

Offshore Wind Access Report 2023

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Acknowledgments

This is the 6th edition of TNO's Offshore Wind Access Report. The previous edition [7] was published in 2022 (click [here](#) to download), and TNO intends to update this report on an annual basis. TNO would like to thank the following companies for providing essential inputs and up to date information to this report (in alphabetical order):

- Ampelmann B.V.
- EAGLE-ACCESS B.V.
- PALFINGER
- SMST Designers & Constructors B.V.
- Ulmatec Handling Systems A.S.
- Z Bridge B.V.

Summary

In order to capture better winds, bottom-fixed offshore wind farms around the world are moving further away from shore, floating offshore wind farms are scaling up, and wind turbine sizes are getting larger. All these developments pose offshore accessibility challenges for the operations & maintenance (O&M) activities of offshore wind.

Better and safer accessibility to offshore wind farm will significantly increase the turbine up-time and energy production, wherein the increased energy production, in turns, has the largest positive impacts on reducing the levelized cost of energy (LCoE) of offshore wind. Improvement in safety by reducing occupational and operational hazards of workforce will also largely benefit LCoE in long term by reducing the risk premiums applied by investors.

The current shortage of vessel for wind farm installation and maintenance presents not only challenges, but also opportunities in thinking what accessibility strategies are available and needed for the upcoming offshore wind farms globally. This has encouraged research into novel access technologies for offshore wind.

This 6th edition of TNO Offshore Wind Access Report presents an updated overview of various access vessels and systems for accessing bottom fixed and floating offshore wind farms, with an outlook of suitable fuel alternatives in an effort to reduce the carbon emission of access vessels and to reduce their dependency on fossil fuels. An overview is given on upcoming technologies that could influence the way O&M is conducted in offshore turbines to answer the need for increased access safety and efficiency, and to alleviate some of the foreseen logistical pressure as a consequence of the rapid expansion of offshore wind energy. The ability to model O&M activities in offshore wind farms using the TNO developed UWISE tool is highlighted to optimise the choice of a combination of specific vessel, system, and access strategies.

Contents

Acknowledgments.....	3
Summary.....	4
Contents	5
1 Introduction.....	6
1.1 Access report overview and outline	8
1.2 Changes with respect to the 2022 Offshore Wind Access Report.....	9
2 O&M Access vessels and vehicles.....	10
2.1 Access vessels	10
2.1.1 Crew Transfer Vessels (CTVs)	10
2.1.2 Service Operation Vessels (SOVs).....	11
2.1.3 Service Accommodation Transfer Vessels (SATVs).....	12
2.1.4 Mini Service Operation Vessels (Mini SOVs).....	14
2.1.5 Alternative fuels and power systems.....	15
2.2 Helicopters.....	16
2.3 Autonomous vehicles	17
2.4 Accessing Floating Offshore Wind Turbines	19
2.4.1 Tug vessels.....	19
2.5 Future developments in access technologies	21
3 Access systems.....	23
3.1.1 Bump-and-jump method	23
3.1.2 Bow gripper systems.....	23
3.1.3 Compact gangway systems.....	23
3.1.4 Motion compensated gangway systems.....	24
3.1.5 Motion compensated cranes	24
4 Commercially available transfer systems.....	25
4.1 Ampelmann.....	25
4.2 EAGLE-ACCESS	27
4.3 PALFINGER.....	27
4.4 SMST.....	28
4.5 Ulmatec	29
4.6 Z Bridge	30
5 Logistics modelling.....	31
6 Conclusions and future outlook	33
7 References.....	34

1 Introduction

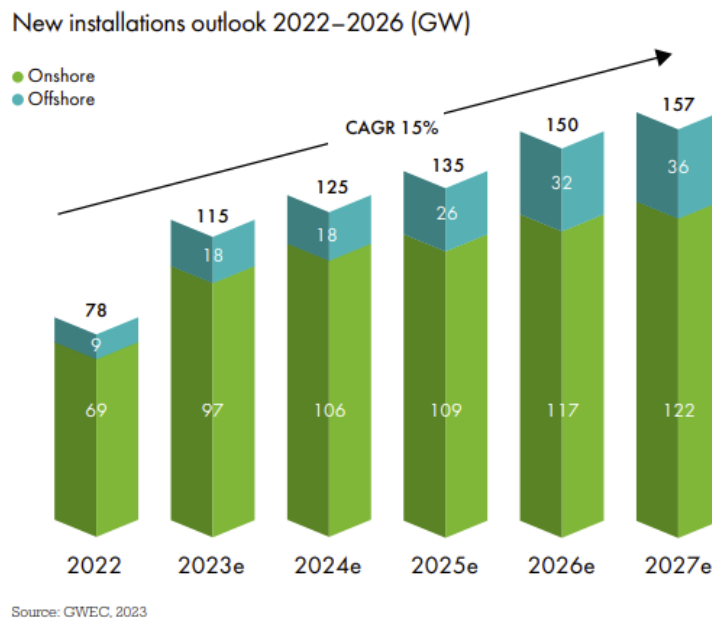


Figure 1. Global offshore wind cumulative installation forecast

The Global Wind Energy Council (GWEC Wind Report 2023) anticipates a global addition of 680 GW in wind capacity from 2023 to 2027, with 130 GW being offshore (Figure 1). Offshore wind is expected to grow significantly, with a projected global addition of over 60 GW between 2023 and 2025 and 68 GW in the subsequent years of 2026–2027. In the near future, there will be a heightened emphasis on the development of floating wind farms. While most of the floating wind projects are projected to be commissioned after 2030, a notable proportion is anticipated to be operational before that timeline. It is noteworthy that floating wind contributes substantially to the current landscape of wind energy leases.

Illustrated in Figure 2 are global wind resources at 100 meters, a height corresponding to modern wind turbine specifications. Regions with consistently high wind speeds worldwide encompass the Great Plains of the U.S. and Canada, Northern Europe, the Gobi and Sahara Deserts, extensive areas of the Australian desert, and sections of South Africa and Southern South America. Globally, high wind offshore regions include Northern Europe, particularly the North Sea, known for strong winds and offshore wind energy development; the East Coast of the United States with its significant wind energy potential; parts of Asia, especially coastal areas in China and Japan; and coastal regions in Southern South America and Southern Africa. These areas offer ideal conditions for offshore wind farms due to their consistent and strong winds. While offshore wind energy is costlier compared to onshore wind energy, it has thus far witnessed substantial deployment in Western and Northern Europe and East Asia. Figure 3 illustrates the global statistics of mean significant wave height, as determined by the CWAVE_ENV algorithm during the winter of 2006 and 2007. The data highlights that in many regions, the mean significant wave height reaches values between 5 and 6 meters, indicating a notably high wave height during this period. The predictability of wind and wave parameters exhibits considerable uncertainty and is prone to seasonal fluctuations. These variations not

only affect the power generation capabilities of wind farms but also have a significant impact on their accessibility, highlighting the importance of considering these metocean parameters in the planning and operation of offshore wind energy projects.

