UNIVERSITY OF EXETER

Cornish Institute of Engineers

FLOATING OFFSHORE WIND TURBINES - INSTALLATION METHODS

13th APRIL 2023

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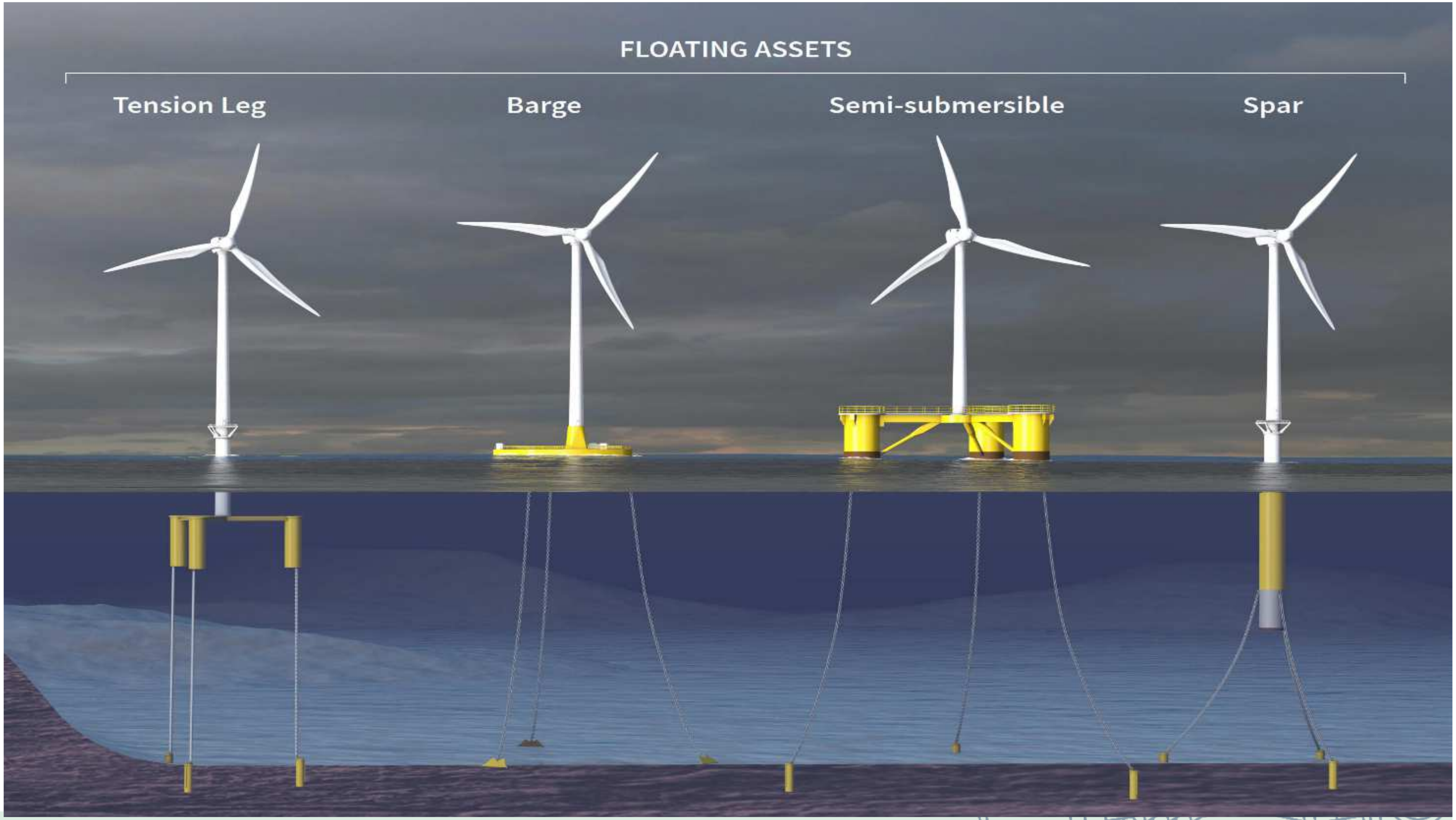
Both University of Exeter, Renewable Energy Department

Floating

Ref[15]



INDEX

Miss ballasting, Ref [27]

▪

Recovery, Ref [27]

Full shape

Built in the dockyard of Hitz

Carried to Sumoto port on 2 May

The floater lost control and leaned on 9 May

The floater recovered stability again on 14 May

SIZE, VESSELS, DEPLOYMENT

YARD, HTV For Windfloat Semisubmersible

Ref[5]

TUG and Cable Layer For Windfloat Semisubmersible

Ref[5]

AREA FOR 3 TOPSIDES, Ref[26]

Type	Deployed	Substructure		MW	No	Total
		Material	Built	each	off	GW
	In place					
Semi	Portugal	steel	Spain	5	3	0.015
Semi	Scotland	steel	Spain	9.6	5	0.048
Spar	Scotland	steel	Spain	5	5	0.025
Stiesdal	Norway	steel	Denmark	2	1	0.002
Pivot X1	Portugal	steel	Portugal	2	1	0.002
Ring barge	France	concrete	France	1	1	0.001
Ring barge	Japan	steel	Japan	2	1	0.002
Pivot barge	Spain	concrete	Spain	1	1	0.001
Spar(3/11)	Norway	concrete	Norway O-G	9	3	0.027
				Total	21	0.123

Type	Deployed	Substructure		MW	No	Total
	In place	Material	Built	each	off	GW
	construction					
Spar	Norway	concrete	Norway to power Oil and Gas	9	8	0.072
TLP	France	steel	France	8	3	0.024
				Total	11	0.096

			By the end of 2023		32	0.219
			Ashore	%		55
		To Power	Oil&Gas	%		45

	Project	Where	Being	MW	No	Total
			Planned	each	off	GW
By 2035	USA	West coast		15	2333	35
By 2035	Scotwind	Scotland		15	1000	15
By 2035	INTOG	Scotland	Oil and Gas	15	333	5
By 2030	Erubus	Wales		15	25	0.375
By 2028	Wave Hub	Cornwall		8	4	0.032
By 2035	Celtic Sea					5

TYPES

Deployed FOWT

- 2 barges
- 5 spars (11 more under construction for Oil and Gas)
- 8 semi submersibles
- 1 submerged ballast
- 2 pivot buoy
- 0 TLPs (3 under construction)

