INSTALLATION ASPECTS OF FLOATING OFFSHORE WIND TURBINES

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Summary Semi Submersible at Fit out Quay   Ref [14]

Summary

Installation aspects for Floating Wind Offshore Turbines'.

This covers subsea cable installation, loadout (or floatout), transport to the fit out port, fitting turbine topsides, installing offshore moorings, tow offshore, connect moorings, connect inter array cables.

Index

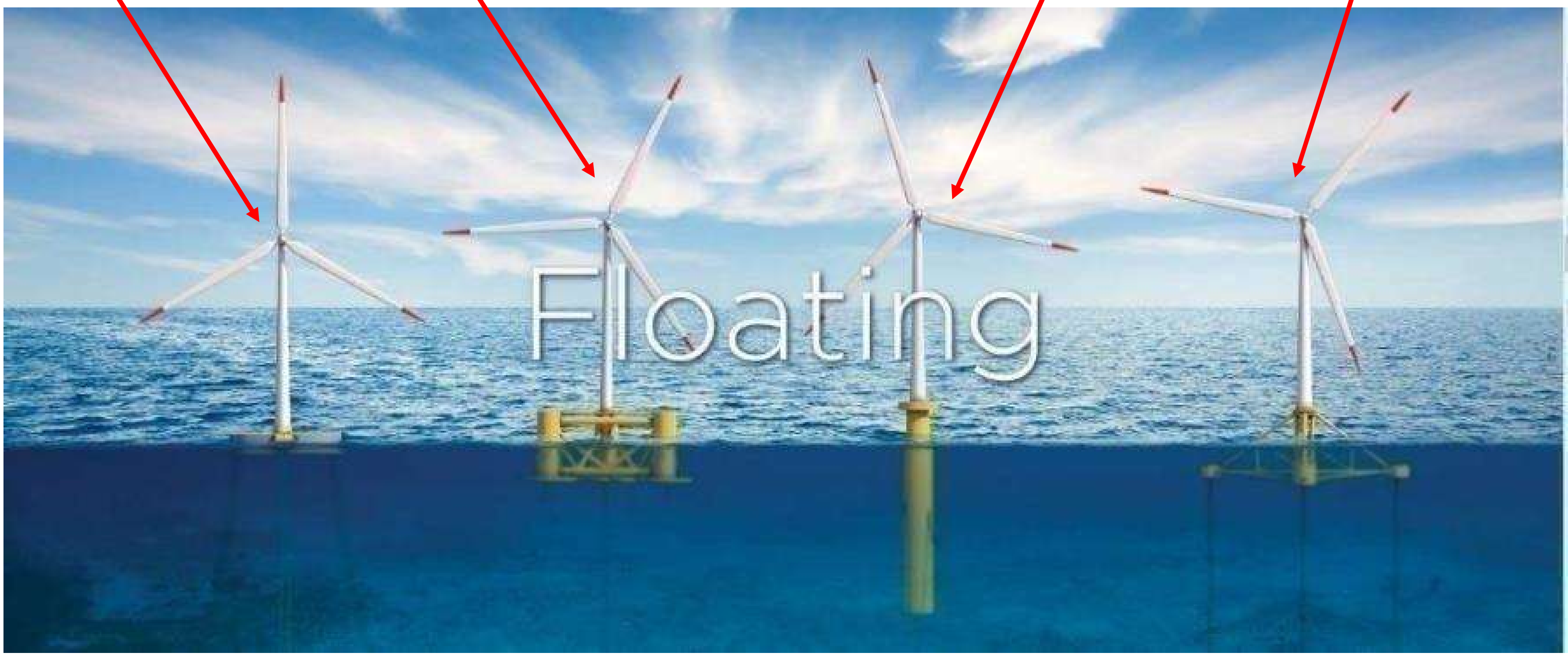
1. Status Of Floating Offshore Wind turbines (FOWT)

Several abbreviations:
FOWT = floating offshore wind turbine
FLOW = floating offshore wind
FOW = floating offshore wind
FWT = floating wind turbines
FOWP = floating offshore wind platform

Floating Substructure Types Ref [15]

Concrete or Steel Construction

BARGE SEMI-SUBMERSIBLE SPAR TLP



1a Buoyant Outlook

The ability of floating turbines to be deployed in deep waters means that new regions are now available for development.

Countries can benefit from their windy oceans, where deep water is close to shore.

Already, countries such as France, Norway, Spain, UK, Japan, China, South Korea and Taiwan have aspirations for floating wind, Ref[15].

Predicted World installed floating offshore wind turbines (GW)				
	2021	2030	2040	2050
Floating wind GW	0.12	11	105	264

Current UK floating wind is about 0.08GW

Water Depths Limits by type

	Water Depth (m)			
	Lower	Upper	Possible	Limit
Fixed Monopile	0	40	50	Monopile weight >1,800t, 11m OD
Fixed jacket	10	60	80	WTIV limit 60-80m
FOWT: Barge	50	100	125	Mooring line length
Semi Submersible	60	250	300	Mooring line length
Spar	80	350	500	Mooring line length
TLP (tension leg)	80	300	350	Tendon weight

Current status of operating FOWT

Name	Type	Sub Structure Built	Sub Structure Material	Turbine Outfitting	Final location	Status
Wind float	Principal Semi sub	Spain	Steel	Portugal	Portugal	Operating (3 * 8.4MW)
Wind float	Principal Semi-sub	Portugal	Steel	Uk	UK Kincardine	Operating (1 * 2 MW)
Wind float	Principal Semi-sub	Spain	Steel	Netherlands	UK Kincardine	Operating (5 * 9.6 MW)
Hywind	Equnor Spar	Spain	Steel	Norway	UK Hywind	Operating (5 * 6MW)
Barge	BW-Ideol Damping pool	France	Concrete	France	France	Demo (1 * 2MW)
Barge	BW-Ideol Damping pool	Japan	Steel	Japan	Japan	Demo (1 * 3MW)
Suspended ballast Spar	Stiesdal TetraSpar	Denmark	Steel	Denmark	Norway	Demo (1* 3.6MW)
Wison	Semi-sub	China	Steel	China	China	Connected (1*5MW)

Several other demonstration FOWT have been decommissioned

Current status FOWT under construction/planning

Name	Type	Sub Structure Built	Sub Structure Material	Turbine Outfitting	Final location	Status
Hywind Tampen	Equinor Spar	Norway	Concrete	Norway	Gulfaks & Snorre	Under construction (11 * 8MW)

Spain, France, Japan, South Korea are planning Floating Offshore Wind Turbines

UK Gov. funding = Scotland and Wales new floating offshore wind ports £160m, Ref [19] Plus the UK Gov. has offered grant funding to two off blades manufacturing companies to boost capacity

Crown Estates Scotland (17 Jan 2022) = Scotwind is aiming to have 15GW of Floating Wind By the 2030s, Ref [20]

The UK Gov.(24 Jan 2022) = awarded £31m for technologies and products for the floating offshore wind industry, Ref [21]

The Crown Estate has plans for 4GW floating wind leasing in the Celtic Sea, Ref [22]

Challenges

The challenges faced come from across the techno-economic-environment

With regards to construction and installation these challenges are:

- Lack of mass production
- TLPs have low intact stability during installation and may require crane vessels or temporary buoyancy during offshore installation
- SPARs require deep water for construction, towout and installation
- Semi submersibles have higher substructure weight than other options
- Barges have higher in place motions

There are other issues which apply to all types to do with:

- Dynamic inter array cables
- Large seabed areas taken up by the anchor lines (barge,semi, spar)
- Requirement for substations (over 50km from shore)

Comparison

FOWT TYPE	Advantages	Disadvantages
Barge	Water ballast only	Long mooring lines (>6*depth)
	Standard anchors	
Semi Submersible	Based on Oil technology	Long mooring lines (>6*depth)
	Standard anchors	(active ballast system on some)
	Water ballast only	Higher structural weight
Spar	Standard anchors	Long mooring lines (>6*depth)
	Based on Oil technology	Needs solid ballast
		Deep water required for inshore construction
		Requires crane vessel to install turbine
		Deep water required for tow to site
TLP	Small area on seabed	Complicated mooring tendons
	Less impact on fishing	Low intact stability during towout
		Need for temporary buoyancy
		Requires specialised offshore crane vessel

2. Installation Sequence
(Semi submersible substructure hull)

Main parts of the semi Submersible type

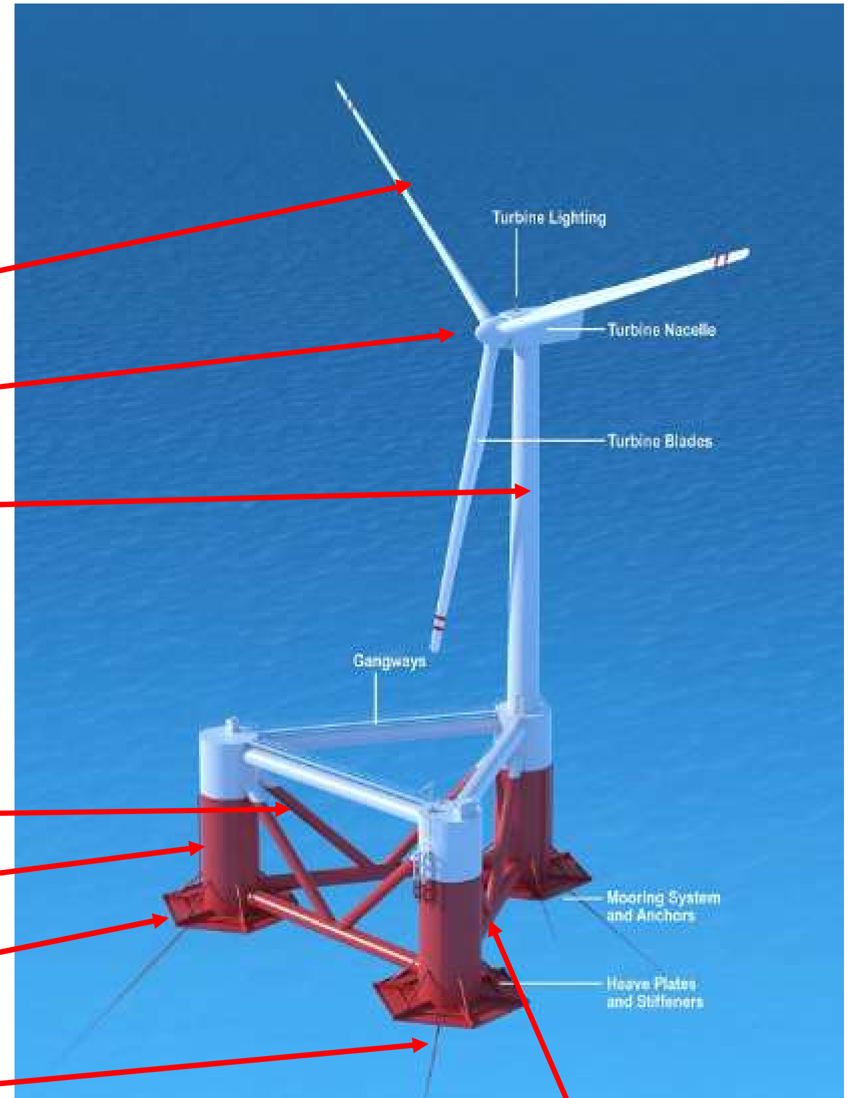
Ref [14]

TOPSIDES
- BLADES
- NACELLE/HUB
- TOPSIDES

SUB STRUCTURE
- BRACES
- COLUMN
- HEAVE PLATES

MOORING LINES

DYNAMIC ARRAY CABLE



Built on land Just before loadout

Ref[14] Ref[39] Ref[40] Ref[42]

SPMT SUBSTRUCTURE HEAVY TRANSPORT VESSEL

Just before loadout Ref[14] Ref[39] Ref[40] Ref[42]

SPMT SUBSTRUCTURE HEAVY TRANSPORT VESSEL

SPMT Loadout

Ref[14] Ref[39]
Ref[35] Ref[40]
Ref[42]

Once the quay was prepared and the specialist seagoing Heavy Transport Vessel docked, there was only a short window in which it could execute each operation. Mobilizing 100 axle lines of SPMTs, Ref[35], split between the three columns of the triangular footprint, the floating substructure was loaded onto the three sets of SPMTs. With theconnection of the sea-fastening, the load-out was complete.

