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OpenWater Renewables
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Historical Review of Installed FOW Projects

1. Introduction

This paper reviews the current worldwide fleet of Floating Offshore Wind (FOW) units and their historical performance. It considers all FOW units that have been installed in open sea with a capacity of at least 1 MW, whether these are still operational or have since been decommissioned.

There has been a slow but steady increase in the global installed capacity of FOW units since the first pilot was installed in 2009, as shown in Figure 1, with a clear acceleration in the last 5 years.

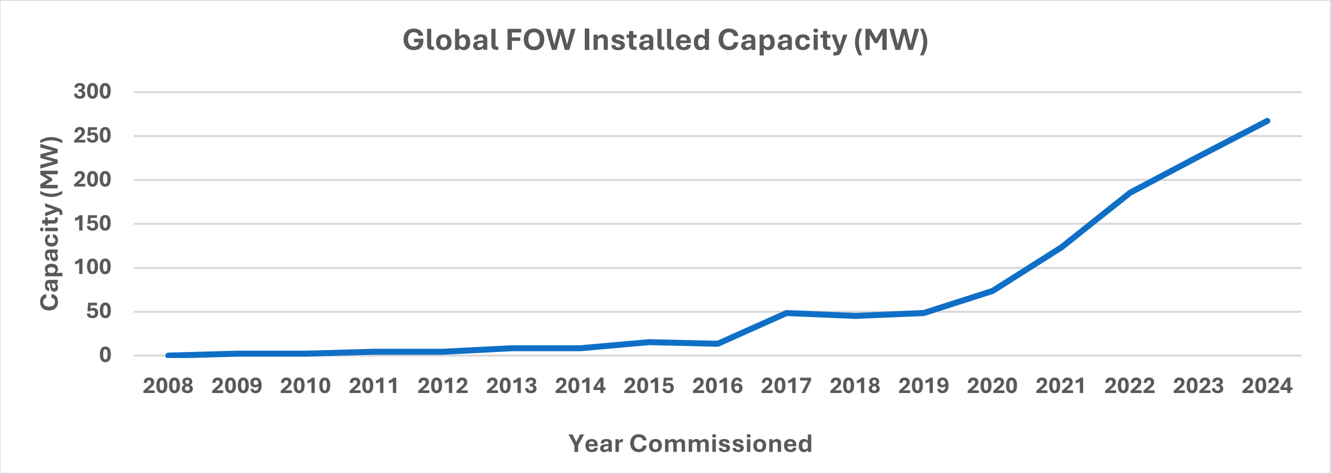

Figure 1

2. Distribution of FOW Technology

From our database, we identified 41 FOW units that meet the above criteria, with a total capacity of 281 MW. Of these, three have been decommissioned, leaving 38 units in operation today, with an installed capacity of 267 MW. (Note - WindFloat-1 was relocated from Portugal to Scotland but has only been counted once.)

The cumulative operating experience of the FOW industry today is around 176 unit-years (defined as 1 unit operating for 1 year), including those units now decommissioned.

We have analysed the global FOW fleet in terms of.

- Location
- Hull type and materials of construction
- Technology providers
- Wind turbine suppliers

The results from this analysis are shown in the following graphs

Firstly, considering the units' location and installed power (including the 3 units now decommissioned), we can see from Figure 2 that Norway and the UK (Scotland) dominate the market, with 173.5 MW installed (62% of the total installed capacity).

European FOW projects, including those in Portugal, Spain and France, make up a further 53.2 MW (19%), and the remaining 54.6 MW (19% of the installed capacity) is in China and Japan.

