

FLOATING WIND JOINT INDUSTRY PROGRAMME

Wet Storage Solutions

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WET STORAGE SOLUTIONS (WSS)

Introduction

The Wet Storage Solutions (WSS) project was delivered by a consortium led by Frazer-Nash Consultancy in collaboration with Tadek and Ryder Engineering on behalf of the Floating Wind JIP.

The project investigated the requirements and limitations associated with wet storage of floating platforms and assessed how limiting parameters vary for the storage of these assets in both grounded and moored scenarios. With the expected near-term construction of commercial-scale floating wind farms, the optimisation of space for the storage of the platforms following fabrication and the streamlining of offshore schedules will be paramount to running efficient installation campaigns.

There are limited insights available from the Oil and Gas (O&G) sector due to differences in project scale and the relatively small number of floating platforms deployed. Floating offshore wind farms may involve a substantial number of platforms requiring wet storage, resulting in a significant demand for storage space. The area required also depends on the speed of component fabrication and assembly, including the integration of turbines onto the platforms. While wet storage may offer opportunities to allow for shorter installation campaigns, reducing both capital expenditure (CAPEX) and operational expenditure (OPEX), it may also introduce challenges, particularly in obtaining consent for an additional storage site.

Project objectives

1. Review and identify the various site features that may be favourable for wet storage locations.
2. Understand the limiting conditions to safely wet store floating offshore wind platforms using a grounded solution.
3. Assess the limitations of different mooring and anchor configurations to safely and effectively wet store floating offshore wind platforms.
4. Evaluate potential changes to the design of the floating platforms substructures, with and without integrated turbines.
5. Examine the conditions and the process for obtaining consent for wet storage areas and the concerns of relevant stakeholders in pre-defining these sites.
6. Compare wet storage (grounded and moored) with traditional installation campaigns (installation without considering wet storage) focusing primarily on cost and considering other practical limitations.

Methodology

Scope and baseline assumptions

The project was organised as outlined in Figure 1. A scoping and identification phase was conducted to define the boundaries of the subsequent work. Various sheltered sites globally, including estuaries and bays, were analysed to understand the features of sites that may be suitable for wet storage. Existing requirements, expected conditions and site features were reviewed to develop a detailed list of bounding assumptions for the assessment of wet storage of floating platforms, considering both grounded and moored solutions.

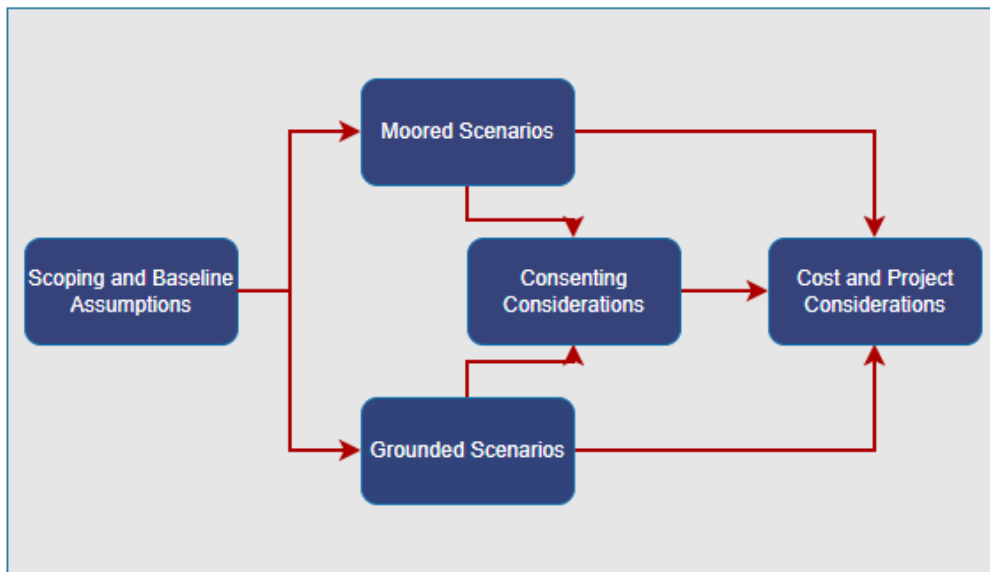


Figure 1. Project workflow

A screening assessment was performed, covering a variety of Floating Offshore Wind (FOW) platform archetypes and locations. This assessment provided clear guidance on feasible solutions across a variety of water depths and environments and supported the identification of scenarios for detailed evaluation in the next phases of the project.