Stern view on loadout

HTV is 45m wide

Ref [14] Ref[39] Ref[40] Ref[42]

Turbine Column 2 mooring lines

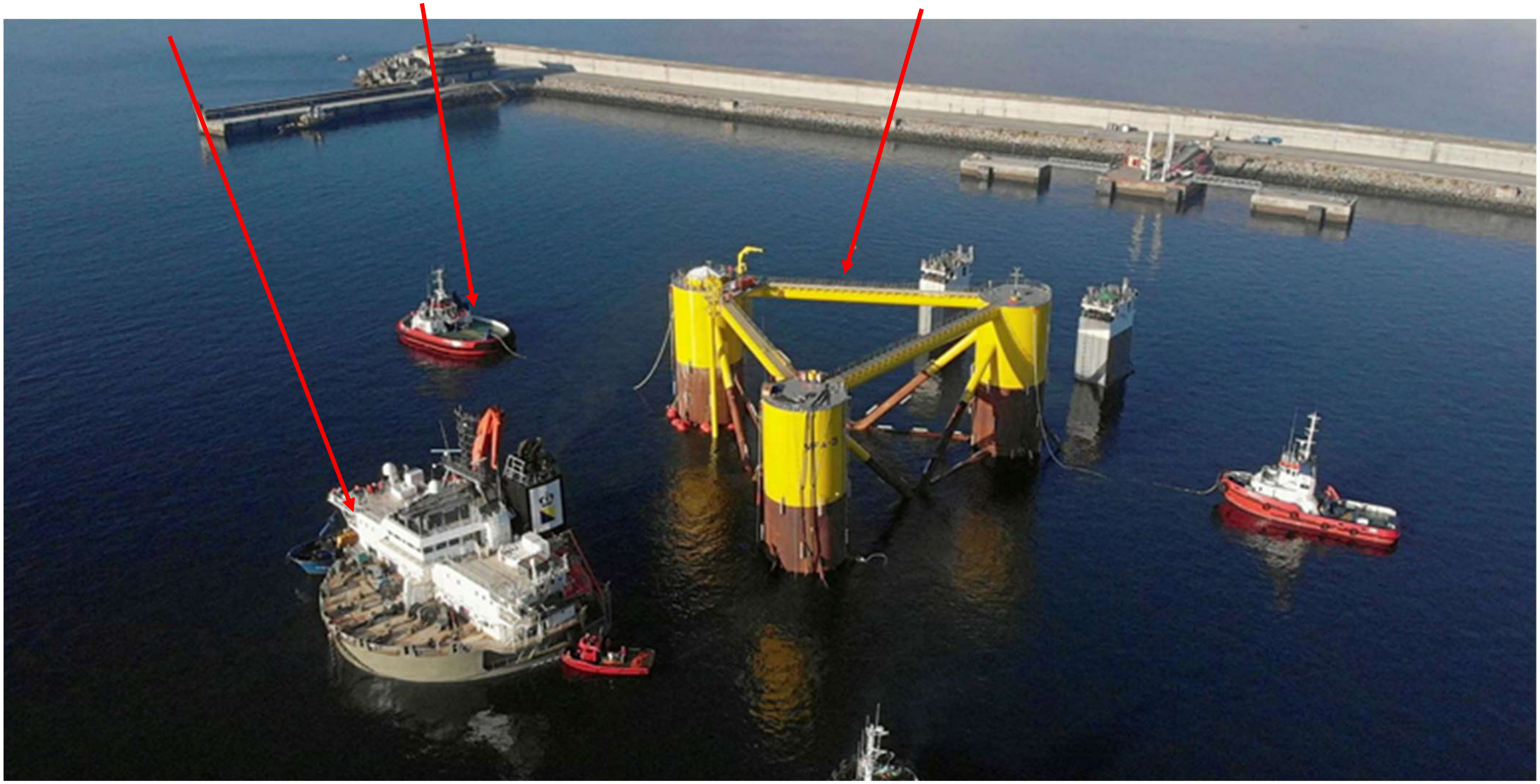
Ocean transport on HTV

Ref[14] Ref[39] Ref[42]

Arrival at fit out port on HTV Ref[14] Ref[39] (FOR KINCARDINE)

Harbour tug   Main towing tug   Substructure   HTV

Float off, at fit out port, from HTV Ref[14] (For Portugal)



Alternate build in dry dock(for Portugal)

Ref[14]

Dry Dock

Substructure columns

Fit out quay (for Portugal)

Ref[14]

Lifting tower Sections by onshore crane at the Fit out quay

Ref[14]

Large onshore crane

Upper tower

Lower tower

Substructure

Lifting nacelle by onshore crane at the Fit out quay

Ref[14]

Large onshore crane

Nacelle

Substructure

Lifting blades by Onshore crane at the Fit out quay

Ref[14]

Wet Storage

Ref[14]

Temporary mooring piles

Harbour tug

Substructure

61m by 61m by 30m

Towout one at a time Ref[14] Ref[39] Ref[42] **Main Tug And Escort Tug**

Mooring connection

Ref[14] Ref[39]

Cable layer for dynamic cable installation Scotland Ref[14]

Cable layer for dynamic Cable installation

Portugal

Ref[14]

Cable installation vessel
For dynamic array cables

Wind farm complete (this one off Portugal) Ref[14]

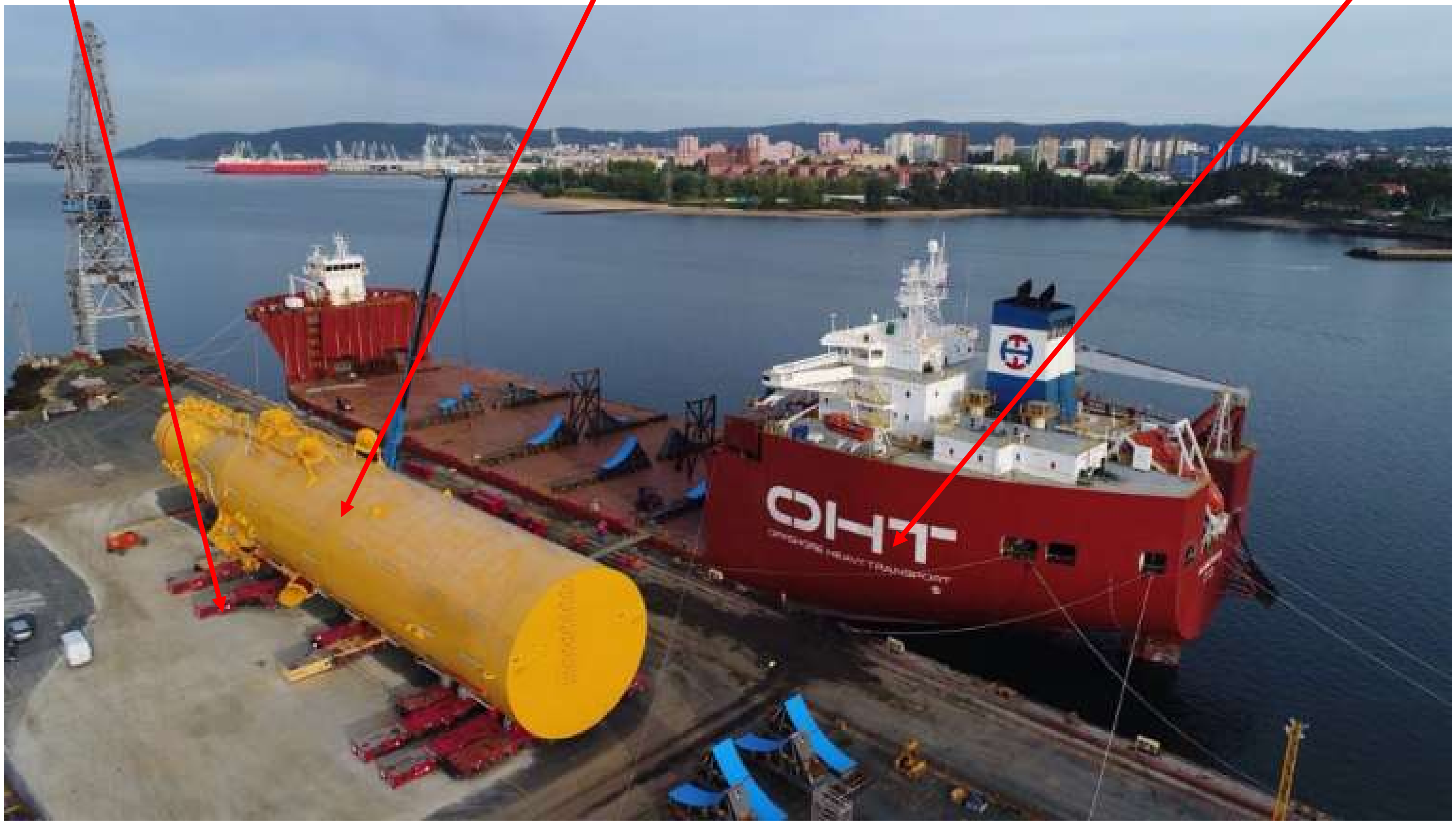
Steel Spar

Steel Spar Loadout Ref[1] Ref[40] Ref[41]

SPMT

Substructure

Heavy Transport Vessel



Transport on HTV, steel spar Ref[1], Ref[37]

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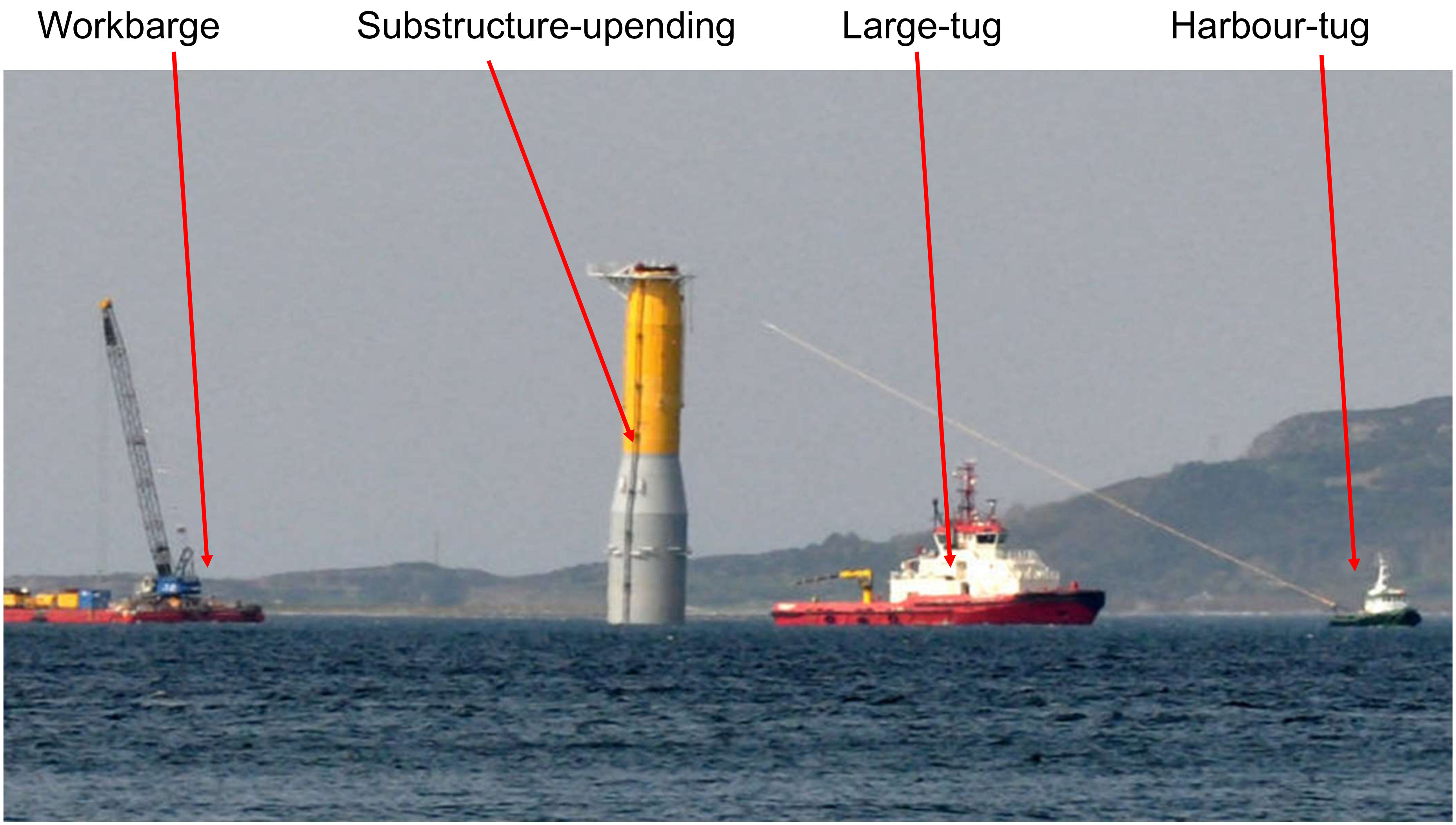
Steel Spar Float Off   Ref[1]

Harbour-tug   Floatoff-substructure   Heavy transport vessel

Upending steel spar, with seawater Ref[1]



Solid Ballasting, steel Spar

Ref[1], Ref[37]

Topsides for steel spar Ref[1]

Onshore-crane

Topsides for steel spar Ref[1]

Saipem S7000, Ref[38], installing topsides

Outfit Barge, steel Spar Ref[1]

Outfitted-Spar, Ref[37], Work-barge, Outfitted-Spar Passenger-vessel

Outfit Barge, steel Spar

Ref[1]

Outfitted Spar

Temporary moorings

Passenger vessel

Outfit barge

Steel Spar Tow Out Ref[1]

Towout-completed=spar   Large AHTS

Kvaernar Ref[36] concrete Spar for Equinor Ref[1]

