CONSTRUCTION OF FLOATING OFFSHORE WIND TURBINES

A.P. Crowle[*1], P.R. Thies[*]

[*]University of Exeter, College of Engineering, Mathematics and Physical Sciences
Renewable Energy Group, Penryn Campus, Treliever Road, TR10 9FE, UK.
[1] Email -ac1080@exeter.ac.uk

SUMMARY

As the floating offshore wind turbine industry continues to develop and grow, the capabilities of shipyard facilities need to be assessed as to their ability to support the expanding construction and installation requirements. This paper assesses current infrastructure requirements and projected changes to shipyard facilities that may be required to fabricate the floating structures. Separate shipyards are required, with large laydown areas, for substructure construction, fit-out of the turbines, moorings, subsea cables and maintenance. The capabilities of established shipyard facilities are assessed by evaluation of size of substructures, height of wind turbine with regards to the cranes for fitting of blades, distance to offshore site and offshore installation vessel characteristics. It is intended that as much work is carried out at a sheltered location inshore but close to the offshore wind farm. This paper reviews the shipyard requirements and defines the role of shipyards for floating wind.

NOMENCLATURE

A nomenclature used in the paper is as follows

[Symbol]	[Definition] [(Unit)]
AHTS	Anchor Handling Tug Supply
Float-out	Substructure floated from dry-dock
FOWT	Floating offshore wind turbine
GW	Gigawatt
HTV	Heavy transport vessel
Load-out	Horizontal movement of substructure from land onto a heavy transport vessel
M	metre
MW	Megawatt
SPMT	Self-propelled modular transporter
SSCV	Semi submersible crane vessel
T	(metric) tonne
UDL	Uniform distributed load

1. INTRODUCTION

This paper reviews the construction and installation of floating offshore wind turbines. The ability to assemble floating offshore wind turbines (FOWT) structures on or near shore means minimising highly weather dependent operations such as offshore heavy lifts and assembly, thus saving time and costs and reducing safety risks for offshore workers. Maintenance might take place in safer nearshore conditions for barges and semi submersibles types.

There is a commercial requirement to minimise the life time cost of energy, i.e. reduce capital and operating costs for floating offshore wind turbines (FOWT). The method of analysis is to use lessons learnt from traditional shipbuilding, from offshore oil and gas construction and from offshore installation of fixed bottom wind turbines. In addition from the concept and early commercial developments of floating offshore wind turbines there needs to be a better understanding of the requirements for shipyards and port facilities.

The floating offshore wind industry is in the early stages of development and shipyard facilities are required for substructure fabrication, turbine manufacture, turbine construction and maintenance facilities.

The function of shipyards for the construction, installation and maintenance of floating wind is varied:

- Supply base for the geotechnical and met-ocean survey of the offshore site.
- Construction of the substructure, possibly an existing shipyard
- Quayside factory for blade manufacture
- Load-out quay for nacelle and tower
- Laydown area for mooring components

- Laydown area for dynamic array cables
- Fit-out quay for installing turbines
- Support harbour during offshore installation phase
- Future maintenance port

The challenges for floating offshore wind turbine (FOWT) depend on the type of substructure, water depth, prevailing weather conditions, seabed soil and size of the wind turbine. To date the largest turbine on a FOWT is 9.6 MW [17]. Larger powered turbines, up to 16 MW, are being ordered for new bottom fixed wind farms.

The remainder of the paper is structured as follows: Section 2 provides a brief literature review for floating wind construction and installation. Options for reviewing floating wind construction shipyards are discussed in Section 3. The analysis of shipyard requirements is considered in Section 4. Results are shown in Section 5. Discussion is in Section 6 and conclusions are given in Section 7.

2. LITERATURE REVIEW

The shipyard for substructure construction can be a long distance from the offshore location. But the fit out yard needs to be as close to the offshore site as possible, to minimise tow out times which are weather restricted. Shipyards are regarded as the pinch points in the deployment of FOWT [1].

The availability of fit out shipyards, and respective water depth alongside the quay, is a major factor in determining the type of floating wind turbine that is to be used. This is important as the design focus for floating wind platforms is often dependent on the offshore wind farm site conditions. Yet, shipyards are a critical engineering constraint to be able to realise the construction and installation of floating turbines.