Fixed bottom

- 4,000+ Monopiles (limit 50m) (China has the most deployed)
- 300+ Jackets (limit 75m)

Reasons for low deployment

- FOWT high capital costs (CAPEX)
- FOWT high operating costs (OPEX)
- In UK still shallow water available for fixed structures
- Lack of ports for construction
- Laydown area for components

FIXED vs FLOATING

Ref[15]

Monopile (<50m) | Jackets (<70m) | Semisubmersible (>60m) | TLP (>100m) | SPAR (>90m)

INSTALLATION CONSTRAINTS

Barges:

- Low freeboards
- Tow out motions high

Semi submersible:

- High steel weight
- 10m to 15m water depth adjacent to fit out quay

Spars

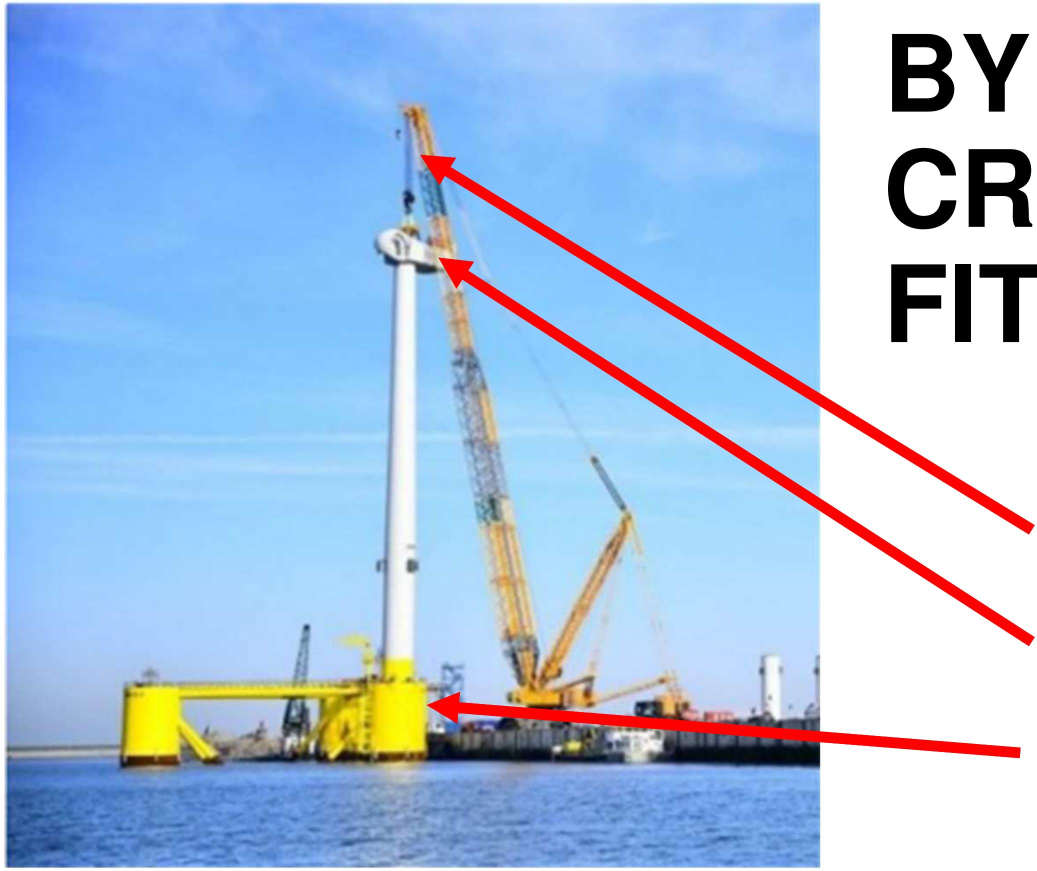
- Deep sheltered water, (70m plus) required for fit out
- Not possible to return to port for heavy maintenance

TLPs

- Low or negative intact stability during tow out
- Very complicated moorings, weather restricted during installation
- Not possible to return to port for heavy maintenance

SEMI SUBMERSIBLE

LIFTING NACELLE BY ONSHORE CRANE AT THE FIT OUT QUAY, ref[5]



LIFTING NACELLE-HUB BY ONSHORE CRANE AT THE FIT OUT QUAY, ref[5]

People needed to make the connection between nacelle and tower

Lifting blades by onshore crane at the fit out quay, Ref[5]

Large onshore crane

Blade handling tool

Substructure

Lifting Blades By Onshore Crane At The Fit Out Quay, Ref[5]

LIFTING BLADES BY ONSHORE CRANE AT THE FIT OUT QUAY,

Ref[5]

May need temporary buoyancy or air bags to reduce draft

WET STORAGE, REF[5]