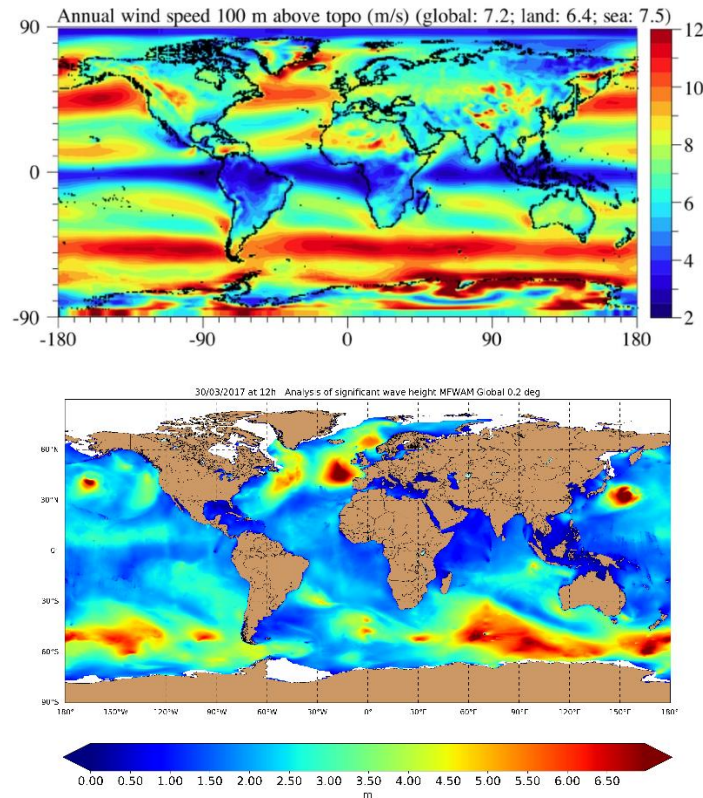


Figure 2. Global annual wind speed at 100m (upper); and global significant wave height (lower)

Ensuring accessibility in wind farms using specialized vessels and systems designed for the installation, maintenance, and decommissioning of wind turbines poses significant challenges. This is particularly true given the trend of newer wind farms moving further offshore and the recent advancements in floating wind turbines, which require specialized vessels and systems for effective operations.

Offshore operations and strategies are devised with the aim of striking an optimal balance between overall O&M (Operations and Maintenance) costs and the annual availability of the wind farm. Typically, for offshore wind farms, a targeted availability of 95% and higher is sought to achieve this balance. Due to limitations in achieving higher reliability of components, there is a growing focus on optimizing maintenance strategies, including the access methods to offshore sites. This optimization is described by the term "accessibility," referring to the percentage of time that an offshore wind farm can be safely accessed by technicians. Accessibility is a crucial element that determines the economic viability of a project, especially considering the inherent uncertainties. Calculations related to accessibility are determined based on the maximum allowable wind and wave conditions, which typically align with the allowable limits for different access vessels and systems as specified by manufacturers.

1.1 Access report overview and outline

TNO's Access report is divided into:

- **Access vessels and vehicles:** The denotation of access vessels and vehicles are collective reference and as such includes a wide array of vessels and vehicles serving various purposes in the offshore wind energy sector.
- **Access systems:** Access systems refer to the transfer systems typically installed on access vessels that provide safe, effective means for crew and cargo transfer during installation and O&M phases of the offshore wind energy sector.

Figure 3 shows several examples for different access vessels and systems. In chapter 2, different access vessels and vehicles are presented. Chapter 3 covers the several types of access systems fitted to various vessels. The characteristics of different commercially available access systems is presented in chapter 4. Chapter 5 gives an introduction into logistics modelling for offshore turbine maintenance, followed by conclusions in Chapter 6.



Figure 3. Access to the boat landing, TP platform landing, helideck/hoisting platform and autonomous inspection (from left to right)

As emphasized in the previous section, accessibility holds paramount importance for offshore wind farms. Expanding the operational weather windows to access far offshore sites is a crucial factor in driving cost reductions in offshore wind projects. Consequently, the market for access vessels and systems is evolving rapidly, with innovative technologies introduced each year. This work aims to present both existing and emerging access systems for offshore wind, along with their specifications.

To differentiate between various systems, the Technology Readiness Level (TRL 1-9) is employed, utilizing definitions from EU Horizon 2020 [6]. The following TRLs are relevant to this report:

- TRL 4: Technology validated in a laboratory environment
- TRL 5: Technology validated in a relevant environment (e.g., simulated space environment)
- TRL 6: Technology demonstrated in a relevant environment (e.g., space)
- TRL 7: System prototype demonstration in an operational environment
- TRL 8: Actual system completed and qualified through test and demonstration
- TRL 9: Actual system proven through successful mission operations

For the demonstrated systems TRL 7-8 applies, while for the commercially available systems the highest level of TRL 9 is used. Conceptual designs (below TRL 4) are therefore not included in this report.

1.2 Changes with respect to the 2022 Offshore Wind Access Report

In this edition, the following changes are made with respect to the previous edition:

In Chapter 2:

- Addition of the Mini SOVs;
- Discussion about alternative fuel and propulsion systems away from fossil fuels;
- Overhaul of the section on autonomous vehicles;
- Expansion of the section about access to floating wind turbines;
- Discussion about upcoming, not yet commercially available, access technologies.

In Chapter 3:

- Addition of CTV access systems.

In Chapter 4:

- Update on the commercial system with inputs from industrial stakeholders.

In Chapter 5:

- Overhaul of the section to discuss modelling of logistics for offshore maintenance.

In Appendices:

- Updated figures based on recent industry inputs.

2 O&M Access vessels and vehicles

2.1 Access vessels

The demand for access vessels and technologies is constantly growing following the global increase in the number of offshore wind farms installed to meet renewable energy targets. The choice of the best combination of access vessels for a specific offshore wind operation can be difficult due to the numerous factors involved, including vessel availability, vessel cost, maximum payload, weather restrictions, emission factor, etc. In the following section we intend to provide information on various access vessel types that are or soon will be available to operate in offshore wind farms. Upcoming alternative fuels to fossil fuels to power various access vessels are also discussed.

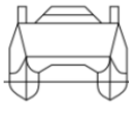
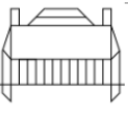
2.1.1 Crew Transfer Vessels (CTVs)

There are several different specialized CTVs that offer access to offshore wind farms. Depending on their seakeeping capability, they can be deployed on wind farms at various distances from shore. Typically, the cut-off points where an offshore accommodation is preferred than CTVs is 40 nautical miles (74 km) from the port [1]. CTVs operate on short missions and always head back to the base port at the end of the day.

With CTVs, personnel are transferred to the turbine by thrusting the CTV against the transition piece ladder, typically with $H_s \leq 1.5\text{m}$. Cargo is hoisted from the deck of the CTV using a crane located on the transition piece platform. To allow the CTV to contact the transition piece, various methods and bow designs have been developed (more details are given in section 3).

In general, CTVs are designed to transit at speeds ranging 15-40 knots and to carry 12 to 24 technicians with their equipment and small-scale parts. Different hull designs have been developed for CTVs which have different seakeeping capabilities, manoeuvrability, maximum speed, and payload capacity. The various hull designs and their characteristics have been discussed in depth in the previous edition, [TNO Access Report 2022](#), and the main characteristics are summarised below in Table 1

Table 1. Characteristics of CTV types

	Monohull	Catamaran	Trimaran	SWATH	SES
Length [m]	12-25	15-27	19-27	20-34	26-28
Transit speed [knots]	15-25	18-27	18-22	18-23	35-39
Passenger capacity [-]	12	12	12	12/24	12/24
Cargo [tons]	5-10	10-15	1-5	2-10	3-5
H _s limit [m]	1-1.2	1.2-1.5	1.5-1.7	1.7-2	1.8-2.2
Sketch					
Image source	[2]	[2]	[3]	[2]	[2]

As CTVs are typically used for daily missions from a harbour to near shore wind farms, they are transitioning towards hybrid or fully electric propulsion with enough battery storage to perform the day missions and recharging at night in the harbour [4] [5]. Hybrid vessels or existing vessels using conventional fuel can also in certain cases be fitted with carbon capture technologies [6]. With the foreseen deployment of green hydrogen produced from renewable sources, CTVs are a viable candidate to convert to this type of fuel [7].

Another axis of development for energy usage optimisation is to challenge the current design point for which propulsion systems are designed. Currently propulsion systems and motorisation are designed to be efficient at high regime, when the CTV transits near maximum speed, and when personnel is being transferred from shore to the workplace and back. However, a large amount of time is spent at low regime to navigate within the wind farm and manoeuvre around each wind turbine. Better solutions could possibly be achieved with a propulsion system optimised for multiple regimes or optimised for a different regime, or even by having two propulsion systems each optimised for a given regime. [8]

2.1.2 Service Operation Vessels (SOVs)

Service Operation Vessels (SOVs) are larger vessels generally used as an offshore accommodation and warehouse platform. As offshore wind farms are getting farther from shore, SOVs are gaining popularity in all phases of wind farm development. The build schedule and shipbuilding costs of SOVs are much larger than those of CTVs.