Upscaling shipyard infrastructure and investments need to be aligned with the long-term use of FOWT [2]. There are several floating wind designs competing for commercial deployment, which will need different infrastructure requirements. The assembly of floating wind systems, as opposed to bottom-fixed turbines, is mostly based onshore. Therefore, shipyards will need expansion of their land area, quay reinforcement, storage for components, cranes and other retrofits to host mass production of floaters and other turbine components.

The floating wind industry could partly use the infrastructure of the existing shipyards, currently used for bottom-fixed offshore wind and offshore oil and gas platforms. Shipyards, existing or future, need to maximise the whole supply chain efficiency of existing bottom-fixed offshore wind platforms. Space is and will become a bigger issue for shipyards. To overcome this, shipyards will require new strategies and regional collaboration.

For example Port Talbot in South Wales [3] is being promoted as a potential shipyard for construction of substructures and fit out of topsides because it has over 15 m of water at low tide in a sheltered location. Shipyard requirements are discussed in [7] for constructing FOWTs in California.

Additional shipyard facilities are needed to support wind turbine manufacturing, substructure fabrication, fit out, and support for offshore installation, operation and maintenance of wind farms. Demonstration scale projects (approximately less than five devices) have different shipyard infrastructure requirements than full commercial scale projects (30+ units), as the supply chain logistics and costs of scale will be significantly different [8].

3. FLOATING WIND STATUS

3.1 GENERAL

The main parts of a FOWT are shown in Fig. 1. The topsides are the blades, nacelle and tower, which are provided by the turbine manufacturer. The substructure is in part limited by the shipyard used for construction and fit out. The moorings include the mooring lines and the anchor type e.g. drag anchors, suction piles, driven piles or drilled piles.

There are dynamic cables from the substructure to the seabed. The export cable is buried in the seabed. The export cable may go to land-based grid, typically via a substation or to supply electricity to offshore oil and gas platforms.

Different types of FOWT are given in Table I. The minimum water depth for alongside quay construction work is at lowest astronomical tide (LAT), with 1 m under keel clearance plus the level trim draft of the FOWT. Shipyards with a water depth of up to 15 m can accommodate semi-submersible, Barge and Tension Leg Platform (TLP) type platforms, whilst Spar platforms require up to 80 m water depths.

Concrete structures, for the same plan dimensions, have a higher weight that steel substructures and so the concrete structures have a deeper draft. Spars both steel and concrete have very deep drafts and gain their intact stability from adding solid ballast to their base. Barges gain their stability from their width and they have the minimum draft, however they have the largest motions in operation. Semi submersibles gain their stability from the second moment of water plane area and have lower motions than barges, multi turbine FOWT are based on very large semi-submersible hulls.

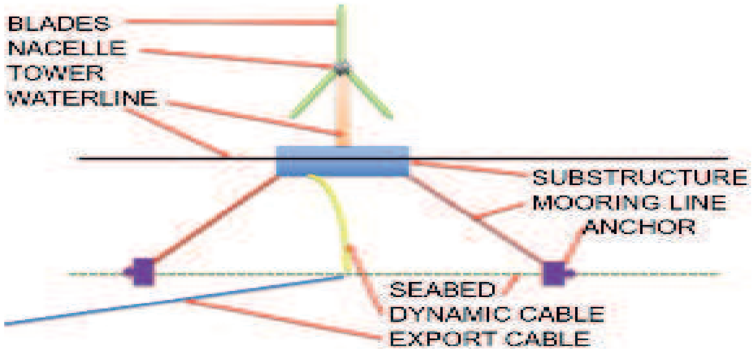

Figure 1 Main parts of FOWT [7]

Table 1 FOWT types fit out quay requirements

FOWT type	Fit out quay Draft range	Substructure construction material
Barge	6 m to 8 m	Steel
Barge	10 m to 12 m	Concrete
Semi-submersible	10 m to 12 m	Steel
Semi-submersible	12 m to 15 m	Concrete
Spar	70 m	Steel
Spar	80 m	Concrete
TLP	10 m to 12 m	Steel
Multi turbine	10 m to 12 m	Steel

The design guidelines for floating wind are provided by classification societies, such as DnV [7].