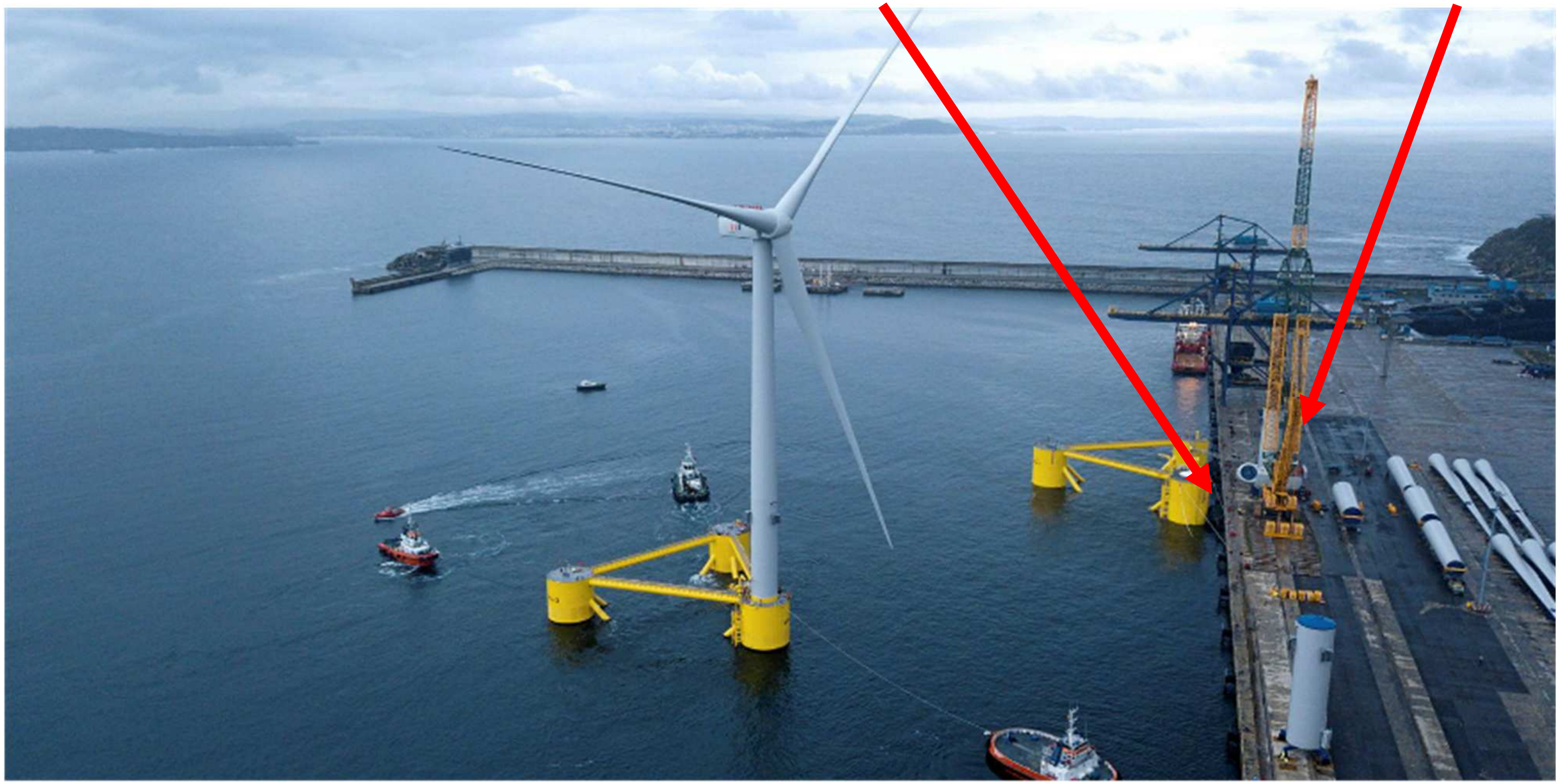
Temporary Mooring Piles

Harbour Tug

FOWT

WINDFLOAT, REF[5], OFFSHORE PORTUGAL

Fender Onshore crane for nacelle/blades



WINDFLOAT, REF[5], OFFSHORE CROMARTY

Potential fit out port

PORT TALBOT PROPOSAL

Fabrication Assembly Loadout onto submersible barge

Towers, Nacelles Blades Out-fit Wet-Storage(15.8m LAT) Tow-out

WISON (China) SEMI SUBMERSIBLE, ref[2]

Substructure
(for 5MW)

91m long
91m wide
31m depth

SPMT Trailers

Submersible
Barge

Harbour Tug

CONNECT MOORINGS Ref[2]

Mooring lines
(3 per column)

Moorings being
tensioned

Tugger lines

SPAR

EQUINOR, REF[4], TAMPEN

Equinor's 88MW Hywind Tampen project in Norway, which is to become the world's first floating wind farm supplying renewable power to offshore oil and gas installations. Loading solid ballast into the base.

HYWIND TAMPEN, ref[4]

Onshore crane
Lifting blades

HYWIND TAMPEN, ref[4]

HYWIND TAMPEN, ref[4]

Subsea 7 has laid the first subsea cables in the water for the 94.6 MW Hywind Tampen floating wind farm offshore Norway.

BARGE

BARGE, ref[11]

Concrete substructure

Crane for outfitting

TLP

Possible Installation Methods

TLP TEMPORARY BUOYANCY Ref [9]

Stiesdal TLP

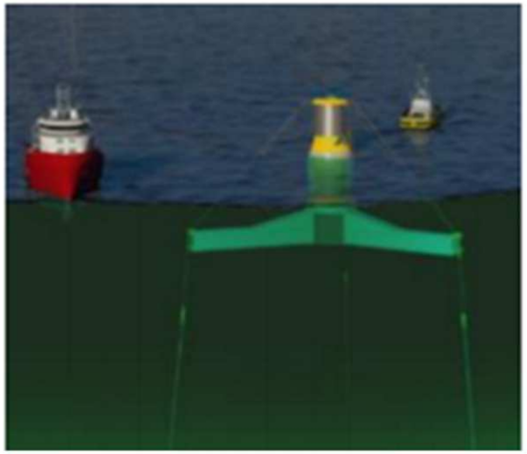
Tow out with temporary buoyancy

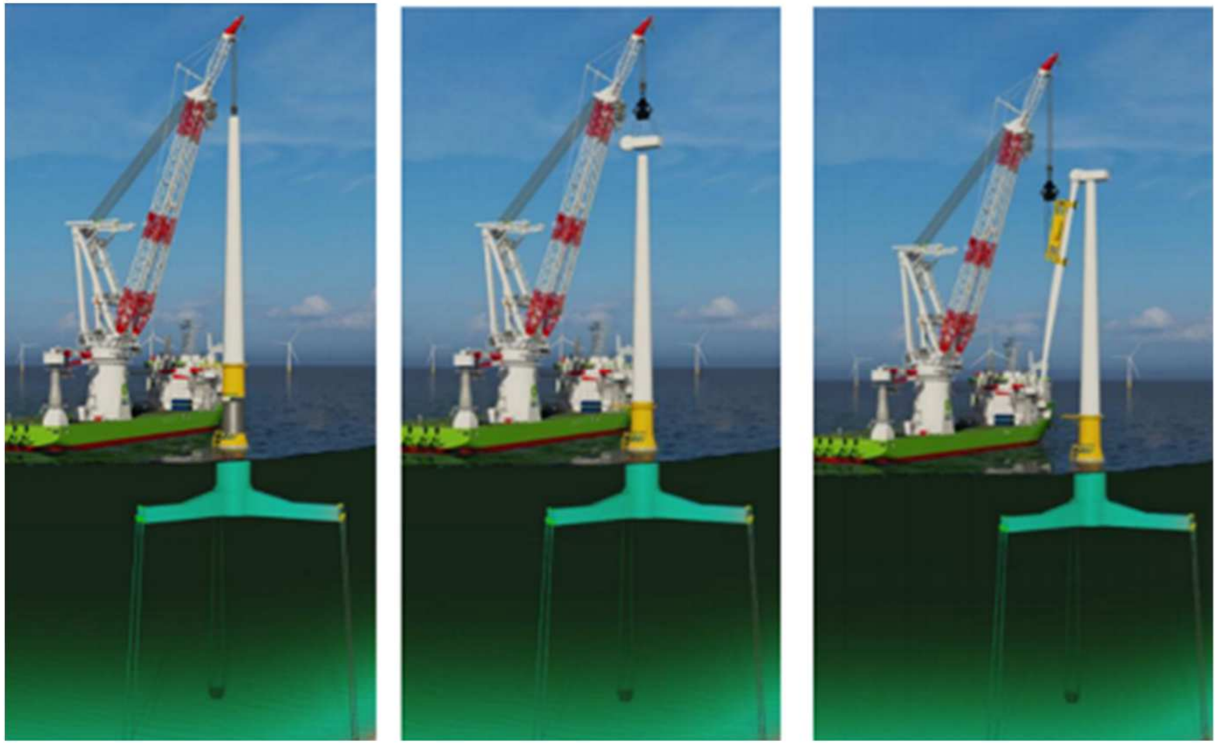
Remove temporary buoyancy after Connecting tendons