SOVs can accommodate up to 60 persons, and often stay onsite for two weeks, after which they return to port for a day to change crew, bunker, and resupply parts. SOVs are primarily designed to provide safer and more comfortable transit, transfer, and accommodation to technicians onboard. SOVs enable technicians to have extended working time by not having to transit back to port at the end of shifts. Equipped with access systems and better sea going capabilities, SOVs allow longer weather windows for transfers as well as less motion-induced fatigue in technicians.

However, SOVs come with drawbacks to their use as well. Firstly, the build schedule, shipbuilding costs, and operating costs of SOVs are much higher than those of CTVs. Secondly, SOVs transit at lower speed from one turbine to the next within the wind farm, and hence it

can take significant amount of time to navigate. That is why SOVs are often equipped with daughter crafts installed on davits that can be used when weather conditions allow.



Figure 4. Service Operation Vessel Vroon VOS Start [9]

Alternative fuel and energy systems for SOVs should focus on enabling longer missions with maximum autonomy and availability of power for the access system and to accommodate the personnel in comfort. This means that green ammonia or green methanol-based fuels produced using green hydrogen are considered as a sensible energy source alternative to conventional fuels.

The low energy density and storage complexity of hydrogen makes this type of fuel somewhat less suitable for long duration supply of power required on SOVs but the relative maturity of the technology motivated the development of hydrogen ready SOVs [10].

The large energy usage from these vessels makes the idea of a hybrid or fully electrical ship less realistic without means of recharging at sea, however solutions to recharge at sea are being developed and fully electric SOVs are on the horizon [11].

2.1.3 Service Accommodation Transfer Vessels (SATVs)

For wind farms located further offshore, SATVs are commonly used as a more suitable alternative to CTVs. SATVs typically leave the harbour for a period of a week and is therefore fitted with accommodation facilities for the crew and maintenance personnel. It also has an extended payload capacity for maintenance equipment and spare parts.

They are larger than CTVs and have better sea keeping capabilities, and they still make contact with the turbines to transfer personnel onto the transition piece (TP) ladder and the TP platform mounted crane to hoist equipment.

SATVs offer a nimbler approach to turbine than their bigger counterparts, SOVs.

In terms of cost, design complexity, and operational variety, SATVs are viewed as an option to bridge the gap between CTVs and SOVs.



Figure 5. Service Accommodation Transfer Vessel designed by BMT [12]

Several SATV have designed (see Figure 5), such as the Ventus Formosa (built and operating on Formosa I wind park), and the Damen FCS 3410 SATV. The first one is a larger 36.3m vessel has a cruise speed of 16 knots, a sprint speed of 19 knots, and can accommodate 10 crew members for a 12-day offshore stay. The second, smaller one at 21.7m, is designed for the US market to host 4 crew over a period of 5 days but no vessel of this category has been built to date.

SATVs are designed to spend relatively extended periods of time at sea which makes them incompatible with a hybrid or fully electric operation as they would also require significant battery storage capacity. This could however be enabled with the development of means to recharge the vessel offshore. Various offshore charging options are being thought of, such as means of connecting directly on the wind turbine to extract power to recharge the batteries [8].

The installation of carbon capture systems (CCS) on hybrid or traditional fuel propelled vessels can be an option to mitigate carbon emissions [6]. Relying on hydrogen or liquid hydrogen as the main source of power could be a valid solution for SATVs with short multi-day missions but probably not week-long missions as hydrogen is a low energy density carrier and requires a significant volume of storage (less so for liquid hydrogen but the storage system is then more complex). In the future, with the development of offshore green hydrogen production, longer missions could be possible if offshore hydrogen refuelling options are being developed, for example by connecting to a turbine fitted with a hydrogen generation system or by connecting to a hydrogen generation platform located in the wind farm.

To enable longer missions with maximum autonomy, green ammonia or green methanol-based fuels produced using green hydrogen seem like the most sensible energy source alternative to conventional fuels.

2.1.4 Mini Service Operation Vessels (Mini SOVs)

Mini SOVs are another solution to bridge the gap between CTVs and SOVs that operates on further offshore wind parks. They have similar range and sizes as SATVs; however, the transfer of personnel and equipment is not done by pressing up against the turbine like atypical CTV. Instead, mini SOVs use crane and gangway systems similar to the ones used on SOVs. The size of the vessel and the number of wind farm personnel accommodated onboard is typically much smaller than on an SOV.

In summary, this solution allows for a greater range and time at sea than CTVs with a reduced operational and asset cost compared to CTVs. With regards to SATVs, their differentiating access system to the wind turbine enables access with a bigger sea state and greater payload at the cost of a higher initial investment for the access system. This makes this type of vessel complementary to SATVs for far offshore wind parks maintenance by extending the operational capabilities of mid-sized vessels. This enables an improvement in the efficiency of windfarm maintenance when performed on a limited number of turbines at a time.

Thus far, three mini SOVs are in operation, the Damen 6017 (equipped with Z-Bridge B2W system), the OSD-IMT9604 “mini-SOV” (equipped with Z-Bridge B2W system) and the DP2, twin-hulled SOV (equipped with SMST system).



Figure 6. Mini SOV 6017 [13] with Z-Bridge B2W system [14]

The alternative fuel and power systems for this type of vessel is similar to the ones discussed for SATVs in section 0, keeping in mind the additional energy need to power the access crane/gangway system.

2.1.5 Alternative fuels and power systems

The different alternative fuels/power sources discussed for the upcoming, carbon neutral access vessels can be stored and converted back to useful energy for the ship in various manners detailed below [6]:

- Electricity can be stored in various types of batteries and used directly to power the ships systems and can power electrical engines for propulsion.
- Hydrogen in gas or liquid form can be stored in storage tanks and later be used for propulsion in 4 stroke engines or converted to electricity in fuel cells to power ships systems or power an electrical engine.
- Methanol in liquid form can be stored in storage tanks and later be used directly in 2 or 4 stroke engines, be used in boilers to produce steam and heat to be used directly or to produce electricity to power the vessel systems or electrical engines. Methanol can also be used directly in fuel cells to produce electricity.
- Ammonia in liquid form can be stored in tanks and used directly in 2 or 4 stroke engines or converted to heat and steam in boilers to then generate electricity or directly in electricity with fuel cells.
- Carbon Capture Systems (CCS) are not directly a fuel or power system but rather a mitigation technology to reduce carbon emissions of conventional fuels whereby the carbon emitted in the exhaust gas is extracted and stored for future adequate disposal before existing the exhaust system of the vessel.

The main challenges with these alternative fuels and energy systems are the storage of the energy carrier. Batteries are expensive and heavy with their efficiency sensible to temperature. Some battery technologies can present risks when operated outside of their optimal design points (overheating of lithium-ion batteries can cause fire or explosions for example [15]) and therefore often require an environmental control system to be installed in the battery compartment to ensure adequate cooling is provided and humidity levels are monitored. Storage tanks for the other gaseous or liquid fuels require more advanced systems than conventional fuel storage (hydrogen is explosive in its gaseous form and takes a great volume, liquid hydrogen needs to be cooled at cryogenic temperatures and kept under pressure, ammonia is highly toxic and can explode, Methanol is very flammable), carbonated fuel options. They also require higher storage capacity as these alternative fuels are less energy dense.

Liquid and gaseous fuels release particles to the atmosphere when being used to produce energy to run the access vessels: Hydrogen conversion releases water and oxygen, methanol releases carbon dioxide and water, the carbon dioxide released is equivalent to the carbon dioxide used to produce the methanol which, in the case of e-methanol, is sourced from carbon capture systems, making the cycle of production and use of methanol carbon neutral (as long as the energy used in the production process is from carbon neutral sources) [16]. The conversion process of ammonia, NH_3 , releases water and nitrogen, the most present gas in the atmosphere, the production process can there again be made to be carbon neutral by using green hydrogen and renewable energy to manufacture this type of fuel [17].

