WORLD FORUM
OFFSHORE WIND

Onsite Major Component Replacement Technologies for Floating Offshore Wind: the Status of the Industry

World Forum Offshore Wind (WFO)

Imprint
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Cover: Photo courtesy of © RWE AG | Matthias Ibeler. Pictured is a rotor blade assembly at RWE's Kaskasi bottom-fixed offshore wind farm during the construction phase.

Status: February 2023

Acknowledgments

WFO's 100+ members represent the entire offshore wind value chain including but not limited to utility companies, manufacturers, service firms, consultancies and other non-profit organizations.

This document is the result of one year's worth of monthly discussions between participating WFO members during meetings of WFO's Floating Offshore Wind Committee (FOWC) on the topic of onsite major component replacement concepts for floating wind. WFO would like to thank everyone who has contributed their time and expertise during the discussions and interviews carried out for this study.

Disclaimer

The views in this report do not necessarily represent the views of all WFO members but are based on a synthesis of recorded insights undertaken by WFO and the WFO O&M Subcommittee Chairman over the last year. The findings are also designed to serve as a general account of onsite floating wind heavy maintenance concepts and therefore are subject to evolve along with the industry.

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1 Foreword

The importance that O&M is finally taking in floating offshore wind conventions and seminars across the globe is both telling and reassuring.

Telling because there is a real awareness by most commercial-scale project stakeholders that poorly built technical and financial OPEX assumptions could lead to catastrophic consequences given the huge cost impact of O&M over the lifetime of an operating asset. Such consequences range from underestimating the OPEX to overestimating it and bidding a consortium out of increasingly competitive tenders.

Preventative as well as corrective maintenance operations, unforeseen and recurrent ones, large and small, deserve careful anticipation and cannot be easily translated into a simple percentage of CAPEX or revenue. Things will surely evolve once there will be GWs of operational track record to learn from; meanwhile, lessons learned from existing and upcoming demonstrations will be key to building the OPEX models based on real facts and data.

The discussions on O&M issues is also reassuring because it shows how many O&M experts, equipment and solution designers, specialist consultants, etc. are investing enormous time and money to bring new floating-specific ideas to the table, to finetune and deliver a variety of dedicated solutions, and to ultimately solve current and upcoming major maintenance challenges. Their efforts undoubtedly contribute to the credibility of this highly promising industry whilst providing increasingly sophisticated lenders and investors, insurance companies and other public and private stakeholders with more and more peace of mind given the billions at stake.

I once again applaud the efforts of our O&M Subcommittee, its chairman and its most active contributors. This second document they produced illustrates once again how timely and relevant the WFO Floating Offshore Wind Committee's work is and how is sets the stage for a better understanding of our industry's real challenges, not without some valuable suggestions and knowledgeable approaches on how to solve them.

Bruno G. GESCHIER
Chairman of WFO's Floating Offshore Wind Committee
Chief Sales & Marketing Officer of BW Ideol
Chairman of FOWT's Scientific and Technical Committee
Founding Chairman of WindEurope's Floating Offshore Wind Task Force (now Work Group)

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Acronyms and Definitions

WFO – World Forum Offshore Wind
FOWC – WFO Floating Offshore Wind Committee
O&M – Operation & Maintenance
FOWT – Floating offshore wind turbine (comprising the floater and the turbine)
MCR – Major component replacement (alternatively “major repairs”, “major corrective”, “major or heavy maintenance”)
Major component – heavy and large components such as blades and gearboxes
Minor repair/corrective – Maintenance activities not involving a major component replacement and typically only requiring a crew transfer vessel to be present
OEM(s) – Original equipment manufacturer(s)
Offsite / onshore – Designation for onshore conditions. In this paper “onshore” is defined as anywhere at or close to a quayside, i.e. not at the project site
Onsite / offshore – Designation for offshore conditions at the project site (“in-situ” term also used)
OPEX – Operational expenditure
LCoE – Levelized Cost of Energy
DP – Dynamic positioning

1 Summary

Amidst the rapid developments the floating offshore wind industry is experiencing, this white paper intends to build a preliminary classification of floating wind heavy maintenance concept types under development. Through a high-level comparative assessment of assigned crane families and an overarching discussion on strategy considerations, this white paper hopes to inform the decision processes of key stakeholders in the field. The findings from this work feed into the wider discussions of WFO’s Floating Offshore Wind Committee (FOWC), where the insurability and bankability perspective reflects on the challenges of floating wind and the new technologies that aim to solve them. These cross-discipline conversations remind us of the need to balance cost reductions and safety measures to preserve the risk perception of floating wind technologies, especially for the first commercial-scale projects.

2 Introduction

2.1 Context of the offshore wind installation and maintenance market

The increasing global demand for offshore wind is creating new growth opportunities in the offshore wind installation and maintenance market. However, existing installation and maintenance practices are being challenged by the following trends: the need to reduce the levelized cost of energy (LCoE), the growing distance from shore and turbine size of bottom-fixed offshore wind farms, and finally the use of floating offshore wind turbines (FOWT).

At the moment, offshore wind operation and maintenance (O&M) costs are high compared to onshore wind. While the drivers of these costs vary per project (broken down in the first White Paper[1]), they may represent a relevant portion of the overall project lifetime cost. Within offshore wind, floating wind O&M costs are projected to be higher than for bottom-fixed due to the maintenance operation and associated downtime.