Kværner Hywind Tampen - YouTube

Next step for Hywind Tampen - equinor.com

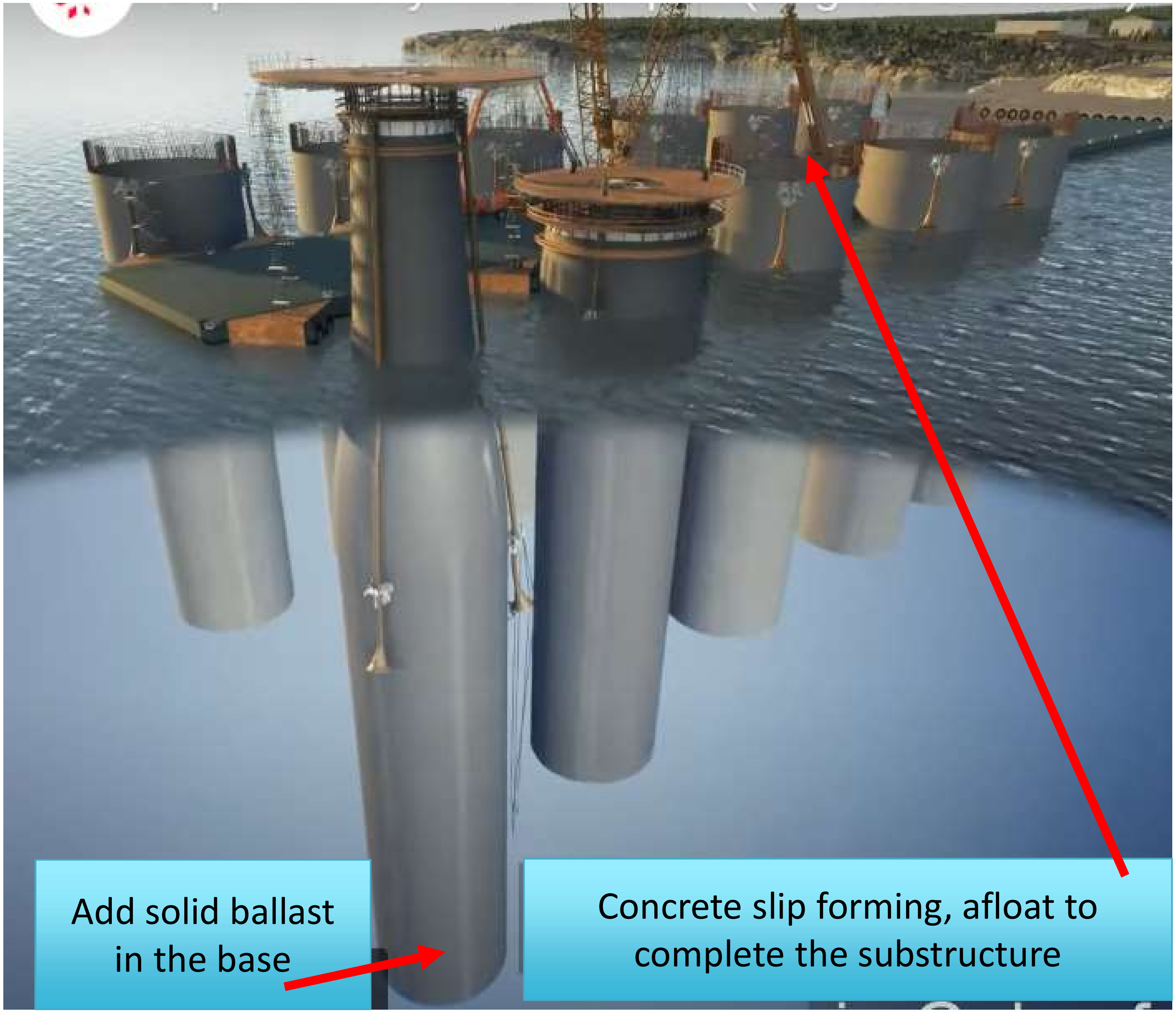
Equinor Tampen **Ref[1]**

Start substructure in a drydock

Equinor Tampen Ref[1]

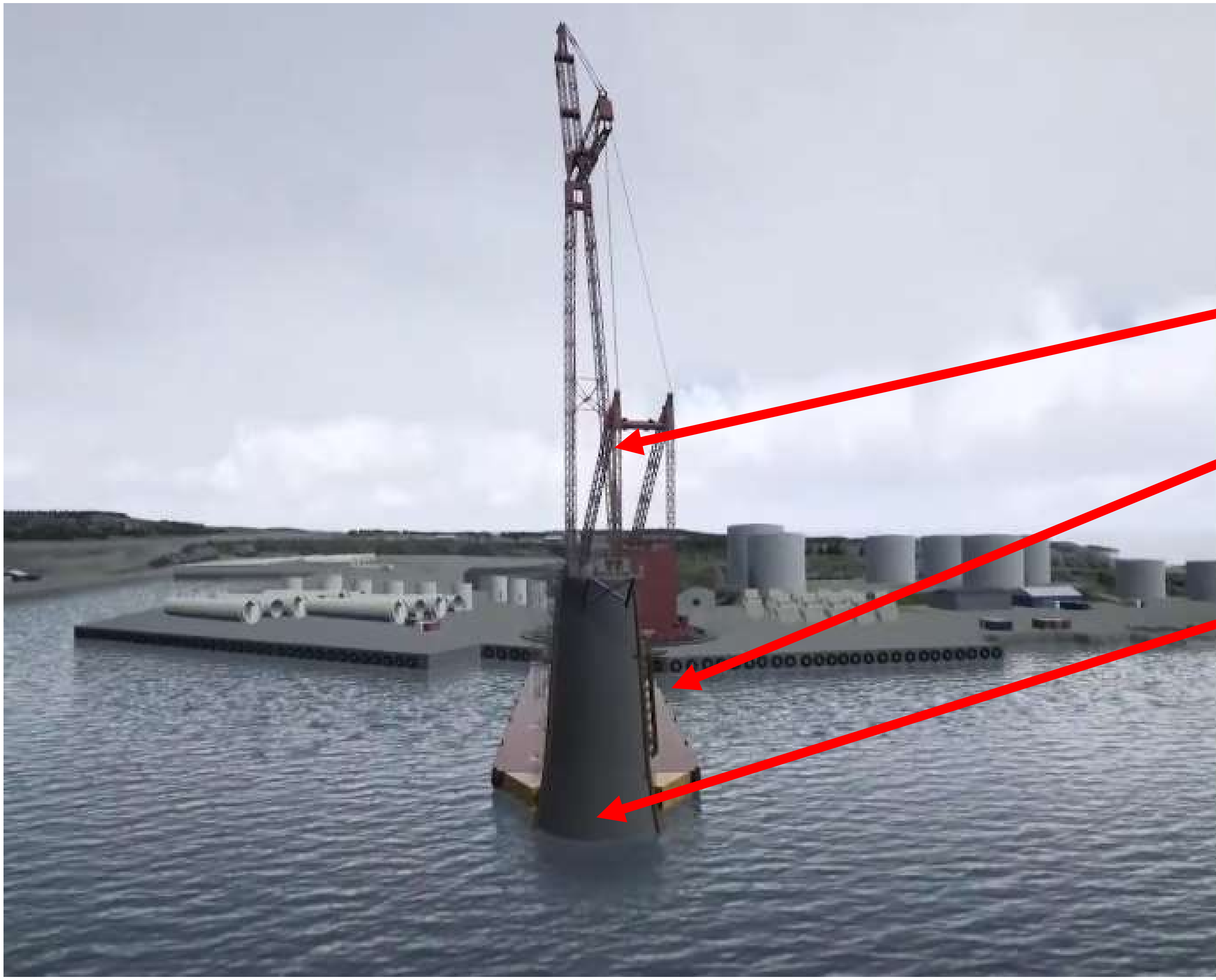
Substructure in a drydock Harbour-tug

Equinor Tampen (Tow lower substructure) Ref[1]



Equinor Tampen

Ref[1]



Equinor Tampen

Ref[1]

Large onshore crane

Spacer barge

Concrete substructure

Equinor Tampen, Towout Ref[1]

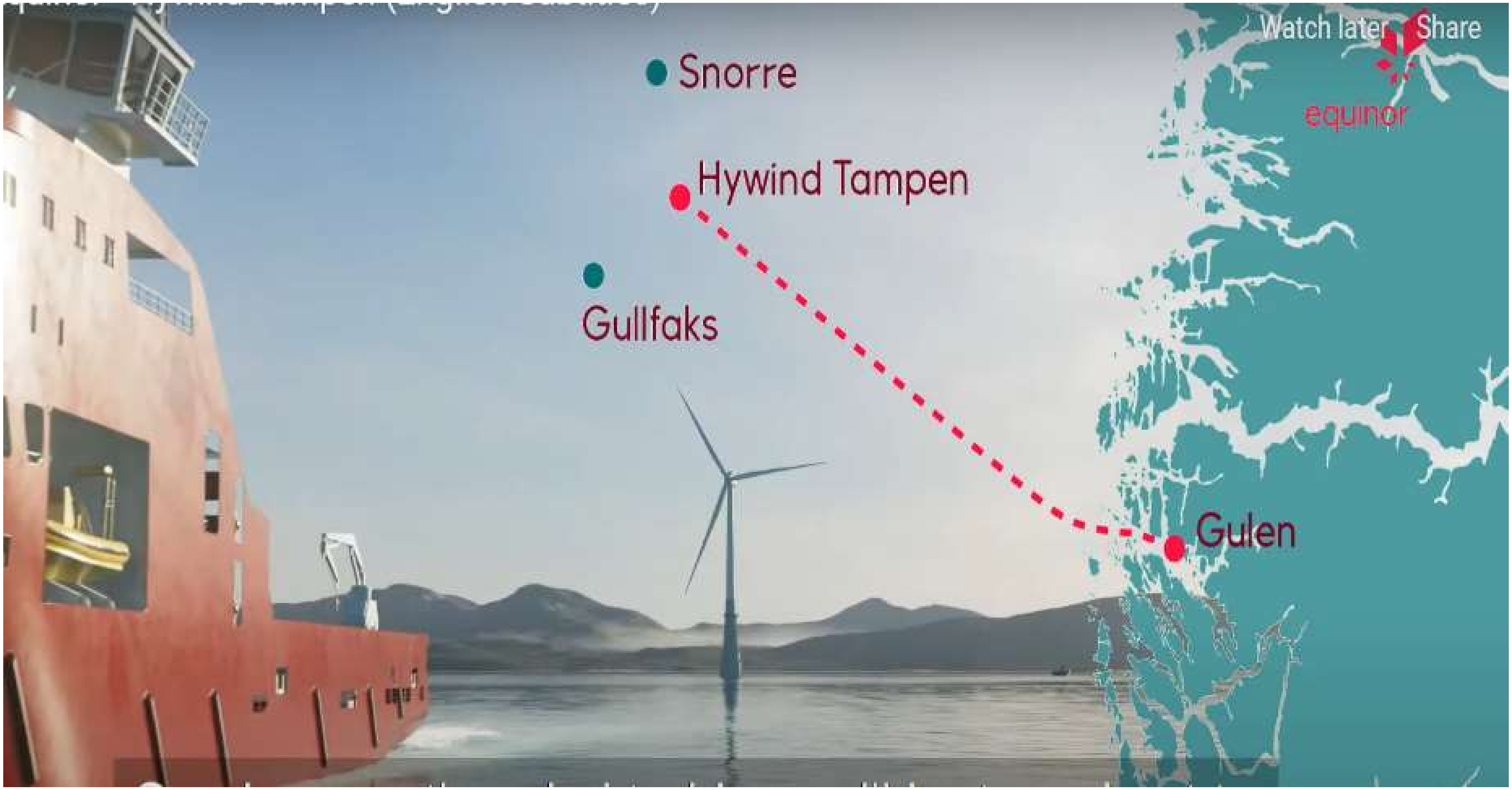


Photo credit: The TetraSpar Demonstrator Project ApS

[The TetraSpar full-scale demonstration project | Stiesdal]

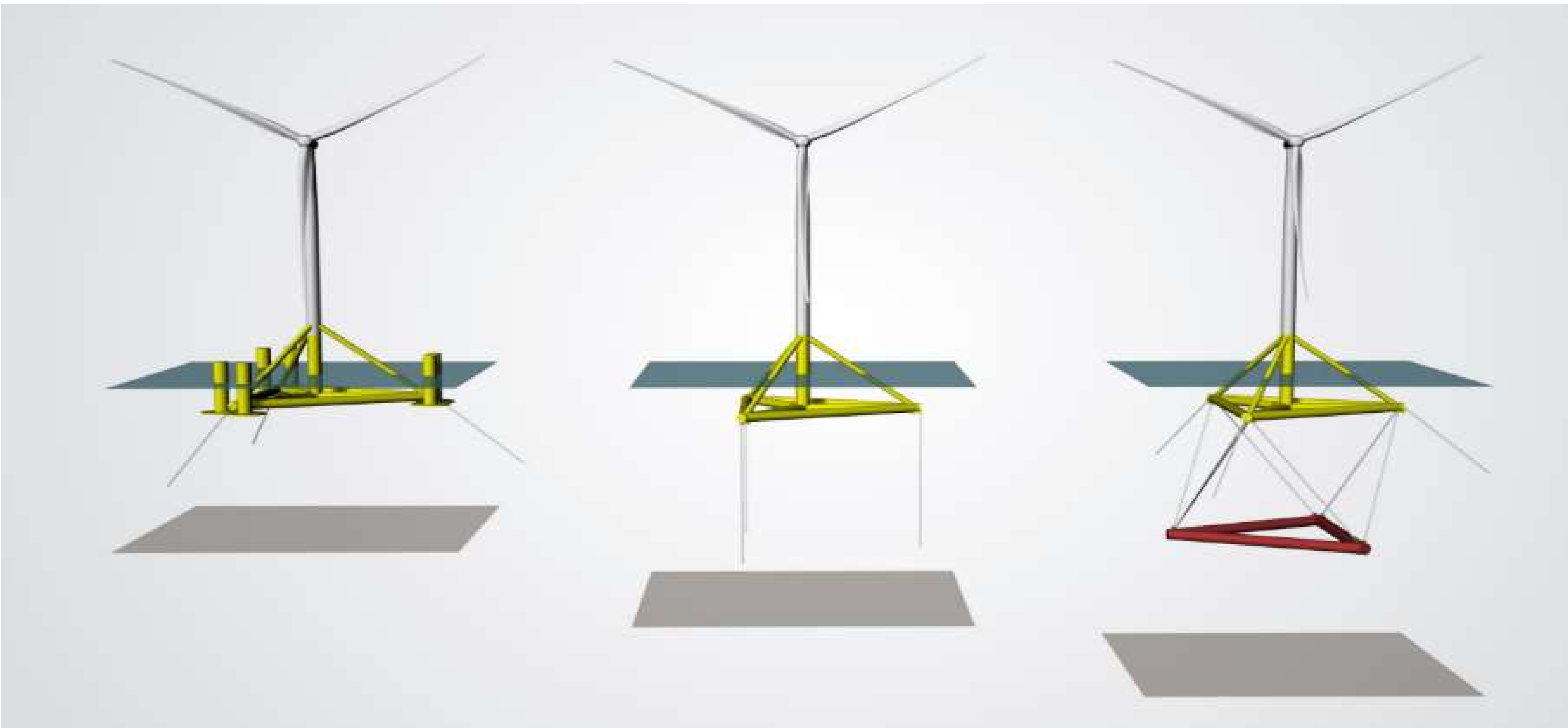
A 3.6 MW wind turbine from Siemens Gamesa Renewable Energy was mounted on the substructure following launch in the harbour basin.