TLP Install Crane Vessel

Ref [10]

Bluewater Tugs Active Heave Compensation Of Hook of DP2 crane vessel





SBM **Ref[23]** Tension Leg Platforms (TLPS)

PROVENCE GRAND LARGE, July 2022, ref [23]

Eiffage Métal's site in Fos-sur-Mer, where the assembly of the structures is being carried out by the French company and Smulders, its Belgium-based subsidiary

SBM Ref[8]

Tow out shallow draft
Large 2nd moment of waterplane area

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

BLUE SATH
PIVOT BUOY
TURRET MOORING

BLUE SATH Ref[12]

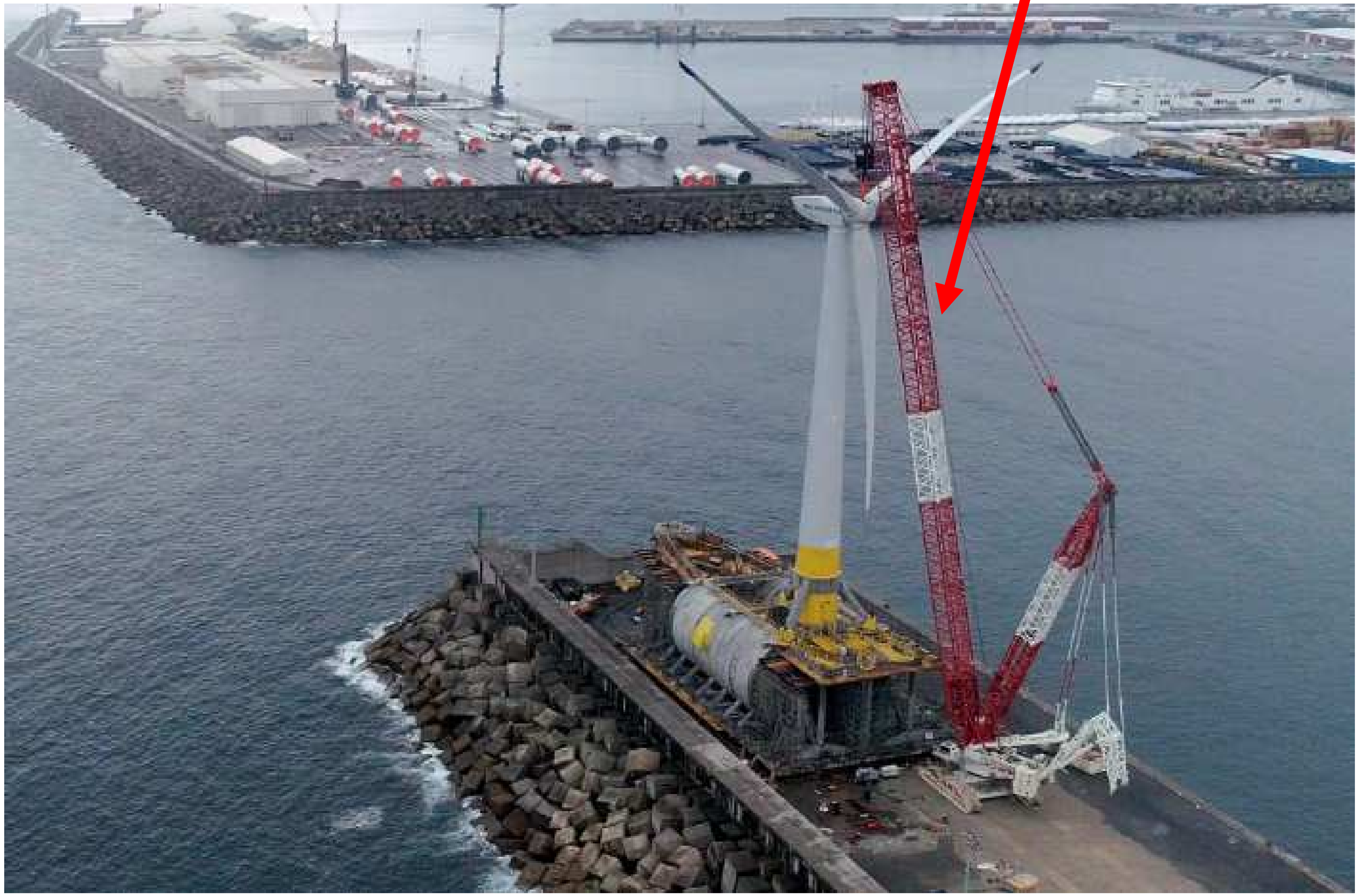
DemoSATH mooring, anchoring and quick connect solution is set for the 2MW turbine.

Maersk Supply Service completed the installation of six mooring lines (comprised by hybrid lines of chain and fibre rope) and six drag anchors with Maersk Mariner.

Once loaded, the vessel left the Port towards the installation site at test area where the elements' connection and laying took place. The lines will be recovered from the seabed for a plug and play connection.

