OpenWater
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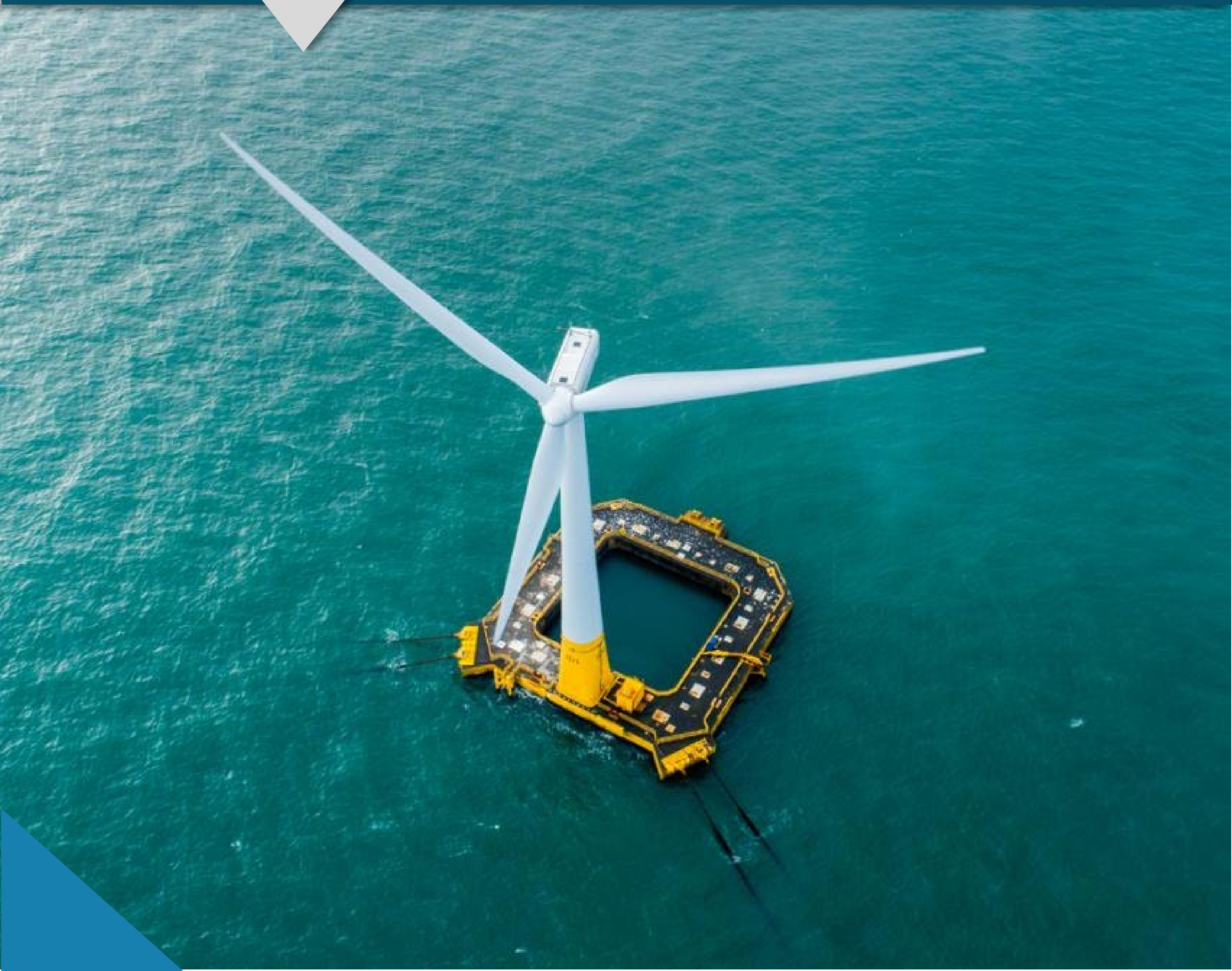
Deepwater Wind Assessment

Final Report



Commissioned by:

technology leadership board

TLB2601 – RP01 – A3

Final Report

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1.0 Executive Summary

In 2025, OpenWater Renewables Ltd conducted a study for the UK Technology Leadership Board to review hull concepts for Floating Offshore Wind that are best suited to North Sea conditions. The present report provides an update to the original study, revising the analysis to include concepts introduced to the market since 31st March 2025, the cut-off date for inclusion in the original.

In addition, this report includes a review of hybrid systems (defined as fixed-bottom deepwater wind concepts) as an alternative to floating, plus a review of UK-based deepwater wind energy concepts – both floating and hybrid – where, for this work, deepwater is considered to be 60m or more.

The views and conclusions herein are those of OpenWater Renewables and are based on the limited and qualitative scope of work which they were asked to complete.

Analyses of the available floating and hybrid concepts are typically conducted by wind farm developers and other interested parties; however, the results have generally not been made public. The Technology Leadership Board's intent in commissioning this study is to widely share the key factors relevant to deepwater wind foundation selection and, through a generic analysis, illustrate how they might influence end users' choice of foundations for their projects.

The study considered a fictional 750 MW wind farm located at a water depth of 100 to 150m in the North Sea off Scotland, using 15 MW turbines, operational by 2030 to 2035. The study findings are also applicable to the Celtic Sea for similar operating conditions.

Data for the study were obtained from the OpenWater Renewables proprietary deepwater wind database, which contained details of 117 floating concepts and six hybrids, as of the cut-off date for the study on 28th February 2026. Hulls in the database are predominantly barges, semi-submersibles, SPARs, and Tension Leg Platforms, and are fabricated from steel, concrete, or a combination of both.

The most appropriate foundations were determined using a proprietary concept-ranking tool developed by OpenWater Renewables. The tool scores concepts against 39 criteria across a range of technical, commercial, and project-execution characteristics. Each score is weighted to reflect the influence of the criterion on the Levelised Cost of Energy and the project risk profile. Further Project Weighting Factors are then applied to selected criteria to account for the specific challenges of a site or project strategy. For the North Sea project, 15 criteria were selected for the application of project weighting factors, covering the critical areas of installation, accessibility, performance, and risk. These factors reflect the risks inherent in an early deepwater wind project, and different factors may be appropriate for later projects when technical and project-execution risks are better understood and mitigated.

The outcome of the analysis was a pool of 15 floating concepts, eight in steel, six in concrete, and one in mixed materials. No hybrid concepts currently score high enough to be included in this pool.

The generic pros and cons of the 15 floating systems, partly based on analysis in the previous report, are shown in Figure 1-1 below, along with analysis of a generic guyed-tower hybrid concept.

Only three of the concepts in the pool of 15 have reached TRL6 (demonstrator in the water) or TRL7 (three years of successful demonstrator operation), whereas it is recommended to select only concepts that have reached at least TRL7 by project FID. The report provides a roadmap for progressing through the TRL framework and discusses its application and limitations.

	CAPEX *	OPEX	LCOE	Ease of WTG Integration	Ease of Installation	Ease of O&M	Reliability	Performance	Ease of Major Repair	TRL/Risk	Examples (TRL)
Barge in Concrete	100%										BW Ideol Damping Pool (7), Aker CONfloat Omega (0), Aker CONfloat 7C (5), Brezo Energy CROWN FW (5), Sevan SWACH Wind (5)
Barge in Hybrid Steel & Concrete	110%										Saitec SATH (6)
Semi-Sub in Steel	105% to 115%										PPI WindFloat-T (7), Saipem Star-1 (5), Aker YFloat (5), Seatrium FWSS (5), JMU Jade Wind Centre (5), PPI WindFloat FC (5), Gusto TriFloater (5), Odfjell Oceanwind Deepsea Star (5)
Semi-Sub in Concrete	100%										Bouygues OO-Star (5)
Hybrid - Guyed Tower	95% to 100%										OSI FTLP+ (5), MPS Pelaflex GS (5), Entrion FRP (5)

* Ball Park total project CAPEX compared to the Concrete Barge case.

Key: Good | Intermediate | Poor

Figure 1-1: Generic Concept Pros and Cons

A review of hybrid deepwater systems identified six concepts under development, and the main features of each are described. The principal limitation of hybrids as alternatives to floating for the study Basis of Design conditions is the current difficulty of installing these in water depths beyond 80m. This limit is imposed by the absence of jack-up Wind Turbine Installation Vessels capable of installing turbines on hybrids in deeper water. Some large semi-submersible vessels are available for turbine installation, but these are too costly to be a practicable solution, and their performance in some North Sea conditions may be challenging. All hybrid concepts have the potential to operate in deeper water if suitable installation methods become available, and some technology providers are already working to develop such methods. However, all hybrids are currently TRL5 or lower since none have a prototype at sea.

A further consideration is that, although the CAPEX of the hybrid hull will generally be lower than that of floating concepts, the installation cost will be higher. A generic analysis of hybrid versus floating cost is included in the report and concludes that the overall total installed cost is similar for both basic concepts. Ideas are being developed to reduce the cost of some hybrid concepts, but these are still conceptual, so they have only been partially considered. It is noted that the CAPEX for both floating and hybrid concepts is likely to decrease with future design and industrialisation optimisation.

A review of UK-based systems identified four hybrid and three floating concepts under active development. Their TRL ranges from three to five, with none having a demonstrator in the water yet.

UK content can be achieved through the implementation of UK-based concepts, and/or solutions from elsewhere engaging with the UK supply chain.

The report makes several recommendations to stimulate the development of UK content, including:

- To allow a detailed comparison of UK-based concepts on a like-for-like basis, conduct FEED-level design competition, including Transport & Installation, UK manufacturing content, and full lifecycle cost analysis. Where international concepts can demonstrate a high UK content, they could also be considered as potential candidates for the above FEED-level design competition.
- Based on the outcome of the design competition, build and test several demonstrator units for the concepts found to have the highest potential. This could be at a dedicated test & demonstration site or as part of, or an addition to, a commercial wind farm.

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2.0 Introduction

2.1 Objectives

The Technology Leadership Board (TLB) is one of the North Sea Transition Forum task forces established by industry and government to provide leadership to the offshore oil and gas sector. Read more about the task forces here.

The TLB includes a workstream focusing on technology enablers for the North Sea Energy Transition, and this report is part of the work to investigate which of the many deepwater foundation concepts available today could be best suited to North Sea conditions. Read more about the TLB here.

OpenWater Renewables Ltd (OWRL) is an independent UK-based consulting company with expertise in fixed and floating structures and offshore renewable energy and has developed a proprietary process for assessing and ranking deepwater wind energy concepts.

The TLB has previously engaged OpenWater Renewables to conduct a study into the Floating Offshore Wind (FOW) foundations (hulls) best suited for the North Sea. This report, Assessment of Floating Wind Turbine Foundations for North Sea Conditions [1], is available here.

The TLB has now commissioned OpenWater Renewables to update the report to include FOW concepts introduced since 31st March 2025, the cut-off date for input to the previous study. Additionally, the report will specifically review hybrid deepwater concepts (defined as fixed-bottom deepwater wind concepts) and UK-based concepts.

2.2 Cut-off Date

This report has been prepared based on the deepwater wind energy concepts available in the market as of the 28th of February 2026. New concepts launched after that date are not included.

3.0 Methodology

3.1 Basis of Design

It was agreed with the TLB that the Basis of Design (BOD) would remain consistent with that used in the previous study [1] and should cover both the North Sea and Celtic Sea. The agreed-upon details are provided in the datasheet in Appendix A.

The study is based on a fictional offshore wind farm in Scotland, using typical information from projects like ScotWind. However, it is neither based on nor directly related to any specific ScotWind project.

The key parameters used for the study are:

- Capacity 750 MW
- Turbine Size 15 MW
- Water Depth 100 to 150 m
- Distance from shore 80 to 120 km
- Start of Operations 2030 to 2035

The project development plan for the floating or hybrid foundation should enable the project to meet the UK Content targets [2], considering a range of supply chain assumptions for wind turbines, cables, and substations, as well as hulls and moorings.

We have not performed a yard survey at this stage and have relied on the findings from others [3, 4]. It is assumed that the current investment plans will be sufficient to generate the required capacity in the required schedule.

3.2 Ranking Process

The method for ranking deepwater technologies is based on a comprehensive database of the characteristics of 117 floating concepts being tracked by OpenWater Renewables, plus characteristics of six hybrid concepts. These characteristics have been validated by many of the leading technology providers. Using this data in the OpenWater Renewables proprietary tool [5], each concept has been scored against criteria grouped into seven categories. These categories cover a wide range of technical, commercial and project-execution details. A weighting is applied to each of these criteria based on a criticality assessment specific to the deepwater wind energy industry, considering the entire project life cycle.

The default weighting factors can be supplemented with project-specific weighting factors to address site- or project-specific requirements. Section 5.1 of this report discusses the project weighting factors employed for the current UK North Sea study.

Radar plots and stacked histograms are used to compare concept scores across the seven criteria categories. The total score from all criteria is used to rank the concepts.

The ranking process used is shown schematically in Figure 3-1 below.

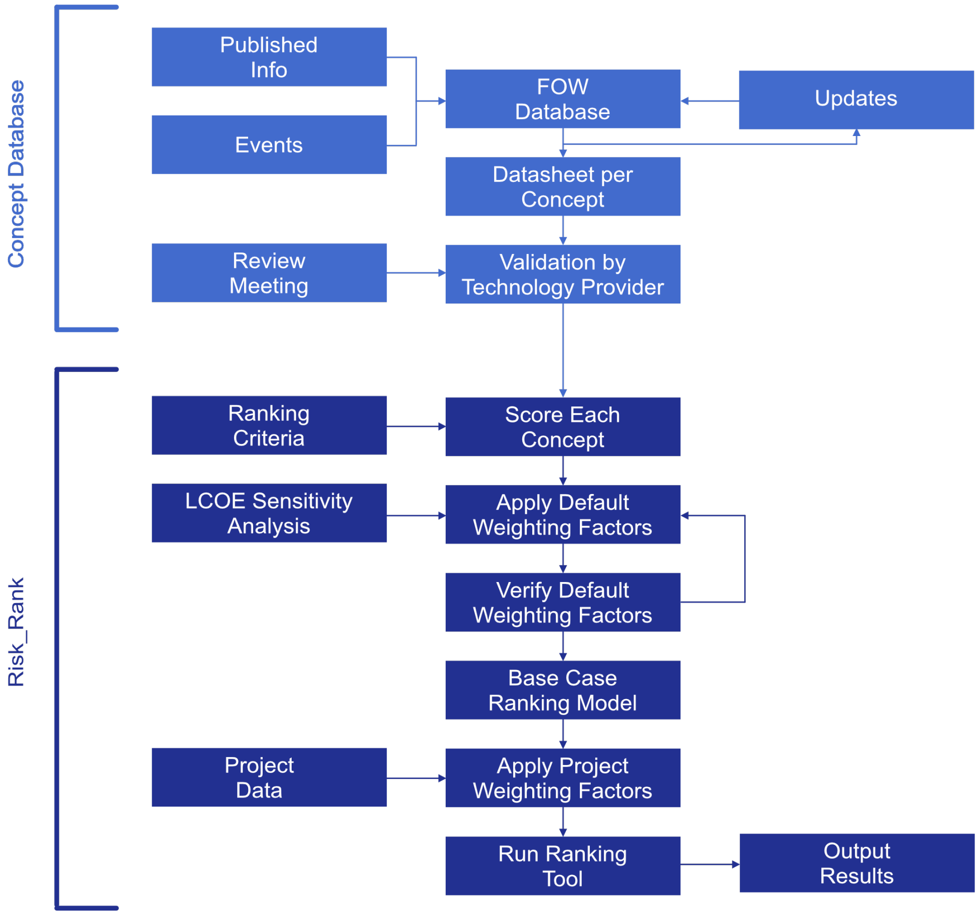

Figure 3-1: Deepwater Ranking Process Flowchart

Further details of the ranking methodology used are provided in Appendix B of this report and in a 2025 OTC paper [5].

4.0 Current status of Deepwater Wind Energy technology

OpenWater Renewables is currently tracking 109 floating hull concepts and six hybrid concepts that may be available to project developers. Eight of these concepts are available in either steel or concrete, bringing the total to 123 concepts in the OpenWater Renewables' database at the cut-off date. Approximately 60% of these concepts are currently being actively developed and marketed, while the remaining 40% have seen little to no development in recent years.

Of the 123 concepts, 84 are based on steel hulls, with steel semi-subs being the most common (58 concepts). There are 29 concrete-hulled concepts, with semi-subs again being the most prevalent (11 concepts). Additionally, 10 concepts feature a mixed-material design using a combination of both steel and concrete.

