 1:60 scale and obtained a Statement of Feasibility from DNV. A ¼ scale prototype (pictured) was installed in an ocean test site off the west coast of Ireland and successfully completed 1,200 hours ocean testing. The technology is now ready to be demonstrated at a commercial scale.

What did the FLW TAC competition enable the project team to achieve?

"The LRD has been demonstrated to be a highly effective and reliable solution to reduce the cost of mooring systems. We were delighted to work with the Carbon Trust, and Joint Industry Project Partners on this breakthrough project." **Darren Hayes, Director of Dublin Offshore**

Mooring line dampener – Intelligent Mooring System (IMS)

Intelligent Moorings and University of Exeter

The Intelligent Mooring System (IMS) is a large diameter braided sleeve surrounding a hydraulic reservoir, which acts as a 'hydraulic muscle' – stretching and contracting in response to external forces - to minimise loads on the mooring system.

Project Summary

During the course of the FLW TAC project, the design progressed from TRL 4 to 5 with development of a detailed design, and successful testing of the IMS at 1:3 (Froude Scale) at the DMAC facilities at the University of Exeter (pictured). Feedback from FLW JIP developers saw the project team change the fabric of the braided sleeve to Dyneema®DM20 – a material which is expected to last the lifetime of the floating wind farm, reducing need for maintenance.

The project team have secured funding to test their mooring line dampener on the Offshore Renewable Energy (ORE) Catapult's Marine Energy Engineering Centre of Excellence (MEECE) test buoy in the Milford Haven Waterway. The mooring line dampener will be tested at an intermediate scale to assess its durability and performance in a real marine environment.

What did the FLW TAC competition enable the project team to achieve?

"Working with the Carbon Trust and the FLW JIP partners provided valuable collaborative input, supporting the IMS technology towards reducing the levelised cost of energy (LCOE) for floating wind applications and accelerating product commercialisation with follow-on funding and sea trials now secured" **David Newsam, CEO, Intelligent Moorings Limited**

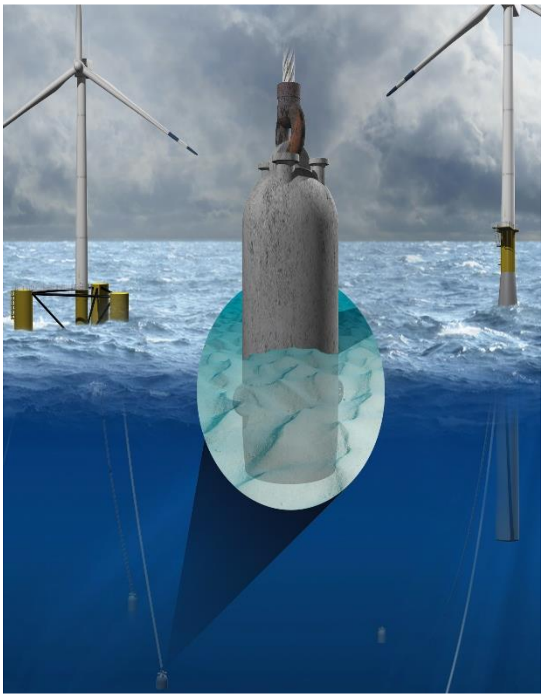
"The project has enabled us to validate the numerical modelling with physical testing to demonstrate the load reduction benefits of nonlinear mooring systems, responding directly to the industry needs." **Philipp Thies, Associate Professor, University of Exeter**

3D-printed concrete suction anchor (3DSA)

Floating Wind Technology Company (FWTC) and RCAM Technologies

Anchors are one of the most expensive elements of a floating wind mooring structure. Typically, steel drag embedment anchors or steel suction bucket anchors are used. There is scope for novel materials and production methods to reduce the cost of anchors. FWTC and RCAM developed a concrete suction anchor which could be produced using 3D printing techniques.

Project Summary



The project developed detailed designs for the 3DSA based on two sites in Scottish waters with different soil conditions, and examined the installation procedure for the 3DSA, including different forms of towing to site. On the production side, key elements of the 3DSA design were printed using concrete 3D printing facilities in the Netherlands. The project also undertook an assessment of the feasibility of carrying out 3D concrete printing of the 3DSA on the quayside of a Scottish port.

The next steps in the development of the 3DSA are to demonstrate 3D printing of a complete 3DSA unit and to test the design in a laboratory and then marine environment.

What did the FLW TAC competition enable the project team to achieve?

"FLW TAC enabled us to devise new solutions applicable to a range of concrete products for Offshore Wind, and in particular to arrive at a complete structural design of a concrete anchor under realistic environmental conditions that now must be proven with dedicated testing." **Rick Damiani, Principal of FWTC**

"The FLW TAC funding gave the team an incredible opportunity to perform the first-ever design, assessment, and proof of concept fabrication of a 3D concrete printed anchor. We project a 75% CapEx reduction compared to steel suction anchors and manufacturing with up to 100% domestic content providing a compelling basis for follow-on development and commercialization." **Jason Cotrell, Founder and CEO of RCAM Technologies**

Stevadjuster®

Vryhof

The Stevadjuster® is designed to be a safer, more cost-effective means of tensioning mooring lines. The Stevadjuster® is designed to be positioned in the lower end of a mooring line, typically as part of the chain which is normally resting on the seabed. One side of the chain attaches the Stevadjuster® to the anchor – this is the passive side. The other side of the chain passes through the device and is connected to the rest of the mooring line and from there to the floating platform. This is the active side. The Stevadjuster® locks the chain in place at the required length or tension. This chain remains locked in place until either the system requires re-tensioning or relaxing.

To adjust the tension, the free end of the active chain is connected to a vessel on the sea surface which pulls the active chain through the Stevadjuster® until the tension increases to the required level and the chain can be locked in the device against fixed chain jaws inside the body.

The subsea chain adjuster removes the need for winches on floating wind platforms and enables vessels to adjust the tension of mooring lines at a safe distance from the platform.

Project Summary

This project accelerated the design, certification and manufacture of a commercial-scale Stevadjuster®. The acceleration of this processed enabled Vryhof to make two commercial sales during the course of the project. One of these is already installed and second is due to be installed by mid-2021.

What did the FLW TAC competition enable the project team to achieve?

"Development of the Stevadjuster® was accelerated from TRL 5/6 to TRL 8 through the FLW TAC, enabling the timely design and production of certified full scale units for marine renewable energy applications, plus investigation of the future commercial potential of the device." **Peter Foxton, Engineering Manager, Vryhof**

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