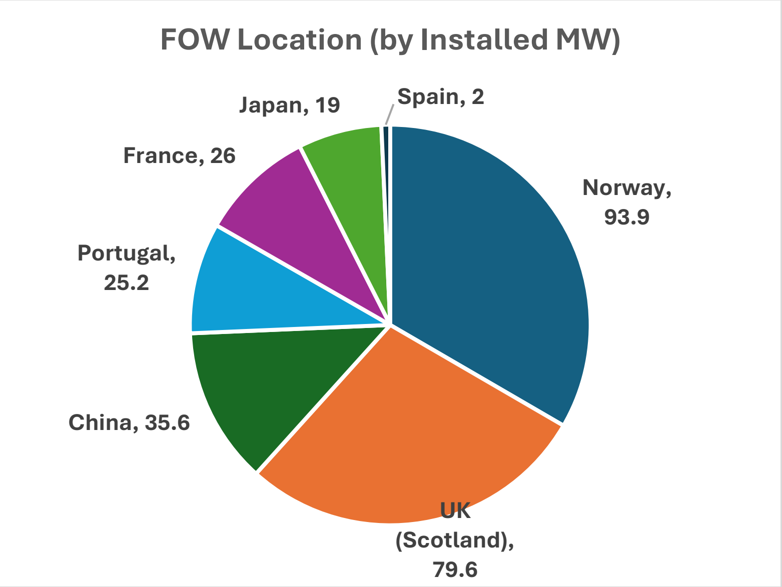

Figure 2

Secondly, looking at the type of hull used around the global FOW fleet, by number of installed units, we find in Figure 3 that SPARs are slightly ahead of Semi-Subs, at 20 units versus 15. In comparison, barges and TLPs have been much less widely deployed to date.

Although Semi-Subs have been selected for more demonstrator projects than SPARs (10 projects versus 6 projects), the large number of units installed on two Hywind projects pushes the total number of SPARs installed into the top position.

When the total installed capacity of the different hull forms is included, the gap between SPARs and Semi-Subs is closer at 47% and 42% respectively, followed by 9% for TLPs and 2% for barges.

Next, we have also analysed the materials of construction for the 41 units, which are shown in Figure 4 below. We can see that most of the units installed today have steel hulls, with 27 units against 13 concrete units and 1 hybrid concrete + steel (Saitec's SATH).

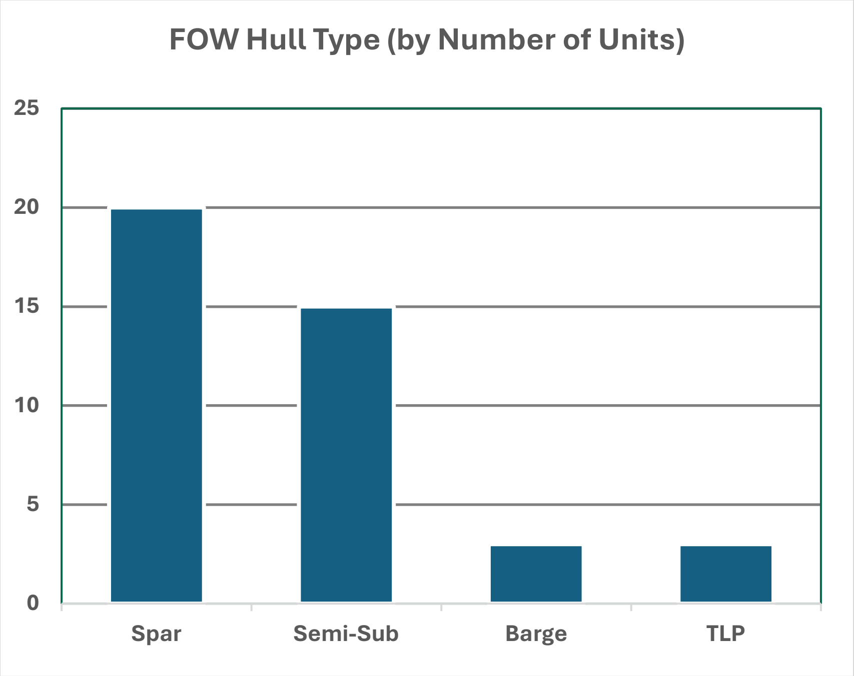

Figure 3

However, many of the concrete-hulled units have been installed relatively recently (such as the Hywind Tampen project and Mingyang's OceanX). If we compare the unit-years of operational experience, we find that 80% of the accumulated experience is with steel hulls, against 19% for concrete and 1% for hybrid. It is interesting to note that Equinor, in its drive to reduce LCOE, switched from steel SPARs on Hywind Scotland to concrete SPARs on Hywind Tampen.