Stiesdal Options Ref[9]

TetraSub: semisubmersible Suited for 60-1000+ m water depth

TetraTLP: Tension Leg Platform. Suited for 100-500+ m water depth

TetraSpar: Spar. Suited for 120-1000+ m water depth.



The assembly involved no welding Ref[9]

Mounting of the diagonals Ref[9]

Loading the substructure onto the submersible barge

Ref [9]

The barge during submerging Ref [9]

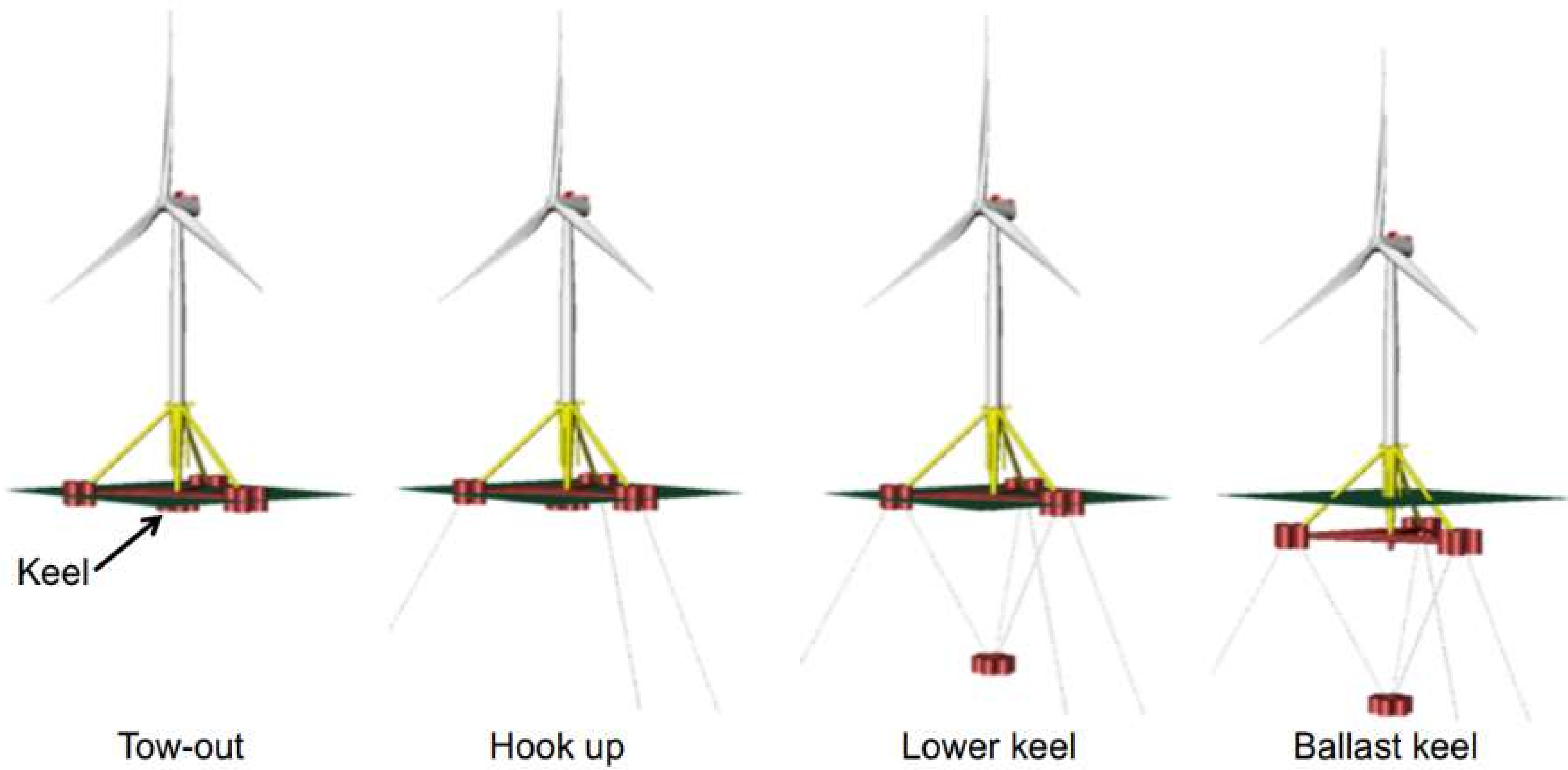
The barge and keel during submerging Ref[9]

Fitting topsides

Ref[9]

Tow out, keel is in place under the substructure Ref[9]

Stiesdal Tetra Spar Installation Sequence Ref[9]



Towing with keel fully deployed

Ref[9]

The subsea cable connection to the Norwegian grid was carried out by Bourbon Subsea Services Ref[9]

BARGES

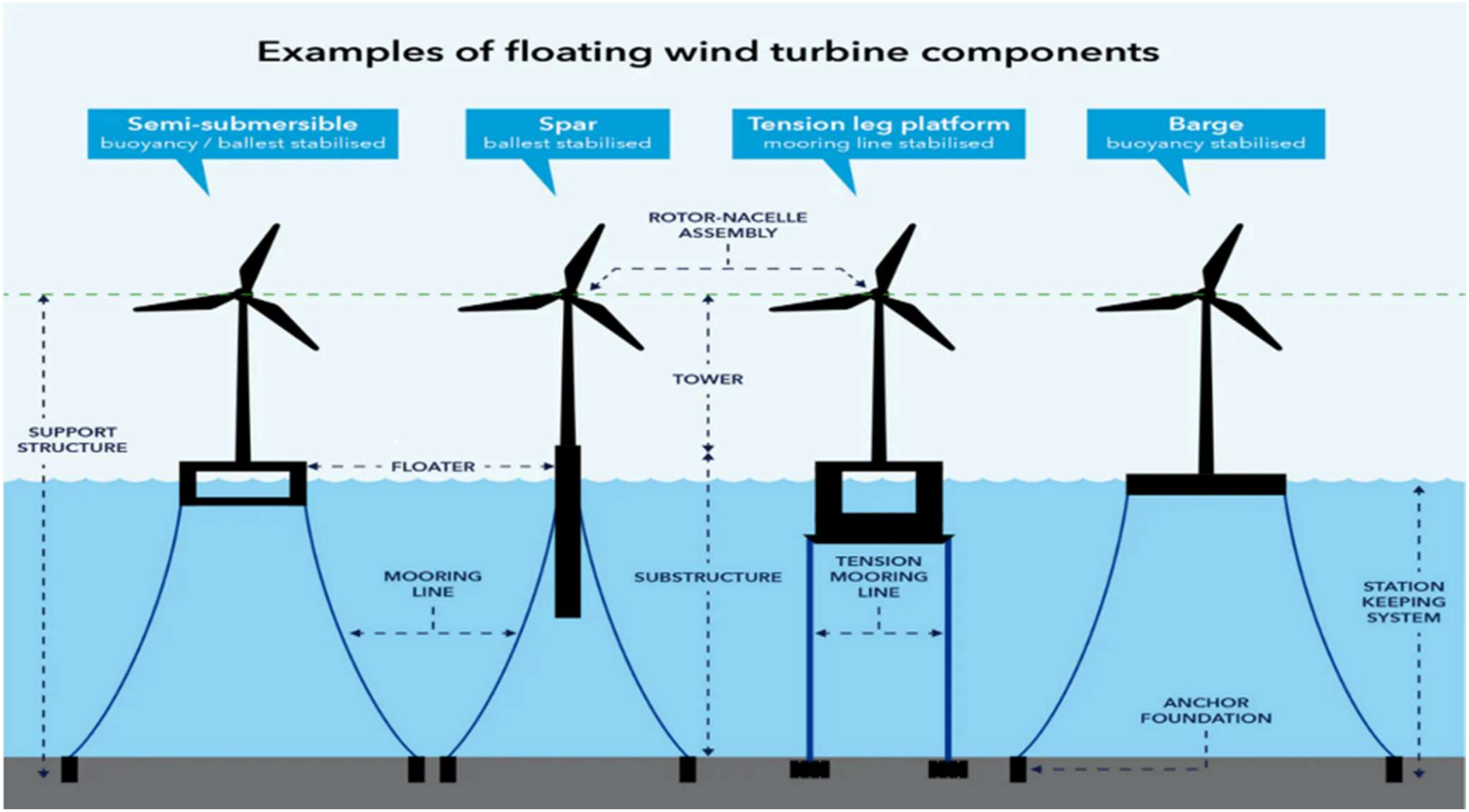
STEEL DAMPING BARGE (2 blades) Ref[26]

Completed-structure   Sheer leg crane vessel used to install topsides

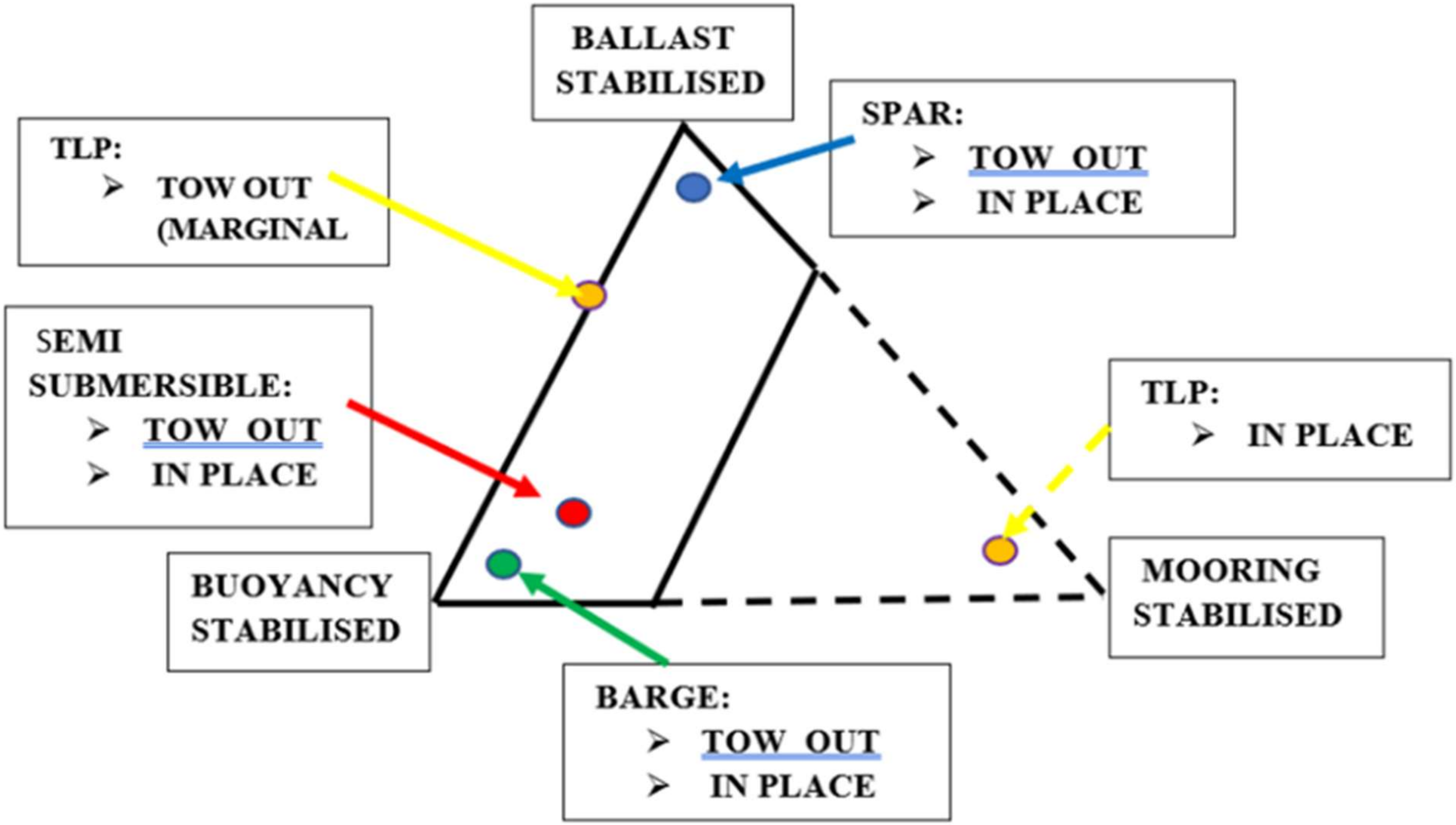
CONCRETE DAMPING BARGE 3 blades Ref[26]

OBSERVATIONS SO FAR

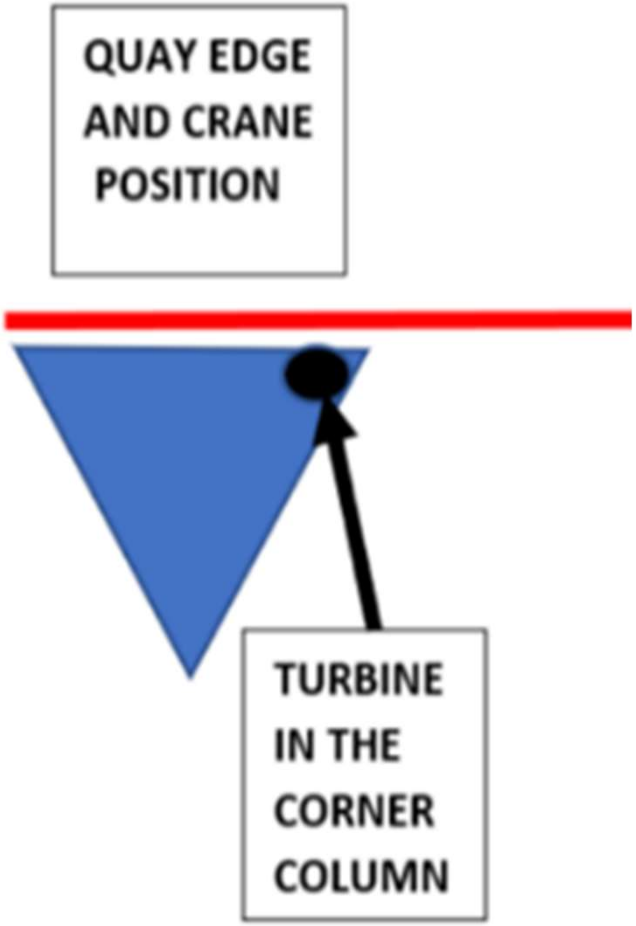
In place stability Ref[15] <u>NOT INSTALLATION</u>