BLUE SATH Ref[12]

Large onshore crane

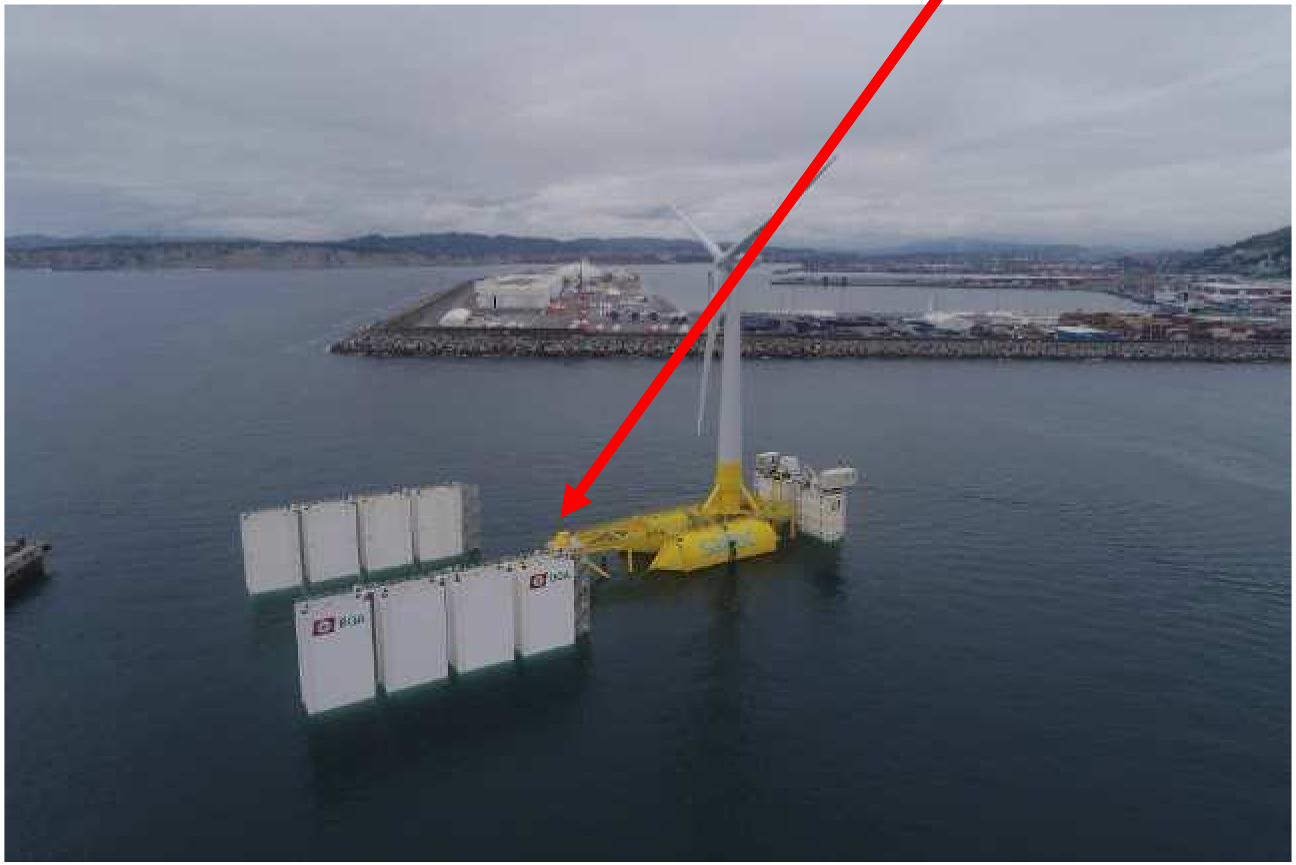


BLUE SATH **Ref[12]**

Submersible barge

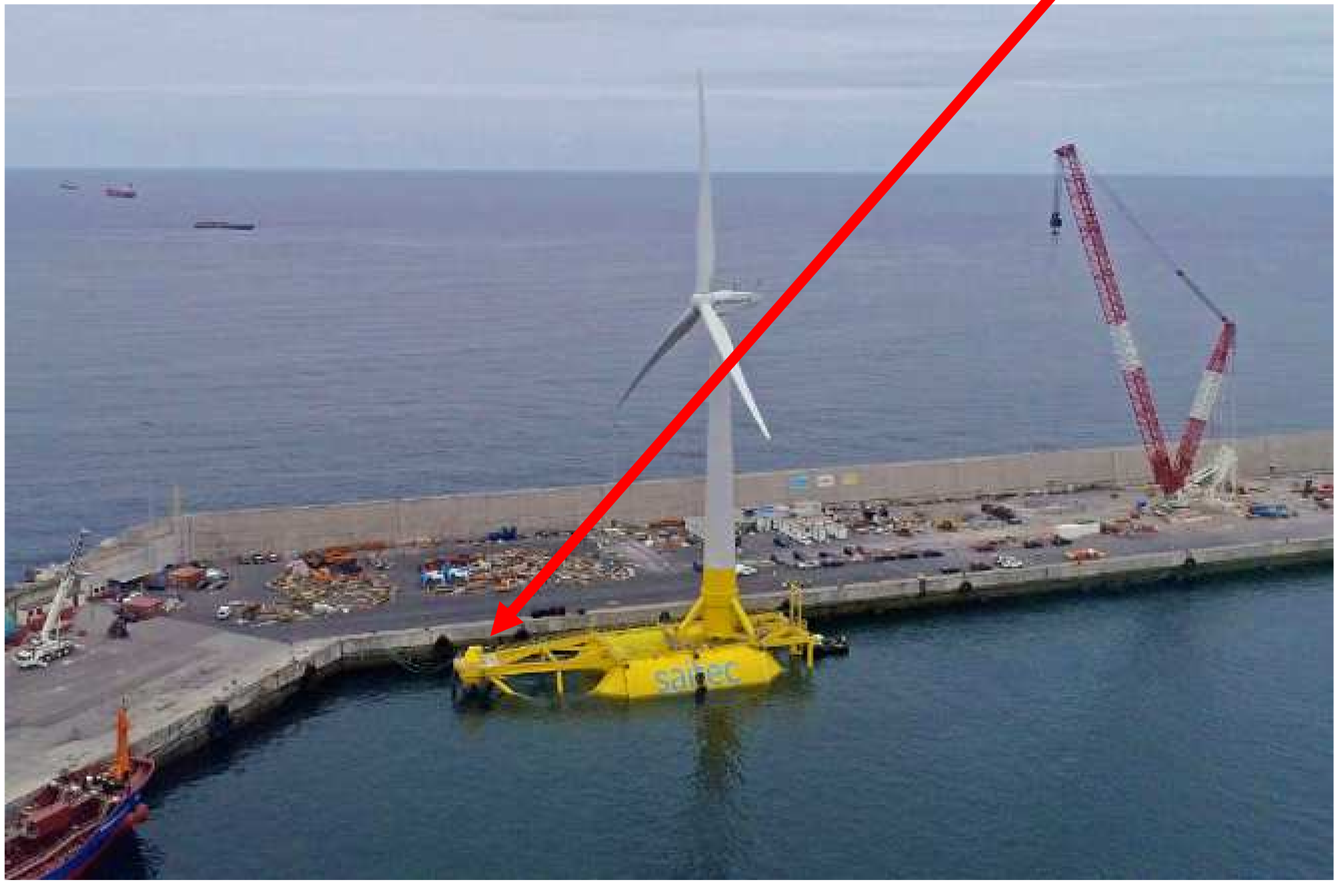
BLUE SATH **Ref[12]**

Turret mooring



BLUE SATH Ref[12]