This is summarised in Figure 4-1 below:

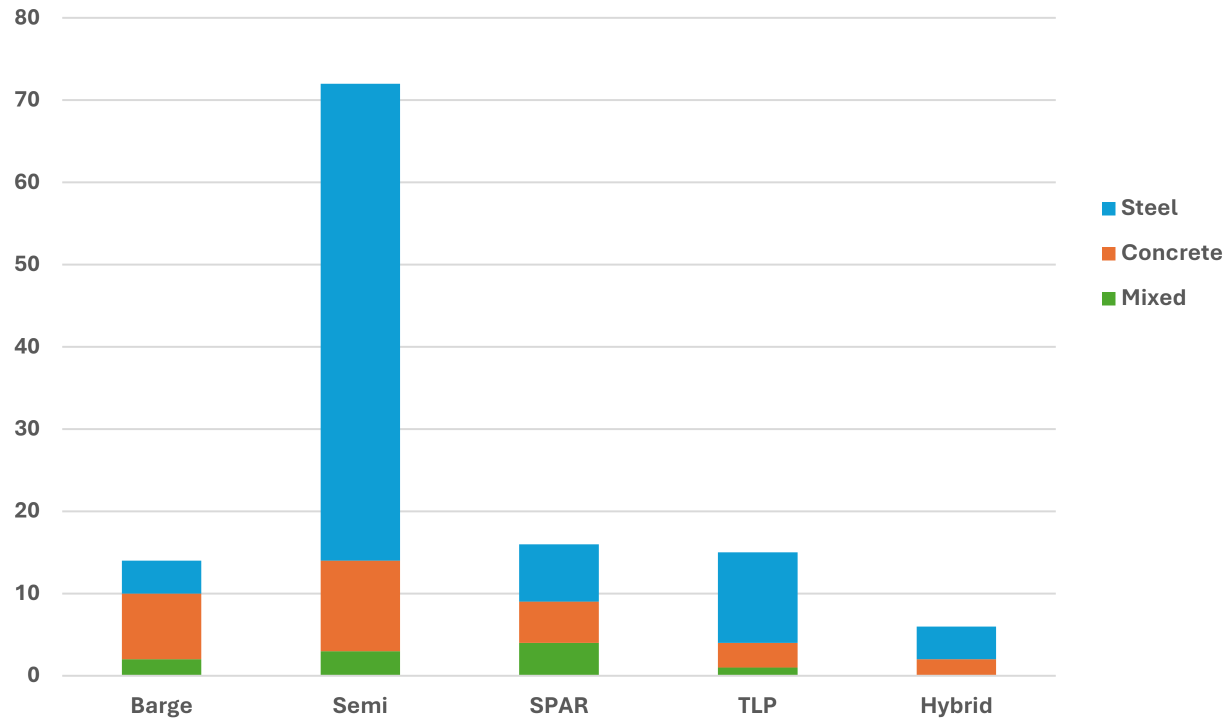

Figure 4-1: Material per hull type

Using the Technology Readiness Level (TRL) process, OpenWater Renewables has estimated the maturity of each concept. As discussed in the earlier report "Assessment of Floating Wind Turbine Foundations for North Sea Conditions" [1], there is currently no universally accepted industry-standard definition of TRL for FOW or hybrids. Consequently, OpenWater Renewables has developed and applied the scale presented in Appendix C of this report. The applicability of this scale to individual projects, and considerations in assessing the suitability of a prototype for a project based on TRL, are discussed in Section 4.1 below.

The OpenWater Renewables definitions of TRL8 and TRL9 refer to commercial farms with at least 100 MW capacity, but no floating or hybrid units have yet reached these TRLs, and the highest TRL achieved is TRL7, as shown in Figure 4-2. Whilst some projects have achieved substantial operating experience, this has not been trouble-free.

An alternative approach to TRL9, instead of a 100 MW farm operating for three years, could be to consider the cumulative performance of multiple smaller farms or demonstrators that have successfully achieved 300 MW-years of cumulative operation. However, OpenWater Renewables does not support this approach since it does not capture the risks associated with the serial fabrication and installation of multiple identical units. From a risk mitigation approach, the OpenWater Renewables definition based on a single farm of at least 100 MW is therefore preferred.

Most of the tracked concepts are at TRL3 or TRL4, indicating they have been validated through numerical simulations or model basin testing. Twenty-seven concepts have progressed to TRL5, but only 15 concepts have reached or exceeded TRL6, which requires at least one prototype or demonstrator to be operational offshore (note that prototype units with WTG of less than 1 MW have been excluded). These include eight semi-subs, four SPARs, two barges, and one TLP. The remaining concepts have not yet reached the stage of having a demonstrator or prototype of ≥ 1 MW at sea.

The overall distribution of TRL levels for the concepts is summarised in Figure 4-2 below. Note that where a concept is available in both steel and concrete, it is counted as a single concept in this summary.

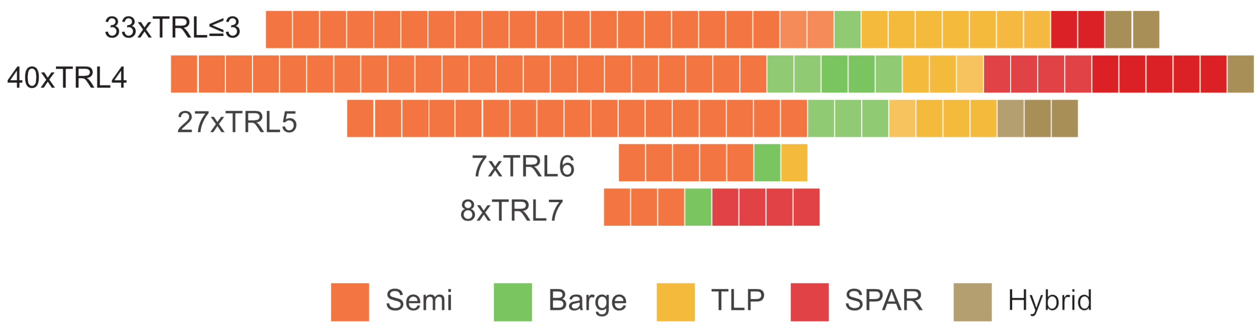

Figure 4-2: Summary of TRL levels by hull type

It should be noted that of the 15 concepts at TRL6 or TRL7, three projects – the JMU Advanced SPAR (TRL7), the Mitsui Compact Semi-sub (TRL7) and the MHI V-Shaped Semi (TRL6) from the Fukushima Forward research project – have now been decommissioned and are no longer under development.

4.1 Considerations in the Application of TRL for Deepwater Offshore Wind

The TRL framework provides a structured methodology to assess the maturity of offshore wind technologies. It also serves as a proxy for technological risk, which influences financing structure, cost of capital, and insurance requirements.

The TRL definitions adopted by OpenWater Renewables are included in Appendix C, and a generic roadmap of the TRL process for deepwater wind energy concepts is included in Appendix D. This roadmap outlines the main activities to be completed to reach each TRL level. However, the roadmap is generic in nature, and novel concepts may deviate from the roadmap activities in some cases.

Adherence to this roadmap will provide significant risk mitigation, although several factors should be considered in its application.

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In the TRL definitions adopted by OpenWater Renewables, TRL7 is reached after three years of successful operation of a prototype. This prototype will usually be a smaller version of the intended commercial unit. In accepting the prototype as representative of a commercial unit, several factors should be considered:

- The scaling factor, i.e. the ratio of turbine capacity between the prototype and commercial unit. This affects not only the total load on the unit, but also the ratio of turbine thrust to wave loading. Demonstrators classified as TRL6 or TRL7 in Figure 4-2 have a minimum turbine capacity of 1 MW, but the actual turbine capacity must be considered in assessing whether the scaling factor to a commercial unit provides adequate technical risk mitigation.
- Consistency of design elements: Significant changes to the structural arrangement or details from the prototype to the commercial unit may compromise the value of the prototype. Changes such as moving from a soft-stiff to stiff-stiff WTG mast, or a change from tubular to flat-panel construction, can introduce new failure modes, which can invalidate some of the conclusions from a demonstrator project.

A further consideration in the definition of TRL7 is the three-year period of successful operation required. This is consistent with API RP 17C, which has been used extensively for the development of subsea equipment systems. The adoption of three years ensures the concept has been exposed to multiple seasonal variations, reducing the probability that it has only seen a benign loading regime if operating for only one year. However, although the OpenWater Renewables definition of TRL7 is based on three years of successful operation, other industry members may consider a shorter duration to be adequate. If a shorter period is to be accepted by a technology provider or project developer, OpenWater Renewables recommend that this is reviewed as part of a project risk assessment, paying particular attention to the metocean conditions experienced by the prototype and any changes introduced to the structural design in scale-up.

To progress from TRL7 to TRL9, the OpenWater Renewables definitions require a wind farm of at least 100 MW capacity to have been installed and operated successfully for three years. This requirement aims to assess the behaviour and performance of the full-scale commercial units, but also the serial construction of the hull structures, O&M logistics, and wake interaction with adjacent turbines.

5.0 Study Results - Floating Concepts for North Sea Projects

5.1 Project Weighting Factors

The Project Weighting Factors (PWF) selected for the Assessment of Floating Wind Turbine Foundations for North Sea Conditions [1] study were maintained for the present study. These were based on a detailed review of 39 criteria from FOW_RANK (one additional criterion having been added since the previous report), to define the preferred characteristics for a 15 MW North Sea FOW unit. This process was carried out in a workshop with members of the TLB North Sea Transition workstream.

A summary of the PWF is given in Appendix E of this report.

Note that the selection of PWF for a given project will depend on project conditions, the project developer's experience and preferences, and the concerns of financiers and insurers, i.e., the PWF adopted would be tailored for a specific deepwater farm development.

For the present study, the PWFs adopted reflect the risk profile of an early North Sea project, with demanding installation conditions and the execution risks of an early large-scale EPCI contract for a deepwater wind farm.

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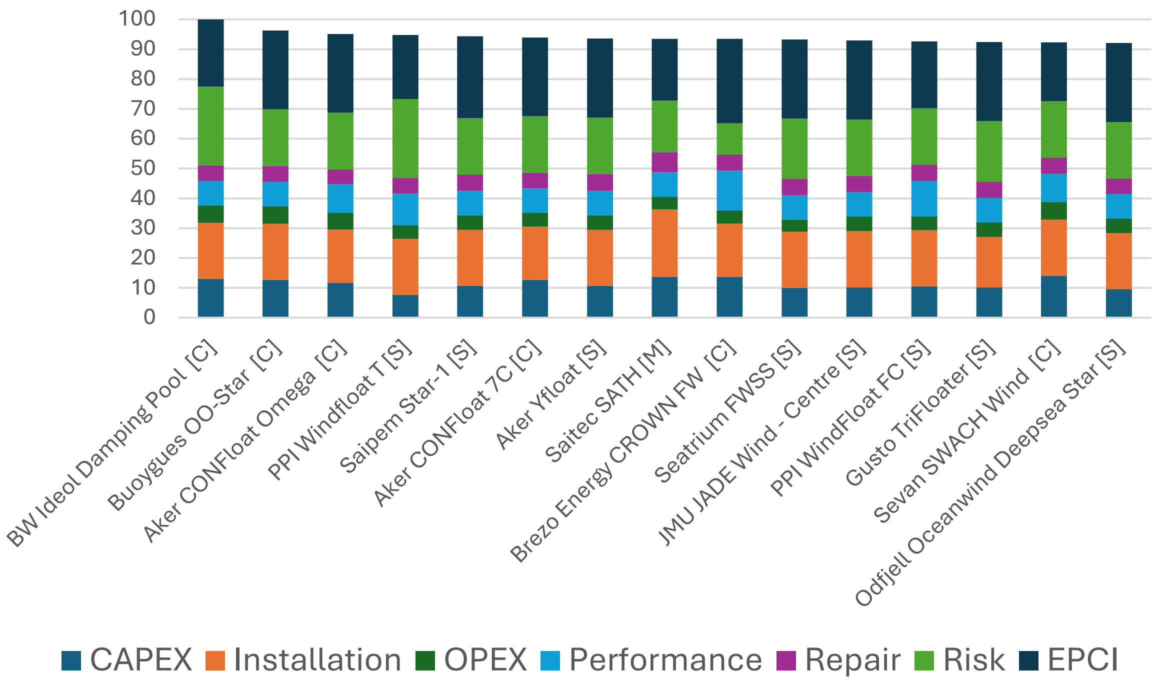
We have also performed a simple sensitivity analysis to investigate the impact of changes in the PWF for the CAPEX criteria. This was done to assess the impact on the ranking order of the 15 highest-ranked concepts to increase weighting on CAPEX. This sensitivity analysis showed concrete hulls ascended in the ranking order as the PWF related to CAPEX was increased.

5.2 15 Highest-Ranked Concepts for North Sea Projects

The 15 highest-ranked concepts for North Sea projects are shown in Figure 5-1 below. The variation in normalised scores ranges from 100 to 92. Due to the relatively small variation in the scores of these highest-ranked concepts, small changes in the assessment criteria or concept features may change the ranking order. Consequently, the 15 concepts identified in this study should be considered as a pool of candidates, with strengths in different categories as shown in Figures 5-1 and 5-2.



[C] = concrete hull
[M] = mixed concrete and steel hull
[S] = steel hull

Figure 5-1: Scoring of the 15 highest-ranked concepts for North Sea projects.

Only two concepts in the above pool, BW Ideol Damping Pool Concrete and PPI WindFloat T, have reached TRL7. Saitec's SATH is at TRL6 and is expected to reach TRL7 during 2026. There are 12 concepts at TRL5, which feature in the highest-ranked list for North Sea projects due to a combination of design characteristics, project-execution experience, and financial strength of the concept developers. Of these concepts, four are barges (Aker's CONFloat Omega, Aker's CONFloat 7C, Brezo Energy CROWN FW, and Sevan's SWACH Wind), and the remaining eight are semi-subs. To mitigate project risk, these concepts would require rapid progress to deploy a prototype of suitable scale to reach TRL7 in time for the development of commercial-scale designs within the target timeframe. OpenWater Renewables strongly recommends that this process be followed in line with the TRL roadmap in Appendix D before progressing to a commercial-scale farm.

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Figure 5-2 below illustrates the relative strengths and weaknesses of these concepts within each assessment category, with those at TRL5 or lower exhibiting low scores in Risk due to their relatively low technical maturity. However, strengths in other categories, such as OPEX for the concrete Bouygues OO-Star, Sevan SWACH Wind, and Aker CONFloat Omega, may encourage project developers to accelerate the deployment of a prototype, thereby increasing a concept's technical maturity.

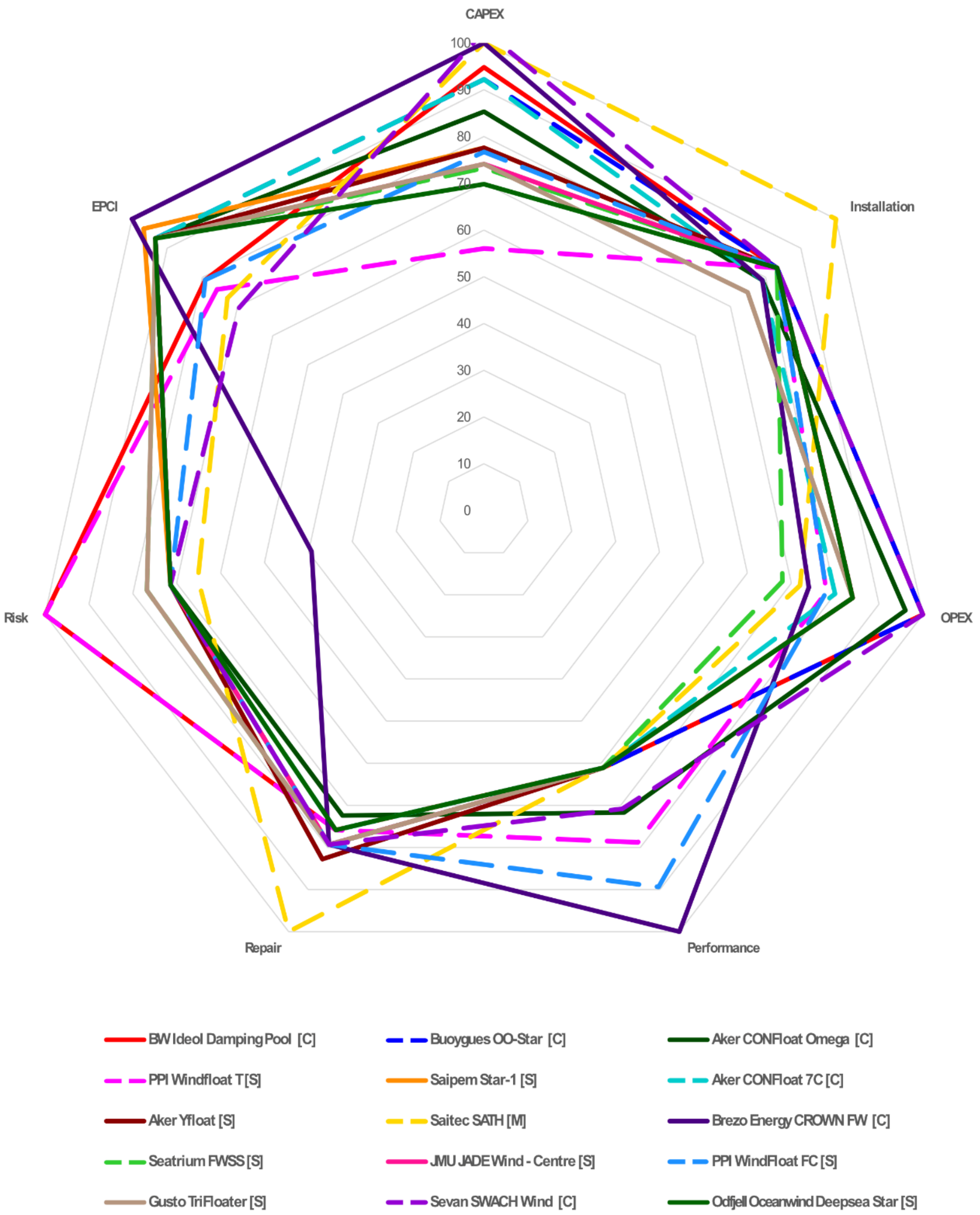

Figure 5-2: Relative score of the 15 highest-ranked concepts for North Sea projects ranking categories.