Two archetypes and two sets of metocean conditions were shortlisted with the aim of covering a wide range of sites with varying conditions and water depths. This approach helped inform the feasibility limits of the identified solutions and assess their impact on the system design.

Key features and project assumptions

The key features and assumptions considered in this study are summarised below.

Table 1. Key project assumptions

Feature	Project assumption
Project Size	33 x 15 MW platforms (495 MW Total)
Platform types	Steel semi-submersible and steel Tension Leg Platform (TLP)
Wind turbine size	15 MW (+ 22 MW sensitivity)
Wind turbine position	Centrally mounted
Wet storage solution	Mooring OR Grounding
Duration of wet storage	2 years

Table 2. Representative site conditions assessed

Feature	Site condition
Water depths	Moored: 5 meters (m) + platform draught ('shallow'); and 50 m ('deep') Grounded: range including both fully submerged and exposed
Tidal variation	±3 m
'Benign' site	2 m significant wave height (Hs); 0.5 meters per second (ms-1) surface current; 25 ms-1 mean 1 hr wind at +10 m
'Harsh' site	5 m Hs; 1.0 ms-1 surface current; 30 ms-1 mean 1 hour wind at +10 m
Wave period	3 x periods, capturing appropriate short and long period waves
Wave directions	0, 30, 60 degrees
Seabed inclination	Up to 5 degrees
Soil Profiles	6 x profiles (2x granular, 3x cohesive, 1x rock)

Scenario definition

The scenario definition was divided into two categories: moored and grounded configurations for wet storage, based on the project baseline assumptions outlined above.

Possible scenarios and solutions for the temporary mooring of floating platforms during wet storage were developed. An archetype screening assessment was conducted considering a variety of mooring configurations and systems to understand if they were appropriate or feasible.

Numerical analysis was performed using OrcaFlex¹ to design suitable mooring systems and evaluate the response of platform and turbine combinations. Key parameters assessed included: loading on the platform, mooring anchor design and loading, platform offset, ground clearance, and platform motions. This analysis was conducted using representative metocean and environmental parameters (highlighted in Table 2) to define what mooring configurations may be suitable for wet storage.

In addition, practical considerations were reviewed to inform recommendations for effective wet storage implementation. These included required site footprint, platform features such as mooring connection points, and the implications for installation.

For the grounded assessment, scenarios for grounding floating platforms during wet storage were reviewed and defined. An analysis was undertaken to determine if there were scenarios or requirements where grounding a platform directly on the seabed is feasible and scenarios where seabed preparation, such as setting landing mats or gravel beds, might be required.

A numerical analysis was performed using OrcaFlex and ABAQUS² to evaluate the response of the floating platforms against representative metocean, geotechnical, and environmental parameters, to define when grounding scenarios may be suitable for wet storage. Key to the success of grounding the platform is the stability of the structure as it rests on the seabed, the established landing area required, and the removal requirements. The platform was analysed as a gravity base structure to apply existing standards and gain insights into its response.

¹ OrcaFlex is a software that simulates and analyses the dynamic behaviour of offshore marine systems under environmental loads.

² ABAQUS is a software package used to simulate how offshore structures behave under real environmental and mechanical loads.