Pivot Buoy Turret mooring

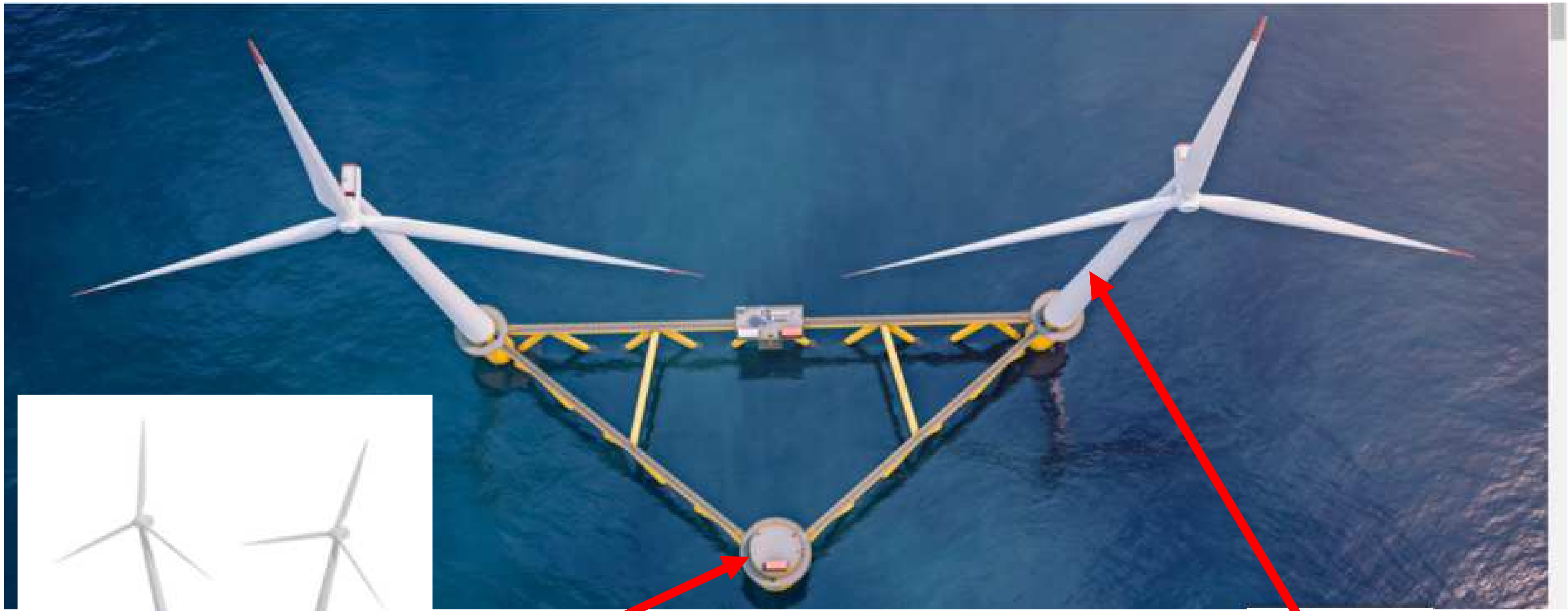


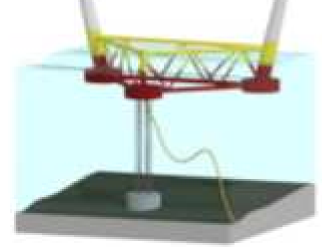
TURRET

Floating Offshore Wind Turbines with turrets. Electrical swivels must be capable of transferring uninterrupted high power while offering significant protection in hazardous areas. Ref [25]

DESIGNS FOR PIVOT BUOY TURRET MOORING

HEXICON TWIN FLOATER TURRET Ref[8]

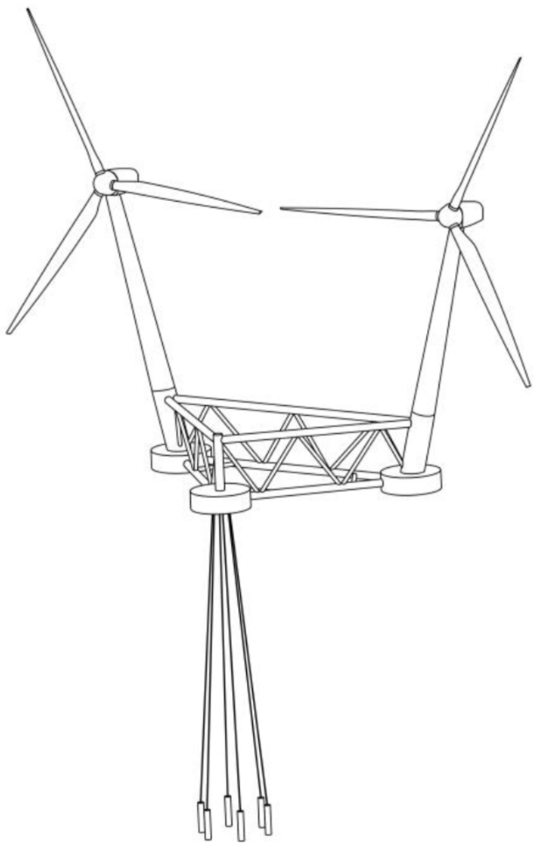




Turret, with fixed moorings and electrical swivel.

Turbines fixed.