3.2. BARGES

A barge is a hull made of either steel or concrete, see Figure 2. It is stabilised in place through its buoyancy (water plane area). The assembly of the structure is performed onshore and towed offshore using tugs. Barge structures have a low draft, making them suitable also for shallow water shipyards, though they have higher motions in waves than other types of FOWT. Some barges are anchored to the seabed using catenary mooring lines whilst one type uses weather vanning technology. Currently structures weigh around 2,000 tonnes (steel) and 4,000 tonnes (concrete).

Figure 2 Steel barge [15]

3.3 SEMI-SUBMERSIBLES

A semi-submersible substructure is a hull with columns which are connected to each other with bracings. The platform uses the buoyancy force to provide stability when floating. The structure is anchored to the seabed using catenary or taut mooring lines. This substructure is assembled onshore and, despite its heavy weight, it has a relatively low draft of approximately 10 m prior to installation of the tower, nacelle and blades. The weight of the structure for a single turbine is between 2,500 tonnes to 5,000 tonnes. The most common steel design uses three columns. Some early designs had the turbine at the centre which has the advantage of minimising active ballast systems but has the down side of requiring much larger onshore crane outreach to fit the nacelle and blades. Most current designs have the turbine either in one corner or one side to maximise use, taking account of onshore crane lifting radius.

Other semi-submersible substructure concepts have multi turbines in a single platform. These structures are moored using a weather vanning system.

Fig. 3 Semi submersible Load-out from land [12]

Figure 3 shows a load out from land onto a heavy transport vessel. The construction of a semisubmersible in a dry-dock is shown in Figure 4.

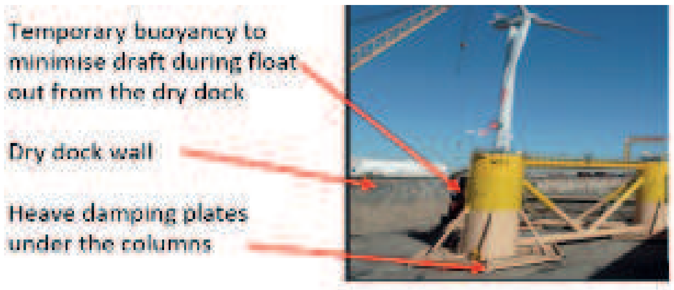

Fig. 4 Semi-submersible in dry-dock [12]

3.4 SPARS

A spar-buoy (or spar) is a cylinder structure. It is stabilised by keeping the centre of gravity below the centre of buoyancy, using a ballast made of one or more heavy materials, topped up with seawter. This is the structure with the largest draft, between 70-90 m once installed, minimising the motions and stabilising the structure. However, this can translate into more complex logistics in the assembly, transportation and installation of the foundation. The structure is anchored to the seabed using catenary or taut mooring lines.

The assembly of the steel substructure is performed onshore by building the spar hull horizontally. The steel weight of one structure is around 2,500 tonnes to 5,000 tonnes before ballasting. The steel substructure is loaded out onto a Heavy Transport Vessel (HTV), taken to deep water in a sheltered location, see Figure 5.

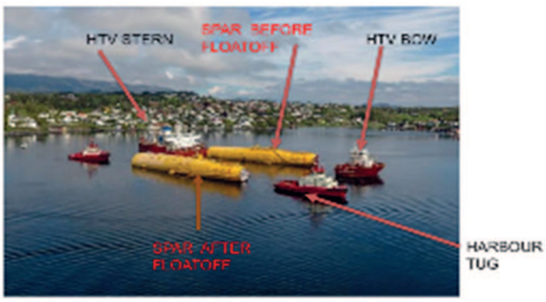

Figure 5 Spar float off before upending [14]

The spar hull is then upended using water ballast. Then solid ballast is added to the base. The turbine is assembled on land and fitted onto the spar hull, in sheltered water using a Semi-Submersible Crane Vessel (SSCV), Figure 6.

Figure 6 Spar topsides lift off quay

The concrete spar starts off by being slip formed vertically in a dry dock. The completion of the substructure continues in deep water using slip forming. Solid ballast and water is added to the base for intact stability. Both steel and concrete types of spar require temporary moorings to be set up in sheltered water and also work barges to be alongside.