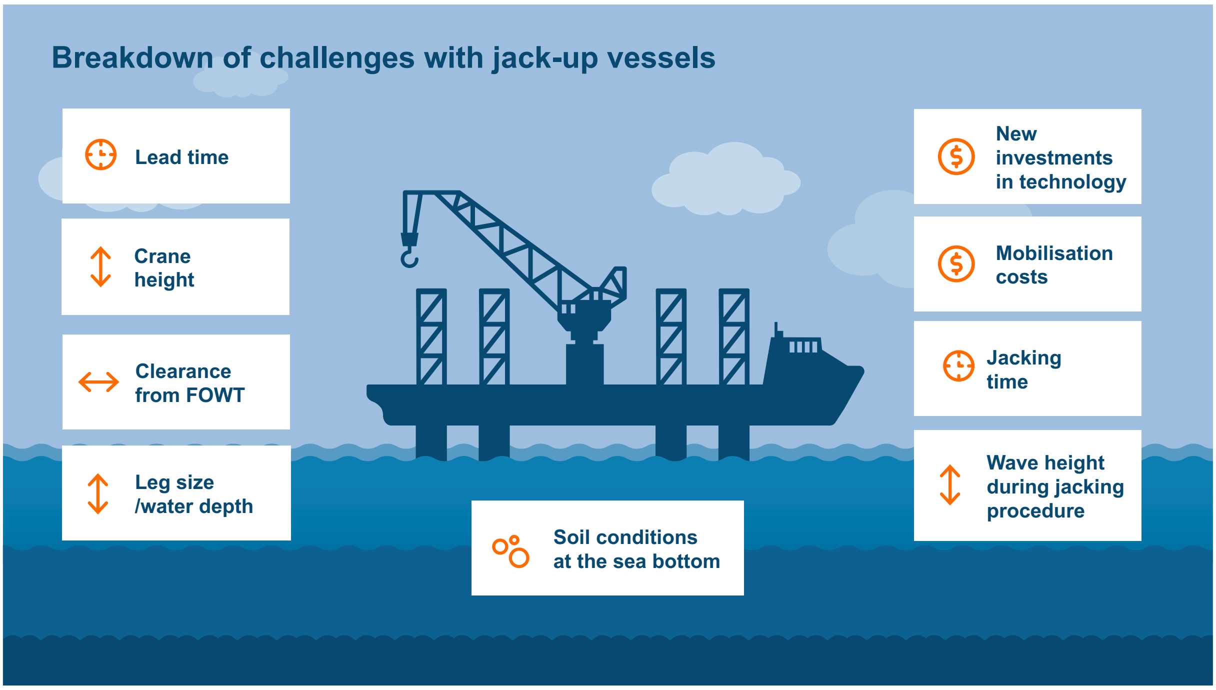

Figure 1. *Breakdown of challenges with jack-up vessels for bottom-fixed and floating offshore wind turbines. Source: PEAK Wind*

The evolving profile of offshore wind farms, characterised by deeper waters and large turbines, are causing difficulties for existing equipment to meet demand. Jack-ups, the predominant commercial option available for installation and maintenance of bottom-fixed wind farms, may not be applicable to new bottom-fixed and/or floating sites due to: crane

[1] For example, weather conditions, distance to port, regional requirements like local content…

height, leg size/water depth, jacking time, wave height during jacking procedure, soil conditions at the sea bottom, and mobilisation costs. For floating wind specifically, the ability to safely set down a jack-up adjacent to a FOWT – in such a case at a workable water depth – may require large clearance between the two bodies depending on the mooring system arrangement (Figure 1).

Leading offshore wind markets are also struggling with vessel availability which can affect project logistics. Some emerging markets in other countries simply do not have a local vessel available for the anticipated installation and O&M activities. These new markets will notably be working with the latest and larger turbine models, further warranting the use of vessel cranes with appropriate lifting height to perform installation and maintenance work.

In addition to the above economic and technical challenges, tendering set-ups are shifting the market from a pure cost perspective to embrace other aspects (e.g. environmental impact, life-cycle assessment, local content). New solutions will therefore have to incorporate these additional requirements.

2.2 Lifting operation categories

For both installation and O&M,[2] the lifting operation can be categorised according to whether the crane support and/or the structure that will support the payload after lifting are either fixed or floating.[3]

- **Fixed-to-fixed** lifting operation, e.g. from a jack-up vessel to a bottom-fixed offshore wind turbine
- **Fixed-to-floating** lifting operation. e.g. from a jack-up vessel to a FOWT at harbor or from a heavy lift crane at the quayside to the FOWT
- **Floating-to-fixed** lifting operation, e.g. from a heavy lift vessel to a bottom-fixed turbine
- **Floating-to-floating** lifting operation, e.g. from a heavy lift vessel to a FOWT

New lifting concepts and tools are being announced across all categories, addressing the installation and/or maintenance requirements of next-generation turbines and new offshore wind markets.

2.3 Floating wind heavy maintenance

Floating wind is a new technology that will help exploit offshore wind energy potential where bottom-fixed turbines cannot. At the moment, only a few projects are in the water, but exponential growth is anticipated in the next decades; the first commercial scale projects

[2] In O&M, specifically major component exchange

[3] COREWIND 2021. D4.2. Floating Wind O&M Strategies Assessment

(200+ MW) are expected to be commissioned in the next 5-10 years, and hundreds of GWs are expected to be online by 2050.[4]

Tow-to-port is treated as the base case for floating wind heavy maintenance. As described in the first O&M Subcommittee White Paper, tow-to-port consists of a reversed-installation process whereby the FOWT is towed to the harbour for repair onshore.[5] The unit is towed by more readily available and relatively inexpensive vessels and then repaired with cranage in onshore-type weather.

The tow-to-port procedure might be complex, long and costly, both in terms of operations as well as downtime. It requires long, suitable weather windows as well as major component replacement (MCR) capabilities at the O&M ports (which is not always the case). These conditions may therefore be unrealisable for certain projects, which is why new solutions for onsite[6] maintenance are emerging. At the time of writing this paper, the industry is experiencing one full-scale operation of the sort at the Kincardine wind farm, where in 2022 the need for major component replacements on two turbines was announced. In this particular case, the order of magnitude for the operation was months, although ideally it should be a matter of weeks if not days.