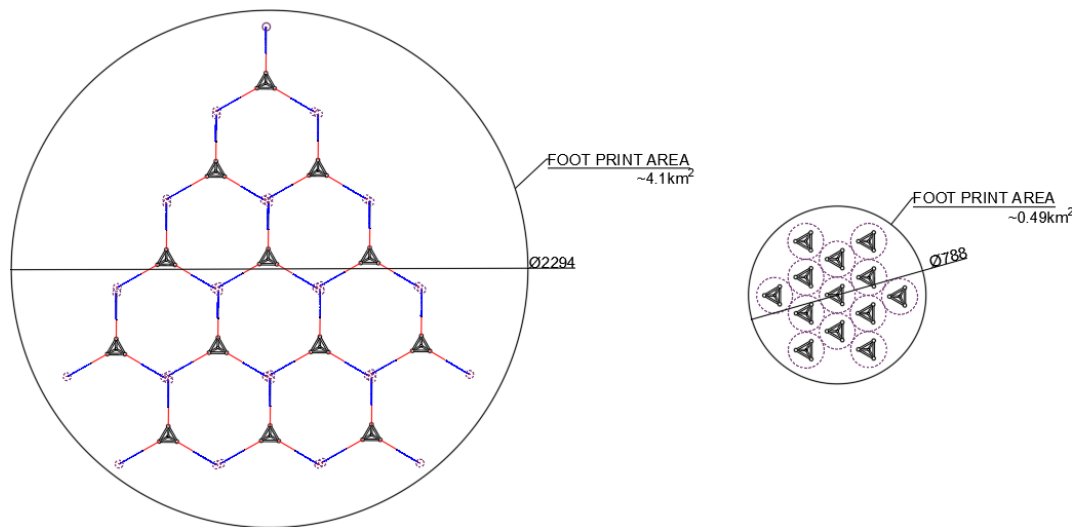


Figure 2. Comparison of space claim between Moored and Grounded Scenarios

Consenting considerations

Consenting is currently a prominent challenge faced across the industry; with wet storage being a novel concept, there is a lack of guidance, or clear precedent, on how to obtain consent for wet storage. A review of requirements was performed for temporary and permanent storage systems based on the current market, novel solutions, and alternative industries.

Following the definition of feasible scenarios for moored and grounded wet storage configurations, industry experts involved in the development of wet storage sites, along with regulatory bodies, were consulted. The engagement helped to understand and define the most likely solutions, balancing technical requirements with potential consenting challenges.

The type of consent needed for these projects is complex. While regulations for offshore wet storage sites may vary between different jurisdictions, a shared objective in all instances is to manage, control and mitigate the environmental effects of the development. However, the differences in regulation, both globally (international requirements) and locally (protected sites, environmental restrictions), can result in a potentially more lengthy and costly consenting process, which can vary greatly depending on which regulatory regime the project falls into.

The main impact from a consenting perspective is related with the repeated use of a wet storage site and the potential challenges and delays of obtaining repeated consent. The project findings and understanding of the project space helped detail the likely pathways for utilising wet storage. This indicated that a 3rd party multi-use site is potentially the most favourable solution, and this assumption formed the basis of the subsequent cost estimation conducted. This solution is considered to comprise a scenario where a single site is owned and operated by an independent owner, who can lease to multiple wind farm operators across a range of projects as needed over time.

Cost and project considerations

The cost and project impacts builds on previous work, which defined various feasible scenarios, to identify the costs that may be incurred by the 3rd party, the wet storage site owner, and the wind farm operator.

A cost model was developed to estimate the potential cost of a wet storage campaign during the construction of a floating wind project. The activities that are likely to incur costs during the development and operation of the wet storage site were identified and categorised into Development Expenditure (DEVEX), CAPEX, and OPEX, as summarised in Figure 3. The total costs were estimated based on the scenarios derived from the numerical analysis of moored and grounded configurations, incorporating various assumptions agreed with wind farm operators.

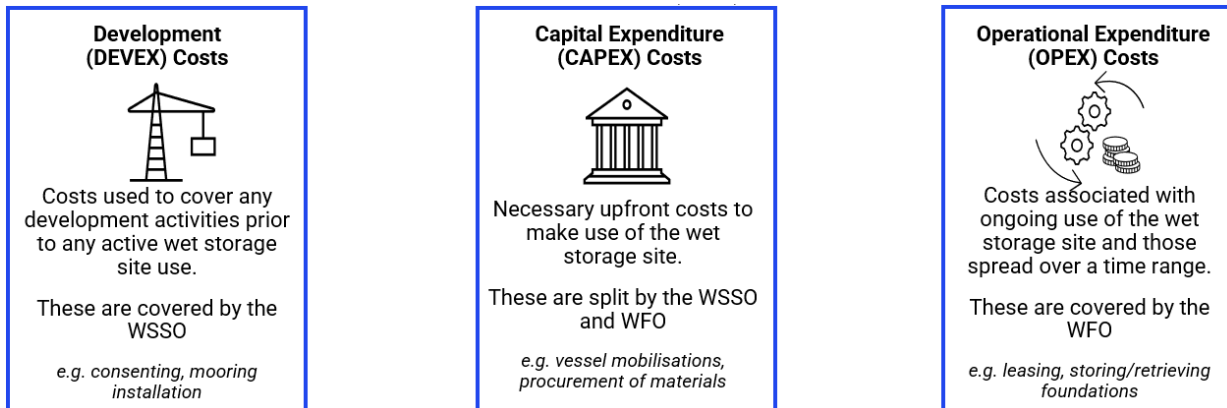


Figure 3 . Definition of DEVEX, CAPEX and OPEX Costs

Practical constraints and limits were evaluated for wet storage of floating platform structures, such as timings and scheduling of the various installation activities and the required capabilities of the various vessels used for installation and retrieval.