It is foreseen that these various technologies will reach technological and basic safety regulation maturity between 2024 and 2032 and become commonly available thereafter [8].

2.2 Helicopters

Helicopters offer a rapid access solution to wind farms with winds up to 20 m/s when the sea conditions are suitable (limits for safe water landing in case of emergency). They can either land on the helideck on the substation or hoist personnel and equipment to and from the hoisting platform atop the nacelle. The counterpoints for the speed and flexibility that helicopter offers are multiple:

- Helicopter operations are expensive (typically 100 to 200 euros per minute);
- The payload is very limited (3 to 6 technicians with about 100kg of equipment and parts per passenger);
- The waiting time in the wind farm is limited (usually less than 30 min), meaning that helicopters either have to land on a fixed landing platform nearby to do round trips to a shore base and come back to pick up the technicians, thereby increasing the costs quite significantly.

When helicopters are used without other access vessels being present in the wind farm, no emergency backup evacuation is possible for the technicians until the helicopter returns.



Figure 7. Offshore wind helicopter access

2.3 Autonomous vehicles

Autonomous vessels have been employed in offshore wind farm development mainly in the survey and maintenance phases. It is observed that the main obstacles to the autonomous use are a lack of standardized regulations and the according insurance, and dependency on manual deployment and retrieval. It is acknowledged that by further developing these technologies to the point where they can run fully autonomous, greater cost savings and enhanced safety may be achieved. Despite the technological challenges and legislative hurdles to fully deploy such systems, there have been substantial efforts in developing these technologies.

Unmanned aerial vehicle (UAV) for inspection

UAVs are firstly deployed to perform visual inspection for external parts of wind turbine tower and blades. A small group of UAVs have been developed to conduct close-contact inspection. UAVs are usually equipped with cameras, measurement sensors so that the data retrieved can be post-processed for detailed imaging and acoustic emissions analysis. The despatch of UAVs reduces the necessity to carry out rope access for technicians, and hence immensely improve the safety of technicians, and increase the accessibility to the wind farm during short weather windows. UAVs could be either tethered or untethered with power supply. Further development focus is to increase power endurance and flight range, to increase workable wind speed limitations and to increase the telecommunication technology so that UAVs can reach higher automation.

Unmanned aerial vehicle (UAV) for payload

Payload drones are also often called cargo drones. Payload UAVs have been designed to transport consumable, spare parts, tools at need. Using drone delivery can reduce significantly time and risks for technicians to bring the goods up to the top-tower or from the shore. The latest sea trial at Hornsea 1 Offshore Wind farm, UAV developed by Skylift demonstrated carrying 68kg payload directly from the vessel deck to the nacelle platform [18]. Further development focuses on increasing power endurance, flight range and payload capacity. Furthermore, with the continuous development in BVLOS (Beyond Visual Line of Sight) capability, payload UAV could reach long distance flight with autonomous navigation via imagery sensors and path planning algorithms.

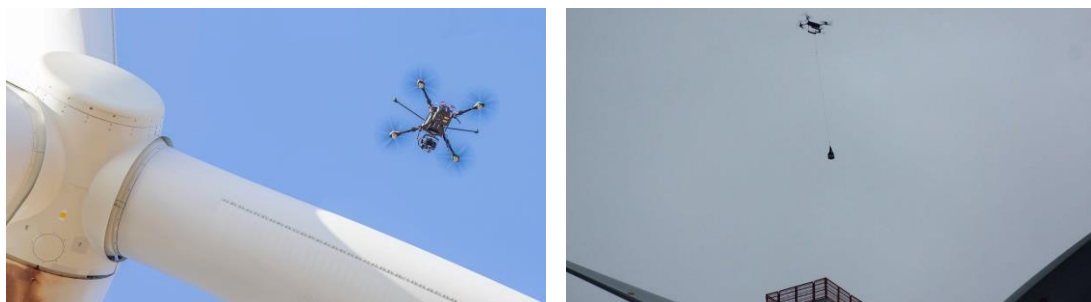


Figure 8 Perceptual Robotics UAV performing blade external inspection (left) [19], and Skylift UAV delivers cargo to an offshore wind turbine nacelle platform (right) [20]

Unmanned surface vehicle (USV)

USVs are often called autonomous surface vehicle (ASV). USVs have been primarily deployed for oceanographic and atmospheric surveys that takes long period of time to collect. USVs are smaller in size compared to CTVs and SOVs, and the fact that no human aboard, the sea state limitations are more flexible. USVs often have catamaran hulls that provides stability, and it

can carry various range of payloads and sensors and telecommunication system of different types onboard tailored to the tasks. With increasing distance to shore of offshore wind farms, the development focus of USVs is to develop more in autonomous navigation, and to work in conjunction with manned vessel and other autonomous systems. For instance, an SOV on-site deploys one or more USVs. This brings potential time and cost reduction in subsea monitoring and inspection actions.

Autonomous underwater vehicle (AUV)

Currently underwater inspections (for turbine substructure and burial depth of cable) are conducted by remote operation vehicle (ROV). ROVs are designed to be tethered for its power supply from a vessel and are controlled from the crew onboard the vessel. AUV are designed to have untethered autonomous navigation. The development of AUV focuses on increasing sea current operation limitations, and longer lifespan of battery or hydrogen fuel cell without returning to a mothership, and to couple with other control systems that can perform repair or maintenance.

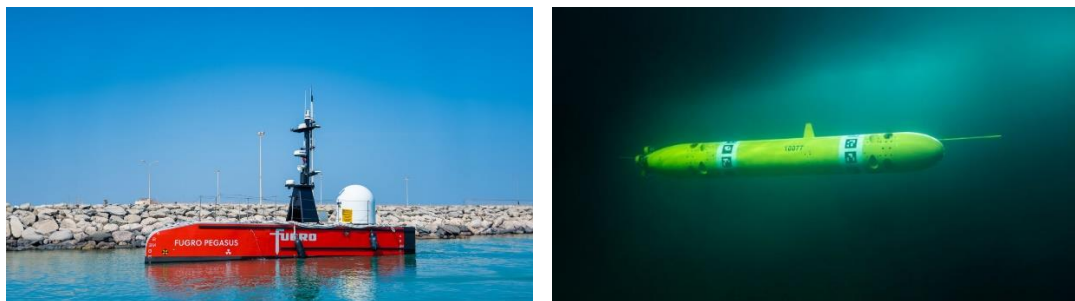


Figure 9 Fugro Pegasus USV was deployed for a subsea inspection (left) [21], and a modular AUV developed by the Maritime Research Institute Netherlands (MARIN) (right) [22]

2.4 Accessing Floating Offshore Wind Turbines

Floating offshore wind presents the advantage of leveraging the maturity achieved by bottom-fixed offshore wind technology. However, the introduction of floating systems brings forth new challenges and constraints, particularly in terms of accessibility. The following challenges are anticipated:

- **Environmental Conditions:** Similar to bottom-fixed wind technology, floating offshore wind (FOW) concepts will be susceptible to access restrictions imposed by adverse weather conditions. Factors such as wind speed, wind turbulence, wave height, and sea conditions will impact accessibility. The increased distance from the shore in FOW installations introduces harsher weather conditions, leading to reduced accessibility. Efficient and profitable operation necessitates careful planning around access and weather windows.
- **Major Component Replacement:** The expected depths of FOW sites render the use of conventional major component replacement vessels impractical. This presents a unique challenge in determining how major component replacements will be executed. Innovative solutions are under consideration, including on-site methods such as floating-to-floating transfer, floating cranes, and self-hoisting equipment. Off-site methods like towing to shore are also being explored. The broader adoption of FOW is constrained by the availability of suitable port and grid infrastructure. Many European ports and harbours lack the capacity to handle the scale of operations required for the installation and maintenance of such assets, becoming a significant issue given the rapid installation pace of new bottom-fixed and floating offshore wind sites.
- **Turbine Motions:** The motion of the turbine becomes a significant factor impacting accessibility. As the process transitions from a floating-fixed to a floating-floating system for on-site inspections, accessing the turbine becomes more challenging for personnel. Additional weather and environmental factors, such as peak wave period and wave direction, will be crucial for assessing the accessibility of the asset.