5.3 Discussion

Since the completion of the previous report, Assessment of Floating Wind Turbine Foundations for North Sea Conditions [1], several new concepts for deepwater wind energy have been introduced to the market, increasing the number of concepts in the OpenWater Renewables database from 107 to 123.

Five of these new concepts have been ranked in the top 15 for North Sea Projects:

- Aker CONFloat Omega
- Aker CONFloat 7C
- Aker Yfloat
- Seatrium FWSS
- JMU JADE Wind - Centre

Aker CONFloat Omega and Aker CONFloat 7C are concrete hulls, whereas the remaining three are steel. These concepts each score highly on industrialised fabrication, strong EPCI experience, and the technology providers' strong balance sheets, contributing to risk mitigation.

The Brezo Energy CROWN FW concrete barge has also entered the 15 highest-ranked concepts due to its continued development, particularly regarding industrialisation.

An additional change between the present and previous analysis [1] is the addition of a 39th criterion in FOW_RANK. This additional criterion addresses the concept's suitability for wet storage, but it has not had a significant impact on the ranking.

Unlike the results of the analysis in the previous report [1], no TLPs are amongst the top-ranked 15 concepts. The top-ranked TLP concept is now at position 24, having been displaced from the top 15 by new semi-sub and barge concepts added to the OpenWater Renewables database since the issue of the last report.

It is also noteworthy that there are no hybrid concepts among the top-ranked 15, principally due to limitations on the water depth in which they can be deployed at present, and the relatively low scores for O&M, including the inability to return to port for major repairs and the lack of suitable vessels to perform offshore repairs.

A review of the IP landscape for deepwater wind energy was beyond the scope of this study. Nevertheless, considering the similarities between many concepts, developers need to determine any restrictions and verify freedom to operate before selecting a concept for a project.

6.0 Hybrid Concepts

Although the approach to developing offshore wind energy in deepwater has primarily focused on floating foundation concepts, as noted in Section 3.2, a small number of hybrid concepts are also under development. All such concepts have a fixed seabed connection at the bottom of the turbine supporting element, as do monopiles, but they also employ additional features to achieve the required strength and lateral stability in deeper water.

6.1 Concept status

Six hybrid concepts have been identified by OpenWater Renewables, as listed in Table 6-1 below, and each concept is discussed in the following sections of this report. The water depth limits for the various concepts typically range from 120m to 130m, and up to 200m in some cases, whereas a depth of 120m would still be adequate for projects in 77% of UK waters [6].

However, at present, hybrid solutions are mainly considered for water depths up to 80m due to the absence of Wind Turbine Installation Vessel (WTIV) jack-ups suitable to install WTG in water depths greater than this. Beyond this water depth, and up to the limit of 120 to 130 m, either a new generation of ultra-deepwater jack-up WTIVs is needed, or the WTG integration would need to be performed with a large and expensive semi-submersible vessel (with potentially high weather downtime). It is worth noting that several hybrid concept developers are also developing concepts for installation means in water depths greater than 80m for their specific concept, but these plans are still at the conceptual stage. Although these vessels are likely to be fabricated outside the UK, an ultra-deepwater WTIV fleet could be UK-based and operated.

Technology Provider	Location	Concept	Development Status
AWC Tech Ltd	England, UK	AWC	Active
Entrion Wind Inc.	USA	FRP	Active
Marine Power Systems Ltd	Wales, UK	PelaFlex GS	Active
OSI UK	Scotland, UK	FTLP	Active
Trivane Ltd	England, UK	Trivane Tower	Active
Wison New Energy Co Ltd	P.R. China	w.BT	Active

Table 6-1: Hybrid concept development status

To varying degrees, the hybrid solutions aim to take advantage of the experience of fabrication and installation of fixed-bottom projects already employed in UK waters. This may bring benefits in cost and risk reduction, whilst introducing several new considerations, primarily the need for installation vessels for the larger structures, and the means of turbine installation offshore in deepwater.

The potential benefits of hybrid structures compared to floating solutions for deployment in the North Sea include:

- Reduced substructure weight.
- Reduced hull CAPEX.
- Use of existing port facilities (reduced draft requirements)
- Elimination of wet storage.
- Reduced turbine motions.
- Small seabed footprint.
- Inter-array cable requirements similar to fixed-bottom projects.

In contrast, potential negative aspects include:

- Increased installation and commissioning costs (both for the foundation installation and integration of the WTG offshore).
- Limit to 80m water depth at present due to lack of WTG installation means for deeper water (unless a large semi-sub crane vessel is used).
- No return to quayside possible for major repairs and maintenance. Reliance on a WTIV returning to perform major work in situ.

6.2 Principal Features

The sections below provide a brief description of each of the six identified hybrid concepts, along with a summary of their strengths and weaknesses for operation in the studies' North Sea conditions. A summary sheet of the key features of each concept is also provided in Appendix F.

Section 6.3 summarises the TRL status of the six concepts, whilst Section 6.4 compares the pros and cons of hybrid systems with floating concepts for North Sea conditions.

6.2.1 Articulated Wind Column (AWC) – AWC Tech Ltd


Courtesy of AWC LTD

The AWC is a buoyant concrete column connected to a concrete gravity base by a steel cardan joint (uni-joint). The column structure is slip-formed in vertical sections, which are upended and then joined together by in-situ cast concrete sections. The final assembled column is post-tensioned.

A concentric damping tank with radial diaphragms can be provided from 10m above the sea surface to approximately 15m below the sea surface. This provides protection against vessel collision, and holes in the radial diaphragms allow water to pass between the tank compartments at a pre-determined rate to damp the motions of the AWC column.

The concrete gravity base is a cellular structure with cells open at the top, allowing ballast to be added after installation.

The cardan joint is a large steel assembly incorporating polyester bushes and thrust washers. The joint connects the column and the gravity base, allowing movement of the column and avoiding moments being transmitted to the base.

For transportation to site, the gravity base with a cardan joint installed is loaded onto a flat barge, and the horizontally floating column is connected to the joint. The system is towed offshore by tugs or AHV, and on site the barge is removed, allowing the weight of the gravity base to pull the floating column into a vertical orientation. The open-topped cells of the gravity base are then ballasted with crushed rock, sand, or iron ore.

The electrical cable is routed through flexible conduits passing through the axis of the cardan joint into a J-tube installed within or on the outside of the column.

AWC Tech AWC	Strengths	Weaknesses
CAPEX	▪ Local fabrication with no transportation. ▪ No mooring legs.	▪ Heavy structure – impacts required quayside bearing capacity. ▪ Single source for cardan joint in the UK. ▪ Onshore storage space required.
T&I	▪ Suitable for shallow-water quayside. ▪ Installation by two AHVs and barge. ▪ Gravity base – no piling required. ▪ No mooring leg installation. ▪ No wet storage required.	▪ WTG integration offshore by jack-up rig (available to maximum 80m water depth at present) or large semi-sub crane vessel.
Performance	▪ Low motions – positive impact on AEP. ▪ Damping tank to reduce motions.	
Risk	▪ Based on North Sea offloading tower and SALM technology.	▪ Novel electrical cable routing through cardan joint. ▪ Low TRL level
O&M / OPEX	▪ Access using standard SOVs. ▪ Low maintenance concrete column and base – good fatigue performance, good corrosion resistance, no coating maintenance. ▪ Low motion should benefit WTG reliability. ▪ High yaw stiffness will reduce compensating rotations of the WTG yaw bearing.	▪ Inspection of cardan joint bush/thrust bearing. ▪ Limited deck space available for maintenance and repair work. ▪ No space for helideck on hull.

Table 6-2: AWC Strengths and Weaknesses

6.2.2 Fully Restrained Platform (FRP) – Entrion Wind Inc.

Courtesy of Entrion Wind

The FRP comprises a tubular central column and transition piece based on large-diameter monopiles with the addition of three pairs of tendons (guys) to restrain lateral movement and reduce moment at the column base.

The tendons comprise wire rope and a top chain segment, which are connected to a Top Mooring Assembly (TMA). The TMA incorporates articulated chain connectors and is fitted to a standard transition piece.

The tendons are pre-tensioned using pre-installed proprietary tensioning devices fitted to each chain connector. The tensioning devices can be removed after tensioning for use on subsequent FRPs and can be refitted if re-tensioning is required during the service life.

The provision of three pairs of tendons provides redundancy and ensures structural integrity in case of a tendon failure.

The central column is installed in the same manner as monopiles. The transition piece is then installed and grouted or bolted to the column, and the pre-laid tendons are recovered, hooked up, and tensioned.

Installation of the WTG in water depths up to 80m can be performed by the latest-generation deepwater jack-up WTIV vessels. In depths of 80 to 120m, either a new generation of ultra-deepwater WTIVs will be needed, or a large semi-submersible crane vessel could be used. However, the latter would be an expensive option, potentially subject to high weather downtime.

Entrion Wind FRP	Strengths	Weaknesses
CAPEX	▪ Simple lightweight column structure (<2,500T for 15 MW WTG) using monopile fabrication techniques.	▪ Redundant mooring tendons are required with associated anchor points.
T&I	▪ Transported to site on vessel - suitable for shallow-water quayside. ▪ Anchor points and wire rope tendons preinstalled. ▪ Column and transition piece installed using existing fixed-bottom tools and techniques. ▪ Tendon tensioning tools can be removed and used on subsequent units. ▪ No wet storage required.	▪ WTG integration offshore by jack-up rig (available to maximum 80m water depth at present).
Performance	▪ Very low motions – positive impact on AEP.	
Risk	▪ Based on monopile and offshore mooring technology. ▪ Static electrical cables.	
O&M / OPEX	▪ Access using standard SOVs. ▪ Very low motion should benefit WTG reliability	▪ R2P is not an option for major repairs. ▪ Steel structure – potential coating breakdown, corrosion, and fatigue damage. ▪ Limited deck space available for maintenance and repair work. ▪ No space for helideck on hull.

Table 6-3: FRP Strengths and Weaknesses

6.2.3 PelaFlex GS – Marine Power Systems Limited (MPS)


Courtesy of MPS

The PelaFlex GS comprises a steel truss central column supporting the WTG, and three sets of tendons (guys) to restrain lateral movement and reduce moment at the column base. The column base also incorporates a flexjoint to reduce moments. The tendons are connected to the central column by articulated connectors and are pre-tensioned using an MPS proprietary device. This device is removed before integration of the WTG, and an alternative device will be used for re-tensioning during the service life if required.

In addition to providing lateral restraint, the arrangement of the tendons also significantly increases the yaw stiffness of the system, reducing the need for the WTG controller to compensate. The provision of pairs of tendons provides redundancy and ensures structural integrity in case of failure of a tendon.

The central column will be fabricated by MPS and delivered complete to the marshalling yard for transportation and installation offshore. The column will be upended and installed using the latest generation of HLV crane vessels used for monopiles, then pre-installed buoyed off tendons will be recovered, hooked up, and pre-tensioned.

After pre-tensioning the tendons, the tensioning device will be removed, and the WTG will be installed on the column. If WTG installation means are available for deeper water in future, the PelaFlex GS could be deployed in water depths up to 120 to 130 m.

Notably, the PelaFlex GS design lends itself to automated fabrication, though the facilities for this are still at the conceptual stage.

MPS PelaFlex GS	Strengths	Weaknesses
CAPEX	▪ Lightweight steel truss structure. ▪ Suitable for automated fabrication (fabrication facility to be developed).	▪ Redundant mooring tendons are required with associated anchor points. ▪ Onshore storage space required.
T&I	▪ Transported to site on vessel - suitable for shallow-water quayside. ▪ No wet storage required.	▪ WTG integration offshore by jack-up rig (available to maximum 80m water depth at present).
Performance	▪ Very low motions – positive impact on AEP.	
Risk	▪ Static electrical cables.	▪ Design novelty.
O&M / OPEX	▪ Access using standard SOVs. ▪ Very low motion should benefit WTG reliability. ▪ High yaw stiffness will reduce compensating rotations of the WTG yaw bearing.	▪ R2P is not an option for major repairs. ▪ Steel structure – potential coating breakdown, corrosion, and fatigue damage. ▪ Limited deck space available for maintenance and repair work. ▪ No space for helideck on hull.

Table 6-4: PelaFlex GS Strengths and Weaknesses

6.2.4 FTLP+ (OSI UK)

The FTLP+ is the evolution of the earlier FTLP and comprises a steel truss central column supporting the WTG, and three pairs of steel tubular tendons (guys) to restrain lateral movement and reduce moment at the column base.

Column sections and tendon sections are joined using OSI's proprietary Merlin connectors. Sections of columns and tendons can be delivered to the marshalling yard by road, where the column is fully assembled. Tendon sections can be assembled offshore. Future development of automated manufacturing facilities at a quayside may allow fully assembled columns to be delivered to the marshalling yard.

The tendons have flexjoints incorporated into the connection to the anchor points, avoiding moments on the base. The base of the column is rigidly connected to the piled base plate and relies on the lateral restraint of the tendons to minimise the moment imposed.

During installation, columns will be upended and installed using the transportation vessel crane, tendons will then be installed, hooked up and pre-tensioned. Pre-tensioning will be achieved by a proprietary hydraulic tensioning device that can be removed for use on later units to be installed. The device can be refitted if re-tensioning is required during the service life. The use of tubular tendons significantly reduces the likelihood of re-tensioning being required.

After pre-tensioning the tendons, the WTG will be installed on the column. If WTG installation means are available for deeper water in future, the FTLP+ could be deployed in water depths up to 150 m.

OSI UK FTLP+	Strengths	Weaknesses
CAPEX	▪ Lightweight steel truss structure. ▪ Can be transported in sections by road to the assembly yard.	▪ Redundant mooring tendons are required with associated anchor points. ▪ Numerous OSI Merlin connectors in each tendon. ▪ Onshore storage space required.
T&I	▪ Can be loaded out to a transport vessel from a shallow-water quayside. ▪ Transported to the site on a vessel, then offloaded for installation. ▪ Assembly of tendons using OSI Merlin connectors. ▪ No wet storage required.	▪ WTG integration offshore by jack-up rig (available to a maximum 80m water depth at present).
Performance	▪ Very low motions – positive impact on AEP.	
Risk	▪ Static electrical cables.	▪ Design novelty.
O&M / OPEX	▪ Access using standard SOVs. ▪ Very low motion should benefit WTG reliability.	▪ R2P is not an option for major repairs. ▪ Steel structure – potential coating breakdown, corrosion, and fatigue damage. ▪ Limited deck space available for maintenance and repair work. ▪ No space for helideck on hull.

Table 6-5: FTLP+ Strengths and Weaknesses

6.2.5 Trivane Tower (Trivane Ltd)

The Trivane Tower is a development based on the Gravity Base Systems (GBS) used in the O&G industry and, to a limited extent, in Fixed-bottom Wind projects [7,8,11]. The concept is a fixed-bottom tower, but it is included here with the hybrid designs, where there is more similarity than with FOW.

The reinforced base structure provides the foundation for a slip-formed tower, which in turn supports the WTG.

The lower section of the tower is slip-formed onshore or in a floodable dock, then towed to deepwater to be ballasted down and connected to a temporary mooring. The upper section of the tower may be slip-formed at the temporary mooring as an alternative to completing all slip-forming in a dock. Once complete, the WTG will be installed - the method not yet publicly disclosed.

After the ballast is adjusted to achieve the required buoyancy, the unit will be towed to the wind farm and ballasted down with seawater to contact the seabed. Steel skirts under the base are provided to increase resistance to sliding. These will initially trap water under the base, which will be pumped out using an installed network of piping to allow the concrete base to contact the seabed.

In the case of major repairs, as an alternative to a deepwater jack-up, the Trivane Tower can be de-ballasted and refloated for return to port or to a deepwater anchorage adjacent to port facilities.