A single set of project parameters was selected, which considered the scaling effects from possible increases in both turbine and project size to help understand the potential implications for commercial-scale wet storage. Features such as proximity to port, inspection requirements, maintenance, pre-installation requirements and any decommissioning activities that may be required, were considered. As an output of this activity, practical guidance was developed for Floating Wind JIP members to consider when conducting future projects, based on the perceived and identified challenges of wet storage.

Key findings

1

A multi-use site could alleviate the challenge of repeated consenting on a project-by-project basis.

- A multi-use site will enable a more efficient wet storage location. There is a long lead time for obtaining consent and by using a multi-use site with consent obtained for multiple projects, delays and impacts between projects could be reduced.
- A third-party site owner would enable independent management and a consenting process separate from the wind farm. The wet storage site owner could, for example, be linked to the port, enabling effective installation campaigns and management of leasing costs for both the port facilities and storage.
- The complexities around the multi-use site mean that some logistical and management activities will likely need to be operated by a third-party, allowing for a more streamlined consenting process for wind farm operators.
- The activities associated with a multi-use site might increase CAPEX and annual OPEX costs but could allow for reduced timelines and therefore savings across the whole project.
- The potential time savings provide opportunities for earlier generation to offset the wet storage cost, with increased benefits from more efficient installation schedules over the course of multiple subsequent projects.

2

Feasibility of moored configurations for wet storage may vary across sites, but there is allowance for adaptation and flexibility in design.

- Taut mooring was identified and allowed for a traditional style mooring system, but with high tensions, it would translate into relatively high installation costs. In a site with more sensitive environmental conditions with minimal (no) mooring seabed interaction, a taut mooring represents a simpler, lower-cost system, but with a more complex and expensive hook-up process for each platform.
- Conventional buoy mooring has higher upfront costs but aligns with the 3rd party wet storage site owner plan, as the buoys and ground chains can be owned independently of the tethers to the platform and reused over multiple projects. It also allows for a reduced footprint, which enables more platforms to be wet stored in a given area, and reduced installation tensions relative to taut mooring, leading to lower hook-up costs. The costs of the infrastructure may be higher due to the buoy and chain costs, but the overall costs (including hookup and disconnection) are expected to be significantly lower and hence this is the overall preferred option for mooring.
- Both solutions are versatile and show that various configurations are available for a number of sites and conditions.

3

Grounded solutions for wet storage are less versatile, but offer simpler solutions in specific conditions.

- Grounded solutions are found to be feasible over a variety of water depths, considering a variable ballast of the platform.
- The feasibility of grounded solutions varies across soil types:
 - a. Granular soil has good affinity to grounding, with easy recovery, high soil friction, and good stability over the expected wet storage durations.

- b. Cohesive soil is less suitable with large extraction forces when left in situ for extended periods, but can be mitigated with site preparation, such as gravel pads.
- The suitability of grounded solutions is more dependent on soil conditions than mooring, which demonstrates a highly versatile and flexible design. However, grounding can reduce costs through limited installation requirements and supporting infrastructure.
- All grounded solutions involve some form of water ballasting to different levels. Platforms (if not already) need to be designed to be able to carry out this operation for grounding options to work.
- For grounded storage, site removal and restoration are expected to be minimal due to the limited preparatory works and temporary nature of all structures. Gravel pads can be assessed at the end of their operational life to determine if removal is required or if they have formed natural reefs and become part of the ecosystem, while large scour areas may be filled through dredging if appropriate.

4

There is opportunity for reduced installation timelines when utilising wet storage.

- Assuming a consistent delivery rate (which is dependent on the availability of fully assembled floating platforms from the fabrication facility) for a 500MW project with 15 MW turbines, the results of this project demonstrate that the total installation duration can be reduced by around 25% when considering wet storage, compared to a project where wet storage is not used. This comprises the duration from the installation from the first to the last turbine. Furthermore, when considering the total time from when the wet storage starts to when the final turbine is installed, the overall reduction in duration from using wet storage is around 33%.
- For a 1GW project with the same individual turbine size, the time savings would increase to around 40% for turbine installation, and around 50% of total installation time when factoring in the time spent in wet storage (including the assumed weather downtime), presenting significant savings compared to a traditional project without the use of wet storage.
- A change to the delivery rate of floating platforms from the fabrication yard would impact the required scale of the wet storage site and the platform installation rate, both within the wet storage site and at the offshore wind farm. The changes to delivery rate could be affected by elements such as modular component design and storage options. Dry storage of assembled floating platforms could also be considered, but this would incur additional costs.
- Wet storage allows for overlap with planned offshore installation activities, reducing vessel downtime during off-seasons by utilising the vessels to install floating platforms into wet storage during these periods.