Performing onshore maintenance in deeper waters[7] means that jack-up vessels cannot be used. As such, floating-to-floating lifts or alternative technologies like add-on cranes used in onshore wind are required. Solutions under development aim at overcoming the following challenges:

- The **lifting height** challenge first mentioned for next-generation bottom-fixed is also applicable to floating wind. There are not many cranes in the world capable of performing the lifts at the required hub heights (over 150m).
- The **availability of onshore cranes** for installation and/or maintenance at the quay is already a constraint. Preparing the quayside could be a challenge in terms of long lead times and high mobilisation costs for a crane (spot market or ports-own). In addition, bringing the turbine to a capable crane can involve long towing and downtime.
- The **availability of fit-for-purpose vessel cranes** that could perform similar operations is also a constraint. The global supply chain capacity for existing and new technologies needs to be able to keep up with the industry’s growth, both in terms of lifting height/weight and number of units.
- **Relative motions experienced in a floating-to-floating lift** or the **swinging motions experienced in an add-on crane lift** add to the lifting height challenge. The nature of a floating-to-floating operation is exposed to many relative degrees of freedom depending on the type of coupling.
- **Weather windows** are therefore extremely sensitive to onsite maintenance when considering the wind and wave impact as well as the distances of the wind farm from shore.

[4] DNV estimates more than 264 GW by 2050.

[5] In this paper, “onshore” or “offsite” is defined as anywhere at or close to a quayside, i.e. not at the project site.

[6] Designation for offshore conditions at the project site (onsite). “In-situ” term also used.

[7] As discussed in the WFO Floating Offshore Wind Moorings Subcommittee, shallow waters are considered to be 60m-200m deep; mid-water depth 200m-350m; deep waters usually +1,000m deep. The largest jack-up vessels under development are planned to work in 80m water depths.

- The **diversity of floating wind concepts** makes it difficult for crane suppliers to understand what designs they should come up with to serve the market. As the industry matures, selected floater designs will be likely to dominate the market, which will clarify the supply chain needs including those for installation and maintenance.

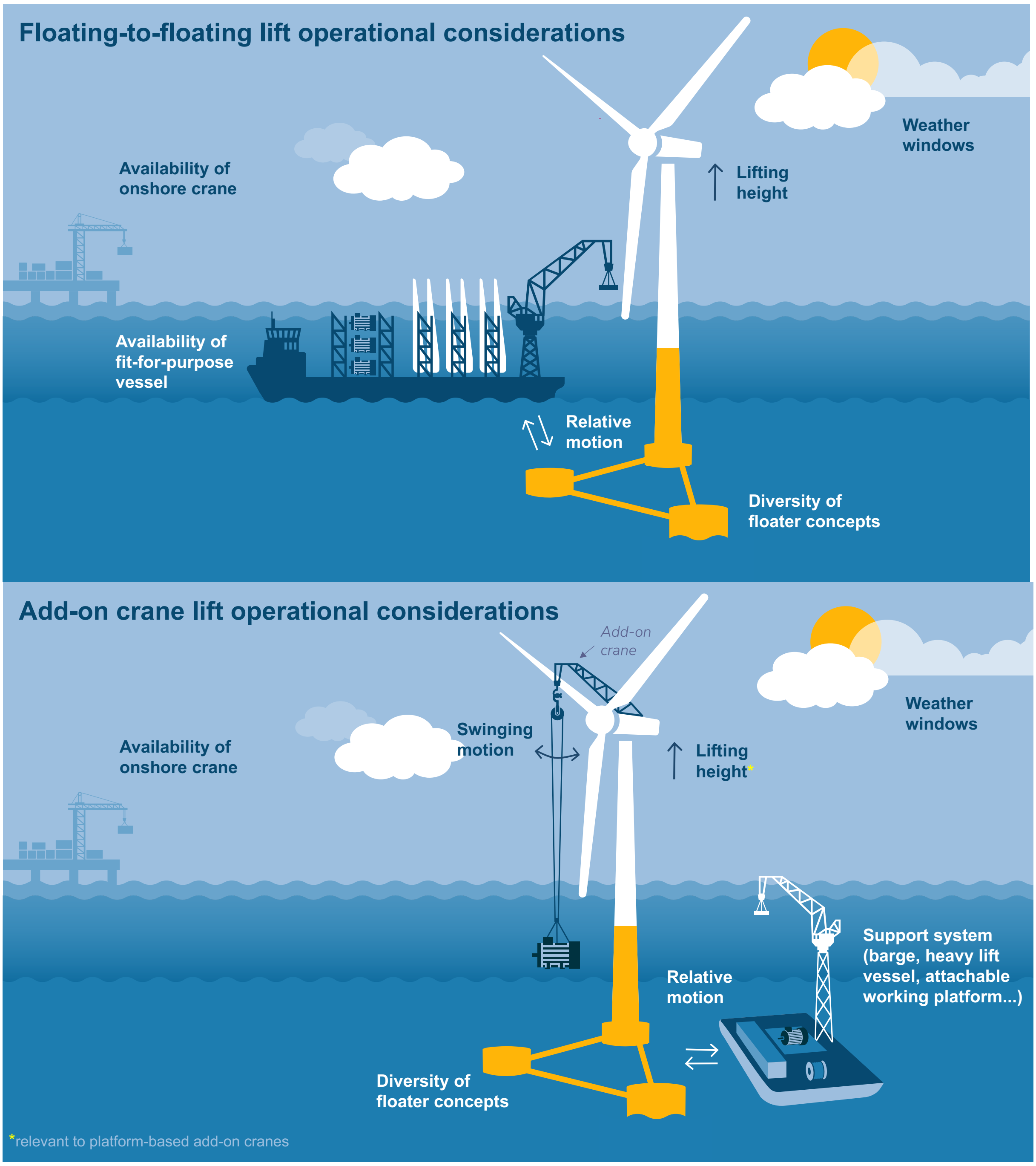

Figure 2. *Operational considerations for a floating-to-floating lift (top) and an add-on crane lift (bottom). In an add-on crane maintenance scenario, a support system transports the add-on crane parts and the spare components. Different concepts can vary strongly in what the support system looks like, hence the generic representation in this figure. Source: PEAK Wind*

As we are still in the demonstration & pre-commercial phase of floating wind technology, suppliers of onsite maintenance concepts are either 1) in the early design and validation phases of new solutions or 2) monitoring the market (e.g. discussing with project developers, identifying which floater concepts to serve, waiting on additional government confidence and/or funding opportunities). The many unknowns in the market are expected in part to be solved by “first mover” decisions -- suppliers that roll out new concepts first, announce testing initiatives on a floating wind demonstration etc. Right now, a mix of established players in the heavy lift space and new, smaller companies are designing solutions.