The network of pipes used to drain the skirts during installation can be used to pump water under the base and break the suction if needed.

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Trivane Trivane Tower	Strengths	Weaknesses
CAPEX	▪ Local fabrication with no transportation. ▪ No mooring legs.	▪ Heavy structure. ▪ Required deepwater anchorage close to port.
T&I	▪ Buoyant structure – towed to site with WTG integrated. ▪ Ballasted down to seabed. ▪ Water pumped out from within skirt cells to allow skirt to penetrate seabed.	▪ WTG integration method under development – not yet disclosed in public domain.
Performance	▪ Very low motions – positive impact on AEP.	
Risk	▪ Based on proven GBS technology ▪ Static electrical cables.	▪ WTG integration method under development.
O&M / OPEX	▪ Access using standard SOVs. ▪ Very low motion should benefit WTG reliability. ▪ The system can be refloated for return to port (deepwater anchorage). ▪ Low-maintenance concrete hull.	▪ Limited deck space available for maintenance and repair work. ▪ No space for helideck on hull.

Table 6-6: Trivane Tower Strengths and Weaknesses

6.2.6 w.BT (Wison New Energies)


Courtesy of Wison New Energies

The w.BT is a compliant tower with the addition of a buoyancy tank at the top to provide restoring force and reduce motion.

The structure is a cylindrical column comprising an upper hard tank (ballast tank), a variable buoyancy tank, a truss structure segment, a lower soft tank, and an integrated suction caisson foundation (SCF). The WTG mast is integrated within the structure in a retracted position, forming a central buoyancy column.

The lower part of the central buoyancy column will be used as a ballast tank during the installation operation, and the upper part forms a water-tight compartment housing the electrical system.

The system is self-installing, and several installation procedures are being considered, one being described below:

- Float out the w.BT substructure.
- Upending of the w.BT substructure by ballasting the soft tank and the lower part of the central buoyancy column with seawater.
- Ballast the soft tank with high-density ballast material and the variable buoyancy tank with seawater to drive the SCF into the seabed (suction applied if required)
- Install the nacelle and blades by crane vessel near the still water level, and de-ballast the variable ballast tank accordingly.
- Lift the turbine tower by de-ballasting the central buoyancy column and locking it through a hydraulic system.

The w.BT is being developed for water depth up to 200m.

Wison New Energies w.BT	Strengths	Weaknesses
CAPEX	▪ Lightweight steel structure.	▪ Onshore storage space required
T&I	▪ Buoyant structure towed to site (hard tank + variable buoyancy tank + truss segment + soft tank + suction caisson foundation + the central buoyancy column of the turbine mast) ▪ Self-installing column and foundation. ▪ Nacelle fitted to pre-installed retracted mast. ▪ Turbine tower raised by de-ballasting the central buoyancy column and locked by a hydraulic system.	▪ Untested procedure.
Performance	▪ Low motions – positive impact on AEP.	
Risk	▪ Based on compliant tower technology. ▪ Tower installation procedure validated on CX-15 Buoyant Tower Platform installed in Peru in 2012 for BPZ Energy.	▪ Novel WTG integration. ▪ TRL2
O&M / OPEX	▪ Access using standard SOVs. ▪ Low motion should benefit WTG reliability	▪ R2P is not an option for major repairs. ▪ Steel structure – potential coating breakdown, corrosion, and fatigue damage. ▪ Limited deck space available for maintenance and repair work. ▪ No space for helideck on hull. ▪ Risk of scour around SCF base.

Table 6-7: w.BT Strengths and Weaknesses

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6.3 Hybrid Concepts TRL Summary

Based on a review of the completed activities for each hybrid system, compared with the roadmap provided in Appendix D, a summary of the TRL status of these systems is presented in Table 6-8 below.

Technology Provider	Location	Concept	TRL				
			2	3	4	5	6
AWC Tech	England, UK	AWC	Complete	Complete	Complete		
Entrion Wind	USA	FRP	Complete	Complete	Complete	Main activities complete	
Marine Power Systems (MPS)	Wales, UK	PelaFlex GS	Complete	Complete	Complete	Complete	
OSI UK	Scotland, UK	FTLP+	Complete	Complete	Complete	Main activities complete	
Trivane	England, UK	Trivane Tower	Complete	Complete	Not required		
Wison New Energies	P.R. China	w.BT	Complete	Main activities complete			

Table 6-8: Hybrid concept TRL Status

Complete — Main activities complete — Not required [Note 1]

Note 1: The Trivane tower will follow previous GBS design methodology. The load path from WTG is a simple stiff cantilever, and wind and wave interaction can be assessed by simulation - model basin testing is not considered essential.

6.4 Pros and Cons of Hybrid Systems vs FOW for Deepwater

The hybrid systems identified each have certain strengths and weaknesses that differ from those of generic Floating Offshore Wind concepts. To discuss these differences, the pros and cons of three generic types of deepwater wind foundations are discussed, being:

- FOW – A Generic Concrete Barge or Semi-Submersible
- FOW – A Generic Steel Semi-Submersible
- Hybrid – A Generic Guyed Tower or Guyed Monopile

For each, criteria related to CAPEX, OPEX, T&I, Performance and Risk are considered, based on a qualitative analysis for a field matching the Basis of Design conditions.

6.4.1 Floating Wind – Generic Concrete Barge or Semi-Submersible

	Pros	Cons
CAPEX	Local Content options are available, and the required upgrades are already underway in some UK yards. Lower-skilled manpower is needed compared to steel hull fabrication, so it should be more readily available. Mooring line redundancy may be avoided if a suitably rigorous inspection plan is put in place and approved by Class. Concrete construction capacity needed is well within the current UK capacity of around 90 million T/yr [12]	Each hull is very heavy, at circa 20,000T for a 15 MW WTG. Around 1 million T of concrete is required per GW. Concrete curing time must be allowed, which impacts the yard storage space and schedule. A wet storage area is needed, which will incur costs and bring extra operational and regulatory complications. A large quayside ring crane is needed for WTG integration (or an alternative means, such as a floating crane). The yard quayside may need to be reinforced for the hull load out. A heavier mooring system is needed for some concrete hulls, due to higher mass and mooring loads. Higher array cable costs compared to hybrids, for dynamic cables and longer cable lengths, due to anchor patterns. Higher insurance costs linked to dynamic cable risk. Need for stiff-stiff WTG towers for large turbines due to hull Response Amplitude Operators (RAOs).
OPEX	Lower O&M costs due to less corrosion and fatigue damage for a concrete hull. Tow to Port option is available for major repair, as well as in-situ repair. Deck space is typically available on the hull for WTG repair work. Helicopter drop space is typically available on the hull for harsh weather access.	In the absence of a redundant mooring system, a comprehensive risk-based Mooring Integrity Management (MIM) strategy from the design phase onwards, including associated monitoring instrumentation, is likely to be required [4]. A dynamic cable monitoring system is needed.
T&I	Simple offshore hook-up using two tugs and one AHV. Fewer anchor points (or piles) are required. Higher weather limits for offshore installation, leading to less downtime.	Around 10m quayside draft needed for WTG integration. Slow tow to site or higher tug costs due to hull mass.
Performance		Higher dynamic motions and static list of the hull and WTG. Dynamic trim control only available on one concept.
Risk	Concepts available from TRL5 to TRL7.	Dynamic cable failure risk. WTG reliability risk linked to higher hull motions. Large mooring footprint – more fishing impact and risk of damage, especially if synthetic lines are used.

6.4.2 Floating Wind – Generic Steel Semi-Submersible

	Pros	Cons
CAPEX	Lighter hulls than concrete, at around 4,500T per 15 MW. Mooring line redundancy may be avoided if a suitably rigorous inspection plan is put in place and approved by Class.	Around 300,000T of steel structure fabrication is needed per GW, which far exceeds the current UK capacity. The execution plan is therefore likely to be based on prefabricated substructures only assembled in the UK. A wet storage area is needed, which will incur costs and bring extra operational and regulatory complications. A large quayside ring crane is needed for WTG integration (or an alternative means, such as a floating crane). Higher array cable costs compared to hybrids, due to the need for dynamic cables, and for longer cable lengths due to anchor patterns. Higher insurance costs linked to dynamic cable risk. Need for stiff-stiff WTG towers for large turbines due to hull RAOs.
OPEX	Tow to Port option is available for major repair, as well as in-situ repair. Deck space is typically available on the hull for WTG repair work. Helicopter drop space is typically available on the hull for harsh weather access.	Steel hulls will require higher levels of maintenance and inspection over the full life compared to concrete. In the absence of a redundant mooring system, a comprehensive risk-based Mooring Integrity Management (MIM) strategy from the design phase onwards, including associated monitoring instrumentation, is likely to be required [4]. A dynamic cable monitoring system is needed.
T&I	Simple offshore hook-up using two tugs and one AHV. Fewer anchor points required. Higher weather limits for offshore installation, leading to less downtime.	Around 8m quayside draft needed for WTG integration.
Performance	Dynamic trim control available on some concepts.	Higher dynamic motions and static list of the hull and WTG.
Risk	Concepts available from TRL5 to TRL7.	Dynamic cable failure risk. WTG reliability risk linked to higher hull motions. Large mooring footprint – more fishing impact and risk of damage, especially if synthetic lines are used.

6.4.3 Hybrid Deepwater Wind – Generic Guyed Tower/Monopile

	Pros	Cons
CAPEX	Light foundation structure (circa 2,500T for 15 MW in 100m WD) resulting in lower material costs for the foundation. Shorter mooring lines/tendons with a compact mooring radius. Shorter array cables, due to a more compact anchor plan. No need for dynamic array cables, as static cables are adequate. Local Content options are planned (but some are subject to pre-investment in new automated factories). No need for stiff-stiff WTG towers.	Higher offshore installation costs, due to the expensive vessels needed for foundation installation and WTG integration offshore, and their very limited availability. Redundancy of the guy wires/tendons is essential to ensure structural integrity. Truss-type columns will require over 150,000T of tubular steel fabrication per GW. Automated factories for this do not yet exist and are still at the planning stage, and are subject to funding. Monopile rolling capacity is currently limited in the UK to around 100 large monopiles per year. Potential for higher insurance costs due to lower TRL and more novelty.
T&I	No quayside is needed for WTG integration, as this is done offshore. Shallow draft ports are suitable. No wet storage is needed, as the towers can be stored in a yard before load out (and may be segmented in some cases).	A large monopile installation vessel is needed to upend and install the foundation structure. Then a large WTIV is needed to install the turbine mast, nacelle, and blades. However, deepwater jack-ups for >80m are currently not available, or under development. The availability and cost pose a major risk. (Proprietary installation vessels are being discussed by some technology providers, but these remain conceptual and subject to speculative investment.) Temporary winches or a hydraulic tensioning system are needed on board for tensioning guy wires and tendons. Multiple piled anchor points are required.
Performance	Low motions, bringing AEP gains and potential for higher turbine reliability. Higher yaw stiffness for some concepts.	
Risk		Concepts are available at TRL4 to TRL5 only, and none have so far been prototyped. Higher risk of installation weather delays due to the increased scope of offshore T&I works compared to FOW projects (see above).

OPEX	Reduced mooring footprint leads to less risk of damage from fishing or work vessels. Easier to access using standard SOVs due to low motions.	Risk of periodic re-tensioning of tendons may be needed to maintain the required pre-tension over time (due to creep). Steel tower (especially truss type) will require more inspection and maintenance over its full life than concrete hulls. WTIV may need to return for major component repairs on WTG. Limited deck space available for maintenance and repair work.

6.4.4 CAPEX Comparison - Discussion

The key differences between the floating and hybrid concepts, which impact CAPEX, can be summarised as follows.

- Hull weight
- Hull fabrication costs
- Wet storage requirements
- Foundation transport and installation
- WTG integration and commissioning
- Array cabling

Hull Weight. The floating steel hulls have weights of around 4,000 to 5,000T for a 15 MW unit, whereas the concrete hulls are around 4 times that weight.

The steel hybrid concepts all claim hull weights around half the weight of a steel semi-sub; hence, the material costs will be lower. The CAPEX savings may be partly offset by the grade of steel required, the type (i.e. use of tubulars vs flat plates), and where the steel is sourced from. However, overall, we can expect a significant saving in steel procurement costs for hybrid concepts.

The AWC concrete hybrid claims a hull weight around half that of a concrete semi-sub or barge, so again, there should be a significant saving in material costs.

Hull Fabrication. For floating hulls, although concrete hulls are heavier than steel, they are more compatible with UK fabrication capacity and are expected to have lower CAPEX, whilst also delivering significant UK content. In contrast, the limited capacity for steel hull fabrication in the UK and the relatively high costs are likely to lead to a strategy of internationally fabricated hull modules being assembled in the UK.

The hybrid concepts using truss structures aim to lower fabrication costs in the future, through fully automated factories. These factories do not yet exist, and they will require large investments. Moreover, they may need to be made on a speculative basis with costs recovered over multiple projects. These plans are generally at a conceptual level today, and the first projects are unlikely to benefit from the potential future fabrication cost savings.

Guyed monopiles may benefit from the new UK monopile fabrication facilities, but capacity is limited and would need considerable expansion to deliver multiple GW-scale wind with UK content. There may also be competition between deepwater projects and other fixed-bottom projects using XXL monopiles. However, smaller projects could potentially benefit from the existing facilities.

For both floating and hybrid foundations, we expect fabrication costs to fall in future, through design optimisation and improved industrialisation.

Mechanical Components. Floating wind concepts typically only use chain connectors, with external tensioning of the mooring legs (and re-tensioning if needed) from an AHV. These are proven from the oil & gas industry.

The guyed towers typically require temporary tendon tensioning devices to be installed during offshore installation, which may need to be periodically refitted during the project life if re-tensioning is needed.

Most hybrid concepts also rely on some form of mechanical components, which may include flexjoints, mechanical connectors, or uni-joints. Again, these are mostly proven from the oil & gas industry. However, they add CAPEX (especially for concepts which use multiple components) and introduce more underwater inspection requirements during the installation and O&M phases.

Anchors. Floating hulls can use a variety of anchor points, depending on soil conditions, such as drag anchors, suction piles, or driven piles. TLPs will be constrained to driven piles due to the uplift loads.

Hybrid guyed units will typically require multiple driven piles for the tendons, due to uplift and the central column, due to the load of the support structure and the WTG.

The AWC and Trivane Tower concrete hybrids avoid this by use of a gravity base foundation, although the Trivane Tower also incorporates steel skirts.

Wet Storage. Post-WTG integration, floating platforms may need to be wet stored before towing to the field for installation. This requires a dedicated and permitted storage facility with pre-installed mooring lines and temporary power cabling, which will be complex and costly. These wet storage facilities may also need speculative pre-investment, which will be recovered over multiple projects.

Wet storage is not required for the hybrids, as the towers/monopiles can be dry stored in the fabrication yard and loaded out directly onto the HLV for installation. This is an important advantage and removes a complex problem associated with floating wind, albeit by deferring the integration work to the offshore site.

Foundation Installation. Towing and installation of FOW units will use standard tugs and an AHV, which are much lower cost and subject to less weather downtime, especially if a Quick Connect/Disconnect system is deployed.

In contrast, hybrid structures for deepwater fields will require the latest generation of offshore Heavy Lift Vessels (HLV) or Monopile Installation Vessels to transport, upend and install the central towers. For guyed monopiles, the vessel will also perform the piling and installation of the transition piece. For some guyed towers, the vessel must hold the tower in place whilst the guy wires/tendons are installed and pre-tensioned.

The largest installation vessels have limited availability and command high charter rates. Moreover, the complex operations have strict weather limitations and may incur significant weather downtime costs. This has been taken into account by simulations performed by Scott Marine Consultants using their proprietary CICADA Express software (see Appendices H & I).

WTG Integration & Commissioning (I&C). For floating units, WTG I&C will take place in the integration yard before the units are towed offshore or wet-stored. This will require the use of an expensive ring crane on the quayside or an alternative suitable floating crane. Weather downtime during integration in the yard may be mitigated by using wet storage to ensure that completed units are available for installation when weather permits (see above).

For hybrid units, WTG I&C will be performed offshore using a dedicated WTIV, following the methodology of fixed-bottom wind farms. However, the largest jack-up WTIV currently in operation can operate in water depths of 75m to 80m (depending on weather conditions). Some ultra-deepwater drilling jack-ups exist for deeper waters, but these are expensive and would require extensive modification to convert them into WTIV service. Three options, therefore, exist for WTG I&C beyond 80m:

a) Wait for a suitable next-generation jack-up WTIV to be ordered, built and become available for charter.
b) Use a semi-submersible WTIV such as the Heerema Thialf. These large vessels are expensive, and weather downtime for operations in the North Sea is likely to be high (based on experience from some fixed-bottom projects).
c) Build a WTIV dedicated to I&C operations for hybrid structures in the North Sea/Celtic Sea. Conceptual plans exist for such vessels, and once the designs are proven, they will require speculative investment, which must be recovered over multiple projects. Hence, whilst such vessels may become available in the long term, we do not expect them to be an option in the short or medium term.