Intact stability in wet tow



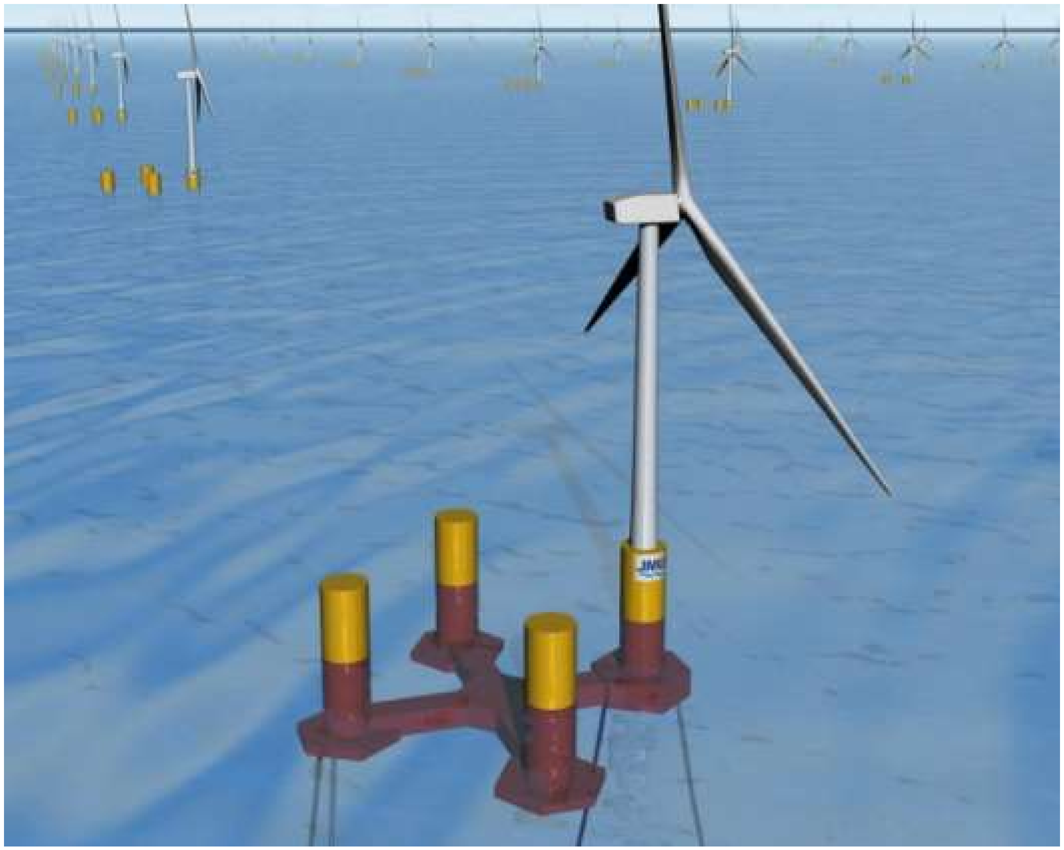
Land Based Out fit Cranes For Semi Submersibles



Equinor Semi Submersible Ref[1],
no active ballast

Wison Semi Submersible (Typhoon design), Ref[5]

Japanese future floating wind substructure



"K" Line Wind Service, Japan Marine United Corporation, Nihon Shipyard, and Toa Corporation have established a consortium it aims to develop a mass production method and cost reduction of floating wind foundations, mooring/anchoring systems, installation at sea in every aspect of Engineering, Procurement, Construction and Installation (EPCI).

Turbine on the side, NOV-Gusto Ref[7]

TLP

Possible Installation Methods

TLP TEMPORARY BUOYANCY Ref [9]

Stiesdal TLP

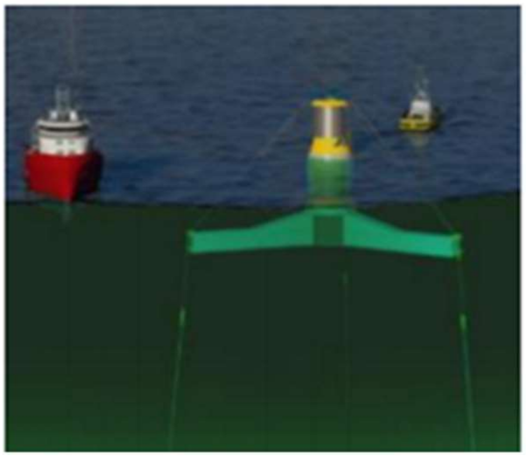
Tow out with temporary buoyancy

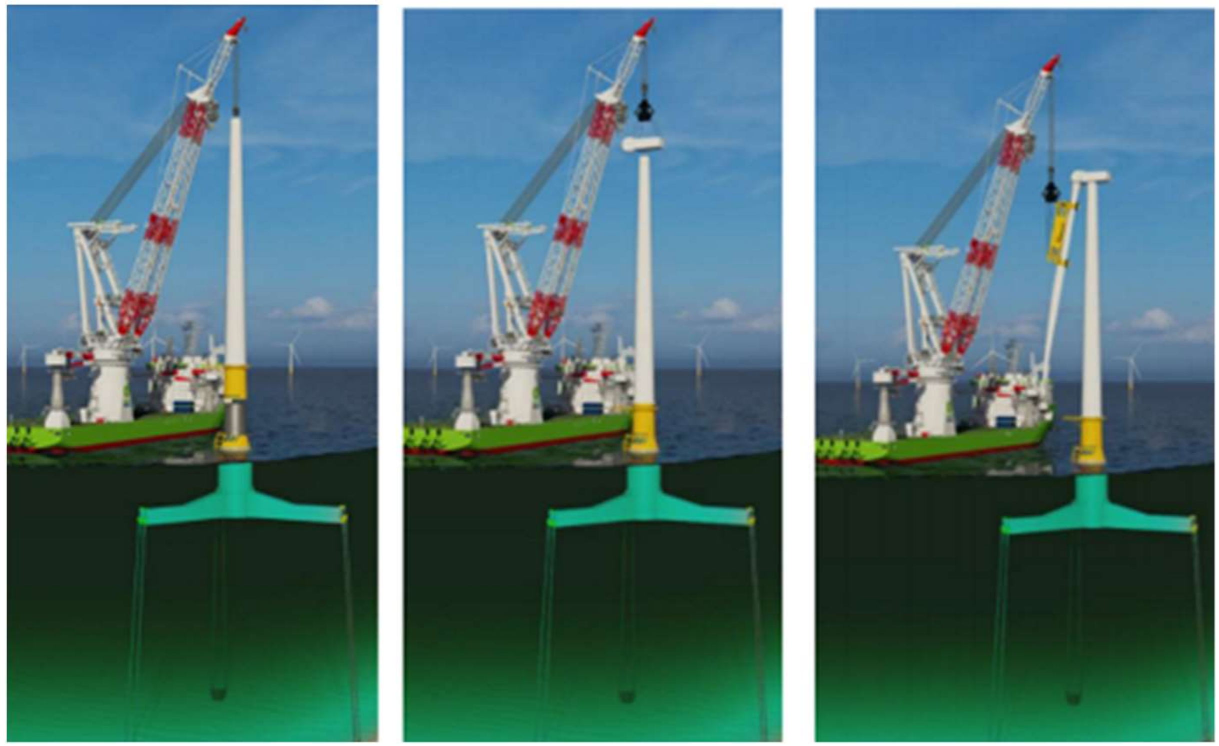
Remove temporary buoyancy after Connecting tendons

TLP Install Crane Vessel

Ref [10]

Bluewater Tugs Active Heave Compensation Of Hook of DP2 crane vessel





SBM Ref[8]

Tow out shallow draft
Large 2nd moment of waterplane area

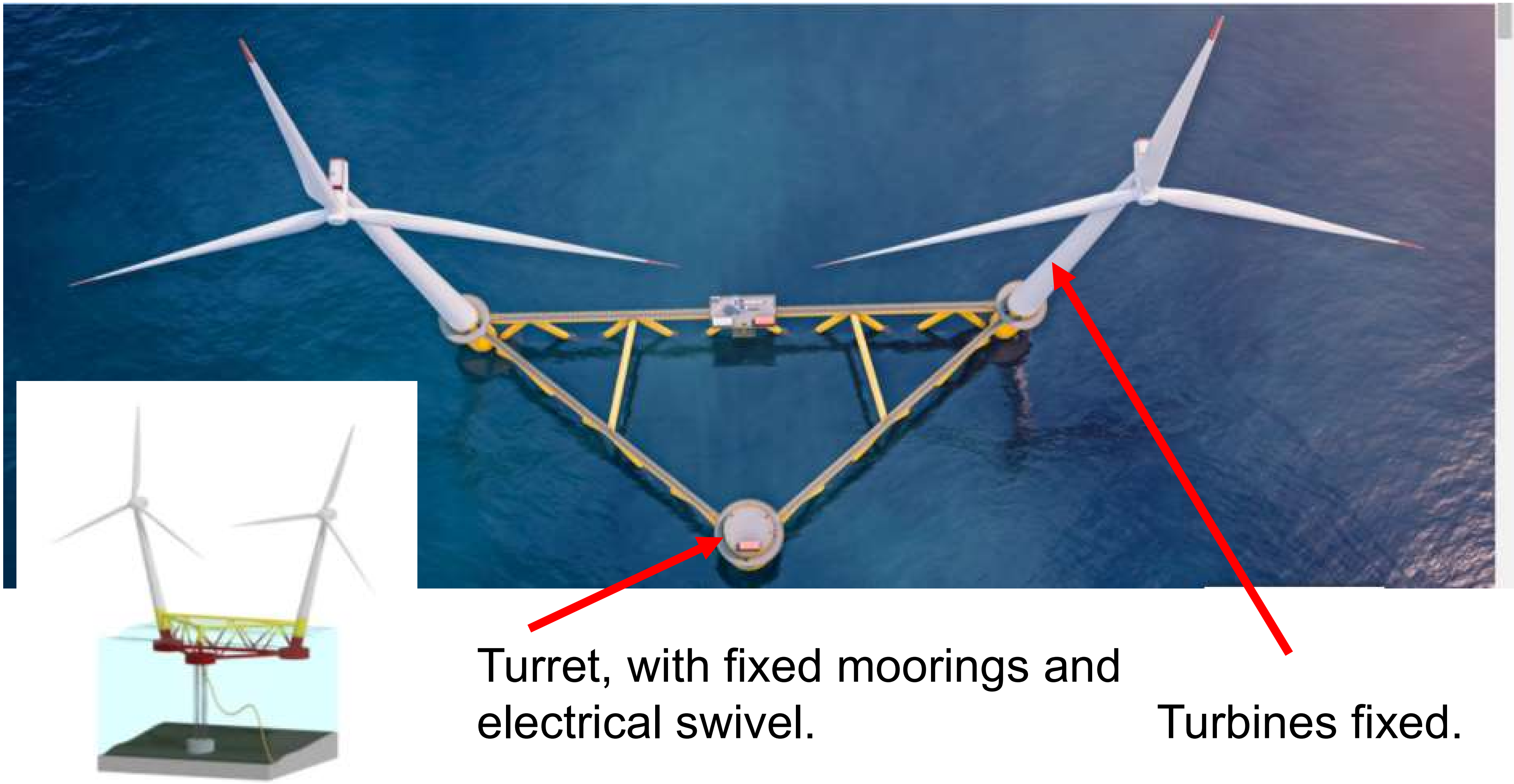
Tension (chain) tethers, ballast down and re-tension

TURRET MOORING

BLUE SATH   Ref[25]

Turret mooring

HEXICON TWIN FLOATER TURRET Ref[24]



Turret, with fixed moorings and electrical swivel.

Turbines fixed.

Disconnectable mooring LMC Ref[34]

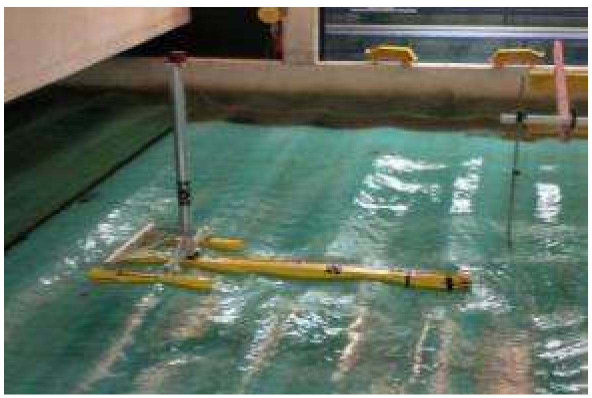
London Marine Consultants (LMC) have been awarded funding from Department for Business, Energy and Industrial Strategy (BEIS) to develop our “Plug & Play” Mooring System for Floating Wind.

The system shall allow a de-coupling of the offshore mooring installation campaign from the platform hook-up, thereby reducing risk, offering schedule advantage, and ultimately contributing towards a reduction in Lifetime Cost of Energy.

The system shall also provide a safe and robust method for disconnection and protection of the mooring and cable system, to support a tow-to-port strategy for maintenance.