Addressing these challenges is imperative for the successful development and operation of floating offshore wind projects, requiring innovative solutions and strategic planning to ensure efficiency and safety in the face of diverse environmental conditions.

2.4.1 Tug vessels

The life cycle of a floating wind farm hinges on a crucial asset, the tug vessel. Whether involved in assembly, installation, maintenance, or decommissioning, the tug vessels play a pivotal role in each phase. Different stages of floating wind farm development require assets with distinct characteristics to allow access to the floating wind turbines. Nevertheless, certain factors such as reliability, storage capacity, safety, and crew comfort consistently hold importance.

The anchor handling tug supply (AHTS) vessel designs range from small to medium, for tow-to-shore options, to large tug vessels, for installation and decommissioning, prioritizing efficient operation and sustainable performance throughout the entire process.



Figure 10. 100t bollard pull vessel from IHC Offshore Energy [23]

2.5 Future developments in access technologies

This section marks a break line from previous subchapters where only mature and commercially available technologies were discussed. Here, some of the technologies under research and development are discussed since they could have an impact on the way offshore wind turbines are accessed in the near future.

Virtual reality (VR)

The logistics of training in the harsh offshore environments where the wind farms are located proves expensive and complicated as the physical space restriction of only allows a very limited number of people to be present simultaneously inside the nacelle of the WTG. With the use of VR solutions, multiple users can access and acquire easy-to-follow information on wind turbine systems. This would benefit the current shortage of technicians and ease the learning curve of new workforce. Additionally, training of maintenance procedure or breakdown in VR can avoid the loss of energy production is hampered when training with a turbine, thus it is advisable to train a fault or breakdown in virtual reality. A further benefit of virtual reality training is that the complexity can be adjusted by changing scenarios, weather conditions, and wind speeds.



Figure 11. Remote wind turbine inspections using VR technology at VR lab [24]

Augmented reality

Technicians performing inspection and maintenance operations in wind turbines receive extensive training regarding procedures and technical details relevant to the turbine model they operate on. However, it cannot be expected of them to know all details about the turbine they operate on, nor to be always able to make clear judgements when confronted to unusual situations. Usual ways to overcome these challenges are limited and can cause delays in maintenance operation (carrying relevant documentation, phoning an experienced colleague not present in the turbine).

Augmented reality offers great opportunities to complement the existing solutions by overlaying relevant information (i.e. text, schematics, images) about the system through a visual medium and facilitating interactions with colleagues working remotely by using either a tablet equipped with a camera or augmented reality goggles. [Remote assistance in Nacelle | TNO - YouTube.](#)

Remote Inspection and Maintenance

The development of robotics to perform inspection and maintenance operation on offshore wind farms is bringing new opportunities to grant remote access to specialised shore-based technicians. These technicians should be able to monitor a larger number of assets when compared to conventional inspection and maintenance techniques, which can in parts alleviate the pressure on the industry to find qualified personnel willing to work offshore.

The development of drones or robots can be tailored to answer a range of needs from the industry, leaving only the critical and large-scale maintenance operation to highly qualified, human, offshore technicians.

Offshore drones can have in parts or fully autonomous operations with the critical decisions and results/quality control to be analysed remotely. Additionally, drones can be either brought to the wind farm on a case-to-case basis or be permanently residing in the wind farm or wind turbine ([AIRTuB-ROMI - World Class Maintenance](#)) depending on the frequency of the missions to be performed and the need to resupply the drone mounted equipment. Bringing the maintenance drones to the offshore wind assets can in some cases be performed by transport drones.



Figure 12. Robot arm remote maintenance in a nacelle - TNO in WCM Zephyros FieldLab

3 Access systems

A range of access solutions have been developed to transfer personnel or equipment to a wind turbine at sea. The main considerations when choosing for a specific solution are the vessel capabilities, the maximisation of wind farm availability, and safety.

Smaller vessels usually are limited to access solutions at sea level while larger vessels have access to a range of gangways and cranes providing a safer and more comfortable access directly to the TP platform at an elevation from sea level of roughly 15 to 20 meters.

Due to the limited accessibility that access vessels can provide, the impact of safety-related risks increases as well as the adverse effects on humans due to motion-induced fatigue. To combat this, some access systems are created to minimize relative motions between the vessel and turbine during people and equipment transfer.

3.1.1 Bump-and-jump method

Smaller vessels are usually limited to accessing turbines near sea level. A way for technicians to access the turbine is the “bump and jump” method whereby the vessel contacts then press against the turbine access ladder thanks to a suitable bow and fender design (making the system vessel specific and decided during the design phase). Technicians then “jump” from the bow of the vessel to the ladder. Equipment can then be lifted from the vessel’s deck using a crane installed on the turbine TP platform.

This method is suitable only when the sea state is fairly quiet as the boats is susceptible to heave and sway under the influence of waves.

3.1.2 Bow gripper systems

Some smaller boat can be fitted with a more sophisticated bow gripper system. This system is also vessel specific, and the vessels need to be designed for the selected gripper technology. The gripper secures the bow of the boat the access ladder, holding the bow of the boat above most waves crests by gripping at an instant when the bow of the vessel in at the top a large wave.

This eliminates the risks of the vessel heaving or swerving when a technician is transferring to the turbine. Equipment is then transferred in a similar fashion to the “bump and jump” method.

The gripper allows to access the turbine safely with a sea state that is not as favourable as with the previous method.

3.1.3 Compact gangway systems

Compact gangway systems can be put on the wind turbine foundation structure or the deck of the ship. For each system, there are different requirements for the boat landing and vessel characteristics, such as sufficient vessel length, adequate deck layout, active or passive ship positioning system,

Gangways systems allow to transfer personnel and equipment from the ship directly to the turbine TP platform.

3.1.4 Motion compensated gangway systems

Gangways system as described previously can optionally be fitted with motion compensation systems to cancel out relative motions between the vessel and wind turbine.

There are two techniques to achieve motion compensation.

On the one hand, passive compensation whereby motion control is achieved by means of a mechanical link that passively adjusts itself. On the other hand, active motion compensation relies on sensors and control mechanisms.

The market for providing access to offshore wind farms using motion-compensated gangways is still developing and various systems that can be installed aboard ships exist to transport technicians to the TP platform.

Active motion compensated gangways make up the majority of the systems giving personnel direct access to the TP's work platform. A growing number of them are also able to lift heavier objects, typically up to 1000 kg.

3.1.5 Motion compensated cranes

The transfer of equipment to wind turbines and sub-stations is a crucial aspect for maintenance operations. Freight can adopt multiple form as either individual items, crates or small containers.

The main factor driving the selection of a suitable mean of transportation and transfer is their weight. Loads up to one ton can normally be lifted from the vessel by the davit crane on the platform of the transition piece or using a suitable motion-compensated gangways as previously mentioned.

However, as the weight of equipment increases, or when the drop zone is harder to reach, dedicated cranes are used. Typically these cranes are fitted with motion compensation systems on the deck of the access vessel.

Some cranes are also suitable to transport personnel.

Despite their relatively recent introduction to the market, it is expected that their use will be democratised as wind turbine systems keep getting bigger and require ever bigger and heavier components.

4 Commercially available transfer systems

This chapter provides an overview of commercially available access systems. Summary tables with complementary specifications on the various motion compensation gangways are available in Appendix A and motion compensation cranes in Appendix B.