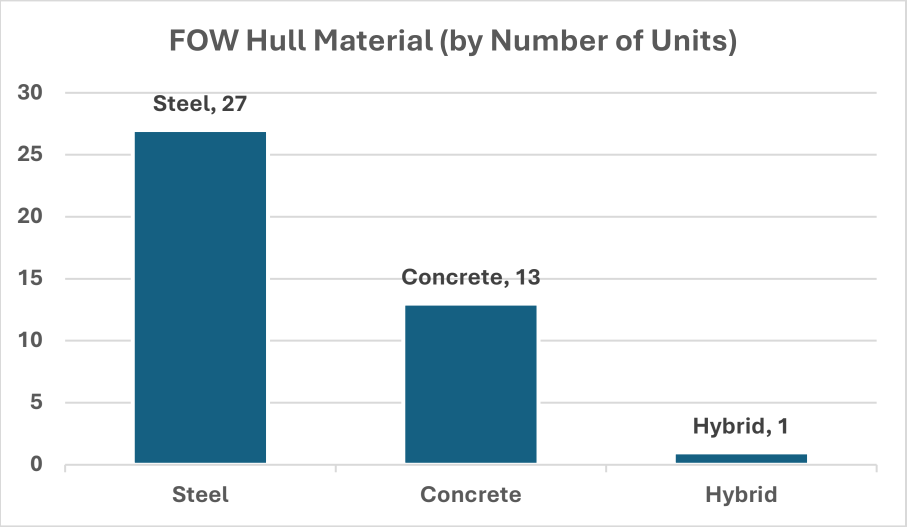

Figure 4

Moving to Technology Providers, the picture becomes more complex as there are already 14 different designs of floating foundations installed, and 2 of these have also been supplied in both steel and concrete materials.

Figure 5 shows that, when considering the number of operating FOW units, the designs from Equinor and Principle Power Inc (PPI) dominate with 63% of the total global fleet between them, followed by SBM Offshore and BW Ideol, ranked third and fourth, respectively.

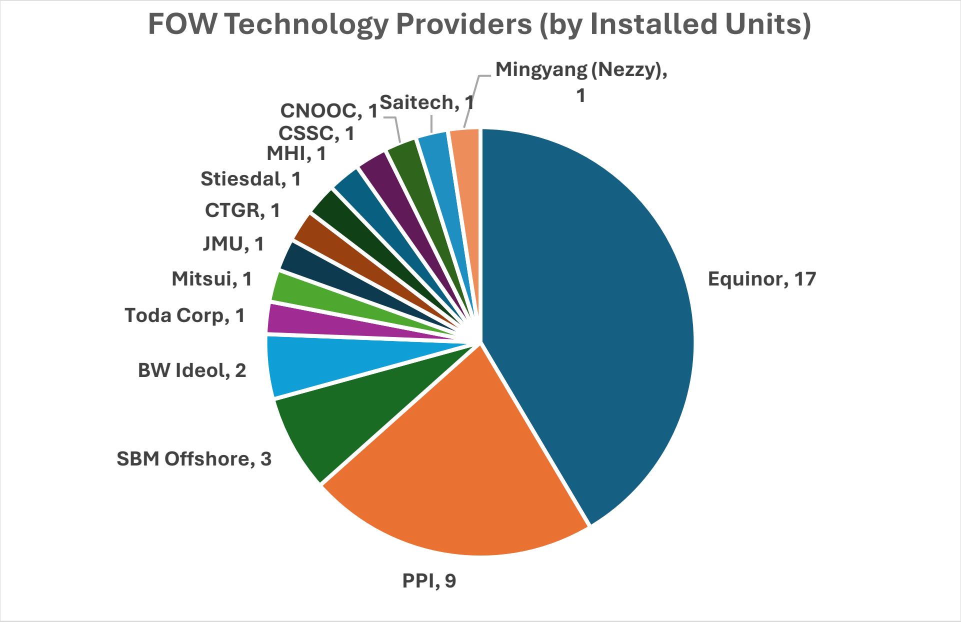

Figure 5

If we include the capacity of the units in the analysis, we get a slightly different view by summing the installed MW from each technology provider. Equinor and PPI still dominate with 69% of the global fleet capacity, and SBM Offshore remains in 3rd place, but Mingyang moves into 4th place due to their large demonstrator installed in China (based on a licence for the Nezzy[2] hull concept (Ref 1)).

BW Ideol drops to 9th position in this analysis, due to the relatively small capacity of their two demonstrator projects in operation.

Finally, if we compare the Technology Providers by the accumulated operating experience of their foundation designs in unit-years (defined as 1 unit operating for 1 year), we get a different picture – see Figure 6 below.