3 Concepts Overview

3.1 Add-on cranes for floating wind major component replacement

Add-on cranes are placed on the FOWT and perform the major component replacement from the unit. Two types of add-on cranes can be identified based on where the crane is secured: tower-based add-on crane (the crane is equipped to the tower) or platform-based add-on crane (the crane is equipped to the floater).

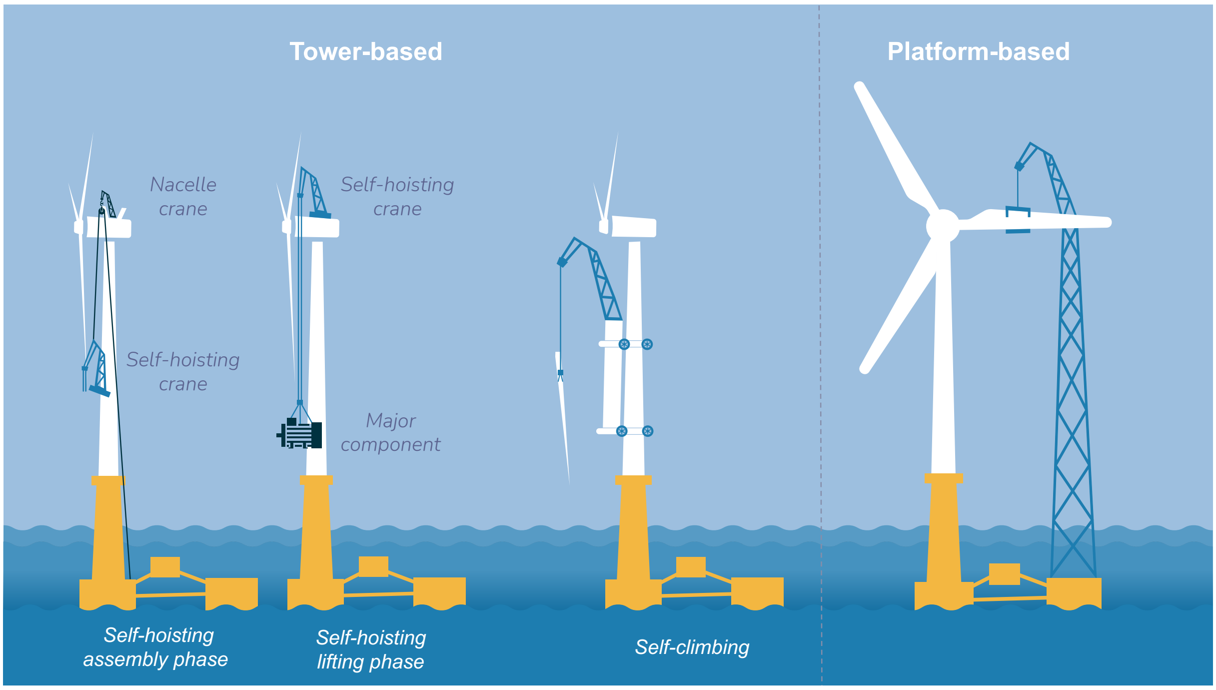

Figure 3. *Generic visual of two types of add-on cranes: 1) tower-based with 1)a) self-hoisting crane and 1)b) self-climbing crane and 2) platform-based. Source: PEAK Wind*

3.1.1 Tower-based add-on crane

a) **Self-hoisting**: Self-hoisting cranes are installed by using wires attached to the nacelle. They have the ability to crawl via those wires from the base station on the ground (or vessels for offshore applications) up to the nacelle and conduct lifting operations of large components, lowering the impact of motion restrictions and wind speeds.[8] Usually, a pre-installed smaller crane at the nacelle is used to lift the parts of the larger self-hoisting crane sequentially.

b) **Self-climbing**: Self-climbing cranes are adapted to the tubular steel tower and are able to climb up to the nacelle. From there, the lifting operation of large components (like blades) to/from the ground or barges can commence.[9] The lifting mechanism can be a

[8] COREWIND 2020. D4.1. Identification of floating-wind-specific O&M requirements and monitoring technologies

[9] COREWIND 2020

brace that secures itself around the tower, or a system that attaches itself directly to the tower using pins. In addition to doing heavy maintenance, self-climbing cranes can be used to assemble a turbine's modular components in a sequential manner.

3.1.2 Platform-based add-on crane

A platform-based add-on crane is secured on an area of the floater. An area of the floater could mean the column or between two columns for a semi-sub (Figure 3), or somewhere on the barge. Ballasting mechanisms are employed to counter the altered distribution of weight from the lifting tool and preserve stability. In the examples witnessed by WFO's Floating Offshore Wind Committee (FOWC), the lifting equipment can either be a crane or a tall framework equipped with a blade handling tool or crane addition at the top.

The first White Paper published in 2021 originally identified tower-based technologies as the only form of add-on crane maintenance. Platform-based concepts have since then emerged, thus widening the definition. We can therefore expect this categorisation to continue to evolve as new solutions come up.[10]

Table 1. *Advantages and challenges of add-on cranes (tower-based and platform-based)*

Advantages	Challenges
▪ Eliminates relative motions for the major component exchange ▪ Tower-based cranes use the tower to achieve height ▪ Use standard heavy lift vessels for transportation and lifting of crane and turbine components ▪ Free up port pace by performing maintenance offshore ▪ Address potential serial defects more effectively (key for large floating wind farms)	▪ Crane hook swinging motions due to floater displacement ▪ Transferring crane and turbine components from the vessel/barge (or similar) to the FOWT - additional risks - weather window sensitivity ▪ Adaptability to different floaters and turbines ▪ Automated aspect that requires built-in redundancy ▪ Question of liability in case of turbine accident/damage

In terms of track record, some of the add-on lifting concepts have already been used in the onshore wind sector and now have intentions to serve the offshore market as well.[11] Newer technologies like those that were explored in the O&M Subcommittee are being developed explicitly for offshore applications and are in the early design phase.