Gangway and crane transfer systems are powered either hydraulically or electrically. Both power options come with pros and cons which can motivate the choice of a system over another. However, electrically powered systems have a few advantages over hydraulic systems when looking through the lens of sustainability [25]:

- Electrical systems are generally more energy efficient as they usually have less losses through heating;
- Hydraulic systems need frequent maintenance with parts replacements and oil changes;
- Hydraulic fluid is generally a petroleum product considered as a consumable;
- In marine environment, hydraulic systems are more robust and durable than electrical systems and they less often require complete overall or replacement.

4.1 Ampelmann

Ampelmann designs and operates several types of gangway systems and is generally known for the hexapod that allows its gangways to compensate for motions in six degrees of freedom. Inspired by the Stewart platform, the six hydraulic cylinders eliminate the relative motions of the vessel. The company has a fleet of close to 70 systems worldwide, featuring several different system types, among which the A-, E-, L-, S- and W-type. Many of Ampelmann's gangways have cargo lifting capacity as well, and the company has developed a system in the past that allowed for Walk to Work access in temperatures as low as -28 degrees Celsius.

Ampelmann A-type: The A-type is the first gangway system that actively compensates for the vessel's motion by use of the hexapod. Since its first operations in 2008, several iterations have been developed and alongside the standard version, there are three models currently commercially available: the A-type, electric A-type, and A300. These vary in terms of utility and actuation but can operate in the same sea states.

Whereas the standard A-type only allows for the transfer of personnel, the A300 is a cargo lifting variation of the former. Operational since 2022, the system can hoist cargo up to 300kg in addition to providing safe and consistent access to personnel.

The electric A-type can be directly powered by the electricity supply from the vessel. The electric actuation allows for power regeneration during parts of the compensation cycle, and a balanced heave compensation technology is integrated which reduces power consumption by 90%.

A lightweight, permanently integrated, variation of the system, the S-type, was also made available in 2022.

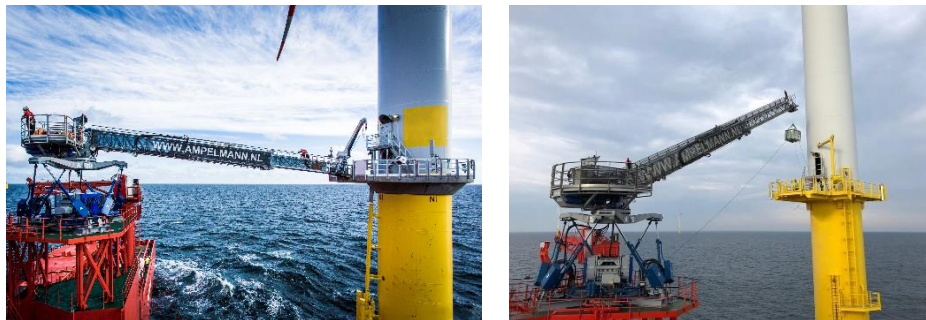


Figure 13. Ampelmann A-type (left) and A300 (right) (Courtesy of Ampelmann)

Ampelmann E-type: The E-type is based on the same technology as the A-type, although it is 1.5 times larger. Because of its increased size, the system is capable of compensating higher sea states. The Ampelmann E-type product line includes the E1000 and E5000 systems. The E1000 and E5000 can also transfer cargo in crane mode. The transformation from the gangway to crane configuration (and vice versa) takes less than one minute.

As the E-type's robust hexapod can compensate for sea states up to 4.5m Hs, it has recently become a tried and tested access solution for operations on floating wind turbines. Due to the challenges caused by the divergent motions of vessels and floaters, particularly in rougher weather, compensating for motion six degrees of freedom significantly improves the workability in these conditions.

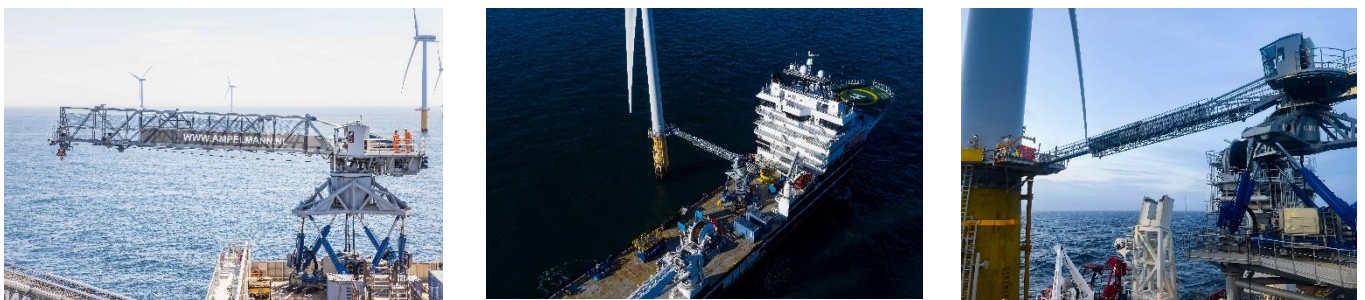


Figure 14. Ampelmann gangways – E5000, E1000, and the E1000 (from left to right) (Courtesy of Ampelmann)

Ampelmann W-type: The W-type is a built-to-order system that can be fully integrated into an SOV. The system is electrically powered to reduce carbon footprint. Instead of using the hexapod platform, the W-type has adopted the elevator tower concept for the stepless transfer of personnel from the vessel warehouse to the gangway. With the gangway moving up and down along the tower and rotating around the base, the system provides motion compensation through gangway luffing, slewing and telescoping.

Ampelmann is developing modular components with the aim of streamlining design loops, reducing maintenance time and further improving customisation options for its clients. Alongside this, the company has integrated digital services into its business model to further enhance the efficiency of offshore operations by way of workability forecasts and data collection.

Ampelmann is currently developing a new type of gangway, the F-type to fill the gap between the L- and A-types for lower sea states, locations and for larger installation vessels that require less motion compensation. The first unit is expected to be ready for the end of 2024.

4.2 EAGLE-ACCESS

EAGLE-ACCESS is a fully electric-powered system, supported by a back-up battery. The lighter weight of the system, which accounts for 27 ton, also leads to lower energy consumption (75kW). A motion compensated tip is used for transferring 1-4 technicians in a safe enclosed cabin or a cargo up to 1 ton directly from the deck to the offshore platform. The capacity can be upgraded to lift a cargo up to 3 tons.

Due to its specific design, it allows 270 degrees of slewing, and the horizontal reach of 27m from the centre pedestal and vertical reach of 25m from the deck level. The system enables to land at any position on the offshore platform. The patented laser measurement system (LMS) enables the access system to be used for float-to-float transfers. The system can be fully integrated or delivered as stand-alone. The system is also capable of delivering cargo at night to the TP platforms thanks to the obstacle measuring systems on the hook assembly.



Figure 15. EAGLE ACCESS with an enclosed cabin for technician transfer (left), and used to hoist and deliver cargo (right) (Courtesy of EAGLE-ACCESS)

4.3 PALFINGER

Offshore Passenger Transfer System (OPTS) is a 3D compensated tool with a personnel transfer/service basket that can be mounted on a wide range of vessels. The system can be fully integrated or delivered as a stand-alone. The OPTS can move freely $\pm 200^\circ$ slewing motion with an outreach of 27m. A maximum of 600kg (6 persons) can be transferred at the same time. The OPTS can also be used for lifting operations up to 1 ton with or without motion compensation.

An upgraded unit which has an improved design based on the prototype version, most improvements is based on system design safety and speeds is expected to be commercially available in Q3 2024.



Figure 16. Palfinger OPTS on a CTV (left) and on an SOV (right) (Courtesy of Palfinger)

4.4 SMST

SMST provides a range of gangways for safe, easy and efficient offshore transfer of personnel and cargo. There are three versions (M, L and XL) of the SMST gangway, Telescopic Access Bridge (TAB), varying in length from 4 up to 58m. The bridges can be actively or passively motion compensated and are available for purchase and specific types are also for rent.