Array Cabling. Floating semi-sub and barge units are typically moored by catenary mooring lines, with long lengths of chain on the seabed. The large mooring pattern radius means the array cables are more sinuous and less direct, adding length. Moreover, floating units require dynamic array cables and may need HV wet-mate couplers to accommodate a return-to-port strategy for major repairs.

In contrast, the compact mooring line radius on hybrid units allows shorter array cables and allows the use of static (or semi-static) array cables, both of which will reduce cost and are likely to reduce failure frequency. There may also be an insurance benefit by eliminating the need for dynamic cables.

6.4.5 CAPEX Comparison - Results

An illustrative CAPEX comparison has been prepared for a fictional field, which considers all the above factors. This is shown in Figure 6.1 below. For this analysis, we have made the following assumptions.

- 750 MW farm using 15 MW turbines, as per the BoD.
- 80 to 100m Water Depth.
- Mooring line redundancy is needed to maintain the structural integrity of hybrids in case of a line failure, but not for floating units, which only rely on mooring lines for station keeping.
- Full UK fabrication of the hulls in both cases.
- Partial credit for automated welding of truss structures.
- A deepwater WTIV is available for the hybrid units, with charter rates similar to current market rates for fixed-bottom.
- Weather downtime in both cases is based on the simulation of the installation sequence of tasks for a typical ScotWind site and was performed by Scott Marine Consultants using their proprietary CICADA Express software (see Appendices H & I). This has been used to fix the expected campaign duration for the marine vessels needed in each phase of the work. The results show the spread of the P10, P50 and P90 durations for each phase. For the CAPEX analysis, we have used the P90 durations to calculate the installation costs.

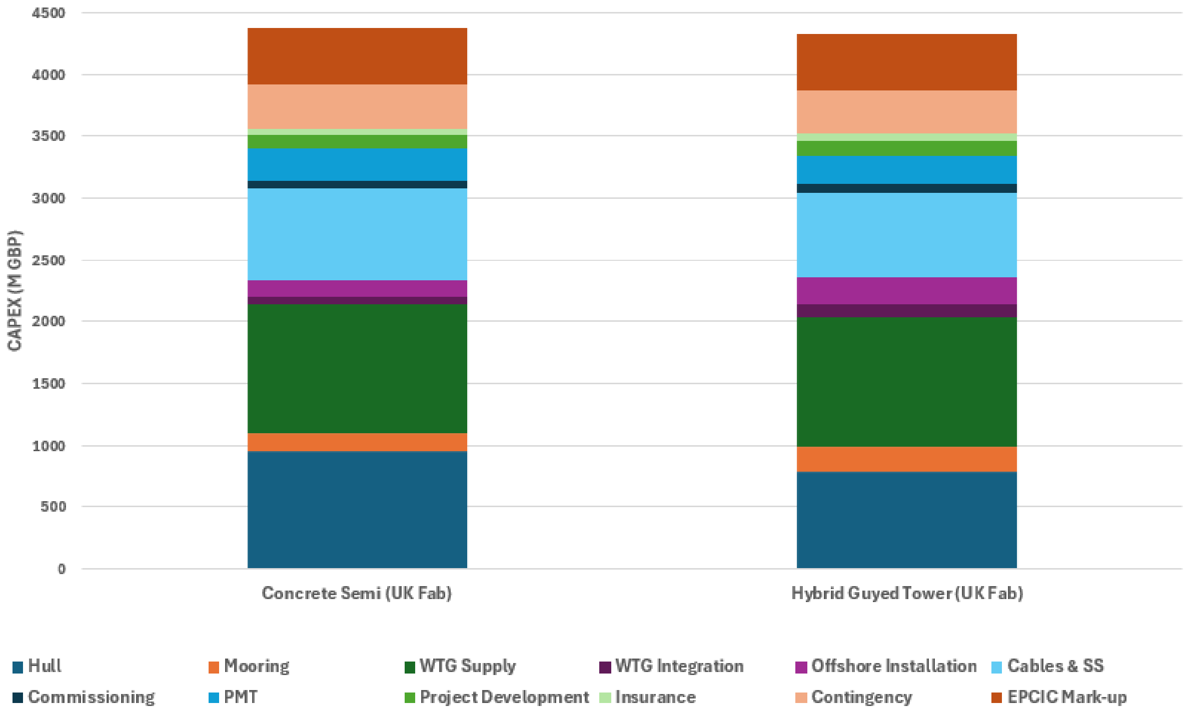

Figure 6.1 CAPEX Comparison (750 MW)

The analysis for this example shows that the hybrid guyed tower/monopile has lower CAPEX in the areas of hull and cables. Conversely, the concrete semi-submersible has lower CAPEX related to mooring, WTG integration, and offshore installation.

Our conclusion from this analysis is that the savings on each side balance out, and that, in this case, the overall CAPEX advantage of the hybrid concept is around 1%, which is within the error margin of the calculations.

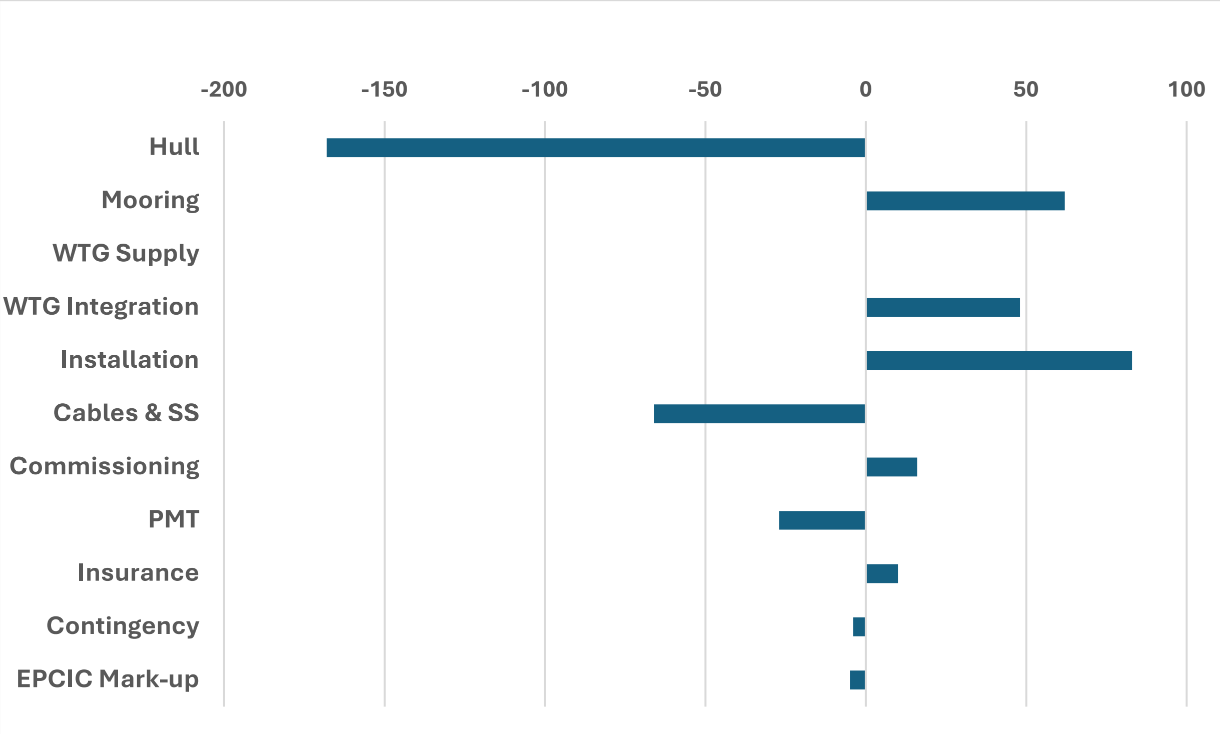

Fig 6.2 CAPEX Delta - Hybrid vs FOW (GBP millions, 750 MW)

It should also be noted that if redundancy is added to the FOW mooring lines (excluded in the above example), the FOW costs could rise by around £200 million, which would increase the cost difference from 1% to around 6%, in favour of the hybrid concept, which is still within the error margin of the calculations.

Some hybrid concept suppliers will claim lower costs and a greater difference from FOW. However, to achieve these lower costs, they require significant speculative pre-investment in automated welding facilities and/or dedicated WTIV vessels, neither of which is yet confirmed or funded. Hence, in our opinion, these claims should be treated as long-term aspirations.

The high offshore installation costs for the hybrid units are based on North Sea conditions. Some Celtic Sea sites have longer wave periods, which can lead to more downtime for critical installation and integration operations. CAPEX for the hybrid concepts will therefore be higher in such locations.

6.4.6 OPEX Comparison

FOW concepts benefit from two OPEX advantages.

a) When Major Component Replacement (MCR) is needed, which is considered likely over a long field life, a FOW unit has the option of either being repaired in situ or being disconnected for Return to Port (R2P). This flexibility can help to reduce the unit downtime. In contrast, when a hybrid unit requires MCR it will need to await the mobilisation of a suitable WTIV, and a suitable weather window, to perform the repair. (Note: the hybrid units proposed today do not have enough laydown space at the base of the nacelle to perform an in-situ MCR using a temporary up-tower crane).

b) A concrete floating hull will have less inspection and repair work needed than a steel hull. Most hybrid units (apart from AWC) are steel truss structures, which require periodic inspection by ROV, incurring OPEX costs. If any hull repairs are needed, floating units can use a Return to Port (R2P) strategy, whereas repair of a hybrid unit offshore would be much more challenging.

Conversely, some hybrid concepts have a significant advantage over FOW in WTG dynamic motions. The guyed towers are effectively fixed, which will reduce motion to levels similar to those of fixed-bottom structures, benefiting AEP and potentially improving WTG reliability.

At this stage, there is insufficient reliability data (MTBF and MTTR) available for WTG on deepwater projects to quantify the OPEX difference between the two options, and this is an area which we recommend for further study in future.

7.0 UK-Based Concepts for Deepwater Wind

The UK Government's 2050 Vision [9], Mission 5, aims to "find and validate a winning home-grown foundation design by 2027". This section identifies the status of UK-based concepts, provides a high-level review of concepts under active development, and outlines a development roadmap that identifies the main activities to be completed to reach each TRL.

7.1 Concept Status

Table 7-1 below identifies UK-based concepts for deepwater wind energy, together with their development status, i.e. whether the concept is being actively developed, or whether development is dormant and development activity has been stopped.

Technology Provider	Location	Concept	Floating or Hybrid	Development Status
AWC Technology	England	AWC	Hybrid	Active
Floating Energy Systems	England	Stinger Keel	Floating	Dormant
Floating Wind Turbines	Scotland	DTI-F	Floating	Dormant
Marine Power Systems (MPS)	Wales	PelaFlex TS	Floating	Active
Marine Power Systems (MPS)	Wales	PelaFlex GS	Hybrid	Active
Ocean Resources	Wales	Ocean Breeze	Floating	Active
OSI	Scotland	FTLP+	Hybrid	Active
Trivane	England	Trivane Trimaran	Floating	Active
Trivane	England	Trivane Tower	Hybrid	Active
TetraFloat	England	TetraFloat	Floating	Dormant

Table 7-1: UK-Based Concept Development Status

In addition to the 10 concepts identified in Table 7-1, a further dormant floating concept was identified, however the technology provider has asked not to be included in this report.

Of the UK-based concepts currently under development, three are floating: PelaFlex TS, Ocean Breeze, and Trivane Trimaran. The remaining four are hybrid systems: AWC, PelaFlex GS, FTLP+, and Trivane Tower. Although Trivane Tower is a fixed-bottom solution, it is classified as hybrid for the purposes of this study.

The four hybrid systems are reviewed in Section 6.0 of this report, so only the three active floating concepts are discussed in this section. The TRL status of all UK-based concepts, both floating and hybrid, is summarised in Section 7.3.

7.2 Principal Features

The following sections contain a brief description of each of the three identified UK-based FOW concepts, currently ranging from TRL3 to 5, together with a summary of the concept's strengths and weaknesses for operation in the studies' North Sea conditions. A summary of the key features of each concept is provided in Appendix G.

7.2.1 PelaFlex TS (Marine Power Systems, MPS)

The PelaFlex TS is a TLP comprising a single central buoyancy chamber with three horizontal steel truss outriggers to connect to the mooring tendons. The buoyancy chamber supports a steel truss structure which passes through the water plane and, in turn, supports the WTG. The use of the open truss structure minimises the wave loading on the unit.

The design enables the outriggers to be folded to lie against the central structure of the TLP, allowing several units to be arranged side by side horizontally on a vessel for transportation offshore. Once on site, a unit is upended and overboarded by the vessel crane, ballasted down to connect to the pre-installed tendons, then de-ballasted to tension the tendons.

In the following operation, the WTG is installed offshore by a WTIV jack-up or a semi-sub crane barge. The maximum water depth for which suitable jack-ups are currently available is 80m, and the installation of the PelaFlex TS in deeper water would depend on the development of suitable installation methods.

It is notable that the PelaFlex TS design lends itself to automated fabrication, though the facilities for this are still at the conceptual stage.

As with all TLPs, uplift on the anchor points will limit the choice of anchor point types that can be deployed for any given soil condition.

MPS PelaFlex TS	Strengths	Weaknesses
CAPEX	▪ Lightweight structure. ▪ Suitable for automated fabrication (facility to be developed).	▪ Redundant mooring tendons are required with associated anchor points. ▪ Onshore storage space required.
T&I	▪ Transported to site on vessel then offloaded for installation. ▪ No wet storage required.	▪ Ballasted for tendon hook-up. ▪ WTG integration offshore by jack-up rig (available to maximum 80m water depth at present).
Performance	▪ Low motions – positive impact on AEP.	
Risk	▪ Based on O&G TLP technology ▪ Small seabed footprint.	▪ Achieving adequate stiffness of synthetic rope for tendons. ▪ Dynamic cables.
O&M / OPEX	▪ Access using standard SOVs. ▪ Low motion should benefit WTG reliability.	▪ Tendon tension is sensitive to reduced buoyancy due to marine growth. ▪ Steel structure – potential coating breakdown, corrosion, and fatigue damage. ▪ Limited deck space available for maintenance and repair work. ▪ No space for helideck on hull.

Table 7-2: PelaFlex TS Strengths and Weaknesses

7.2.2 Ocean Breeze (Ocean Resources)

Ocean Breeze is a TLP comprising 5 cylindrical steel buoyancy chambers connected by a steel tubular framework around a central small-diameter column, which supports the WTG. The buoyancy chambers and connecting framework are below sea level, leaving only the central column cutting the water plane and exposed to wave loading.

The mooring system of 5 tendons, each connected to one buoyancy chamber, provides redundancy and ensures stability of the floating system in the event of the loss of one tendon. Nevertheless, the system can accommodate 10 tendons if required by a project BOD.

As with all TLPs, uplift on the anchor points will limit the choice of anchor point types that can be deployed for any given soil condition.

Ocean Resources Ocean Breeze	Strengths	Weaknesses
CAPEX	▪ Simple geometry of five connected buoyancy cans. ▪ Tendon redundancy not required to ensure stability.	▪ Five anchor points required.
T&I	▪ WTG integrated at quayside – no offshore integration.	▪ Temporary buoyancy for tow and installation, and for R2P. ▪ Wet storage may be required to meet installation schedule. ▪ Temporary buoyancy potentially required during wet storage.
Performance	▪ Low motions – positive impact on AEP.	
Risk	▪ Based on Ocean Resources tension leg buoy and O&G TLP technology. ▪ Small seabed footprint.	▪ Dynamic cables.
O&M / OPEX	▪ Access using standard SOVs. ▪ Low motion should benefit WTG reliability.	▪ Tendon tension is sensitive to reduced buoyancy due to marine growth. ▪ Steel structure – potential coating breakdown, corrosion, and fatigue damage. ▪ Limited deck space available for maintenance and repair work. ▪ No space for helideck on hull.

Table 7-3: Ocean Breeze Strengths and Weaknesses

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7.2.3 Trivane Trimaran (Trivane Ltd)

Trivane Trimaran is a semi-submersible barge featuring concrete pontoons and three steel floaters, which provide column-stabilised behaviour. There is an option to fabricate the aft floaters in concrete.

The Trivane Trimaran is moored by a turret, i.e., a single-point mooring, allowing the system to weathervane to adopt the position of least resistance to the prevailing weather and thereby reduce mooring loads. The turret provides the entry route for the electrical power cable and supports an electrical swivel to transfer power between the weathervaning and geostationary parts of the Trivane.

The forward section of the hull can be ballasted to reduce the negative trim generated by the thrust on the turbine. Carbon Trust indicates that static incline has more of an impact on performance than dynamic motions [4] and has extensively studied the impact of static pitch angles on AEP [10].