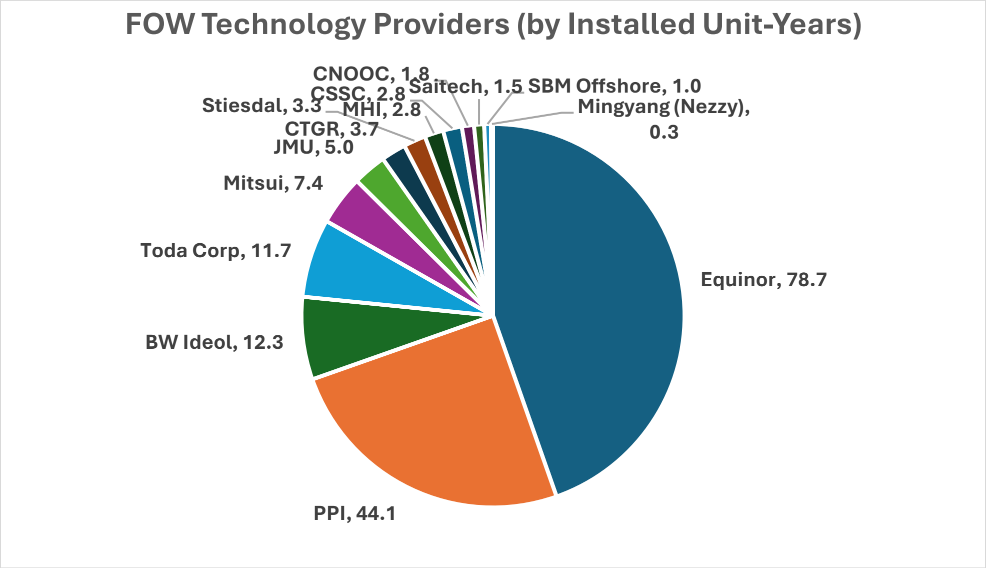

Figure 6

Whereas the Equinor and PPI designs still have the most operating experience, at 122.8 years (70% of the total), BW Ideol now comes third with 12.3 years (7%). Two Japanese companies, Toda Corporation and Mitsui, have also built considerable experience from their demonstrator projects in Japan, with a total of 19.1 years (11%) between them.

The two new demonstrator projects using technology from SBM Offshore and Mingyang (Nezzy[2]) currently rank lowest since both have only been operating for a few months.

Figure 7 below shows the leading FOW turbine suppliers, again by installed unit-years of operating experience on the floaters. We see that Siemens Gamesa dominates the market with 83.1 years (47% of the total operational years), followed by Vestas and Hitachi.

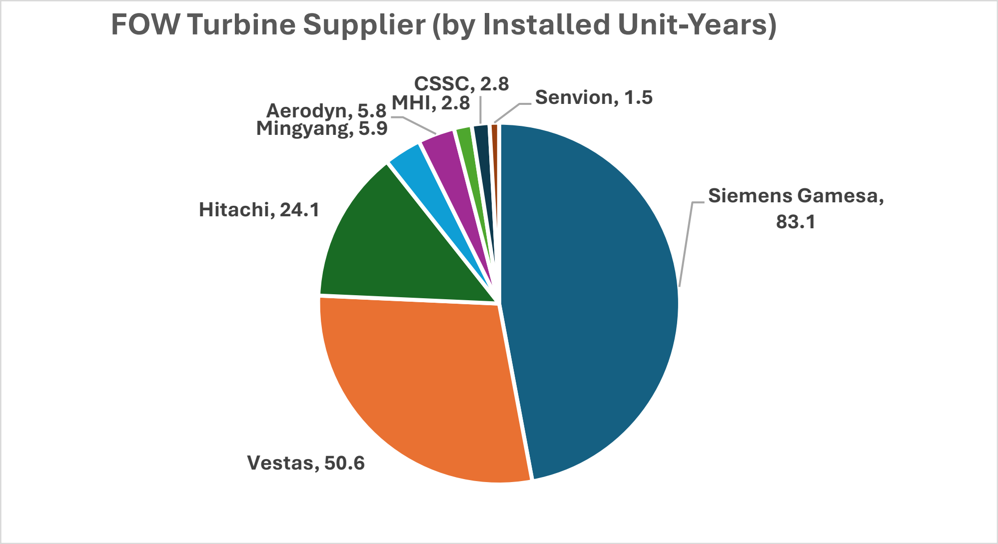

Figure 7

If, instead, we plot the total installed turbine power, SG and Vestas still dominate with 80% of the total installed capacity, but Mingyang (at 10%) moves ahead of Hitachi mainly due to their large new demonstrator project in China.

3. Historical Performance

We have gathered information from the public domain for each of the demonstrator and pre-commercial projects and analysed this in the following 7 categories.