The modular setup of the SMST gangway systems enables setting up a TAB that meets all project-specific requirements. Working on various heights is possible by means of stacking modules and a Height Adjustment System that travels vertically along a rail system, enabling connections with large differences in landing heights and extreme heights (as shown in figure 22). The modularity of the gangways ensures fast and easy mobilization. In addition, the TAB-L has also been offered as an integrated design with the new-build SOV's, together with an Access and Cargo tower including elevator.

For cargo handling the gangways can be equipped with a lifting winch on the bridge tip, a cargo travel system under the bridge and/or a cargo transporter. The cargo handling options are also available for the rental setups.



Figure 17. SMST M series (left), L series with Height Adjustment System (middle) (Both courtesy of SMST), and L series together with an Access & Cargo Tower (Photo copyright of Ørsted)

SMST gangways are capable of performing floating-to-floating operations by default. The connected mode creates a safe and robust connection, which allows for free movement of the two floating objects. Furthermore, the automation packages offer improved workability with regards to floating-to-floating. SMST offers three sizes of the 3D motion compensated

cranes (M, L and XL) and are designed to be mounted on Service Operation Vessels (SOVs) and Walk-to-Work vessels. The 3D crane can safely transfer equipment to an offshore structure, even in harsh conditions. The vessel's motions are compensated in all directions by means of the 3D motion compensated knuckle. The modular setup of the crane allows the 3D knuckle to be easily exchanged with a subsea knuckle for deep-water operations.

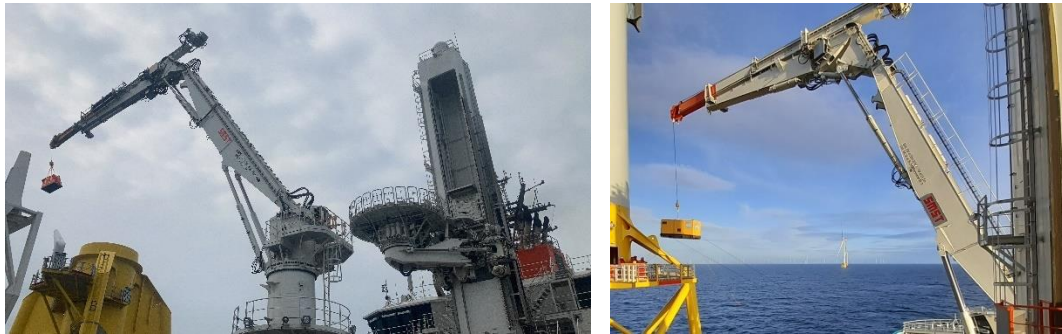


Figure 18. SMST motion compensated crane in operation (Courtesy of SMST)

4.5 Ulmatec

The Ulmatec AMC gangway system is an active motion compensated gangway. It is powered by environmentally friendly hydraulic oil and can slide vertically on a rotating tower. Personal and goods are brought from deck to gangway level with an internal elevator. There are currently two sizes of gangway, 32m and 25m. The 32m system provides higher workability with its 12m telescopic compensation, that allows adjustable access height to the wind turbines. Whereas the smaller sized 25m system has its competitive advantage in better sea and weather conditions and services without cargo transfers. Besides, the Ulmatec hybrid gangway, which uses 50% less energy when comparing with a wire-suspended full-electric gangway.



Figure 19. Ulmatec AMC 32m (Courtesy of Ulmatec)

4.6 Z Bridge

Z bridge has developed two gangway systems, Z-Bridge W2W and Z-Bridge B2W. W2W is a patented motion compensated gangway system that eliminates the rotative (pitch & roll) movement of the mast. The system's elevator provides direct access for 4 people or 500kg cargo to the offshore platform, but the capacity can be upgraded to allow 8 people or up to 1000kg cargo. The landing height is adjustable from 2.5m up to 23m.

B2W is built based on the patented motion compensated pedestal of the W2W system. It is provided with an elevator for transporting up to 6 personnel or cargo up to 1000kg. The elevator can be upgraded to lift up to 3000kg. The system can also be used as a 3D motion compensated crane to hoist up to 3 ton of cargo from the deck to the platform. With its relatively low weight, the system can be installed on a CTV, which is able to transfer from vessel deck to the platform while the CTV thrusts against the boat landing area.

Since the previous issue of the Offshore Access Report, the BSW system has been further developed to allow stepless entrance in the trolley for integration on a mini-SOV. Specially in pulling operations for cable projects and/or the installation of power packs for commissioning work, the system proved to be very efficient.



Figure 20. Zbridge W2W with system's elevator (left), Zbridge B2W used as a crane (right) (Courtesy of Z Bridge)

5 Logistics modelling

TNO's [Unified Windfarm Simulation Environment](#) (UWiSE) platform offers a sophisticated solution for simulating logistics within offshore wind and solar PV farms. By seamlessly integrating advanced discrete event simulation logics with a map-based graphical frontend, UWiSE provides a powerful tool for industry professionals.

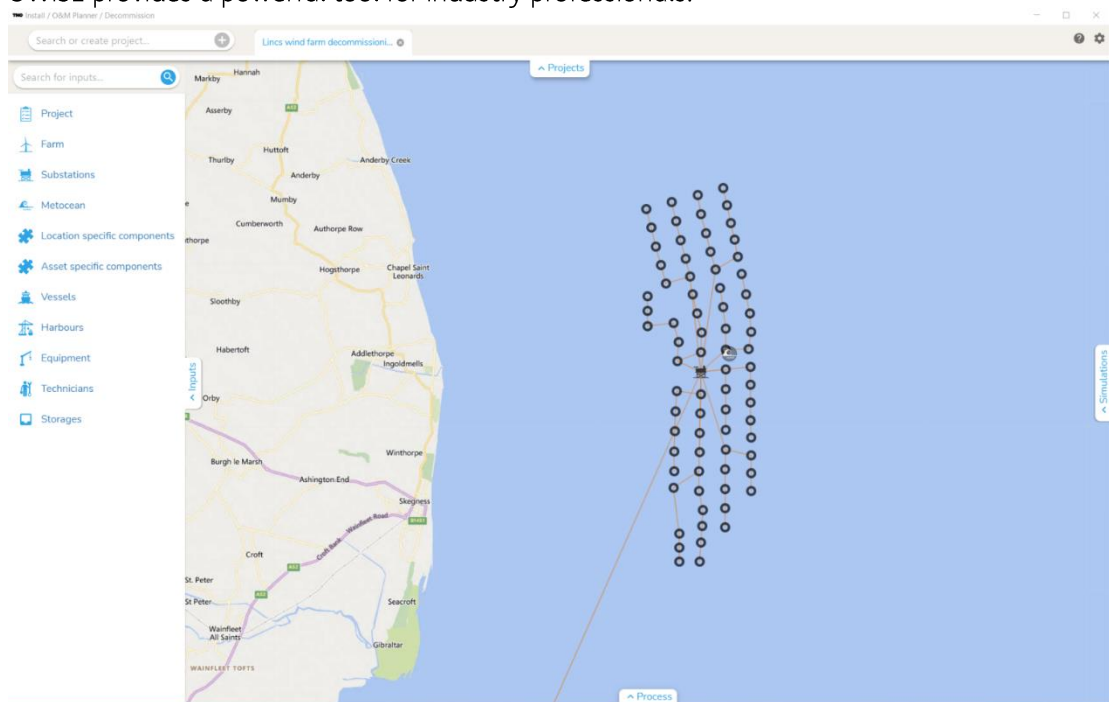


Figure 21. UWiSE graphical user interface

Drawing on TNO wind group's extensive expertise, the platform evolved from the Excel-based logistic cost simulation tool "ECN O&M Tool," a standard in the wind energy industry since 2005. In 2011, an upgrade to a MATLAB-based simulation software called "ECN O&M Calculator" further enhanced its capabilities. As the wind energy industry continues to progress, UWiSE aims to model the increasingly complex logistics involved in different life cycle phases of offshore wind farms. The platform introduces four dedicated modules: Install, O&M Planner, Decommission, and Despatch. These modules enable users to conduct multi-year simulations, calculating O&M costs, wind farm availability, and energy production. The simulations take into account uncertainties related to weather and wind farm component reliability.