5

Upfront costs can be recovered through leasing fees to multiple developers.

- A 3rd party multi-use site model allows for a portion of the DEVEX and CAPEX costs to be split between wind farm operators. It should also reduce the timeline for projects in the longer term, with reduced delays from installation and decommissioning due to re-use of the same site.
- It also allows for leasing costs to recover the expense of the consenting process and site development. With the increased efficiency of the use of the wet storage site, it should allow for multiple wind farm operators to continuously operate over the years, with each wind farm operator bearing a portion of these costs.

6

Wet storage solutions and sites will require engagement and identification in line with floating wind growth.

- The differences in floating platforms, mooring solutions, environment and location can drive the selection of the ideal wet storage solution and impact the scope of the project.
- With wet storage representing a key phase of the project, it will require individual study and assessment in a similar fashion to installation, transportation or any other project phase.
- Key features such as load points and load paths on floating platforms, and the understanding of corrosion and fatigue over extended periods, will impact the various options and design choices for wet storage.
- Wet storage can work in a range of site conditions, but there are advantages to be realised by selecting the most appropriate location. The key project features would revolve around harbours and locations, defining and driving the scenarios to be considered. These are heavily dependent on the project location globally, but some prominent features include:
 - a. Granular soil would allow for more versatility in both anchoring moored solutions and the grounded scenario.
 - b. The proximity to the port allows for more efficient travel times and can reduce costs.
 - c. The amount of neighbouring marine traffic influences site suitability of the site and impacts on the port, and hence the likelihood of obtaining consent.
 - d. The site selected and any restrictions such as conservation or protected areas as this would significantly impact the consenting process.
- Decommissioning of the wet storage site is assumed to require full removal and the return of the seabed to its original condition, as per the current guidance, unless extenuating circumstances can be demonstrated around damage to the environment, technical feasibility, risk or cost.
- As the size of the wet storage site is small when compared to a commercial-scale wind farm and the operational lifetime is planned for 20 years, full decommissioning is expected to be feasible in line with the development path of current technologies such as vibro-hammer removal of smaller diameter piles.

7

Wet Storage remains feasible with increasing turbine size; however, bespoke solutions will be required.

- The study found that the wet storage concept and identified mooring and grounding solutions are suitable even with increases to the floating platform and turbine size, with only a moderate increase in equipment size required to wet store floating platforms.
- The benefits of wet storage demonstrated for a 15 MW turbine are expected to also be achieved with larger turbines. An assessment conducted for a 22 MW turbine showed that the increased turbine size had a minor impact on loading and mooring configuration. This means that the same schedule efficiencies associated with wet storage can be realised, while enabling greater generation capacity through the use of larger turbines.
- The key challenges include turbine availability and delivery rate, vessel availability for handling the units, facilities for fabrication, assembly and integration of floating platforms and turbines, and the space required for wet storage.

Industry needs/innovations

1

Early identification of suitable wet storage sites and stakeholder and regulator engagement is needed.

- Identification of suitable sites for wet storage, ideally located around hotbed sites, with a high concentration of planned floating wind projects, will require the identification and integration of the following aspects:
 - a. Location: As there is no definitive site selected, this study has considered a range of generic conditions that are intended to be sensible and representative. The definition of a distinct site will impact consenting, site conditions (both metocean and geotechnical), costs, port capabilities, and scheduling. These factors should be identified by wind farm operators and leasing entities, such as the Crown Estate in the UK, when developing offshore wind leasing rounds.
 - b. Floating platform: With a 'generic' steel semi-sub and TLP used for this analysis, the modelling and systems designs in this study are limited in their application. Selection of a floating platform design and the confirmation of archetype and material will provide more information and will likely impact the fabrication requirements and rates, mooring design, grounded scenario definition, wet storage space requirements, integrity management, turbine integration options and handling and installation requirements. The wind farm operators should understand the consequences of floating platform selection. This is expected to allow for more tailored consideration of the design choices and limiting criteria during development.
 - c. Environmental drivers: Due to the variation and growth of floating wind, the expected loads and site properties will vary. The changes to site properties, such as metocean data and water depth limitations, could impact the selection of the wet storage configuration. Seabed data and geotechnics could drive the suitability of grounded solutions, while the maturity of metocean data could provide a different risk profile based on restricted data sets and small sample sizes. This variability could impact the mooring solutions and consequently affect the consenting through impacts such as ground chain scour. This should be considered by the wind farm operators and original equipment manufacturers (OEMs) involved with the project.
- To facilitate the development of wet storage sites, the industry must engage early to understand potential site owners, nearby stakeholders and existing facilities, and to collaborate with the authorities responsible for regulating and managing these sites.