3.1 Capacity Factors

A key attraction of FOW is to obtain higher Capacity Factors by moving further offshore, where wind speeds are generally stronger and more persistent. This is borne out by the published data from several of the demonstrator projects.

Based on published data for various UK (Scotland) and Norwegian projects (Ref 2, 3, 4, 5, 6), we find the following typical Capacity Factors.

• Peak Monthly Average (Winter)	62%-73%
• Peak 3 Monthly Average (Winter)	57% - 60%
• Peak Yearly Average	56%-57%
• 5-Yearly Average	50% - 54%

This compares to the average fixed bottom wind farm capacity for Scotland over the last 5 years of 34%, as reported by the Crown Estate in their Offshore Wind Report 2023 (Ref 7). The figure for England and Wales is higher, at around 40%. (Note that the above data for FOW does not yet include the impact of the recent major breakdowns, discussed below).

The difference in Capacity Factors between floating and fixed wind farms is due to a combination of factors, including site wind conditions, average turbine size, reliability of more modern machinery, and turbine power density selected (the ratio of rated output to rotor swept area). Moreover, losses due to wake effects, which impact many large offshore fixed wind farms, are not yet a factor for smaller FOW demonstration projects.

The Capacity Factor is also expected to vary between FOW foundation types, because of different performance for static incline and dynamic motions, and the contribution of the hull to the overall availability of the unit (since this is an integral part of the Capacity Factor). However, there is currently insufficient information in the public domain to compare the respective Capacity Factors of different hull types, and this will be an area of future study.

3.2 Availability

The average availability for FOW units, which is publicly reported, ranges from 93% to 98% (Ref 6, 8, 9). However, this is not broken down between the turbine, hull, mooring systems and cables, and it also excludes the major breakdowns reported below, as they are relatively recent.

For UK fixed wind, the Crown Estate (Ref 7) report a 10-year average availability of 97.6%. The lower availability of FOW may be due to several factors, such as the prototype nature of these projects, more difficult crew access in deeper water and harsher locations, or the effect of motion on the turbines. So far, there is insufficient data to draw any firm conclusions, but this is a critical area, worthy of a more detailed study.

It should be noted that availability is an inherent part of the Capacity Factor, as it impacts the amount of annual energy produced. Hence, it is interesting to note that, despite their lower availability, FOW units still typically report higher overall Capacity Factors than fixed wind.

3.3 Major Breakdowns

Three major FOW breakdowns have been reported, all linked to the wind turbines.

The most serious are two failures which, impacted multiple units in both cases (Ref 14).

- Hywind Scotland, where all 5 SPARs returned to a deepwater port in Norway in the summer of

2023 for a major overhaul of the 6 MW Siemens Gamesa turbines, after less than 6 years in operation. The exact nature of the failure has not been made public, but Equinor reported that each nacelle was removed from the SPAR and returned to an onshore workshop for overhaul (Ref 10, 11, 12).

- Kincardine, where 3 of the 5 Semi-sub units required the main generators on their Vestas 9.5 MW turbines to be replaced, after one failed in the first year of operation. Two units have been towed back to Rotterdam for repair (in 2022 and 2023), and a third was repaired in situ offshore in 2024 (Ref 13, 14, 15). Repairs may still be needed on the two remaining units.

The changeout of the 30-tonne generator offshore on the Kincardine project was a complex operation and highly weather-dependent (Ref 15); therefore, performing the same procedure on the new generation of 15 MW turbines could be even more challenging. For this reason, unless there is rapid development of new technology or specialised vessels for in-situ WTG repairs, we expect to see "return to port" becoming the default strategy for major turbine repairs, using either a quayside crane or a temporary up-turbine crane in sheltered port conditions.

A third major breakdown was the repeated failure of the MHI 7 MW turbine on the Fukushima Forward Shimpuu project (Ref 16). This was a novel turbine with a hydraulic-drive system, which had such poor reliability that the project was eventually decommissioned after less than 3 years of service.

In general, hulls and moorings have been very reliable, with no reported major incidents. However, the vast majority are still relatively young, and any asset integrity issues are more likely to appear in later life.

Of the numerous small-scale (< 1 MW) prototypes deployed, three have sunk. Two of these (one in Norway and one in Spain) sank in bad weather when the scale model of the hull was swamped by large waves (Ref 17, 18). The third, in Japan, coupled a vertical axis turbine with a submerged tidal energy wheel on a single hull, but it failed once (in 2013) and then sank (in 2014) during re-installation, before being abandoned (Ref 19, 20).