Trivane Trivane Trimaran	Strengths	Weaknesses
CAPEX	▪ Light mooring system (weathervaning hull). ▪ Simple concrete pontoon form. Simple flat plate floater form. ▪ Simple low-cost turret design.	▪ HV Electric Swivel ▪ Turret and bearing system. ▪ Downwind WTG
T&I	▪ WTG integrated at quayside or onshore – no offshore integration. ▪ High stability, low drag during tow. ▪ Conventional mooring leg hook-up by AHV.	▪ Wet storage may be required to meet installation schedule.
Performance	▪ Forward ballast to reduce negative trim under wind loads.	▪ Larger motions than hybrid systems and TLPs.
Risk	▪ Based on O&G semi-submersible technology (column stabilisation)	▪ Dynamic cables – larger offsets than hybrid systems and TLPs.
O&M / OPEX	▪ Low maintenance concrete pontoons – good fatigue performance, good corrosion resistance, no coating maintenance.	▪ Steel turret inspection requirements (bearing and electrical swivel). ▪ Deck space could be provided for maintenance and repair work, though not yet detailed. ▪ No space available to fit a helideck on the hull.

Table 7-4: Trivane Trimaran Strengths and Weaknesses

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7.3 UK-Based Concepts TRL summary

Based on a review of the completed activities for each UK-based concept, compared with the roadmap in Appendix D, a summary of the TRL status of these concepts is provided in Table 7-5 below.

Technology Provider	Location	Concept	Floating or Hybrid	TRL				
				2	3	4	5	6
AWC Tech	England	AWC	Hybrid	Complete	Complete	Complete		
Marine Power Systems	Wales	PelaFlex TS	Floating	Complete	Complete	Complete	Main activities complete	
Marine Power Systems	Wales	PelaFlex GS	Hybrid	Complete	Complete	Complete	Complete	
Ocean Resource	Wales	Ocean Breeze	Floating	Complete	Complete			
OSI	Scotland	FTLP+	Hybrid	Complete	Complete	Complete	Main activities complete	
Trivane	England	Trivane Trimaran	Floating	Complete	Complete	Complete	Complete	
Trivane	England	Trivane Tower	Hybrid	Complete	Complete	Not required		

Table 7-5: UK-Based Concept TRL Status

Complete — Main activities complete — Not required [Note 1]

Note 1: The Trivane tower will follow previous GBS design methodology. The load path from WTG is a simple stiff cantilever, and wind and wave interaction can be assessed by simulation - model basin testing is not considered essential.

7.4 Discussion

The seven UK-based concepts cover a wide range of system arrangements: four hybrid concepts and three floating concepts, comprising three in concrete and four in steel. None are in the 15 highest-ranked concepts for North Sea conditions despite incorporating some interesting and innovative features. The reasons for their lower ranking vary between the concepts, but include complex installation requirements, low technical maturity, limited EPCI experience, and high OPEX. If funding were available to accelerate development of one or several of these concepts, selection based on a FEED-level design competition would allow the concepts to be assessed in detail on a like-for-like basis.

The four hybrid solutions are limited by the lack of installation means available to install WTG in water depths over 80m. Several technology providers are engaged in developments to overcome this limitation, and if proven and cost-effective installation means are available in future, some hybrid solutions could enter the top 15.

Of the floating solutions, the PelaFlex TS has the same installation limitations as the hybrids, and its deployment in water depths above 80m is dependent upon the development of suitable installation means, or use of an expensive semi-submersible crane barge.

Both the remaining FOW concepts, Ocean Breeze and Trivane Trimaran, are in principle suitable for deployment in North Sea conditions. However, Trivane has reached TRL5 compared to TRL3 for Ocean Breeze and has advantages in T&I: Trivane is stable during tow and has a conventional hook-up to a catenary mooring, whereas Ocean Breeze requires temporary buoyancy for stability during tow and has the complexity of hook-up inherent in TLP design. T&I issues are one of the factors contributing to no TLPs ranking in the top 15 concepts for North Sea conditions.

It is also notable that floating systems with catenary or semi-taut moorings, such as the Trivane Trimaran, could in principle be adapted to use Quick Connect/Disconnect (QCDC) mooring systems with limited modifications to the floater design. QCDC systems would provide benefits in reduced time for hook-up and disconnection for R2P, and could also be adapted for connection and disconnection of electrical cables.

Development of generic QCDC systems for integration into multiple FOW concepts could provide economic benefits to projects and additional engineering and manufacturing opportunities in the UK.

7.4.1 Acceleration towards the commercialisation of UK-based concepts

Before the development of a commercial wind farm, OpenWater Renewables strongly recommends that the selected concept has reached TRL7 to minimise technical risk and incorporate lessons learned into the commercial-scale units. However, at present, UK-based concepts only range from TRL3 to TRL5, with 4 concepts (PelaFlex TS, PelaFlex GS, FTLP+, and Trivane Trimaran) having completed at least the major activities required for TRL5.

To enable and encourage the selection of UK-based concepts for inclusion in commercial wind farms, accelerated development to TRL7 is critical. Based on the roadmap provided in Appendix D, OpenWater Renewables estimates that if resources and a test site are available, progressing from TRL5 to TRL7 (3 years of successful operation of a demonstrator) will take 60 to 72 months.

UK-based developers with concepts at TRL5 have varying levels of EPCI experience, so external assistance with project-execution plans would improve the likelihood of them successfully achieving TRL7 in the target timescale.

On attainment of TRL7, based on the activities on the roadmap, progress to TRL9 (3 years successful operation of a commercial farm) will take an additional 72 to 84 months. A commercial-scale farm of 100 MW will require finance and EPCI experience that will likely be beyond the resources of the technology developer and is expected to be supplemented by the wind farm project developer.

The overall timescale to commercialisation, to progress from TRL5 to TRL9, is estimated at 11 to 13 years. This assumes that development is sequential, preparation for TRL8 (design, contracts, permitting and consenting, etc.) is completed before the end of the TRL7 period, and that TRL8 activities begin immediately on attainment of TRL7.

A FEED-level design competition, as proposed in the section above, would allow a more accurate assessment of the timescale required to develop each concept, and definition of the support that the technology developers would need to achieve at least TRL7. Support may include financial aid, technical and project-execution input to complete the roadmap activities, and provision of a test site or assistance with permitting and consenting.

For hybrid concepts and PelaFlex TS, TRL6 and above cannot be reached for water depths greater than 80m without the development of means for the installation of the WTG offshore.

8.0 Conclusions

The main conclusions from this work are as follows.

At the cut-off date for the study on 28th February 2026, the OpenWater Renewables database contained details of 117 FOW concepts and six hybrids, meaning that 16 concepts have been added since the 2025 study [1].

The TRL matrix proposed by OpenWater Renewables in the 2025 study has again been used and further developed with a Roadmap (see Appendix D). The newly added concepts have TRL levels between TRL4 and TRL5, and there are still no concepts rated TRL8 or TRL9, as these relate to commercial-scale farms.

The ranking process for the fictional North Sea field has been repeated, resulting in an updated pool of the 15 highest-rated FOW concepts, comprising eight in steel, six in concrete, and one in mixed materials with a concrete hull and a steel turret mooring system.

This ranking resulted in six changes to the 2025 pool of the highest-ranked concepts. Three more concrete barges have entered the pool – two being newly launched concepts and one with an increased score due to further development. Similarly, three different steel semi-submersibles have entered this pool, all being newly launched.

No TLPs are included in the pool, due to the complex installation procedure in North Sea conditions. Deep-draft SPARs were again excluded from the shortlist due to the absence of deepwater construction ports in the UK.

A review of hybrid deepwater concepts identified six under active development. Four of these are fabricated in steel: two guyed towers, one guyed monopile and one buoyant tower. Two others are in concrete: one articulated column and one self-installing GBS. Most of these hybrids have water depth limitations below the 150 m specified in the BOD for this study. Moreover, all have limitations related to the installation of the WTG in water depths beyond 80 m, due to the current lack of ultra-deepwater WTIV jack-up rigs capable of operating beyond this limit. Although very large semi-submersible crane vessels are available, they can be prohibitively expensive and may experience prolonged weather downtime in the North Sea during sensitive WTG installation operations.

Some of the CAPEX advantages claimed for hybrids depend on speculative future investment in automated fabrication facilities and deepwater installation vessels. Since these are still conceptual, only partial credit has been taken for the cost savings. Moreover, costs for some FOW concepts are likely to fall with future design and industrialisation optimisation.

For these reasons, none of the above six hybrids is included in the pool of the 15 highest-ranked concepts. However, for shallower fields (60 to 80m), some of these concepts would score highly.

The generic pros and cons of the FOW and hybrid systems are shown in Figure 8.1 below.

	CAPEX *	OPEX	LCOE	Ease of WTG Integration	Ease of Installation	Ease of O&M	Reliability	Performance	Ease of Major Repair	TRL/Risk	Examples (TRL)
Barge in Concrete	100%	Good	Good	Good	Intermediate	Good	Good	Intermediate	Intermediate	Good / Intermediate	BW Ideol Damping Pool (7), Aker CONfloat Omega (0), Aker CONfloat 7C (5), Brezo Energy CROWN FW (5), Sevan SWACH Wind (5)
Barge in Hybrid Steel & Concrete	110%	Intermediate	Intermediate	Good	Good	Intermediate	Intermediate	Intermediate	Good	Intermediate	Saitec SATH (6)
Semi-Sub in Steel	105% to 115%	Intermediate	Intermediate	Good	Intermediate	Intermediate	Good	Good / Intermediate	Intermediate	Good / Intermediate	PPI WindFloat-T (7), Saipem Star-1 (5), Aker YFloat (5), Seatrium FWSS (5), JMU Jade Wind Centre (5), PPI WindFloat FC (5), Gusto TriFloater (5), Odfjell Oceanwind Deepsea Star (5)
Semi-Sub in Concrete	100%	Good	Good	Good	Intermediate	Good	Good	Intermediate	Intermediate	Intermediate	Bouygues OO-Star (5)
Hybrid - Guyed Tower	95% to 100%	Good	Good	Poor	Intermediate	Intermediate	Good	Good	Poor	Intermediate	OSI FTLP+ (5), MPS Pelaflex GS (5), Entrion FRP (5)

* Ball Park total project CAPEX compared to the Concrete Barge case.

Key: Good | Intermediate | Poor

Figure 8-1: Generic Concept Pros and Cons

The study also identified 10 UK-based systems, of which seven are actively under development: four hybrid concepts and three FOW concepts. This includes four of the hybrid concepts listed above (two guyed towers, one articulated column and one self-installing GBS) and three FOW concepts (two steel TLPs and one mixed-material semi-sub). The TRLs of these concepts range from TRL3 to TRL5, and recommendations to improve their ranking are included below.

9.0 Recommendations

9.1 To enable a detailed like-for-like comparison of UK-based concepts, conduct FEED-level design competition, including Transport & Installation, UK manufacturing content, and full lifecycle cost analysis. The pool of candidates for the FEED could include the following:

- AWC Tech AWC
- OSI FTLP+
- Ocean Resources Ocean Breeze
- MPS PelaFlex GS
- MPS PelaFlex TS
- Trivane Trimaran
- Trivane Tower

9.2 Accelerate the TRL progress for promising FOW concepts that are not yet at the prototype or demonstrator stage. Where these concepts can demonstrate high UK content, they could also be considered as potential candidates for the above design competition. Potential candidates include the 12 concepts below, which are all part of the shortlisted pool of concepts for the fictional North Sea project:

- Bouygues OO-Star
- Aker CONFloat Omega
- Saipem Star-1
- Aker CONFloat 7C
- Aker Yfloat
- Brezo Energy CROWN FW
- Seatrium FWSS
- JMU JADE Wind - Centre
- PPI WindFloat FC
- Gusto TriFloater

- Sevan SWACH Wind
- Odfjell Oceanwind Deepsea Star

9.3 Based on the outcome of the above design competition, build and test several demonstrator units for the concepts found to have the highest potential. This could be at a dedicated test & demonstration site or as part of, or an addition to, a commercial wind farm.

9.4 Review common deepwater wind details and construction methods that would benefit from the development of advanced manufacturing techniques. Conclusions should be in the public domain to assist industry in decision-making.

9.5 Conduct a study of UK manufacturing capacity for both steel and concrete deepwater units, identifying bottlenecks, and where development of supply chain skills should be accelerated. Conclusions should be in the public domain to assist industry in decision-making.

9.6 Review potential installation means for water depths greater than 80 m, which would be suitable for all or most proposed hybrid concepts. The target should be to develop means that are sufficiently flexible for WTG installation of multiple hybrid concepts.

9.7 Develop concepts for a fleet of vessels for the installation of hybrids in water depths greater than 80m with potential for UK-content and/or UK supply-chain involvement.

9.8 Investigate transportation and installation time and costs for hybrid versus floating units for installation in the Celtic Sea.

9.9 Investigate the long-term escalation of OPEX for ageing deepwater units, including the OPEX difference between concrete and steel structures. This should include the potential benefits of designing to reduce O&M activities.

9.10 Conduct further studies into the impact of floater motions on WTG reliability.

9.11 Accelerate the development of QCDC systems for mooring and array cables that can be fitted to FOW units with limited modification to the floater design.

9.12 Develop an industry standard definition for TRL for deepwater wind projects, including an accompanying Roadmap.

10.0 Glossary

AEP	Annual Energy Production (total energy output of a wind turbine over the course of a year)
AHV	Anchor Handling Vessel
BOD	Basis of Design
BT	Buoyant Tower
CAPEX	Capital Expenditure
CFD	Contract for Difference
CRL	Commercial Readiness Level (see Appendix C for definition)
CTV	Crew Transfer Vessel
EPCI	Engineering, Procurement, Construction, and Installation
FID	Final Investment Decision
FOW	Floating Offshore Wind
GBS	Gravity-Based System
HLV	Heavy Lift (Crane) Vessel
Hs	Significant Wave Height
I&C	Integration and Commissioning
IRM	Inspection, Repair and Maintenance
LCOE	Levelised Cost of Energy
MCR	Major Component Replacement
MRL	Manufacturing Readiness Level
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
OWRL	OpenWater Renewables Ltd
O&G	Oil and Gas
PEP	Project Execution Plan
PWF	Project Weighting Factors
QCDC	Quick Connect and Disconnect
RAO	Response Amplitude Operator
R2P	Return to Port repair strategy.
SCF	Suction Caisson Foundation
SOV	Service Operations Vessel
SPAR	Single Point Anchor Reservoir
SPM	Single Point Mooring
TLB	Technology Leadership Board
TLP	Tension Leg Platform
TRL	Technology Readiness Level (see Appendix C for definition)
T&I	Transportation and Installation
W2W	Walk to Work
WTG	Wind Turbine Generator
WTIV	Wind Turbine Installation Vessel
WOW	Waiting on Weather

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11.0 References

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Appendix A – Basis of Design

TLB2601 - FOW Ranking Report

Datasheet

Datasheet	DS01	REV: A1	By: MWW	SHEET 1
TITLE:	Basis for Study			

	Subject	Units	Data
1	FOW Farm Location		North Sea or Celtic Sea
2	Capacity	MW	750
3	Turbine Size	MW	15
4	Number of Units		50
5			
6	Water Depth	meters	100 to 150
7	Soil Conditions		Suitable for drag anchors or suction anchors
8			
9	Distance from shore	km	80-120
10	Distance from Assembly port	km	125
11	Distance from O&M port	km	125
12	Water depth at port	meters	12 min (at low tide)
13			
14	Date - Start of Operation		2030-2035
15	Schedule		Install over 1 or 2 summer seasons
16	Field life	Years	25 to 30
17	Foundation Material		Open - Concrete, Steel or Mixed
18	Coatings		Suitable to ensure full design life without need to recoat
19			
20	Mooring Redundancy		None, unless required for stability
21	Accessibility		CTV, W2W from SOV, Helicopter drop onto nacelle as a minimum
22	Laydown		Space for at least 1 container loaded from an SOV
23			
24	Contract Basis		EPCI
25	Local Content Requirements	%	Minimum 50% UK expenditure over life cycle (CAPEX + 6 years OPEX)
26	Module Fabrication Site		Open, subject to the above Local Content requirements
27	Assembly & Commissioning Site		UK port
28			
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Appendix B – Ranking Methodology

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The ranking of concepts is based on the procedure illustrated in Figure B-1 Below.