3.5 TLPS

A TLP has a high buoyancy force which requires the anchoring mooring lines to be fully tensioned to provide in place stability. However, during the fit out and tow out the TLP has low or negative intact stability and thus unique methods of installation are required.

Options for TLP installation include:

- add temporary buoyancy to the hull
- construct offshore using a crane vessel with active heave compensation
- use a variable draft i.e. large water plane area for float out and a draft with low water plane area during operation

Each of these options will require different shipyard facilities. The advantage of the TLP floater is that it has a lower footprint on the seabed below the structure compared to a catenary moored FOWTs and has lower in place motions. There are three TLPs are under construction, in the South of France, [17]. TLP vertical tension mooring technology leads to complex installation. The weight of this platform can be lower than the semi-submersible types.

3.6 OFFSHORE TURBINES

Turbine blade lengths and nacelle diameters are typical manufacturer's information. Table 2 gives offshore turbine dimensions and weights of the nacelle.

Table 2 Turbine Dimensions and Weights

Power	Blade Length	Hub Height	Total Height	Nacelle Weight
MW	m	m	m	t
8	84	116	202	443
10	94	126	222	579
12	103	135	241	675
14	111	145	260	868
16	118	154	278	1019

The hub height at which the nacelle has to be installed is a limiting factor for available onshore cranes and for existing floating crane vessels. It is assumed that there is an air gap of 30 m between a blade at its lowest point of rotation and the still water surface at low tide.

4. METHODS OF REVIEWING SHIPYARDS

This section gives an overview to the construction and installation phases that need to be accommodated by the shipyard. It is separated into categories as follows:

4.1 SUBSTRUCTURE

The substructure can be built as follows:

- In a dry-dock: This is applicable to barge types, medium sized semi submersibles and the lower part of concrete Spars. Temporary buoyancy may be required to minimise draft and keep trim and heel to zero. There are constraints on dry-dock width and water depth over the sill, and also on availability.
- Or on land: This is possible for barges, semi submersibles, steel Spars and TLPs. A typical yard is a shipbuilding facility or offshore construction site. Load-out is by self-propelled modular transporters (SPMT) onto a submersible barge or HTV. In this case the minimum ground bearing capacity is 10 tonnes/m^2.

FOWT substructure fabrication will generally require buying pre-rolled and weld prepared steel tubulars which require assembly into larger units [12], which in turn needs;

- large storage space
- complex high strength steel welding
- FOWT substructure fabrication is labour-intensive, with many hours of manual welding required.
- cranes for up-righting and gradual assembly.
- large spaces for FOWT manufacture

FOWTs are complicated to fabricate as a serial process because of the large space required for each substructure. Manufacturing facilities may be co-located or spread over a number of highly specialised locations, with additional steps required for ocean transit of goods (i.e., via SPMTs around site and submersibles barges between sites).

There are further practical constraints, such as gaps between orders, meaning that shipyards are not able to retain all the skilled labour hired for a project. Each new job must therefore carry some cost of hiring and allow time for a certain amount of learning on the first units produced, causing process inefficiencies something which is minimised where the same teams are working continuously from one project to the next.

Installation vessels are continuing to increase in size, which is further increasing the available water depth limits for quayside load-outs. Some sites have short windows during high tide to complete load-outs, increasing the load out time and cost.

4.2 BLADE MANUFACTURE

Because of the length of the turbine blades, (see Table II) they need to be manufactured close to a load out quay as they are too long to be transported on public roads. They may be loaded by crane, either individually as shown in Figure 7, or in bundles of three onto a transport vessel.

Figure. 7 Blade load out [16]

Shipyards will continue to increase the use of roll-on/roll-off (RO-RO) vessels particularly for transporting large components (i.e. nacelle, blades). This reduces time and logistical costs compared with traditional methods for component delivery [4].

4.3 LOADOUT QUAY FOR MOORING EQUIPMENT

The mooring system needs to be installed prior to the offshore arrival of the completed FOWT. The mooring lines and anchors will be delivered from their respective construction shipyards to a mobilisation shipyard close to the offshore location. Chain is used for the complete mooring system in shallow water. In deeper water chain is required where the mooring line is on or close to the seabed. Part of the mooring lines may be synthetic fibres or steel wire ropes and would be stored on reels. Specialised installation equipment will need to be stored on land and to be loaded onto installation vessels e.g. work class ROVs, hammers for driven piles, drilling equipment for drilled piles or subsea pumps for suction piles, Figure 8.