[10] Already, we know of "out-of-the-box" concepts like the Skylifter, a solar electric air-crane that aims to perform maintenance of nacelle components and blades.

[11] For example, Liftra is a company that develops add-on cranes for onshore wind major component replacement. Recently, its LT1200 self-hoisting crane performed a successful offshore major component replacement operation on a 3 MW turbine at the Swedish lake Vänern.

3.2 Technical considerations for add-on cranes (tower-based and platform-based)

One of the main opportunities of onsite maintenance in floating wind is the reduction in downtime and ultimately costs by using one crane (add-on or vessel crane) to service multiple floaters on a wind farm rather than towing individual floaters back to port. This is a key benefit for larger wind farms that risk experiencing multiple defects.

Nevertheless, there are some important design elements to consider that would make an add-on concept compatible with a floating wind farm:

- **Hook-up/hang-off points** on the tower and/or nacelle to secure add-on crane elements to the turbine.
- **Nacelle crane compatibility** to perform the preliminary lifts to assemble a tower-based crane. For example, the small nacelle crane could first assemble the elements of a medium crane, and the medium crane could finally assemble the parts of a larger crane that can perform the MCR (from the nacelle).
- **Base plate compatibility** to be able to secure any transition piece that could host the platform-based crane on the floater.
- **Access to the tower** to equip elements of the tower-based cranes from the supporting vessel or the distance between the platform-based crane and the turbine all depend on the floater design.
- **Landing zone space** by nature of the floater to accommodate components directly on the deck or by use of an additional platform that is attached to the floater (e.g. working deck, blade rack)
- **Ballasting** as provided by the floater alone or with additional tooling that would minimise floater ballasting to support the lifting operations (e.g. counter-weights).
- **Support vessel** used to transport and lift the add-on crane, major components and additional equipment. Could a standard heavy lift vessel be used? Or does it have to be a bespoke vessel design?
- **Motion compensation** used on the crane line and supporting vessel, to counter swinging and relative motions
- **Control system** to ensure full automation of the operation and levels of redundancy

These considerations must be included early in the design phase of the project, for both the turbine and the floater. For the turbine, this implies a different approach to design from bottom-fixed turbines (which are serviced by jack-up vessels). For the floater, focusing on select platform concepts would help clarify the design elements of an add-on crane solution (amongst many other supply chain requirements like mooring components). For example, the space available on the platform for any add-on operations as well as the field layout and cable/mooring routing are FOWT characteristics impacting the major maintenance approach.

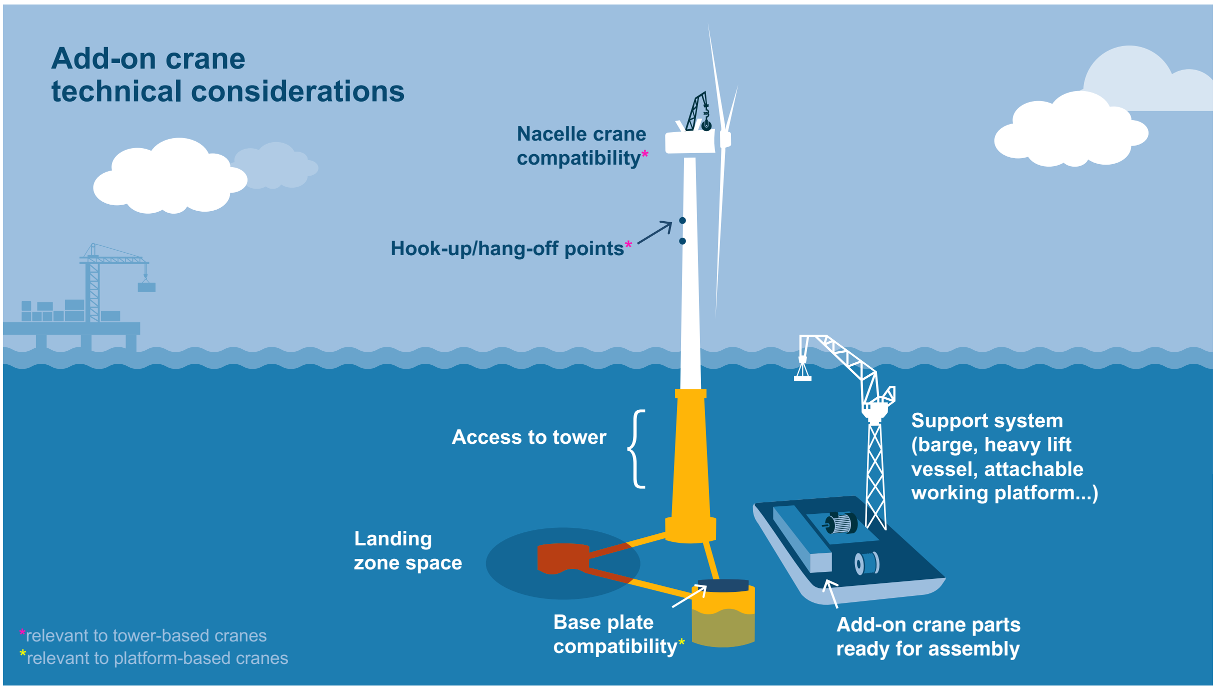

Figure 4. *Add-on crane technical considerations (tower-based and platform-based). The base plate compatibility is relevant to platform-based cranes and the nacelle crane compatibility plus hook-up points are relevant to tower-based cranes. Source: PEAK Wind*

3.3 Vessel cranes for floating wind major component replacement

Vessel cranes would be used in the floating-to-floating lift scenario. These are equipped with cranage that can transfer components to and from the FOWT directly. The lifting operation needs to be efficient, quick and operate directly by the floating wind unit.