3.4 Asset Integrity

Only 2 units have been operating for more than 10 years – the Hywind Demo (now Zephyros One) and Toda Corporation's Sakiyama Pilot in Japan. Both are steel SPARs.

The Sakiyama Pilot project has been in operation for almost 12 years. Eight similar SPARs are currently being built to be installed nearby (Ref 21), but this project has been delayed by 2 years after the discovery of structural defects on some of the new SPARs.

The oldest installation, the Hywind Demo / Zephyros One, has been operating for almost 16 years. Zephyros Ocean, now the owner and operator, presented information on operational experience over the last 5 years at a recent Wind Europe event (Ref 22). They performed an uptime improvement and maintenance programme between 2019 and 2022, which resulted in an 18.1% increase in uptime over the complete year, for all seasons. Key to this was a preventive maintenance program and life extension project. An essential element was to address hull corrosion, and as a result, Zephyros Ocean is now understood to favour concrete hulls for future projects.

3.5 Accessibility

Further feedback from Zephyros Ocean (Ref 23) was that the sea states at the METcentre, 10km off Karmøy, Norway, are such that access by boat can be difficult, making maintenance problematic. A small helideck has therefore been added to the SPAR to enable the above preventive maintenance program to be safely implemented.

The ability to perform a medical evacuation by helicopter from an FOW hull was demonstrated by BW Ideol in May 2022 from their WindFloat Atlantic project, by making use of the deck space available on their Floatgen barge hull (Ref 27).

3.6 OPEX

There is little published data available for actual floating wind OPEX.

WindFloat Atlantic reports (Ref 9) that 18,000 hrs per year are spent on corrective and preventive maintenance. This looks consistent with a typical OPEX estimate of 2% to 3% of CAPEX per year (noting that this includes other elements such as spare parts and logistics, as well as manhours).

There is little information yet on how this OPEX may escalate with time as the condition of the units deteriorates, although some data has been published for smaller onshore turbines (Ref 21). This is another area worthy of further study, especially to investigate any difference between concrete and steel hulls.

3.7 Cyclonic Conditions

Three FOW units in China have been developed for cyclonic environmental conditions. The China Three Gorges Renewables (CTGR) Yangxi Shapa III project uses a Mingyang MySE5.5 typhoon-resistant wind turbine (Ref 24). Mingyang's OceanX twin turbine 16.6 MW demonstrator is also designed for cyclonic conditions and in 2024 withstood Super Typhoon Yagi in the South China Sea (Ref 25). A third demonstrator in China, CSSC's

These three demonstrator projects show that FOW units can be successfully designed, built and operated to withstand severe cyclonic conditions.

Fuyao project, also has a typhoon-resistant CSSC turbine rated at 6.2 MW (Ref 26).

4. Conclusions

The total number of FOW units in operation is growing steadily, and the average size of these units is increasing as there is a move from demonstrators to pre-commercial farms. However, despite 14 different hull technologies already being deployed, only a few technology providers have the EPCI and operational experience to execute commercial-scale projects with a tolerable level of risk.

The situation is the same for the wind turbine suppliers, where 90% of the FOW operational experience is shared amongst only 3 manufacturers - 2 from Europe and 1 from China.

Capacity Factors for North Sea projects confirm the benefits of moving into deeper water with better quality winds, resulting in levels around 30% higher than typical UK fixed wind farms.

Availability data for FOW units is still scarce, but so far indicates levels below that of fixed wind. Similarly, little OPEX and Asset Integrity feedback is available. All three areas merit more detailed investigation, especially to compare the relative robustness of steel versus concrete hulls, and the possible link between floater motion and reliability.

Of the 8 FOW units that have required heavy turbine maintenance so far, 7 were returned to port for repair, and only 1 has been repaired in situ, and we expect to see "return to port" becoming the default strategy for major repairs.

5. Glossary

CAPEX	Capital Expenditure
FOW	Flowing Offshore Wind
LCOE	Lowest Cost of Energy
MTBF	Mean Time Between Failures
MW	Mega Watt
OPEX	Operating Expenditure
PPI	Principle Power Inc
SPAR	Single Point Anchor Reservoir
WTG	Wind Turbine Generator

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7. Acknowledgements

This paper was prepared as part of a study for the Technology Leadership Board (TLB) in June 2025, as an Appendix to the main report.

The full report is available from https://www.the-tlb.com/tlb-news/concrete-comes-out-on-top-in-floating-wind-turbine-foundations-study.

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