Figure 8 Suction pile anchors [14]

The moorings have involve the following marine activities:

- Anchor load out by crane onto cargo ship
- Offload anchor by crane from cargo ship onto mooring storage quay
- Mooring line load out by crane onto cargo ship
- Offload mooring line by crane from cargo ship onto mooring storage quay
- Load onto mooring installation vessel

Mooring and anchor systems can be stored in a separate shipyard and do not need particularly high lifting capability. There is potential to use drums to store synthetic rope, which would require less space.

4.4 LOAD-OUT QUAY FOR SUBSEA CABLES

Subsea cables need to be stored onshore prior to deployment offshore. The cables are usually installed prior to the installation of the FOWT. There are export cables which are buried in the seabed and dynamic array cables which connect the export cables to the FOWT.

The export cables may be built and loaded out a long way from the final location as they require specialising manufacturing facilities. The multiple dynamic array cables can also be built a long way from the offshore location, so a marshalling shipyard may be required for the cables.

A secondary shipyard may be required for concrete protection mat construction and storage. These concrete mats are used to protect the export cable from damage, from dropped objects, trawl boards and ships anchors.

4.5 LOADOUT QUAY FOR NACELLE AND TOWERS

For smaller wind turbines the tower and nacelle may be built away from a loadout quay. However, with the expectation that the turbine minimum size of commercial FOWT is 8 MW, with the likelihood that the wind turbines will be at least 10 MW capacity on FOWT the nacelle and tower will be too big to be transported on public roads.

4.6 FIT OUT QUAY

A fit out shipyard will need access to a large laydown area to store nacelles, blades, towers.

For turbine assembly, a shipyard will need to have cranes capable of lifting the nacelle, the heaviest and highest lifting operation and thus one of the limiting factors. Mobile cranes with sufficient lifting and reach capability are limited in global availability. There are high costs to mobilise as it is transported in sections and needs to be assembled for use. Figs. 9 and 10 show a 9.6 MW being lifted by a large onshore crane. As an alternative, a very large inshore sheer crane might be used for inshore assembly but they are limited in availability, too.

After turbine assembly in shipyard, there is paint touch-up, bolt tensioning checks, electrical circuits and safety system checks to be carried out by technicians. The fit out shipyard requires a large storage area and needs to have a minimum overall strength of 15 t/m^2 as a uniform distributed load (UDL).

Figure 9 shows the lifting of a 675 t nacelle for a 12 MW turbine, [5] wind turbine and blades onto a FOWT [13].

Figure 9 Nacelle lifting [5]

Areas assigned for heavy lifting crane operations must accommodate a minimum surcharge load of 30-40 t/m^2 (UDL) which increases to a maximum surcharge of 50-80 t/m^2 by operation of the main crawler crane on a single track to the load spreading surface, figure 10.

Figure 10 Blade lifting [13]

4.7 WET STORAGE

Substructures need to be wet stored prior to fitting the turbine topsides. This requires the laying of temporary moorings. Similarly, after fitting the turbines more wet storage may be required prior to tow offshore, whilst waiting on weather or available installation vessels. In this case, the temporary moorings have to be stronger than prior to fitting the turbine because of the high wind loads on the topsides.

4.8 NAVIGATION OUT OF FIT OUT YARD

Navigation and fit out shipyard requirements are summarised in Table 3. Regarding the air draft limit there should be no overhead power cables or bridges between the fit out shipyard and the open sea.

Weather forecasts are suitably accurate for up to 3 days in advance. The fit out yard is to be a maximum of 2.5 days sailing time from the offshore location. This allows 0.5 day to get at least 2 mooring lines connected to the FOWT. If the fit out shipyard is too far from the offshore location then a staging shipyard may need to be designated.