Three main types of heavy lift vessels used in the offshore wind industry could also be considered for floating wind:

1) **Semi-submersible vessel**: In the energy sector, semi-submersibles have first been used to transport and lift offshore oil & gas platform parts. Existing models have been used for the installation of both bottom-fixed and floating wind turbines. However, these vessels are in short supply, expensive, and over-dimensioned in terms of lifting capacity. Offshore wind-specific models that are fit for the weight and height requirements of turbine lifts are under development.
2) **Mono-hull heavy lift vessel**: Existing models are used for the transportation and installation of bottom-fixed offshore wind turbines. Potential applications to floating-to-floating lifts were discussed but are not straightforward.
3) **New generation jack-up vessel**: New concepts are being developed for the next generation of offshore wind turbines. These vessels have longer legs to reach deeper depths as well as higher cranes to perform lifts at the nacelles. There is an opportunity for these vessels to be employed for floating wind sites in the shallowest waters (60m-

80m). Jack-up vessels[12] could also be used to service floating wind turbines outside the port (after an initial towing operation). This could be a solution for ports that do not have an onshore crane.[13]

3.3.1 Advantages and challenges of vessel cranes

The main advantage of vessel cranes is that they are a **mobile solution** that can perform the maintenance of **both bottom-fixed and floating wind turbines**. There is already a **track record of applications** for fixed-to-fixed, fixed-to-floating, floating-to-fixed[14] and recently floating-to-floating lifts.[15] However, suitable vessel cranes for floating-to-floating lifts are currently **not available or under development** with expected **high rates.** There are also **relative motions between the floater and the vessel** as well as **accentuated variable motions with a higher crane reach**.

To solve the problem of relative motions, **dynamic positioning**[16] (DP) and **motion-compensated systems** can be equipped to the vessel and crane respectively. Equipping a vessel with DP can compensate for its horizontal drift (surge, sway, yaw motion). Three-dimensional motion compensated offshore cranes can be used, although they will have to address the lifting height, outreach and maximum load requirements[17] for floating wind heavy lifts. To the forum's knowledge, there are developments along this line; the design of motion compensated cranes is currently being upgraded to actively bring the load into motion in order to follow any movements of the FOWT.

Rather than a fully compensated crane, active and passive motion compensation tools can be attached to the vessel's crane hook to control the heave movements of the lifts. Unlike motion compensated cranes that are fixed to the vessel, active heave compensation tools are rented as standard or tailor-made products. Other innovations, e.g. the stability frame equipped to the floating vessel crane for the installation of Hywind Scotland, can be applied to enable floating-to-floating lifts from existing vessels.

[12] A jack-up vessel solution was mentioned specifically by ABP in their development plan of Port Talbot. In addition, one stakeholder mentioned the use of a floating sheerlegs crane vessel for maintenance by the quayside.

[13] DNV presentation at Floating Offshore Wind 2022 conference in Aberdeen: DNV performed a cost analysis for major component replacements with different methodologies: tow-to-port to an onshore crane (crane spot market or ports own crane); using a jack-up vessel; using a floating vessel.

[14] COREWIND 2021. D4.2. Floating Wind O&M Strategies Assessment

[15] FOWT assembly of the Hywind Scotland spars with a floating crane vessel in sheltered waters near the quay

[16] Dynamic positioning: Computer controlled system that compares real-time GPS (global positioning system) location data with desired position of vessel set by helmsman, and takes control of all vessel propulsion to pilot the vessel to desired location and maintain it there against currents and wind drag. Baldock et al. (2014).

[17] COREWIND 2021. D4.2. Floating Wind O&M Strategies Assessment

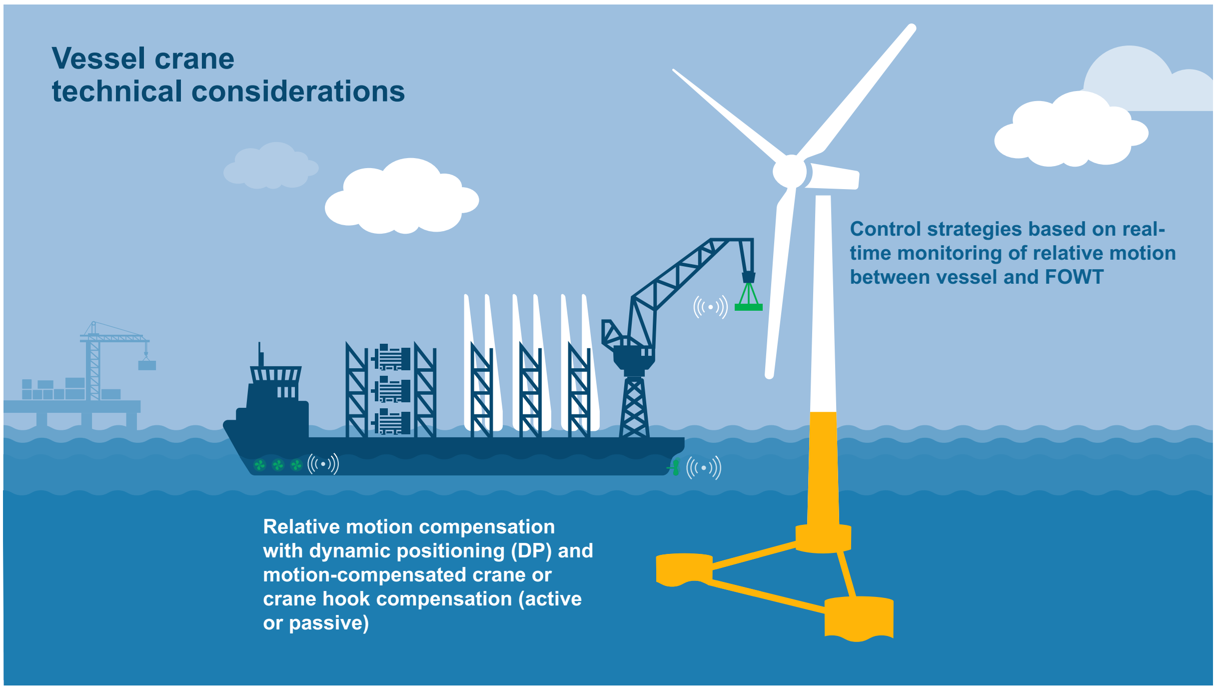

Figure 5. *Vessel crane technical considerations. Source: PEAK Wind*

As mentioned earlier, new vessel concepts with appropriate motion compensation systems and proportions for crane height and lifting capacity are being developed but for a wider range of applications that includes bottom-fixed and floating wind as well as installation and maintenance activitites. However, such assets require direct incentives from the market to be developed. With the volume of projects coming from national tenders, i.e. ScotWind, there could be an opportunity for developers of different sites in relatively close proximity to share the costs of a new crane vessel. Such a business model has worked across oil & gas projects, where the repair vessel is made more readily available, and developers agree on a schedule for maintenance. The development of the bottom-fixed offshore wind industry also showed that growing installed capacity helped solve the challenge of availability of suitable jack-up vessels for O&M.