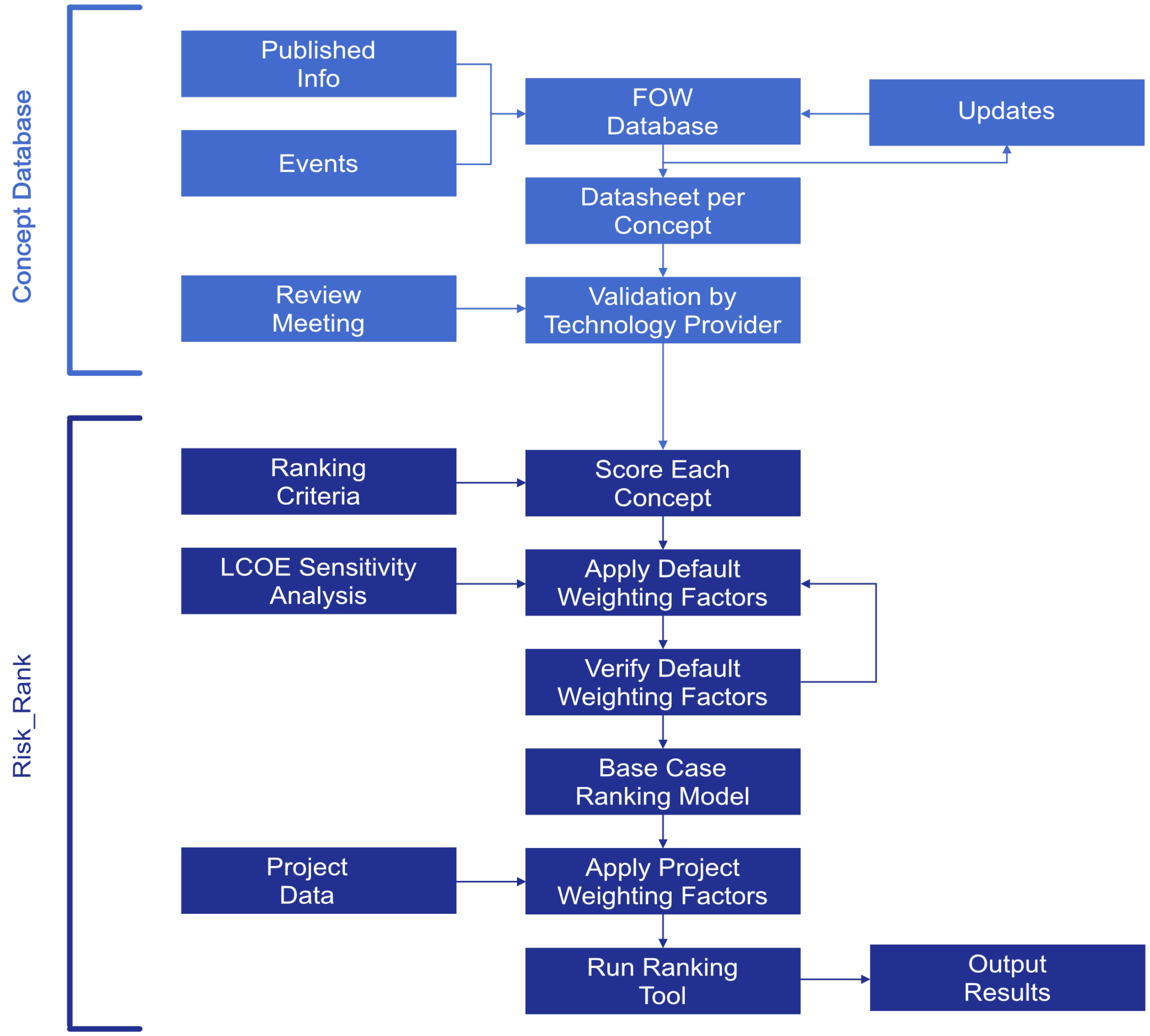

Figure B-1: FOW Ranking Process Flowchart

Using the data for each concept contained in the FOW database, 39 criteria for each concept have been systematically scored to create a concept profile in FOW_RANK. These criteria were developed through workshops led by an experienced team covering design, construction, installation, operations and maintenance, project management, and risk.

The criteria are grouped into seven categories:

- CAPEX (including materials of construction, ease of fabrication, transportation, ease of assembly, mooring system configuration, local content opportunity, etc.)
- OPEX (including the need for ballast systems, reliance on large mechanical components, surface coatings, accessibility for inspection and maintenance teams, etc.)
- Ease of installation (including towing requirements, the need for temporary equipment, offshore heavy lift requirements, etc.)
- Ease of Major Repair (including disconnection, reconnection, stability, and towing requirements)
- Performance (including the level of nacelle motions, provision for trim and yaw control, etc.)
- Risk (including TRL, CRL, financial strength of technology provider, etc.)

- EPCI (including execution experience and strength of the technology provider, yard partnerships in place, schedule constraints, etc.)

Each criterion has a different level of impact on the project's LCOE or risk profile. To reflect this, weighting factors are applied to each score before they are added to determine the total score for each concept.

FOW_RANK uses two sets of weighting factors: Default Weighting Factors and Project Weighting Factors (PWF), which are described below.

Default Weighting Factors

A Default Weighting Factor is applied to each criterion, based primarily on a sensitivity analysis of its impact on LCOE and the risk profile. Additionally, the overall weighting factor for each category has been adjusted to balance the relative contributions of each category. Default weighting factors remain constant for all ranking studies performed by OpenWater Renewables.

Project Weighting Factors (PWF)

The default weighting factors can be supplemented with Project Weighting Factors (PWF) reflecting the specific challenges of a site or the particular concerns of the project developer. For the North Sea study, PWFs were determined through a workshop with OpenWater Renewables and the TLB NST workstream, and these are detailed in Section 5.1 of this report. More information on FOW_RANK can be found in a paper presented at the 2025 OTC conference [5].

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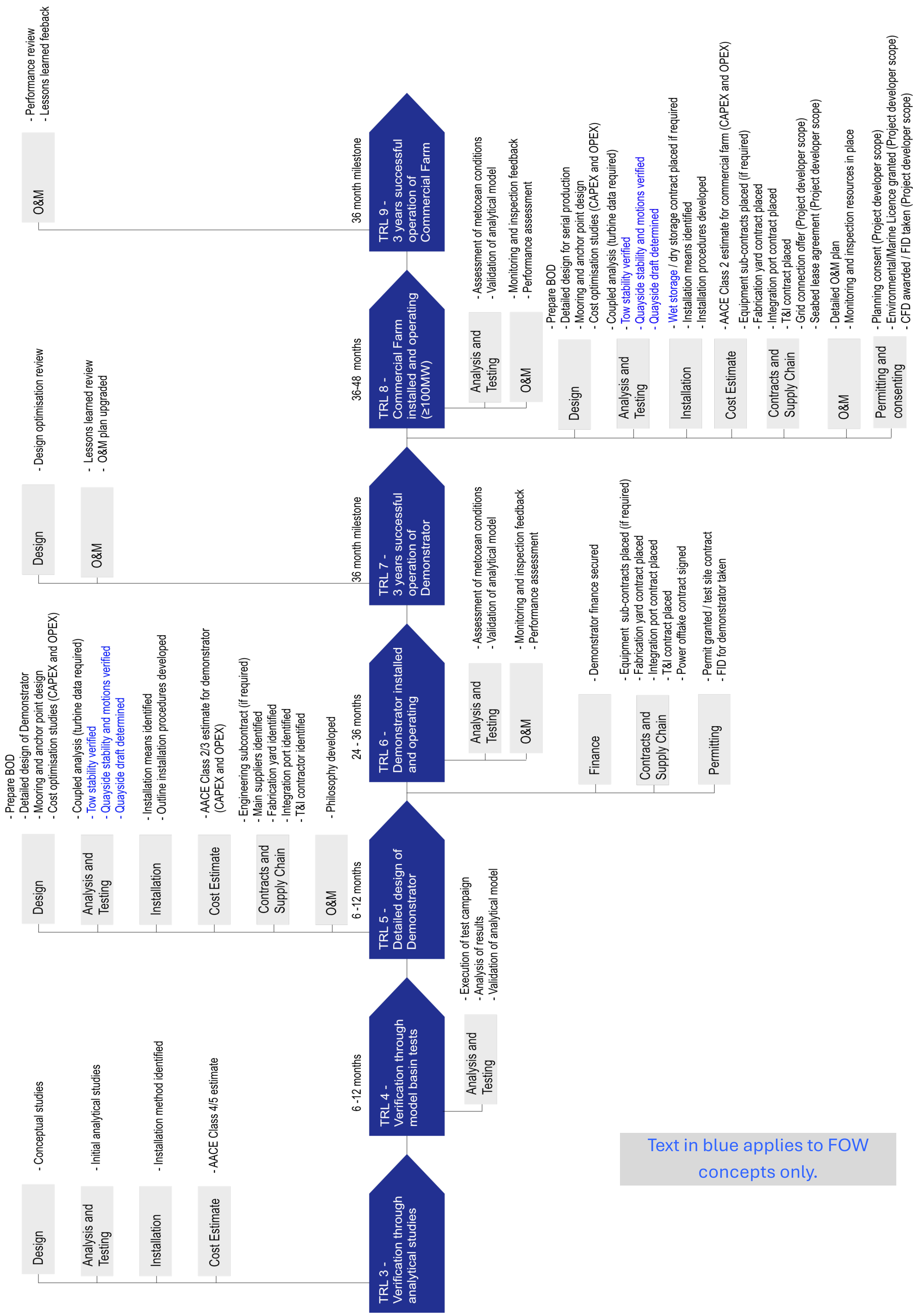
Appendix C – TRL Definitions

TRL	European Union (Horizon 2020)	Current NASA usage	DNV for FOW	Carbon Trust	OWRL Scale for FOW
9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies, or in space).	Actual system "flight proven" through successful mission operations	Floating wind turbine ready for fabrication and installation at large scale	Commercial project (>50 MW)	Commercial units with turbine of 100 MW minimum capacity successfully completed three years' operating at sea.
8	System complete and qualified.	Actual system completed and "flight qualified" through test and demonstration	Components, e.g. floater design, ready to be integrated in a floating wind turbine. Wind turbine design qualified.	Pilot array (20-50 MW)	Commercial units with turbine of 100 MW minimum capacity installed and operating at sea.
7	System prototype demonstration in operational environment	System prototype demonstration in a space environment	Prototype wind or farm in-place and operating.	>5 MW demo	Demonstrator with turbine of 1 MW minimum capacity successfully completed three years operating at sea.
6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies).	System/subsystem model or prototype demonstration in an operational environment	Prototype wind turbine designed for specific application.	1 – 5 MW demo	Demonstrator with turbine of 1 MW minimum capacity installed and operating at sea.
5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies).	Component and/or breadboard validation in relevant environment	Design of component/wind turbine verified.	Scaled testing (<1 MW)	Detailed design of demonstrator completed for target offshore environment. Turbine capacity of 1 MW minimum.
4	Technology validated in lab.	Component and/or breadboard validation in laboratory environment	Laboratory tests confirmed concept design.	Tank testing	Model basin test campaign successfully completed.
3	Experimental proof of concept.	Analytical and experimental critical function and/or characteristic proof-of concept	Concept feasible.	Numerical modelling	Verification of the concept through analytical studies completed (CFD, coupled aero-hydro analysis, FEA, etc.).
2	Technology concept formulated.	Technology concept and/or application formulated	Not defined	Proof of concept	Concept drawings of the platform configuration produced and validated by basic calculation.
1	Basic principles observed.	Basic principles observed and reported	Not defined	Initial concept	Basic concepts identified – for stability, station keeping, and principal systems.

Table C-1: Comparison of FOW TRL definitions

Appendix D – TRL Roadmap



TRL 3 - Verification through analytical studies
Design
- Conceptual studies
Analysis and Testing
- Initial analytical studies
Installation
- Installation method identified
Cost Estimate
- AACE Class 4/5 estimate
TRL 4 - Verification through model basin tests
6 -12 months
Analysis and Testing
- Execution of test campaign
- Analysis of results
- Validation of analytical model
TRL 5 - Detailed design of Demonstrator
6 -12 months
Design
- Prepare BOD
- Detailed design of Demonstrator
- Mooring and anchor point design
- Cost optimisation studies (CAPEX and OPEX)
Analysis and Testing
- Coupled analysis (turbine data required)
- Tow stability verified
- Quayside stability and motions verified
- Quayside draft determined
Installation
- Installation means identified
- Outline installation procedures developed
Cost Estimate
- AACE Class 2/3 estimate for demonstrator (CAPEX and OPEX)
Contracts and Supply Chain
- Engineering subcontract (if required)
- Main suppliers identified
- Fabrication yard identified
- Integration port identified
- T&I contractor identified
O&M
- Philosophy developed
TRL 6 - Demonstrator installed and operating
24 - 36 months
Analysis and Testing
- Assessment of metocean conditions
- Validation of analytical model
O&M
- Monitoring and inspection feedback
- Performance assessment
Finance
- Demonstrator finance secured
Contracts and Supply Chain
- Equipment sub-contracts placed (if required)
- Fabrication yard contract placed
- Integration port contract placed
- T&I contract placed
- Power offtake contract signed
Permitting
- Permit granted / test site contract
- FID for demonstrator taken
TRL 7 - 3 years successful operation of Demonstrator
36 month milestone
Design
- Design optimisation review
O&M
- Lessons learned review
- O&M plan upgraded
TRL 8 - Commercial Farm installed and operating (≥100MW)
36-48 months
Analysis and Testing
- Assessment of metocean conditions
- Validation of analytical model
O&M
- Monitoring and inspection feedback
- Performance assessment
Design
- Prepare BOD
- Detailed design for serial production
- Mooring and anchor point design
- Cost optimisation studies (CAPEX and OPEX)
Analysis and Testing
- Coupled analysis (turbine data required)
- Tow stability verified
- Quayside stability and motions verified
- Quayside draft determined
Installation
- Wet storage / dry storage contract placed if required
- Installation means identified
- Installation procedures developed
Cost Estimate
- AACE Class 2 estimate for commercial farm (CAPEX and OPEX)
Contracts and Supply Chain
- Equipment sub-contracts placed (if required)
- Fabrication yard contract placed
- Integration port contract placed
- T&I contract placed
- Grid connection offer (Project developer scope)
- Seabed lease agreement (Project developer scope)
O&M
- Detailed O&M plan
- Monitoring and inspection resources in place
Permitting and consenting
- Planning consent (Project developer scope)
- Environmental/Marine Licence granted (Project developer scope)
- CFD awarded / FID taken (Project developer scope)
TRL 9 - 3 years successful operation of Commercial Farm
36 month milestone
O&M
- Performance review
- Lessons learned feeback
Text in blue applies to FOW concepts only.

Appendix E – Project Weighting Factors

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Criteria Group	Criteria	PWF
CAPEX	Draft after Turbine Integration	2
	Local Content Opportunity	2
Installation	Ease of Installation	4
	Use of Temporary Buoyancy	4
	Use of Temporary Winches	4
	Offshore Vessel Requirement	4
	Towing Costs	4
OPEX	Accessibility	2
Performance	Nacelle Motions	2
Repair	Ease of Disconnection	3
	Laydown area	2
Risk	TRL	3
	Financial Strength of Company	3
EPCI	Engineering Strength	3
	Project Execution Strength	3

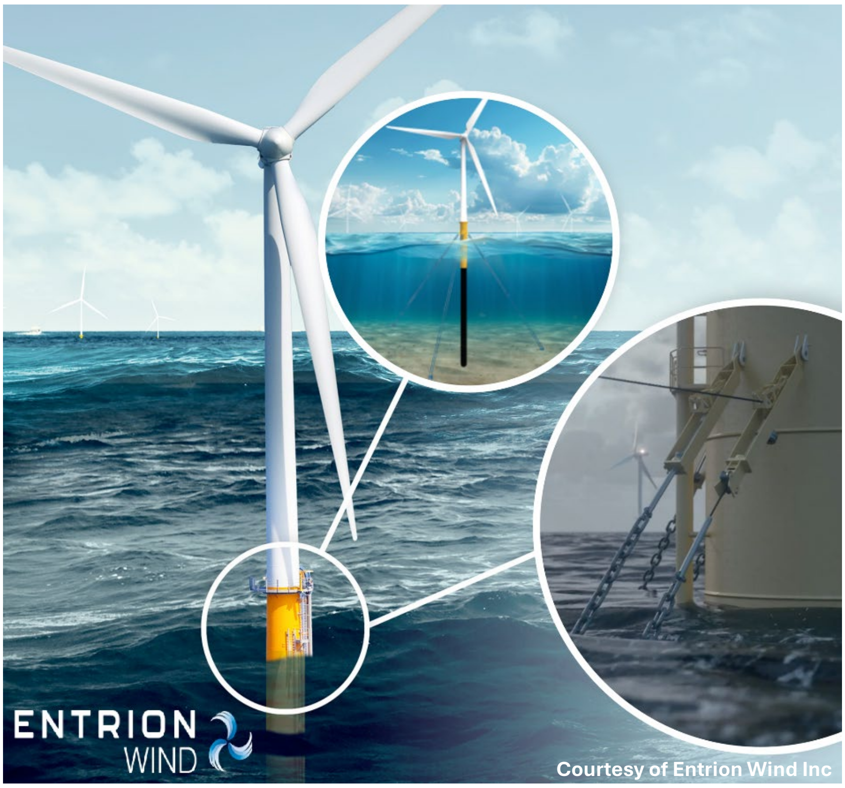
Table E-1: Project Weighting Factors for North Sea Study

Appendix F – Summary sheets for Hybrid concepts

Articulated Wind Column (AWC)

Technology Developer	AWC Tech Ltd
Headquarters	Cobham, UK
Type	Hybrid – articulated buoyant column
Material	▪ Concrete column ▪ Cast steel articulation (cardan joint) ▪ Concrete gravity base (sand, crushed rock, or iron ore ballast)
Associated technology	North Sea oil offloading towers, Single Anchor Leg Moorings (SALMs)
Principal characteristics	▪ Buoyant column connected to gravity base by a steel articulation (cardan joint) with polymer bearings. ▪ Articulation at the base provides column compliance
Fabrication	▪ Column slip formed as 5 sections. Assembled column post-tensioned ▪ Reinforced concrete gravity base cast with open cells to allow ballasting. ▪ Horizontal buoyant column is mated with gravity base supported on a dumb barge.
Quayside draft	Not applicable – base loadout on barge / buoyant horizontal column
Water depth limits	90 – 200m
TRL	4
UK content opportunities	All UK content, but a single source for cast articulation
Installation requirements	▪ The complete unit (column, articulation, and gravity base) is towed to site by two AHVs, with the column floating horizontally. ▪ The gravity base cells are then flooded with seawater to achieve a vertical orientation of the column before ballasting the base. ▪ Turbine integration offshore by jack-up rig.