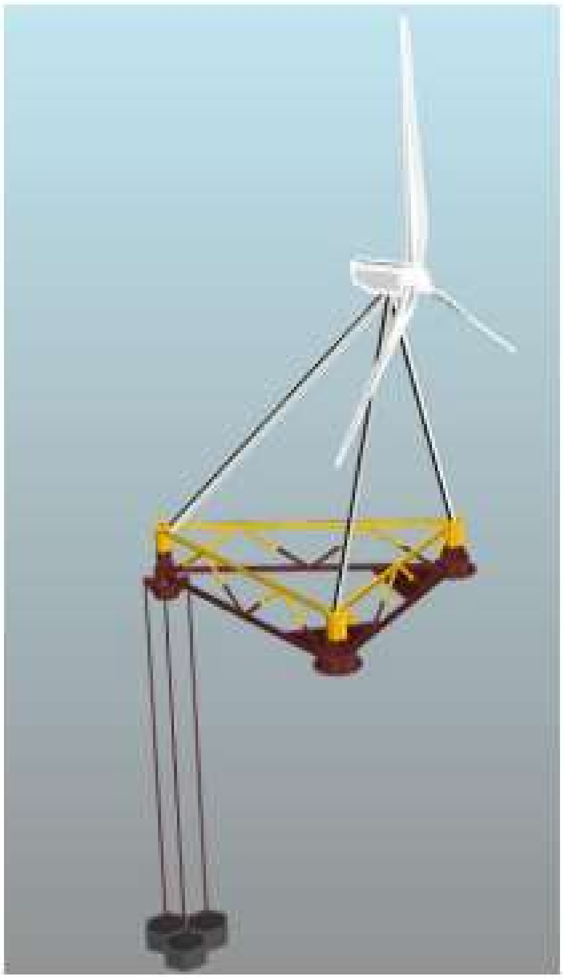
During the development this year LMC will be performing basin model tests in collaboration with University of Plymouth, and scale function tests.

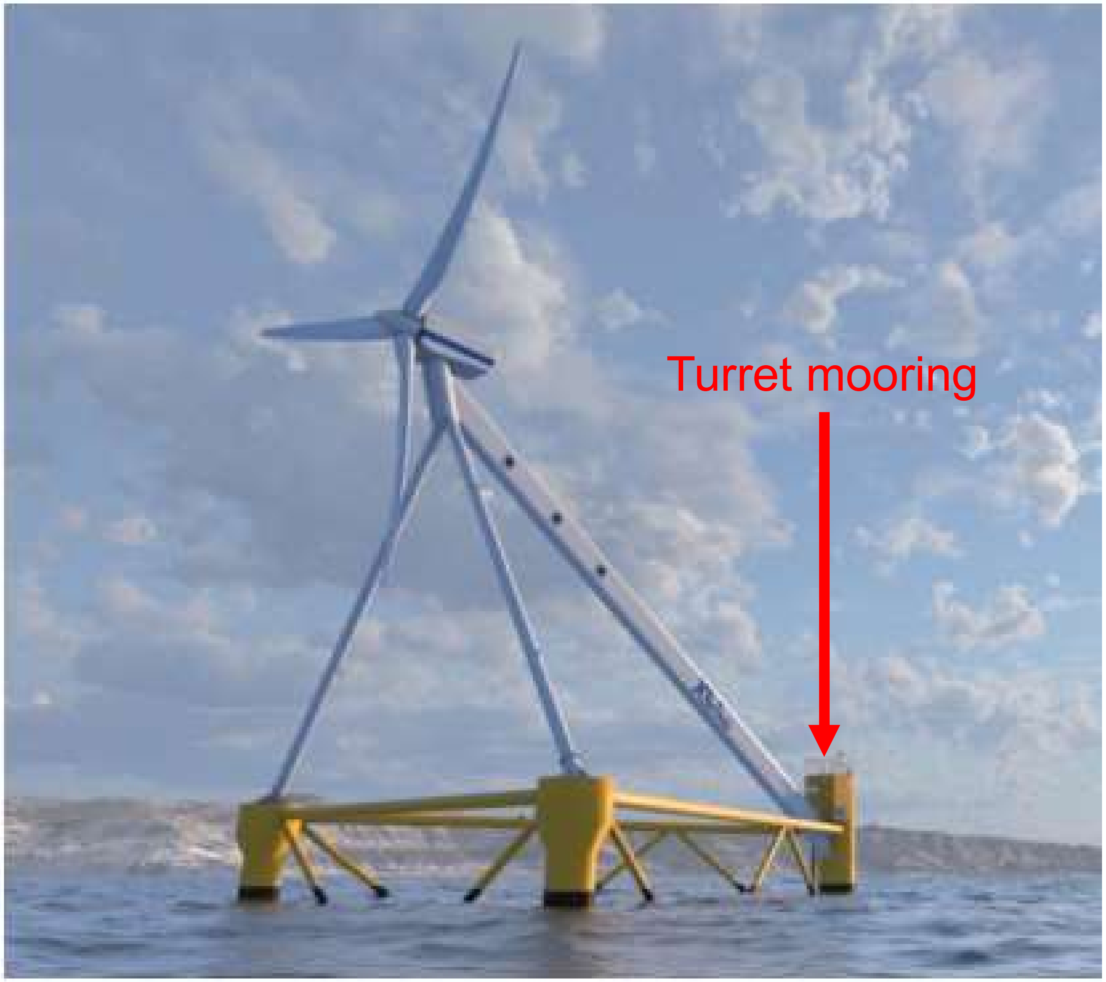
TRIVANE, TURRET MOORING Ref[23]



Model test University of Plymouth
scale 1/50
Next step 1MW demonstration unit.

PIVOT BUOY (X1Wind) For Canary Islands Ref[27]

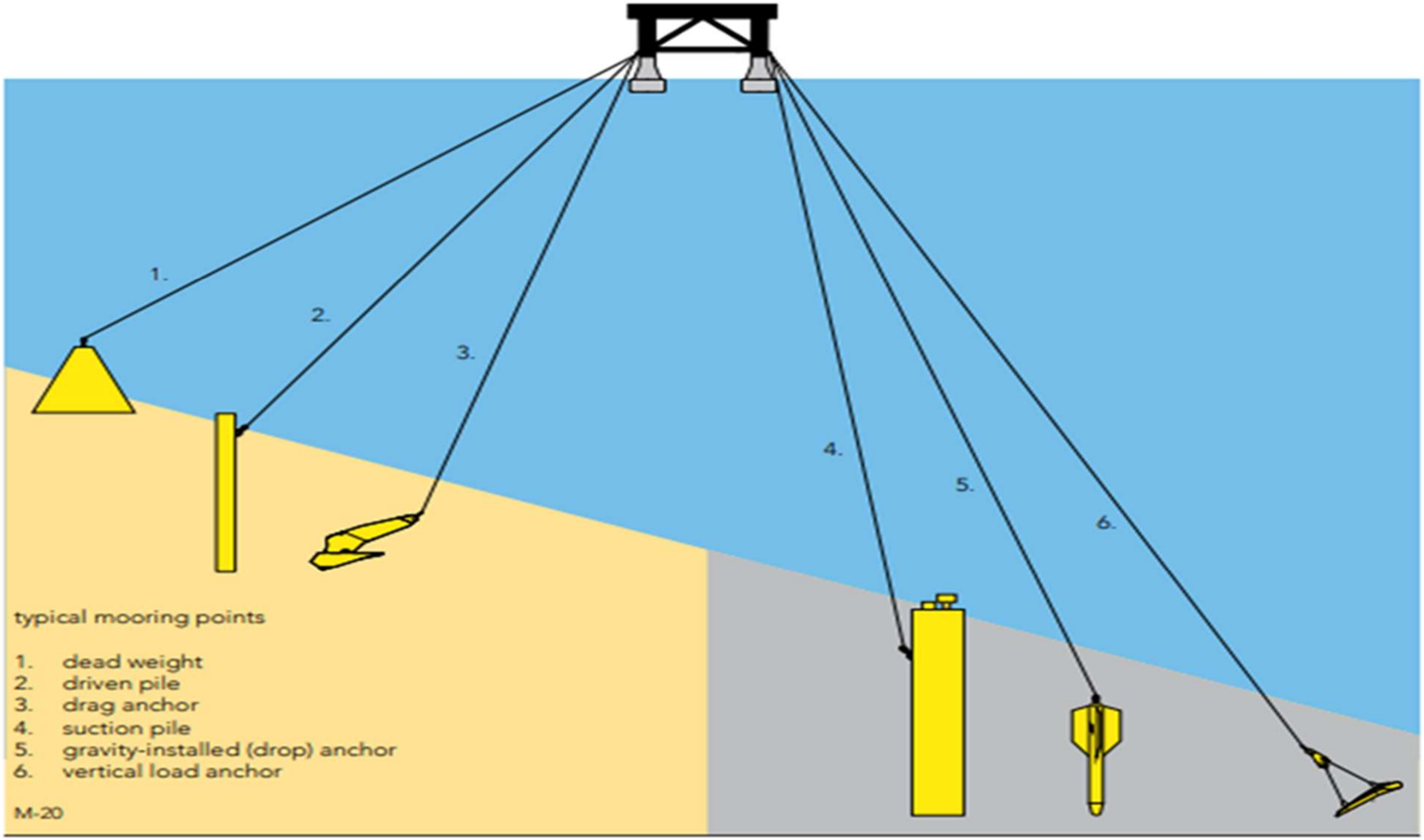




ANCHORS

Anchors

ref [11]



Anchor discussion

Anchor Type	Vessel for anchor installation	Vessel for mooring line laydown	Advantages	Disadvantages
Gravity-base anchor (dead weight)	Floating crane vessel with DP2	AHTS	OK for temporary moorings in sheltered waters	Very heavy, not for soft seabed
Driven pile or drilled pile anchors	Floating crane vessel with DP2	AHTS	All types	Underwater vibrations
Drag-embedded anchor	AHTS	AHTS	Very Experienced	Not for TLP
Suction pile	Floating crane vessel with DP2	AHTS	Some experience	Needs soft/medium soil
Gravity installed drop anchor	AHTS	AHTS	Lightweight	Limited experience
Vertical loaded anchor	AHTS	AHTS	Lightweight	Limited experience

AHTS = anchor handling tug supply

WHAT TO DO WITH ELECTRICITY

Existing technology

- Send to shore directly (Hywind & Kincardine, Scotland)
- Send to a fixed platform (China)
- Send via fixed HVAC platform
- Send via fixed HVDC platform

Under construction

- Send to offshore oil and gas platforms (Hywind Tampen)

Innovation:

- Floating HVAC(current) or HVDC(current)
- Produce liquid hydrogen
- Desalination plant
- Large battery storage

FOWT CHALLENGES

a. To reduce FOWT costs sustained mass production is needed

b. There are ongoing developments in turbines (Vestas 15MW, China 16MW) for fixed structures

c. Commercial FOWT will use >10MW turbines

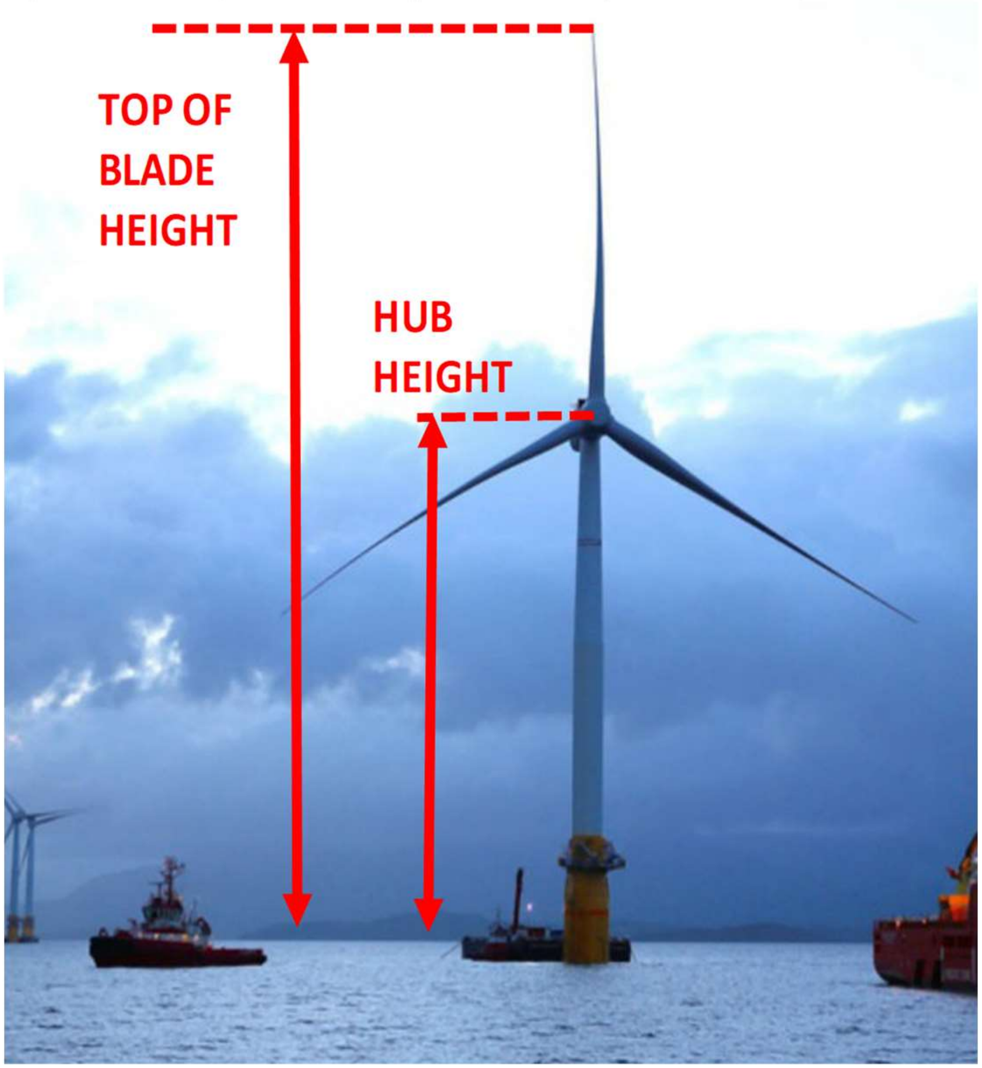
d. Probably no visual impact for FOWT in operation, but large view when fitted out inshore.