4 Discussion

Many floating wind projects in the pipeline have commercial operation dates around 2030. At this time, the industry is set to have reached commercial status compared to bottom-fixed wind. We can therefore expect heavy maintenance technologies for floating wind to be ready for 2030.

Until then, it is difficult to estimate how these technologies will evolve: will we see developers of large projects investing in new concepts? Or joint solutions between floater designers, turbine original equipment manufacturers (OEMs) and add-on crane providers? When could we expect a standardised pairing of heavy lift concepts to floater designs? As mentioned earlier, the many existing unknowns in the market are expected to be in part solved by "first mover" decisions.

Below we discuss some of the major strategy considerations that these suppliers face to be a part of the competition.

4.1 Floater design

In this stage of the industry where a large focus is on the floater design – what its stabilising mechanism is, the materials used, mooring and anchoring configuration applied, etc. – the O&M phase remains a crucial consideration from a project developer's and insurer's perspective. More specifically, the in-and-out and business interruption (i.e. pause of energy production) costs of a repair concept impacts the operational expenditure (OPEX) and insurance claim. As such, it is important that platforms have a quick assembly time, enable options for inspection, condition monitoring, heavy maintenance, and safe transfer of technicians. Onsite heavy maintenance may have a significant impact on the platform design (laydown areas, hard points) and ballast system design (in order to allow for additional topside payload), which is why the heavy maintenance approach must already be conceived in the early design phase of the project.

From the perspective of the heavy maintenance concept provider, there will be a benefit to technologies that are relatively "structure neutral", or at least that can work with a general substructure type.[18] However, for repair solutions using an additional working deck that secures itself to the tower or a support structure that sits directly on the floater, the foundation design impacts the possibility for attachment. Barge and semi-submersible floaters can more easily host an add-on crane, its associated equipment (e.g. additional deck) and/or the spare parts for the replacement.

Ballasting is also an important requirement when the installed crane and sometimes spare parts on the FOWT add weight to specific locations on the floater. Onsite installation and maintenance technologies can have a stabilising mechanism included in their solution to increase stability during the lifting operation. Similarly, the floater's ballasting system can also

[18] Spar, semi-sub, barge, TLP

be used for this purpose. At the same time, however, there are benefits to floaters without ballasting systems since they would require less maintenance during the lifetime.

4.2 Opportunities for multi-application: bottom-fixed/floating, installation/O&M

Some of the add-on crane concepts under development are explicitly tackling the installation and/or maintenance of bottom-fixed wind first with the intention to address floating wind at a later period.[19] This widens the applications of these new technologies, which can help justify the cost of their development as well as address some of the uncertainties surrounding the growth of the floating wind market (i.e. timing of market growth and maturity, investment commitments…). Servicing bottom-fixed wind turbines also unlocks testing opportunities sooner,[20] which is important to be able to achieve technological maturity.

As for floating-to-floating lifts, there is already a young track record in the installation phase with Hywind Scotland. Vessel crane concepts under development that are targeting the bottom-fixed wind industry (for installation and maintenance) can also find, if applicable, opportunity in floating wind. Lastly, jack-up vessels for bottom-fixed wind can potentially be used to support floating wind O&M closer to shore. However, across all meetings and interviews, the costs of these vessels would be the main showstopper for practical applications.

4.3 Turbine development

Growing turbine size was identified by some stakeholders as a barrier to securing initial investments since there is a risk that new maintenance concepts can become out-dated quickly. Add-on crane suppliers targeting floating wind must keep growing turbine size in mind, and some suppliers already specify their intention to work on next-generation turbines (≥15 MW) by having favourable scaling properties in their designs. However, other stakeholders in the Subcommittee view turbine size as a short-term challenge since we may be approaching an upper limit.

The overarching trend of the turbine OEMs' conservatism vis-a-vis floating wind specialisation impacts the approach of heavy maintenance solution suppliers: at the moment, crane suppliers are highlighting the little-to-no turbine modification requirements associated with their concepts. They are also actively engaging with the turbine OEMs to improve their designs' compatibility with existing and/or next-generation models.

[19] For example, Dolfines at Seanergy 2022 announced that the OHMe system could also be used on a jack-up vessel to install or repair blades of bottom-fixed turbines at higher hub heights. They also told stated in a WFO communication that they are studying the use of its tool as a conventional harbor crane so that it could perform FOWT fabrication and maintenance activities.

[20] ESTEYCO plans to test its ATOMS system on a bottom-fixed offshore wind turbine [WFO presentation]

Turbine OEMs are also driving developments themselves to remain competitive; some are designing their own crane concepts or investing in existing ones. Other product design improvements like modularised nacelle design can facilitate logistics (e.g. correspond to shipping container standards) and heavy lift operations.