HEXICON FOR WAVE HUB Ref[8]

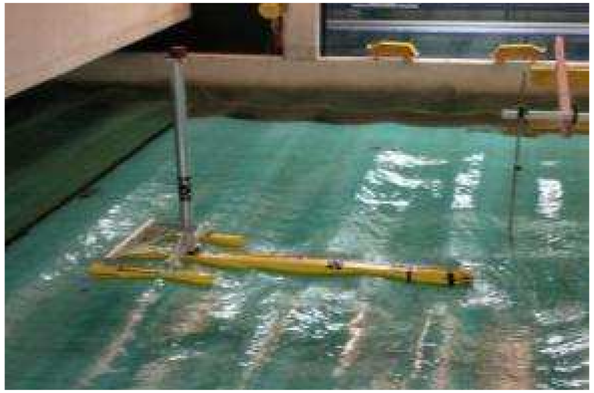


Using 8MW MING Turbines
- Each blade length 85m
- Each 173m diameter
- Each nacelle 420 tonnes
- Nacelle above water 120m

Substructure (approximate)
- Length hull 120m
- Width hull 80m

Overall dimensions
- Length 280m
- Height 204m

TRIVANE, TURRET MOORING   Ref[7]

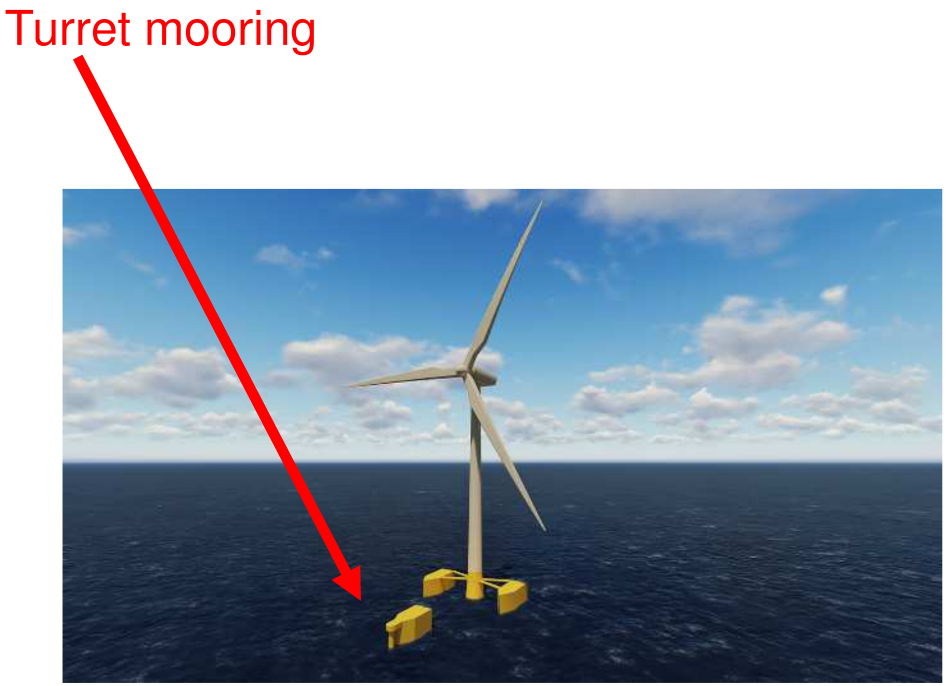


Model test University of Plymouth scale 1/50

TRIVANE, TURRET MOORING   Ref[7]

Trivane at 6 metre draft

for Assembly and Tow



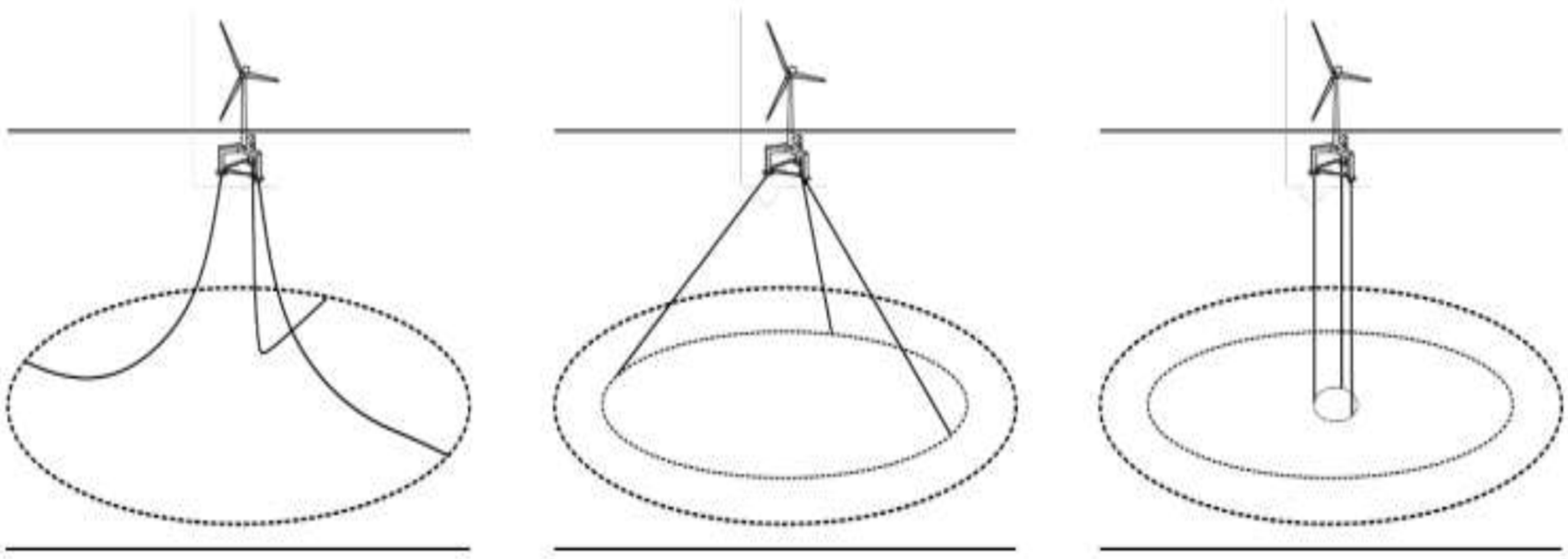
Trivane operating offshore
at 20 metre draft

PIVOT BUOY (X1Wind) For Canary Islands Ref[8]

MOORING

MOORING TYPES, ref [16]