Table 3 Fit out shipyard minimum requirements, [6]

Primary Criteria	Semi-Submersible	Barge	Spar
Material	steel	steel	steel
Air draft	No limit	No limit	No limit
FOWT width	90 m	30 m	20 m
Channel width, with tugs	140 m	110 m	90 m
Quay length	120 m	60 m	80 m *
Water depth, at low tide	12-14 m	10-12m	90m
Substructure Shipyard	6 hectare	4 hectare	5 hectare
Area fit out	6 hectare	6 hectare	6 hectare
Fit out quay UDL	15 t/m^2	15 t/m^2	15 t/m^2

*The Spar quay length is for a crane vessel to come alongside the turbine construction site. In addition, the Spar needs a water depth of at least 90m at the sheltered inshore location.

5. RESULTS

Applying the review criteria for each phase a range of constraints and practical requirements regarding weather restrictions, and required shipyard areas have been established.

5.1 WEATHER RESTRICTIONS

The weather restrictions are expected to be as follows for the shipyard activities, Table 4.

Table 4 Shipyard Weather restrictions

Location	Hs [m]	Tp [sec]	Wind [m/s]	Current [m/s]	Visibility [m]
Load-out onto HTV	<1.0	<8	<10	<0.5	400
Float-out from Dry-dock	<0.5	<7	<10	<0.5	400
Float-off HTV	<0.5	<7	<10	<0.5	500
Fit out crane	<0.5	<7	<10	<0.5	300
Wet storage mooring	3.0	10	30	1	500

5.2 SHIPYARD AREAS

The approximate shipyard area requirements for the different factors are shown in Table 5. Shipyard area directly depends on:

- Type of FOWT
- Size of turbine
- Number of turbines in the wind farm
- The number of turbines to be installed in one summer season

Table 5 Shipyard laydown area estimates

Wind farm size	25 MW pre commercial	300 MW commercial
Turbine size	5 MW	10 MW
Number of units	5	30
Tower manufacture	2 hectares	25 hectares
Nacelle manufacture	3 hectares	15 hectares
Blade manufacture	4 hectares	32 hectares
Dynamic cable storage	2 hectares	12 hectares
Export cable storage 50 km length	10 hectare	12 hectares
Substructure construction	10 hectares	100 hectares

It can be expected that as larger turbines become available for bottom fixed structures they will also be deployed on FOWT.

5.3 SHIPYARDS FOR STEEL AND CONCRETE SUBSTRUCTURE

Steel substructures have the following advantages in shipyard construction [9]:

- Transferrable experience from other industries
- Assembly can be executed relatively fast if components are pre-fabricated
- Lighter substructures are possible (compared with concrete) which minimises water depth requirements at the shipyard, dry dock and the fit out shipyard

Concrete substructures have the following advantages in construction shipyards [10]:

- Concrete supply adaptable to local conditions
- There are opportunities for local content
- No specialized equipment,
- Low costs of concrete as a raw material

Steel substructures, [10], have a long history of being used offshore and steel is much easier to recycle. However, steel is subject to corrosion (as is concrete via internal reinforcements, but to a lesser extent). Floating wind substructures made of steel can be assembled faster as these are not as sensitive to environmental conditions (e.g. frost and heavy rain) and are not exposed to concrete curing time

5.4 VISUAL IMPACT DURING CONSTRUCTION

One of the benefits of floating wind is that they will be deployed in locations where they will not be visible from the shore. However there is high visual impact from floating wind turbine during manufacturing, assembly, repair (near shore or in shipyard) and decommissioning. However, it is expected to encounter low opposition as these are short-period tasks that will bring jobs to the area close to the FOWT shipyard, [11].

6. DISCUSSION

The market for floating platforms is still in its infancy. There are many platform types, and only few have been demonstrated pre-commercially. Existing shipyards and fit out quays have been used. Different manufacturing techniques will require different facilities, from large yards to covered premises, to dry docks [11]. Floating offshore structures are large and will need large storage areas and/or transfer to assembly facilities. It is likely that wet storage will be used, so shipyards able to offer sheltered moorings ahead of turbine integration will have an advantage. Storage and assembly may happen at different shipyard locations and could be done at quayside (with onshore cranes) or in sheltered locations using floating assembly bases or floating cranes.

Industrialization of floating wind technology is the key for future cost reductions. Shipyards form an important element in the commercialisation of floating wind and should actively plan for these requirements.