e. Spar and TLPs to stay offshore and will need large crane vessels for in place major maintenance

f. Dynamic array cable

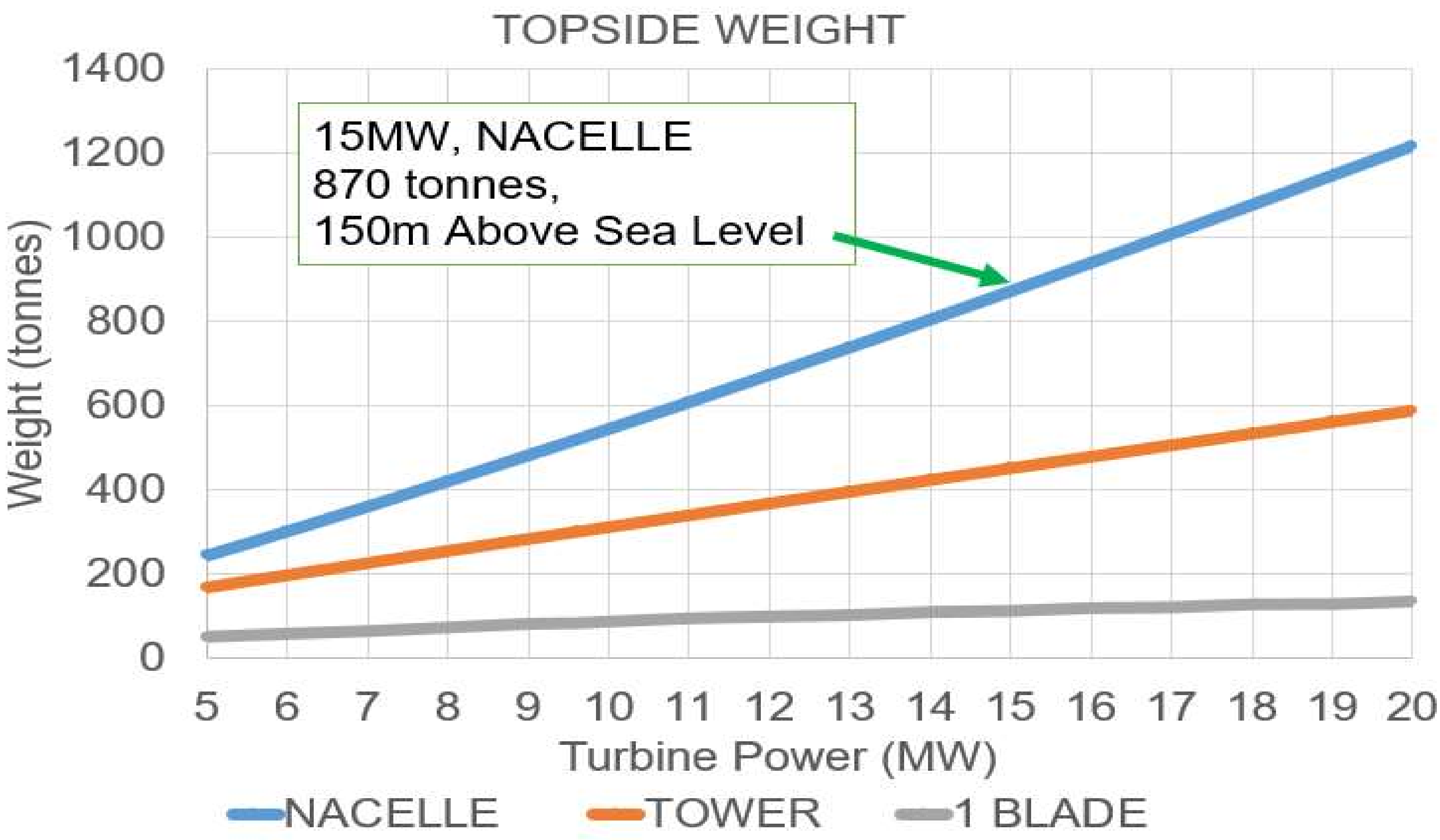
AIR DRAFT Ref[13]

TURBINE CAPACITY	BLADE LENGTH	HUB HEIGHT	TOTAL HEIGHT	LOCATION
		ABOVE WATER		
MW	m	m	m	
2	43.3	68.8	113.2	
3	52.8	80.1	133.9	
5	67.6	97.4	166.2	
6	73.8	104.6	179.8	
8	84.9	116.3	202.6	Hywind Tampen
9.6	92.7	124.1	218.3	Kincardine
10	94.6	126.1	222.2	
11	99.1	130.6	231.2	
12	103.3	135.8	241.7	Dogger Bank
13	107.4	140.4	250.9	Dogger Bank
14	111.4	145.4	260.7	
15	115.2	150.2	270.3	Germany
16	118.8	154.3	278.6	China
17	122.4	157.9	285.7	
18	125.8	161.8	293.6	
19	129.1	165.1	300.3	
20	132.4	168.9	307.8	

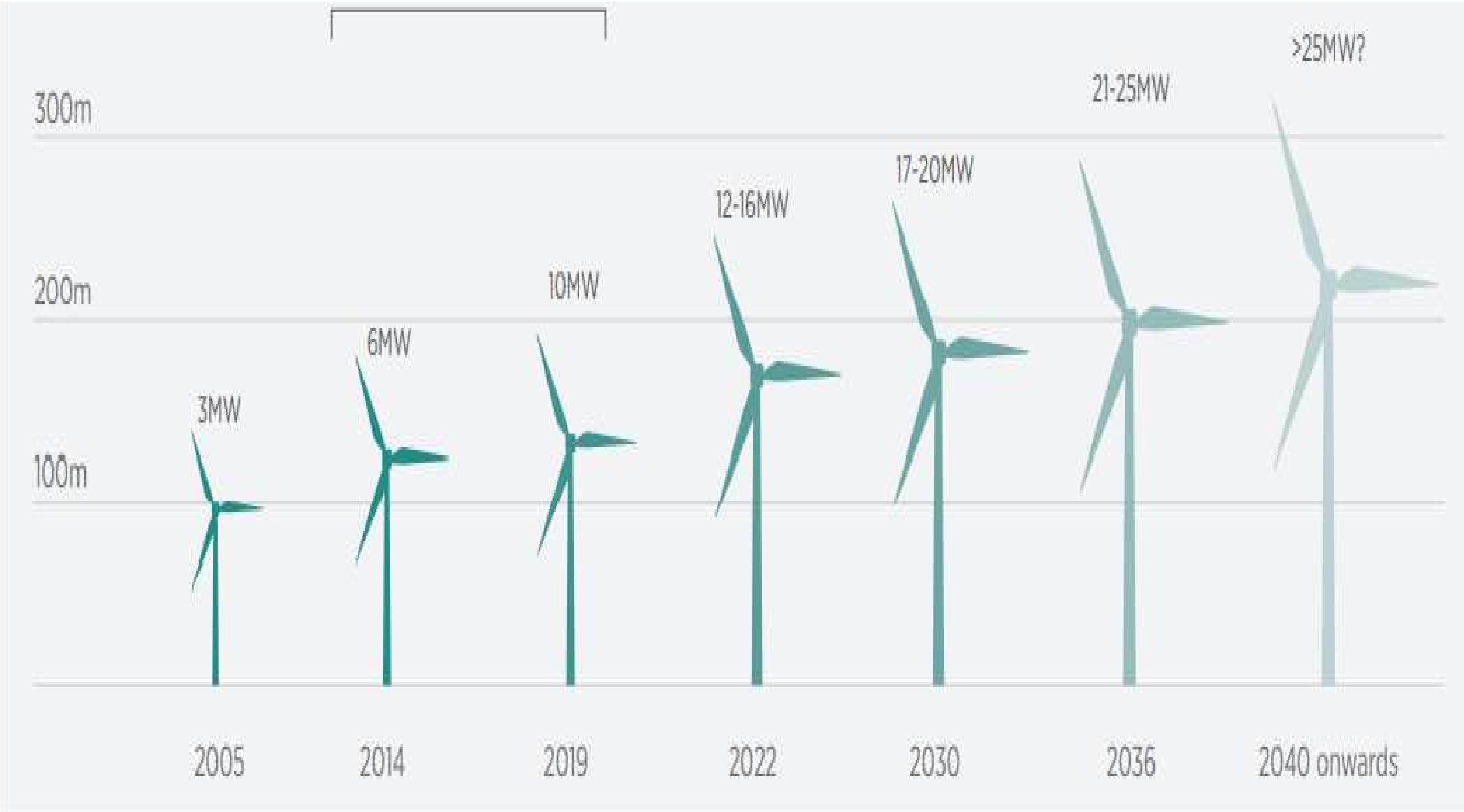


TURBINE WEIGHTS FOWT

Ref[13]



3.11.2 Turbine Size Ref[13]



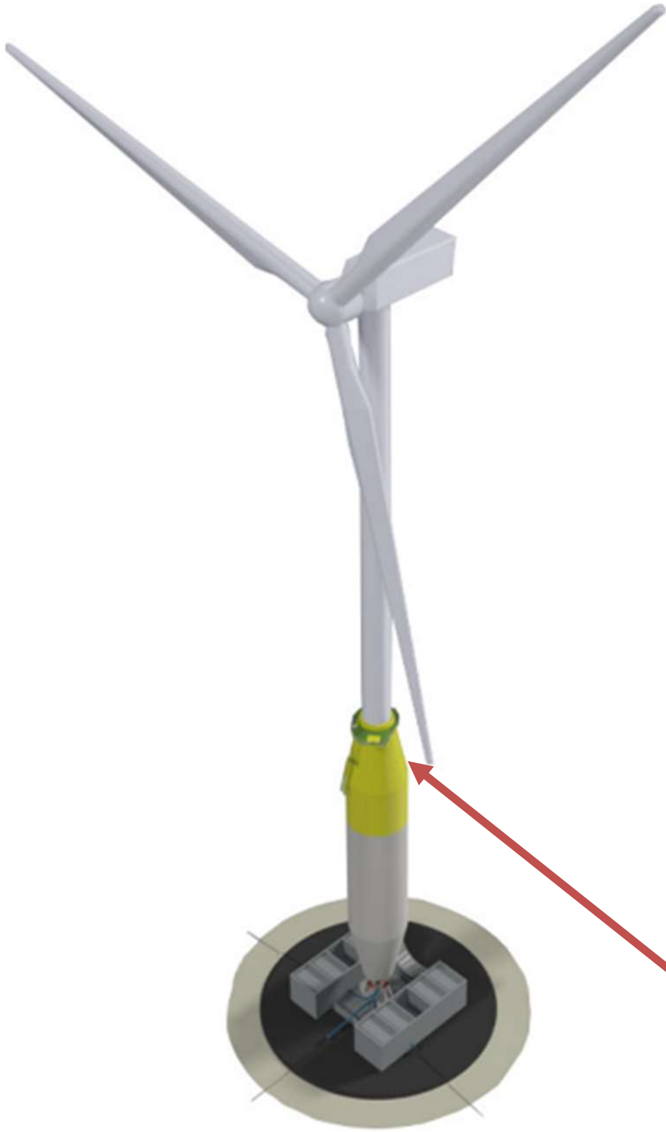
Innovation

See above

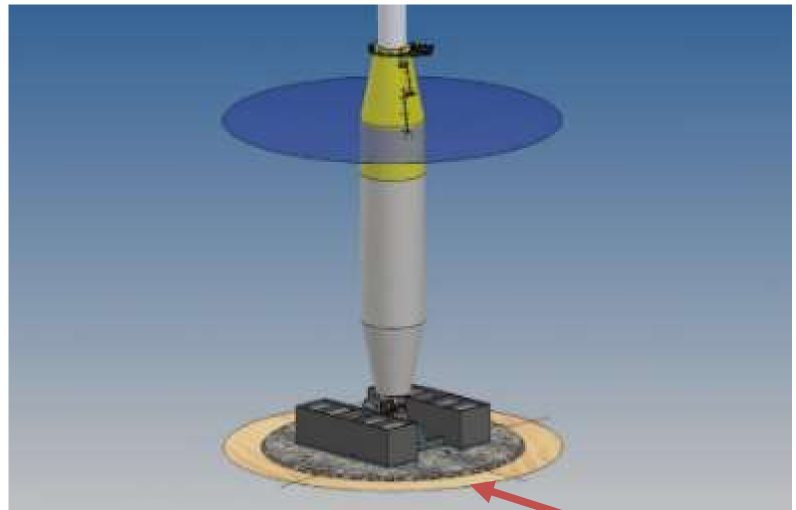
- Trivane

See below

- ODE Articulated Wind Column Buoy
- SENSE Self Installing nacelle and blades
- Saipem Hexafloat, with submerged pendulum



Offshore Design Engineering Ltd (ODE) has been selected by AWC Technology Ltd to oversee the concept and pre-FEED works for the AWC Demonstration Project, Ref[29]