Fully Restrained Platform (FRP)



Technology Developer	Entrion Wind Inc
Headquarters	Houston, Texas
Type	Hybrid – Guyed tower
Material	▪ Tubular steel column ▪ Steel wire rope tendons with chain segment at top
Associated technology	O&G mooring systems
Principal characteristics	▪ Central column member supporting turbine (monopile) ▪ Tendons providing lateral stability. ▪ Top Mooring Assembly fitted to standard transition piece. ▪ Hydraulic system to pre-tension tendons
Fabrication	▪ Prefabricate column and transition piece transport to marshalling yard
Quayside draft	Not applicable – loadout on vessel
Water depth limits	60 - 120m
TRL	5
UK content opportunities	All UK content possible subject to monopile fabrication
Installation requirements	▪ Installation based on same vessels as used for fixed-bottom offshore wind. ▪ WTG integration by jack-up rig

PelaFlex GS

Technology Developer	Marine Power Systems Ltd
Headquarters	Swansea, UK
Type	Hybrid – Guyed Tower
Material	▪ Steel truss column ▪ Wire rope tendons ▪ Flex joint at column base
Associated technology	O&G mooring systems
Principal characteristics	▪ Central column member supporting turbine. ▪ Tendons providing lateral stability. ▪ Proprietary tensioning device to pre-tension tendons
Fabrication	▪ Steel column fully fabricated and delivered to port
Quayside draft	Not applicable – loadout on vessel
Water depth limits	60 - 130m
TRL	5
UK content opportunities	All UK content possible
Installation requirements	▪ Column and tendon bases and piles pre-installed. ▪ Column legs and tendons connected to base anchor points. ▪ Tendons pre-tensioned using proprietary tensioning device. ▪ WTG installation by jack-up rig

FTLP+

Technology Developer	Oil States Industries (UK) Ltd
Headquarters	Aberdeen, UK
Type	Hybrid – Guyed Tower
Material	▪ Steel space frame column ▪ Steel tubular tendons
Associated technology	Tension Leg Platforms
Principal characteristics	▪ Central column member supporting turbine. ▪ Tendons providing lateral stability. ▪ Hydraulic system to pre-tension tendons ▪ OSI flexjoints at tendon bases to provide articulation
Fabrication	▪ Steel column fabricated by OSI UK or subcontracted. ▪ Road transport to assembly yard. ▪ Tendon sections joined by OSI Merlin connectors
Quayside draft (turbine integrated)	Not applicable – loadout on vessel
Water depth limits	80 - 150m
TRL	5
UK content opportunities	All UK content possible
Installation requirements	▪ Column and tendon bases and piles pre-installed. ▪ Column legs (4 No) and tendons connected to bases by latches. ▪ Tendons pre-tensioned by hydraulic system (freestanding column safe for man access without WTG integrated). ▪ WTG installation by jack-up rig.

Trivane Tower

Technology Developer	Trivane Ltd
Headquarters	Newquay, UK
Type	Gravity Based Concrete Tower
Material	▪ Concrete base and tower ▪ Steel skirts on underside of base
Associated technology	O&G Gravity Based Systems (GBS)
Principal characteristics	▪ Prestressed concrete tower on concrete base (base raft) with steel skirts
Fabrication	▪ Concrete base ▪ Concrete lower tower slip-formed on the completed base ▪ Float out to deeper water and ballast down at temporary anchorage. ▪ Completion of slip-forming ▪ Installation of WTG (method under development)
Quayside draft (turbine integrated)	7m
Water depth limits	Not determined
TRL	3
UK content opportunities	All UK content
Installation requirements	Anchor legs and mooring legs pre-installed.

w.BT

Technology Developer	Wison New Energies Co. Ltd
Headquarters	Shanghai, PRC
Type	Hybrid – Hybrid SPAR
Material	▪ Steel column ▪ Steel buoyancy chambers
Associated technology	O&G compliant towers
Principal characteristics	▪ Compliant tower with buoyancy chamber at top of column ▪ Integrated suction caisson at base ▪ Rigid connection of column to caisson
Fabrication	▪ Steel column and suction caisson fabricated in Wison New Energies' yard
Quayside draft	Not applicable – towed out horizontally
Water depth limits	80 – 200m
TRL	2
UK content opportunities	Fabrication in PRC.
Installation requirements	▪ Column structure towed out horizontally ▪ Column structure upended by ballasting the soft tank and the lower part of the central buoyancy column with seawater. ▪ Soft tank ballasted with high-density ballast material and the variable buoyancy tank with seawater to drive the SCF into the seabed (apply suction, if needed) ▪ Nacelle and blades installed by crane vessel near the still water level, and de-ballasting the variable ballast tank accordingly. ▪ Lifting the turbine tower by de-ballasting the central buoyancy column and locking it in position with a hydraulic system.

Appendix G – Summary sheets for UK FOW concepts

PelaFlex TS

Technology Developer	Marine Power Systems Ltd
Headquarters	Swansea, UK
Type	Floating – Tension Leg Platform (TLP)
Material	▪ Steel structure ▪ Steel wire rope tendons
Associated technology	O&G TLPs
Principal characteristics	▪ Upper steel truss column ▪ Steel buoyancy chamber below truss ▪ Steel outriggers for tendon connection ▪ Tendons have mild inclination from vertical
Fabrication	▪ Prefabricated system delivered to marshalling yard ▪ Potential for automated fabrication
Quayside draft (turbine integrated)	Not applicable – loadout on vessel
Water depth limits	90 - 500m
TRL	5
UK content opportunities	All UK content possible
Installation requirements	▪ Tendon anchor points pre-installed ▪ Hull transported to site on vessel. ▪ Hull upended, offloaded, and ballasted down. ▪ Tendons hooked up ▪ System de-ballasted to achieve required tendon tension

Ocean Breeze

Technology Developer	Ocean Energy and Resources Ltd (Ocean Resources)
Headquarters	Portskewett, UK
Type	Floating – Tension Leg Platform (TLP)
Material	▪ Steel tubular frame and buoyancy cans ▪ Wire rope and chain tendons
Associated technology	Ocean Resources tension leg buoys, O&G TLPs
Principal characteristics	▪ 5 peripheral buoyancy cans plus central can ▪ Redundancy with 5 tendons (stable with 4)
Fabrication	▪ Modules assembled onshore. ▪ Turbine integration at quayside.
Quayside draft (turbine integrated)	Less than 10m
Water depth limits	Not determined
TRL	3
UK content opportunities	All UK content possible.
Installation requirements	▪ Suction piles or gravity bases pre-installed. ▪ Temporary buoyancy to provide stability during tow with turbine integrated. ▪ Tensioning system required to submerge buoyancy cans and allow hook-up of mooring.

Trivane Trimaran

Courtesy of Trivane Ltd

Technology Developer	Trivane Ltd
Headquarters	Newquay, UK
Type	Semi-submersible
Material	▪ Concrete pontoons and transition piece ▪ Concrete or steel aft floaters ▪ Steel forward floater ▪ Steel turret
Associated technology	O&G semi-submersibles, FPU turrets
Principal characteristics	▪ Trimaran semi-submersible with a turret mooring system. ▪ The turret mooring, to which all moorings and export cables are connected, allows the Trivane to weathervane and alight with the predominant weather conditions.
Fabrication	▪ Square section prestressed reinforced concrete pontoons. ▪ Steel sections from stiffened flat plates, with the exception of the tubular turret cylinder.
Quayside draft (turbine integrated)	4m (loadout on barge)
Water depth limits	Not determined
TRL	5
UK content opportunities	All UK content (swivel from Moog)
Installation requirements	Anchor legs and mooring legs pre-installed. Mooring leg hook-up by AHV

Appendix H – Wind Farm installation duration – FOW concept

SCOTT MARINE CICADA EXPRESS

The following is an extract from the full report provided by Scott Marine Consultants to OpenWater Renewables on the 25th of February 2026, Reference J2606. The study used the proprietary Cicada Express software. For more information on Cicada Express, refer to:

https://www.scott-mc.com/operational-simulation

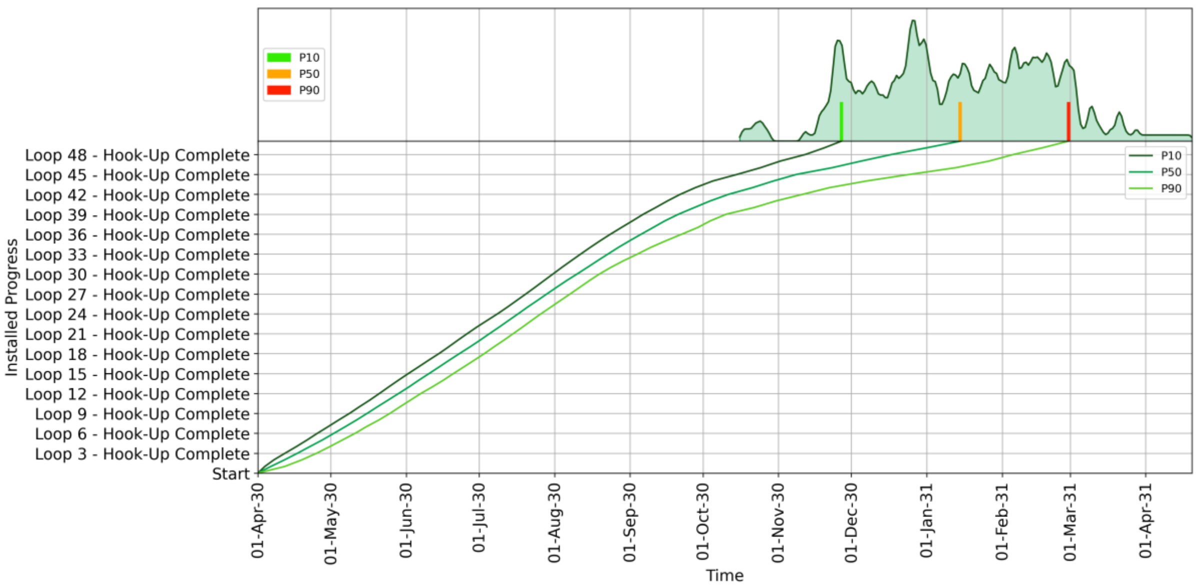
Case 1 – Generic Concrete FOW Installation

A summary of the primary findings is provided below. These outcomes are derived from the procedures outlined in the report. Unless otherwise specified, all results referenced herein are based on the following:

- Historical Hindcast Data for simulations starting between 1979-01-01 00:00:00 & 2023-04-06 00:00:00
- 64665 simulations
- Operation start date of 01/04/30.

Based on a start date of 01/04/30 ± 14 days, the programme duration, including the impact of weather, is shown in the S-curve presented in Figure 5 and tabulated in Table 3 for the P10, P50, and P90 scenarios. For clarity, only the tasks specified by the client are included and displayed on the S-curve.

The distribution of simulation runs is shown at the top of the S-curve, illustrating the frequency of completion dates across the simulations. Areas of high density indicate a greater number of simulation runs completing on those dates, while areas of low density reflect fewer completions. It is recommended to interpret any tabulated results in conjunction with this run distribution as described in Section 4.2.



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Appendix I – Wind Farm installation duration – Hybrid concept

SCOTT MARINE
CICADA EXPRESS

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https://www.scott-mc.com/operational-simulation

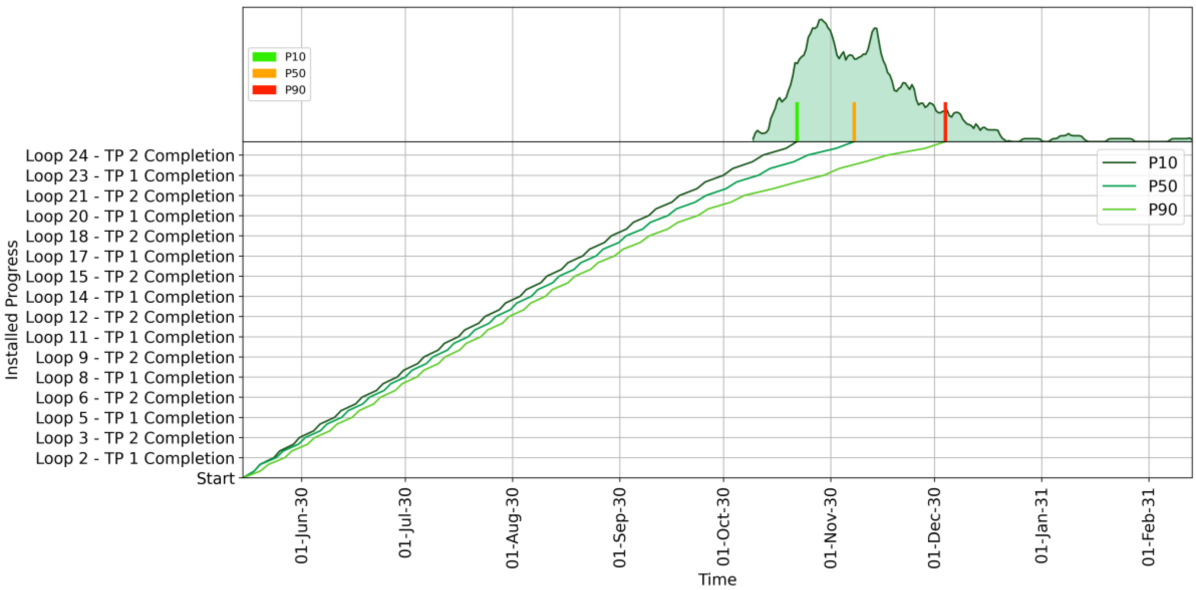
Case 2a – Generic Guyed Tower: Foundation Installation

A summary of the primary findings is provided below. These outcomes are derived from the procedures outlined in the report. Unless otherwise specified, all results referenced herein are based on the following:

- Historical Hindcast Data for simulations starting between 1979-01-01 00:00:00 & 2023-06-06 18:00:00
- 64912 simulations
- Operation start date of 15/05/30.

Based on a start date of 15/05/30 ± 14 days, the programme duration, including the impact of weather, is shown in the S-curve presented in Figure 5 and tabulated in Table 5 for the P10, P50, and P90 scenarios. For clarity, only the tasks specified by the client are included and displayed on the S-curve.

The distribution of simulation runs is shown at the top of the S-curve, illustrating the frequency of completion dates across the simulations. Areas of high density indicate a greater number of simulation runs completing on those dates, while areas of low density reflect fewer completions. It is recommended to interpret any tabulated results in conjunction with this run distribution as described in Section 4.2.



SCOTT MARINE
CICADA EXPRESS

Case 2b – Generic Guyed Tower: WTG Installation

A summary of the primary findings is provided below. These outcomes are derived from the procedures outlined in the report. Unless otherwise specified, all results referenced herein are based on the following:

- Historical Hindcast Data for simulations starting between 1979-01-01 00:00:00 & 2023-07-09 18:00:00
- 65044 simulations
- Operation start date of 15/06/30.

Based on a start date of 15/06/30 ± 14 days, the programme duration, including the impact of weather, is shown in the S-curve presented in Figure 5 and tabulated in Table 4 for the P10, P50, and P90 scenarios. For clarity, only the tasks specified by the client are included and displayed on the S-curve.

The distribution of simulation runs is shown at the top of the S-curve, illustrating the frequency of completion dates across the simulations. Areas of high density indicate a greater number of simulation runs completing on those dates, while areas of low density reflect fewer completions. It is recommended to interpret any tabulated results in conjunction with this run distribution as described in Section 4.2.