4.4 Market scenarios

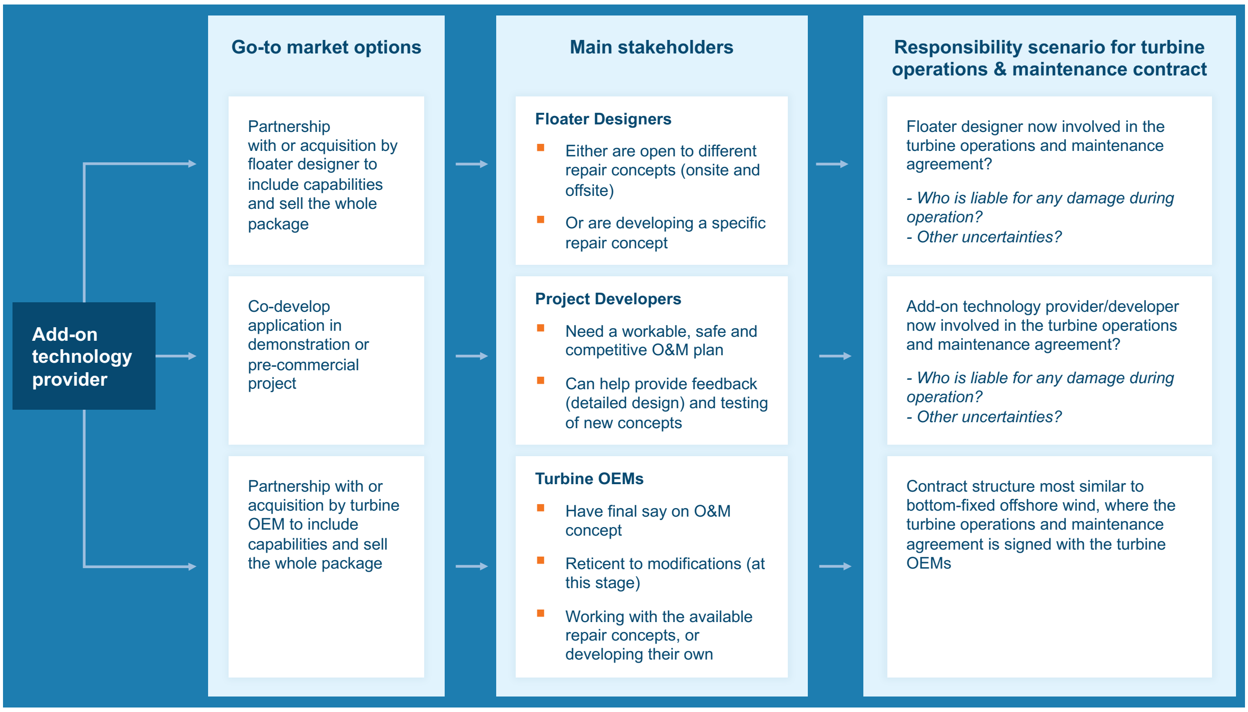

Figure 6. *Stakeholders in the add-on crane market. Source: WFO engagement with supply chain*

In bottom-fixed offshore wind, the turbine operations and maintenance agreement is signed with the turbine OEMs. For floating wind, however, we could see different responsibility scenarios depending on how a crane concept is brought to a project (Figure 5). Crane suppliers, project developers, floater designers and turbine OEMs all play a role shaping these route-to-markets, with the final goal of proving concepts for commercial-scale floating wind.[21]

Government funds and/or industry research projects can facilitate the development of new heavy maintenance concepts (qualification, testing) as well as pair them with demonstration projects.[22] These funds would either support the technology provider or the project developer to take on the investment costs and risks associated with new technology.

[21] We can already see offshore wind developers liaising with onsite heavy maintenance solution providers. For example, in late 2022, RWE signed a Letter of Intent (LoI) with WindSpider, an offshore self-climbing technology provider for the installation and component replacement of bottom-fixed and floating wind turbines.

[22] Examples: Innovation Norway funding WindSpider; Carbon Trust Phase 5 study on self-hoisting cranes will "suggest next steps to commercial deployment, which may include demonstration of concepts within the commercial and operational environment."

5 Conclusion

The offshore wind installation and maintenance market is changing to keep up with the progress of the industry. Bigger turbines, more distant wind farm sites and floating foundations require new equipment and approaches. Given available technology, tow-to-port is treated as the base case for floating wind heavy maintenance. So far, the industry has experienced only a few cases of tow-to-port maintenance at project scale (Kincadine).

However, tow-to-port may not be a feasible heavy maintenance approach for certain commercial-scale floating wind projects, which is why new solutions for onsite maintenance are emerging. Add-on cranes can be placed on the FOWT and perform the major component replacement from the unit, thereby eliminating relative motions between two bodies (e.g. the floater and a vessel crane). Several add-on concepts are under development, with varying hoisting or climbing capabilities and support system designs. Vessel cranes are a mobile solution that can perform the maintenance of both bottom-fixed and floating wind turbines. The vessel crane market, which has historically been serving bottom-fixed wind farms, is upgrading concepts to address the key challenge of relative motions between the floater and the vessel.

Onsite heavy maintenance has the potential to reduce repair time and downtime as well as eliminate the need for disconnection of the FOWT; however, technology track record, cost and overarching floating wind market uncertainties are key challenges for new technologies to reach the market in the next decade. At the moment, heavy maintenance concept providers are making strategic decisions based on stakeholder priorities. For project developers and insurers, cost reduction potential is paramount. For turbine OEMs, there is particular interest in applications that require the least amount of turbine modifications possible. Floater designers who develop platforms with the technical requirements for onsite heavy maintenance (e.g. ballast system, landing zone) could facilitate their market entry. Ultimately, heavy maintenance suppliers will need to choose the size of the envelope they want to design for until there is a standardisation of floater designs.

The active communication between suppliers, project developers, turbine OEMs and floater designers will shape go-to market routes (Figure 5). At this stage, government funds and/or industry research projects can facilitate the development of new technologies (their qualification, testing) as well as pair them with demonstration projects, bottom-fixed and/or floating.

In addition to a well-planed heavy maintenance and spare parts strategy, projects should have strong inspection and monitoring regimes that can enable “predictive maintenance.” Remote monitoring technologies (sensors, big data, digital twins) can help projects identify early signs of fatigue or failure. Inspection or maintenance activities can then be scheduled as necessary and around favorable weather conditions, improving financial and health & safety outcomes. The digitalisation of the monitoring and inspection regime is something to be explored further by the O&M Subcommittee.

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