Utilizing the Monte Carlo sampling technique for multi-year simulations considering weather uncertainty, UWiSE becomes an invaluable tool for decision-making in the planning, design, and operation of offshore wind farms. By running simulations for multiple weather years, the software generates statistical estimates, revealing the frequency and duration of favourable weather conditions for specific operations. This aids in identifying patterns, seasonal variations, and assessing the probability of encountering adverse weather. Furthermore, the modules assess the impacts on different key performance indicators when deploying various types and numbers of vessels, each with its own weather limits of operation. It is therefore a

precious tool to evaluate different access vessel and access systems combination to perform various missions. UWise's modules aim to:

- Model detailed logistics associated with real offshore assets, balance of plant, components, and storages.
- Rely on robust power output calculations, considering failure generation mechanisms and handling weather parameters and locations.
- Allow users to inspect every detail of a simulation and build their own logic for advanced asset behaviour
- Facilitate the evaluation of alternative options using quantitative and objective performance indicators.

6 Conclusions and future outlook

The main objective of this report was to present an overview of the current and future access solutions for offshore wind O&M activities.

This report covers a wide variety of access vessels are being used for offshore wind O&M, fitted with various access systems to meet the needs of various projects. This review of access solutions has also highlighted the emergence of innovative unmanned access solutions that brings increased flexibility, safety and broadened access opportunities to the sector, with drones or vessels evolving towards autonomous or semi-autonomous operations.

A review of the additional means necessary to access floating wind assets has also been presented, and the section on commercially available systems was updated with the latest information from access system providers.

Lastly, the relevance of modelling tools such as TNO UWISE in the context of access solution development and selection has been highlighted.

TNO will follow the developments of offshore wind access vessels and systems and intends to update this report every year.

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Title appendix

Appendix A Motion compensated gangway system specifications

Gangways - 1 of 3 - Updated 2023

	Ampelmann L-type	Ampelmann A-type	Ampelmann E-type	Ampelmann W-type	EAGLE-ACCESS	PALFINGER OPTS
Min length gangway [m]	8	16	21 (E1000) 22 (E5000)	21 (32m)	-	8
Max length gangway [m]	13	25	30 (E1000) 31 (E5000)	32	27	27
Max working angle (people transfer) [deg]	±17	±17	±17	±10	-	70
Height from deck [m]	-	-	-	-	23	25-27
Vertical reach [m]	-	-	-	-	25	20-27
Gangway width [m]	0.6	0.61	0.66	1.2	-	-
System weight [ton]	8	40	105 (E1000) 151 (E5000)	Subject to tower height & vessel interfaces	27	16 (fixed) 24 (mobile)
Footprint on vessel [m²]	14.5	41.8 (hydr.) 36 (elec.)	95	Integrated to the vessel	4	2.4 x 3.6 (fixed) 12 x 3 (mobile)
Significant wave height [m]	≤ 2.0	≤ 3.0	≤ 4.5	≤ 3.5	4.5	≤ 2.5
Vessel length [m]	30+	55+	70+	Subject to tower height	60+	50+
Power cons. [kW]	22	2x200 (hydr.) 47 (elec.)	2x400	175	75	2 x 75
Max load [kg]	-	300 (hydr.) 400 (elec.)	1000 (E1000) 5000 (E5000)	2000 (750 trolley)	1000	600 basket (personnel) 1000 cargo
No. of systems built [-]	17	45 (hydraulic) 2 (electric)	17 (E1000) 1 (E5000)	7 under construction	1	3 mobile units under construction
No. transfers [-]	>50 000	>7 300 000	>1 530 000	0	500	-

Gangways - 2 of 3 - Updated 2023

	SMST TAB M	SMST TAB L	SMST TAB XL	Ulmatec 25m	Ulmatec 32m	Z Bridge W2W	Z Bridge B2W
Min length gangway [m]	13	15-19	28-38	-	-	15	18
Max length gangway [m]	21	25-31	45-58	25	32	24	27
Max working angle (people transfer) [deg]	-20 +25	-20 +25	-23 +27	±25	±22	±15	-55 +10
Height from deck [m]	Up to 30	Up to 30	Variable	Variable	Variable	13	7-21
Vertical reach [m]	5-40 (adjustable)	5-40 (adjustable)	46	Variable	Variable	12.5	14
Gangway width [m]	0.6	0.9-1.2	1.5	0.8	1.2	1.2	1.2
System weight [ton]	-	-	-	-	-	50	27.5
Footprint on vessel [m²]	20ft container	Various	dia. 3.2		Dia. 4	15	5
Significant wave height [m]	2.5-3.5	3-4	> 4	3.5	4.5	4	3
Vessel length [m]	Various	Various	Various	45-200	60-500	>50	Various
Power cons. [kW]	55	100	86		44	50	50
Max load [kg]	300	1000/6000	10000	500	3000 (crane) 1000 (pallet)	1000	1000
No. of systems built [-]	11+4 under construction	22+18 under construction	5	2	2	1	6
No. transfers [-]	-	-	-		-	>1200	>6500

Gangways - 3 of 3 – Last updated in 2022

	Uptime 23.4m	Uptime 30m	Uptime 40m	Uptime 42.5m	Uptime 46.5m	Uptime 57.5m
Min length gangway [m]	15.4	20	25	30.5	30.5	37
Max length gangway [m]	23.4	30	40	42.5	46.5	57
Max working angle (people transfer) [deg]	-10 +15	±20	±20	-16 +24	-16 +24	-16 +24
Height from deck [m]	Custom	Custom	Custom	Custom	Custom	Custom
Vertical reach [m]	7.1	19	20	20	22	26
Gangway width [m]	1.2	1.2	0.9	1.2	1.2	1.5
System weight [ton]	28	36	50	78	0	140
Footprint on vessel [m²]	10	10	15	20	20	30
Significant wave height [m]	3.5	4.5	4.5	6	6	6
Vessel length [m]	>60	>60	>60	>80	>80	>80
Mobilisation time [h]	30	30	50	50	50	60
Personnel transfer time [s]	60	60	90	180	180	180
Power cons. [kW]	320	550	300	210	230	500
Max load [kg]	700	3000	1000	3600	3600	-
No. of systems built [-]	26	6	-	52	34	1
No. transfers [-]	1 000 000	500	-	1 000 000	1 000 000	-

Appendix B Motion compensated crane systems specifications

	EAGLE-ACCESS	SMST M	SMST L	SMST XL	Barge Master BM-T40	Uptime M3D 240	Uptime M3D 240/M3D 400	Uptime M3D 500
	Updated in 2023				Last updated in 2022			
Ability to transfer personnel [-]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Max safe working load for cargo [ton]	1	3-25	5-70	15-150	15-20 (at 10m radius) 5-8 (at 20m radius)	5 (3D) 10 (onboard)	7 (3D) 12 (onboard) 20 (onboard with separate winch)	-
Max crane lifting height [m]	30	-	-	-	35	17 (3D) 29 (Onboard)	17 (3D) 29 (Onboard)	-
Max radius [m]	28	31	35	45	-	26	26	33
Compensation DOFs [m]	3	3	3	3	3	3	3	-
Significant wave height [m]	4.5	4.5	4.5	4.5	3	3	3	2.5
Wave period limits [s]	-	-	-	-	4-18	-	-	-
Max wind speed [m/s]	24	25	25	25	-	25	25	25
Foundation footprint [m]	4	Dia. 2.2	Dia. 2.6	Dia. 3.2	4 x 8m (Barge Master) 3 x 7m (HPU) 3 X 7m (crane)	Dia. 2.0	Dia. 2.25	-
Weight [ton]	27	45 with knuckle boom crane	66 with knuckle boom crane	130 with knuckle boom crane	85 (Barge Master) 34 (HPU) 35(crane)	38.8	49.8	88

Energy & Materials Transition

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3