2

The industry needs to establish clear standards and requirements for wet storage assessment.

- The industry should work to develop and align the requirements and standards used to support wet storage with other class societies and international standards bodies, where relevant.
- The wind farm operators and industry bodies will likely need to engage with standards organisations, potentially through working groups. This engagement allows insights from industry experts to inform the development of guidance for wet storage. Such coordination is crucial for the categorisation and assessment of wet storage, as well as for defining the suitability of the design of mooring and grounded solutions.
- Consensus should be reached on the baseline metocean data requirements and load cases to be assessed as part of the wet storage site development. Wet storage should be considered as a key project phase of equal importance to installation and resourced accordingly.

3

Consenting pathways should be further investigated in collaboration with local authorities to enable streamlined processes.

- The consenting pathway for wet storage should be developed in line with local authorities and relevant advancements in guidance. This process should consider both a national and local factors, including environmental, navigational, other users and marine industry.
- Engagement is needed with countries that are leading the development of floating wind, such as France and Scotland, with development of floating wind storage sites such as Port-la-Nouvelle and Moray Firth. This will be valuable to align on recommendations and create consistent practices.
- Engagement with other industries is beneficial to develop an understanding of the legislation relative to consenting pathways for various locations globally across a range of sites and conditions.

4

Design integration with turbine and floating platform OEMs is needed to fully realise the benefits of wet storage.

- Engagement with floating platform OEMs is needed to understand the modifications required to the design of the platform components to allow for wet storage and the practicalities of these changes.
- Floating platform design requirements would be key considerations to discuss with floating platform OEMs, including:
 - a. Floating platform loading due to alternate or adjusted attachment points.
 - b. Corrosion requirements for extended operational life offshore.
 - c. Fatigue loading on key components.
- Turbine OEMs could be engaged to understand the opportunities to install the turbines before removing the floating platforms from wet storage - for both the moored and grounded scenarios -, prior to transport and installation offshore. The benefit would be to make use of existing WTG installation vessels, rather than mobilising huge ringer cranes to remote assembly sites.
- The challenges associated with turbine integration during floating platform wet storage require further investigation due to the additional load that would be introduced on both the turbine and the platform if kept in a parked condition for extended periods.

ABOUT THE FLOATING WIND JIP

The Floating Wind Joint Industry Project (Floating Wind JIP) is a collaborative research and development (R&D) initiative between the Carbon Trust and 17 leading international offshore wind developers: bp, EDF Renouvelables, EnBW, Equinor, Kyuden Mirai Energy, Ørsted, Ocean Winds, Parkwind, RWE Renewables, ScottishPower Renewables, Shell, Skyborn Renewables, SSE Renewables, TEPCO, Tohoku Electric Power Company, Total Energies and Vattenfall.



The primary objective of the Floating Wind JIP is to overcome technical challenges and advance opportunities for commercial scale floating wind. Since its formation in 2016, the programme scope has evolved from feasibility studies to specific challenges focusing on:

- Large scale deployment
- De-risking technology challenges
- Identifying innovative solutions
- Cost reduction

Stage 3 of the Floating Wind JIP commenced in 2022 and projects are expected to run until early 2027. With several commercial scale floating offshore wind farm projects in design phase and having the ambition to be commissioned by 2030, the industry needs to address several challenges. The 17 Floating Wind JIP partners agreed on six research areas where further understanding and advancement is required to reach full commercialisation of floating offshore wind projects.

Electrical systems	Mooring systems	Logistics	Windfarm optimisation	Floating platforms	Asset Integrity and monitoring

The Wet Storage Solutions project addresses the ambitions of the logistics research area:



4

Understand how wet storage will be managed/addressed by the port and the wider industry.

The Stage 3 summary reports can be found here: [Phase I](#), [Phase II](#).



ABOUT THE CARBON TRUST

Who we are

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We have been climate pioneers for more than 20 years, partnering with leading businesses, governments and financial institutions to drive positive climate action. To date, our 400 experts globally have helped set 200+ science-based targets and guided 3,000+ organisations and cities across five continents on their route to Net Zero.

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