Shipyard facility requirement criteria will differ for each shipyard classification and substructure technology as the functions and installation vessel requirements are different. Because the industry is at an early stage, and deployment technologies and methodologies are still in development, the requirements presented are intended only as a broad review of likely shipyard facility requirements based on available data and technology.

Key outcomes from the research include the following for semi-submersible FOWT construction. Steel barge requirements are similar. Spars are similar but need deep sheltered water close to the shore. TLPs requirements are under development:

- Quayside capacity up to 20 tonnes/m^2.
- A protected harbour
- Floating wind substructures will require deep draft channels.
- For tow-out of an assembled unit there must be no air draft restriction, from bridges or power cables
- Rail and road connections will likely be required for transport of materials

The need for port capacity is increasing, however shipyard development is a long process. In addition, there is a lack of capacity in infrastructure, including cargo vessels, heavy transport vessels, wide roads and trains. The supply chain struggles keep up with the fast developments and everything getting larger, heavier and needing to done more quickly. Cost efficient floating wind turbine substructures are needed for industrial-scale projects. The life time cost of energy is minimized by the low weight of the hull and shallow draft at along the quayside enabling the use of local port infrastructure. Future FOWT need to be based on a modular approach allowing flexibility in fabrication and maximizing the use of the existing local supply chain, whilst reducing quayside and offshore operations to allow units to be installed and fully commissioned at a rapid rate.

7. CONCLUSIONS

Shipyards are important to facilitate the assembly, installation and operations of FOWT. For commercial projects with multiple turbines, shipyards need to be able to construct several FOWT at one time.

For substructure dry ocean transport there are no limits on shipyard locations. However the shipyard requires a quay strong enough for SPMTS to have a side load out onto a HTV. There must also be sufficient water depth for the HTV to stay afloat at low tide with 1m of under keel clearance.

Table 6 summarises shipyard sailing times to the offshore location and functions showing that there up to 17 shipyard/port facilities required.

Table 6 Shipyard Location

	Function of shipyard	Sailing time to
1	Support base for seabed surveys	3 days to wind farm
2	Substructure component fabrication	no limits for cargo ship
3a	Substructure assembly and load out	no limits for HTV transport
3b	Alternate assemble in a shipyard dry dock short distance to fit out quay	
4	Blade construction on load out quay	no limits for cargo ship
5	Nacelle close to load out quay	no limits for cargo ship
6	Tower on load out quay	no limits for cargo ship
7	Wet storage of substructure	1 day to fit out quay
8	Fit out of topside onto substructure	3 days at about 3 knots
9	Wet storage of completed FOWT	1 day from fit out quay
10	Anchor load out shipyard	no limits for cargo ship
11	Chain load out shipyard	no limits for cargo ship
12	Mooring assembly shipyard	5 days to wind farm
13	Export cable load out facility	no limits for cable lay ship
14	Export storage of concrete protection of export cable	5 days for cable lay ship
15	Dynamic array cable load out facility	no limits for cable lay ship
16	Support base for operations including support vessels	2 days to wind farm
17	Support base for offshore installation	2 days to wind farm

The mooring assembly area for anchor systems requires a large laydown area, with adequate mobile crane, before deployment to the offshore wind farm. Mooring lines and anchors require a large space with nearby access to water but do not need particularly high lifting capability. There is potential to use drums to store synthetic rope, which would require less space.

Future decommissioning port requirements needs to be considered but this will depend on the vessels that are available at the end of life of the floating offshore wind farm.

A shipyard looking to take on the final assembly and staging of floating wind projects will need access to a large laydown area to store nacelles, blades, towers. Large space for very big onshore cranes to be assembled and then for there use in lifting FOWT topside components.

For turbine assembly, a shipyard will need a lifting capacity of 1,000 tonnes for the nacelle, the heaviest lifting operation. Mobile cranes with sufficient lifting and reach capability are limited in global availability and to mobilise it is transported in sections and needs to be assembled for use.

Different types of substructures have different shipyard requirements. Shipyard capability is likely to influence substructure design choices. Semi submersibles and barges require large quayside areas (up to 80m x 80m). Spars require a deep-water sheltered area for turbine mating TLPs have a low water plane area and will probably have low stability during towing, so final assembly may take place offshore instead.

Training of personnel in the ports and shipyards is an issue requiring consideration.

8. ACKNOWLEDGMENTS

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