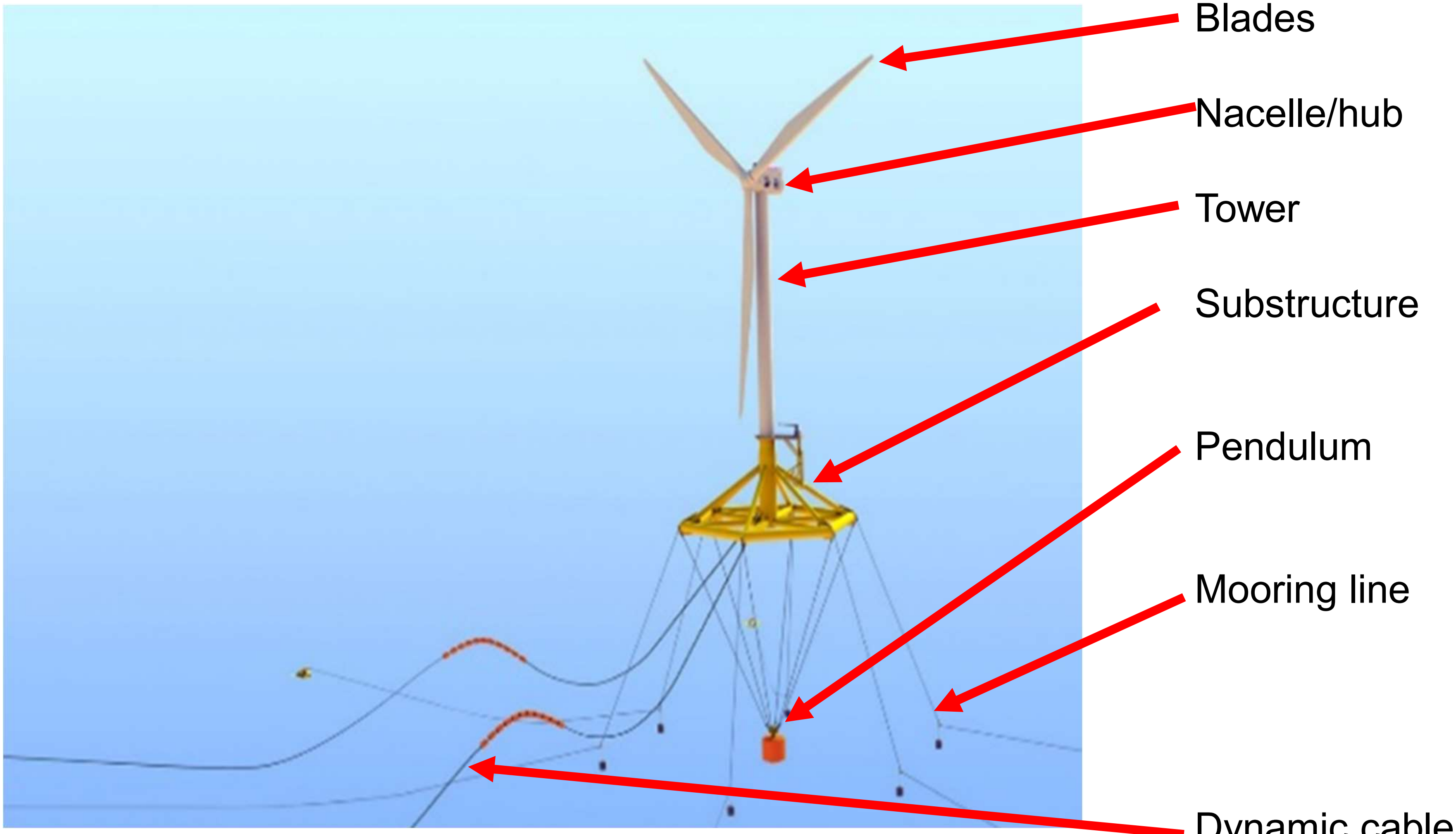


The project focuses on an articulated joint which connects to a compliant vertical column with a base located on the seabed.

SENSEWind, Glosten, and Subsea Micropiles, and six delivery partners to design and construct a SENSE PelaStar floating wind turbine demonstrator off the coast of Scotland. Ref[30]

The SENSE concept (stands for Self-Erecting Nacelle and Service) looks to upend the conventional approach to installation and O&M by eliminating the need for special cranes and allowing the full rotor nacelle assembly to be installed and serviced directly on site and is particularly suited to deepwater floating projects.

Saipem Hexafloat Ref[38]



FUTURE WORK

Floating wind will be an important component in the offshore wind industry's future. In some markets – such as Spain, Japan, Norway, West Coast of the U.S. and island communities – there is limited shallow waters and so floating wind is a potential solution.

In other markets, floating wind will be used more once we run out of sites that can accommodate bottom-fixed wind turbines.

There is one key factor involved in taking floating offshore wind mainstream – time. It will take time to better understand the risks and give investors the assurances they need. It will take time to scale up production of floating wind components.

Research work

- Shipyard requirements for mass production
- Fit out quay requirements (strength of quay wall and water depth and available cranes)
- Tow out and installation of TLPs
- Heavy maintenance offshore of Spars and TLPs

CONCLUSIONS

To facilitate the installation process and minimize costs, the main installation aspects have to be considered:

> Floating offshore wind turbine type (substructures different)
> Inshore vessel requirements (inshore floating crane)
> Shipyard location
> Distance from the shipyard to the fit out port distance
> Distance from fit out port to offshore wind farm site (3 day tow)
> Minimise weather downtime during installation
> Number of anchor handling vessels (3 or 4)
> Whether an offshore crane vessel is required (TLP)

THANK YOU FOR YOUR TIME

DO YOU HAVE ANY QUESTIONS?

email ac1080@Exeter.ac.uk

Abbreviations

AHTS - Anchor handling tug supply
CAPEX - Capital expenditure
DP - Dynamic positioning
FOWT - Floating offshore wind turbines
HTV - Heavy Transport Vessel
OPEX - Operating expenditure
SPMT - Self propelled modular transporter
TLP - Tension Leg Platform
WTIV - Wind turbine installation vessel

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Appendix Questions

Questions

	Question	Answer
1	Discus future floating wind developments in the world	Floating offshore wind turbine farms are being planned for UK, France, South Korea. It is recognised that between California and Oregon there is very deep water close to the shore which may result in a huge FOWT development in the future.
2	Explain the Hexafloat floating concepts?	The Hexafloat has a suspended pendulum ballast weight. A test 10kw, scale 1to6.8, has been installed off Naples. Ref[38]. The Hexafloat offshore wind floater is a pendulum lightweight structure composed by: • A submersible Floater made of tubular elements • A counter weight connected to the Floater with tendons • Simple Mooring lines with drag Anchor • Lazy Wave dynamic Cable
3	What portion of the costs of a wind turbine does installation comprise? Is it significantly different for the different types of FOWT?	Some aspects of installation are the same for all types i.e. export cable and dynamic array cable. It can be expected that semi submersible and barge types will have the least installation cost as they will be outfitted alongside a quay on which is mounted a large onshore crane inshore. The Spars will incur extra cost due to the need for inshore temporary moorings, use of ballast transfer ship, inshore barges and use of a large crane vessel. TLPs will probably be the most expensive to install as they require the addition of temporary buoyancy and possible use of a DP2 crane vessel with active heave compensation, plus the seabed mooring complexity and the tendon is more complicated to install that for other substructure types.

4	What is the approximate current cost per MW of FOWT ? What is the desired cost per MW ?	Just a few floating offshore wind turbines have been constructed and deployed, so there is limited data on costs. At present floating offshore wind turbines are more expensive to construct and install than fixed bottom wind turbines in the water depths, where both are technically viable i.e. 50 to 70m of water. FOWT are more expensive, than fixed wind turbines, because they are not being mass produced.
5	Is there scope to launch the semisubmersible options either off a quay/beach or from a barge as we used to do for barge launched jackets. There will be barges that could do this?	The traditional ship launch method is feasible for semi submersible and barge types. Large launch barges are still operational and could be used to get semi submersible, barge and maybe some TLPs. However the expected method will be to use SPMT (self propelled modular transporters) to load-out the substructure onto a submersible barge or submersible Heavy transport Vessel and then to float off close to the fit out quay.
6	Is there not a need to reconsider the fundamental design of the wind turbine. Could the axis not be vertical. Could the generator not be at the base of the tower?	There are designs for vertical axis wind turbines. They have the advantage that the generator is at a low level, giving easier access for cranes and improving intact stability. However the horizontal axis turbines are higher which takes advantage of wind speeds increasing with elevation above sea level.
7	If the fields have much larger numbers of WTGs, approaching a thousand, then it is economic to build a purpose-built vessel, possibly a U shaped semi-submersible, that can also be used for ongoing maintenance?	It is possible to build a U shaped vessel for the offshore installation of TLPs. There are not needed for semi submersible or barge or Spar types, as they are fitted out inshore.

8	What does the UK government or UK industry need to do to increase the UK content of the construction .	The Scotwind offshore floating wind development requests 60% UK construction. Presumably any developments in the Celtic Sea will make similar requests. There are plans to develop old oil rig construction yards as shipyards for construction of FOWT substructures.
9	As the FOWTs get bigger, what are the limiting conditions on towing?	The substructure construction can take place anywhere in the world, followed by ocean transport on a Heavy Transport Vessel(HTV). However the fit out port, where the turbine is lifted onto the substructure, needs to take place as close as possible offshore site as these FOWTs have a slow towing speed. Tow out restrictions can be expected to be Hs<3m, Wind<10m/s and tow speed less than 3knots. The turbine blades are feathered to minimise the wind loads during tow out.
10	Liquid hydrogen is not feasible for such short distances you need to be talking of several thousand miles. However, it could be pressurised to around 700 to 1000 bar and loaded into containers for transport to shore and then delivery to fuel stations. This avoids the electricity transmission by a grid to compress the hydrogen. This allows delivery to multiple locations. Low pressure transmission of hydrogen via pipeline over longer distances is cheaper than DC electricity transmission. Ammonia is suitable for transmission by pipeline over distances up to 1000 miles.	The wind industry will need to decide whether it is better to export the electricity ashore where it can be used to produce hydrogen, or to make hydrogen offshore which requires pipeline or special hydrogen tankers. Motions of floating process structures will need to be developed if hydrogen is to be produced offshore.
11	How long does it take from planning stage , design, building and commissioning ?	On Scotwind the expectation is that it will take several years to plan, design, construct, install and commission the 15GW of floating wind turbines and the export cables and onshore terminals .

12	Isn't the challenge of anchoring underestimated? Especially for TLP like solution, the tensile load applied to the anchors could lead to enormous anchors. There is also the challenge of anchor sharing, environmental restrictions (limitation on pile driving).	The anchor system chosen depends on substructure type. For barges, semi submersibles and spars have catenary moorings and can use drag anchors, suction piles driven piles or drilled piles depending on seabed conditions. For these catenary moorings they are pre laid and tensioned prior to the arrival of the completed FOWT structure. The TLP moorings are vertical and see large tension loads, which means that drag anchors are not possible. The TLP moorings can only be installed after the arrival of the TLP completed structure thus causing further weather restrictions during their installation. With regards to anchor sharing this is limited to drilled or driven piles. Note that drag anchors are installed with anchor handling tugs. The various pile options require a DP2 crane vessel and anchor handling tug for the mooring installation. Driving piles requires an air bubble curtain to keep marine mammals away.
13	Why do you think the industry has not yet settled on one floating wind design solution?	There are few FOWT in operation that it is not possible to conclude if there is best type. The TLPs will be difficult to install but have the least seabed area requirement as the moorings are vertical, whilst for the other options there are long catenary moorings, making fishing not possible. The Spar required sheltered deep water at the fit out location and on the tow route to the offshore site. Both TLPs and Spars will be difficult to return to shore for heavy maintenance. Barges and semi submersibles have heavy substructures but their installation methods are relatively simple compared to other options.

14	You mentioned nacelle and rotor mass 870 tonnes - how does this compare with current crane capacities (and cranes under development)? - quayside cranes, cranes on DP vessels, cranes on jack-up barges	With regards to wind turbine installation vessels (WTIVs) existing cranes are being modified to deal with larger nacelle weights and also that the turbine hub is getting higher above the sea as turbine power output increases. A few very large crane capacity WTIVs are also under construction. These WTIVs are just about keeping up with the requirements of the turbine installation on the latest fixed wind platforms. It may be that these WTIVs are used to install the turbines on FOWT at the fit out locations. There are land based cranes for the installation of very large turbines at fit out quays, onto FOWT, but they are few in number and being used for other onshore construction work.
15	What research is needed for floating wind?	The floating offshore wind industry can learn from oil and gas installation activities over the last 50 years and from the offshore fixed wind farms over the last 20 years in UK waters. There will be new lessons to learn for FOWT, requiring research, especially with regards to mass production, offshore maintenance and dynamic array cables.
16	What about dynamic inter-array cable installation ? Any innovation to reach the fixed offshore wind lay rate?	There is ongoing research into accelerated development of Higher-voltage array cables for Dynamic applications is required and research has started. No dynamic cable rated above 66kV has ever been deployed in an offshore wind environment. Due to increased turbine sizes, distances from shore, and water depths, in the 2020s the industry will require significantly higher voltage dynamic cables. FOWT structures will be installed one at a time and each one will have its moorings completed before starting on the installation of the next structure.

17	Explain Floating wind CAPERX cost comparison with fixed wind platforms?	The existing pre commercial floating offshore wind turbines are roughly double the CAPEX, per MW of power output, compared to Fixed Wind Structure.
18	Is the turret mooring option from Hexicon a semi sub or a TLP from a stability point of view, or is it more of a hybrid option? Does it have the same disadvantages as a TLP in terms of mooring and anchoring?	In terms of construction it is similar to a semi submersible but the mooring installation is almost as complicated as that of a TLP.
19	How feasible is towing the structures back for major repairs given you'd have to “unplug” (and store) cables/moorings, maybe also have to de-energize the WTGs on same string?	TLPs and Spars need to have all maintenance done offshore using climbing cranes on the tower or active heave compensation on floating cranes. Storing mooring lines and dynamic cables on the seabed after unplugging is complicated and this may mean that barge and semisubmersibles also require offshore heavy maintenance to be done offshore.
20	Where are the possible substructure construction yards in the UK?	Regarding reuse of old oil rig yards, for construction of FOWT substructures, this includes not only the jacket and module yards on the East coast of England and Scotland but also the large building docks used for gravity base structures on the west coast of Scotland. Port Talbot is offering itself as a shipyard location, in Wales, for floating wind.

21	What is your opinion on the level of redundancy in semi-submersible mooring systems where only 1 line is used per column, especially as we move to larger wind farms?	Having just one mooring line per column means that the effects of a mooring line break need to be considered by insurance companies. The effects on the dynamic array cables in the event of loss of mooring line on one column need to be considered.
22	Is this why you need a very large number of WTGs?	A commercial floating wind farm will need have sufficient turbines to justify the construction and installation of the export cable. In addition some redundancy is required in case a turbine breaks down or a broken mooring line needs to replaced.