Catenary | Taut / Semi-Taut | Tendon lines



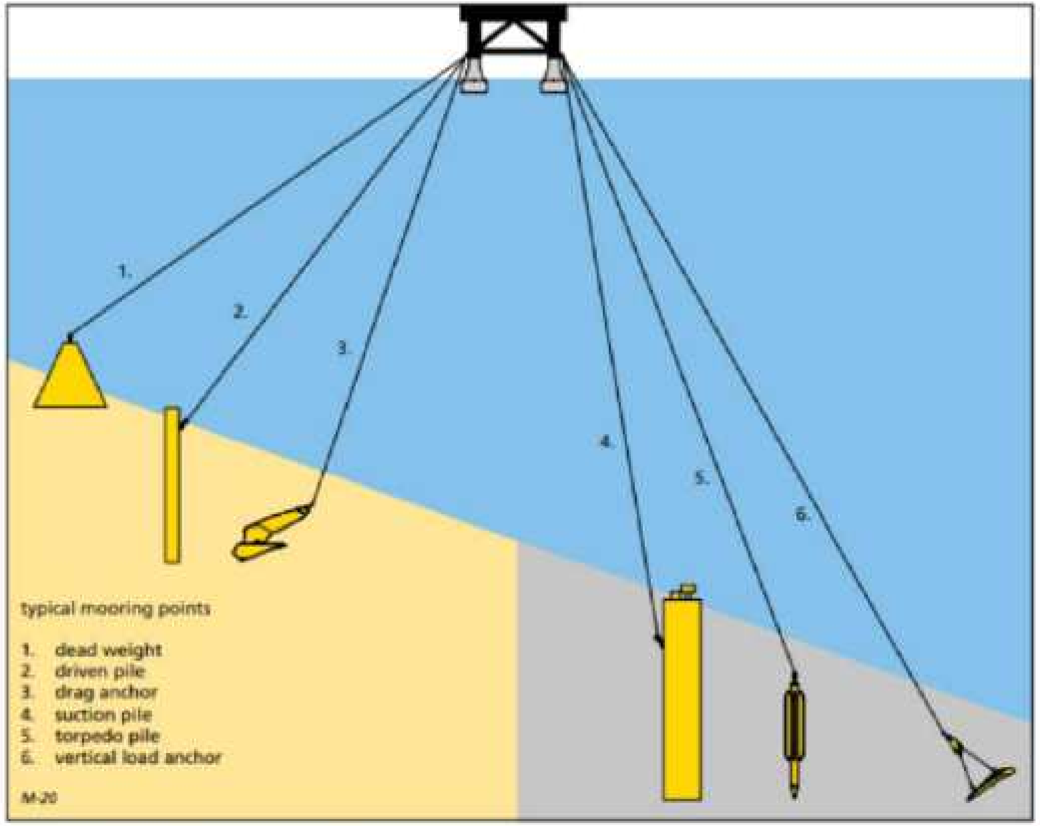
Source: Trubat Casal, P. (2020). Station keeping analysis and design for new floating offshore wind turbines.

ANCHOR TYPES, ref [17]

Gravity

Driven piles

Drag embedded anchor



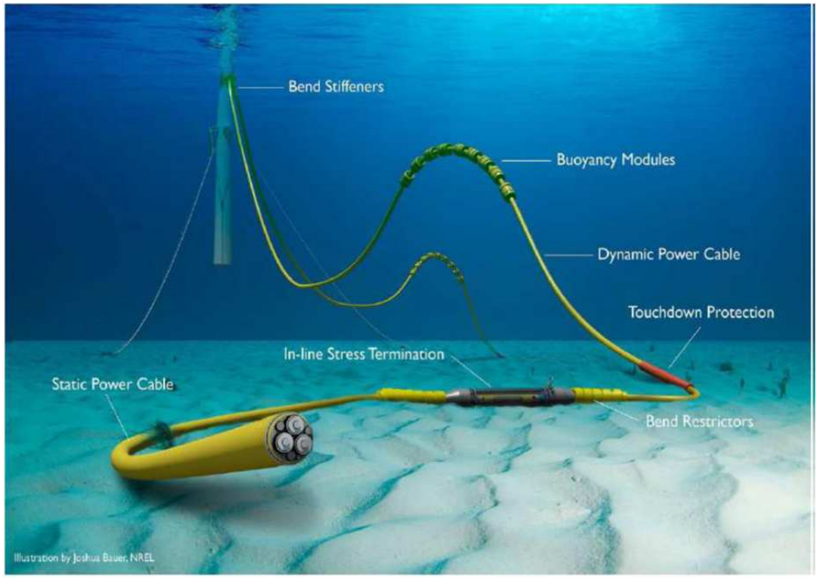
Suction

Free-fall

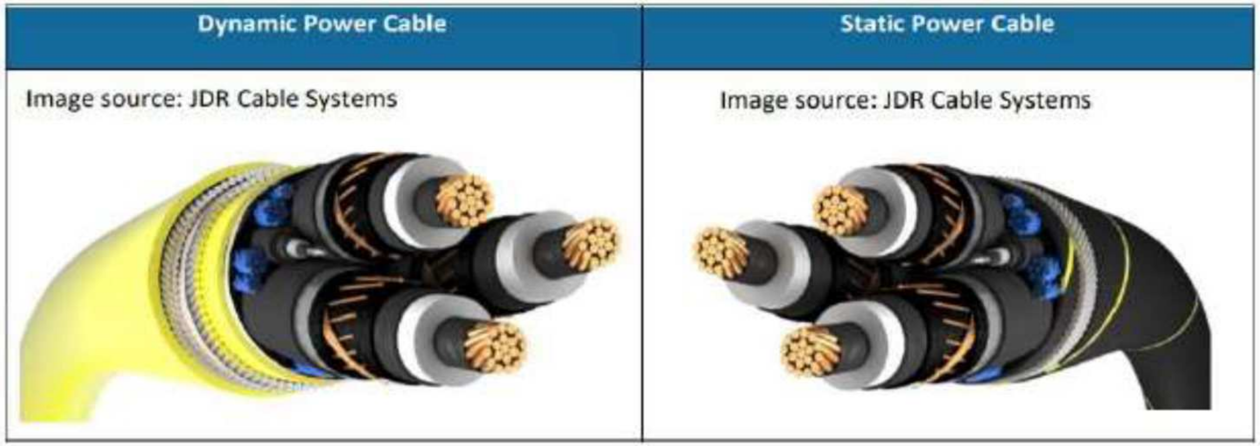
Plate anchor

CABLES, ref [18]

Inter Array Cable (IAC)
- Between Wind Turbines
- MV 66kV
- 3-core AC
- Dynamic and Static cable



Export cable
- From substation to shore/O&G facilities
- HV 132 345 kV cables, 3-core AC
- HV320 kV single core DC

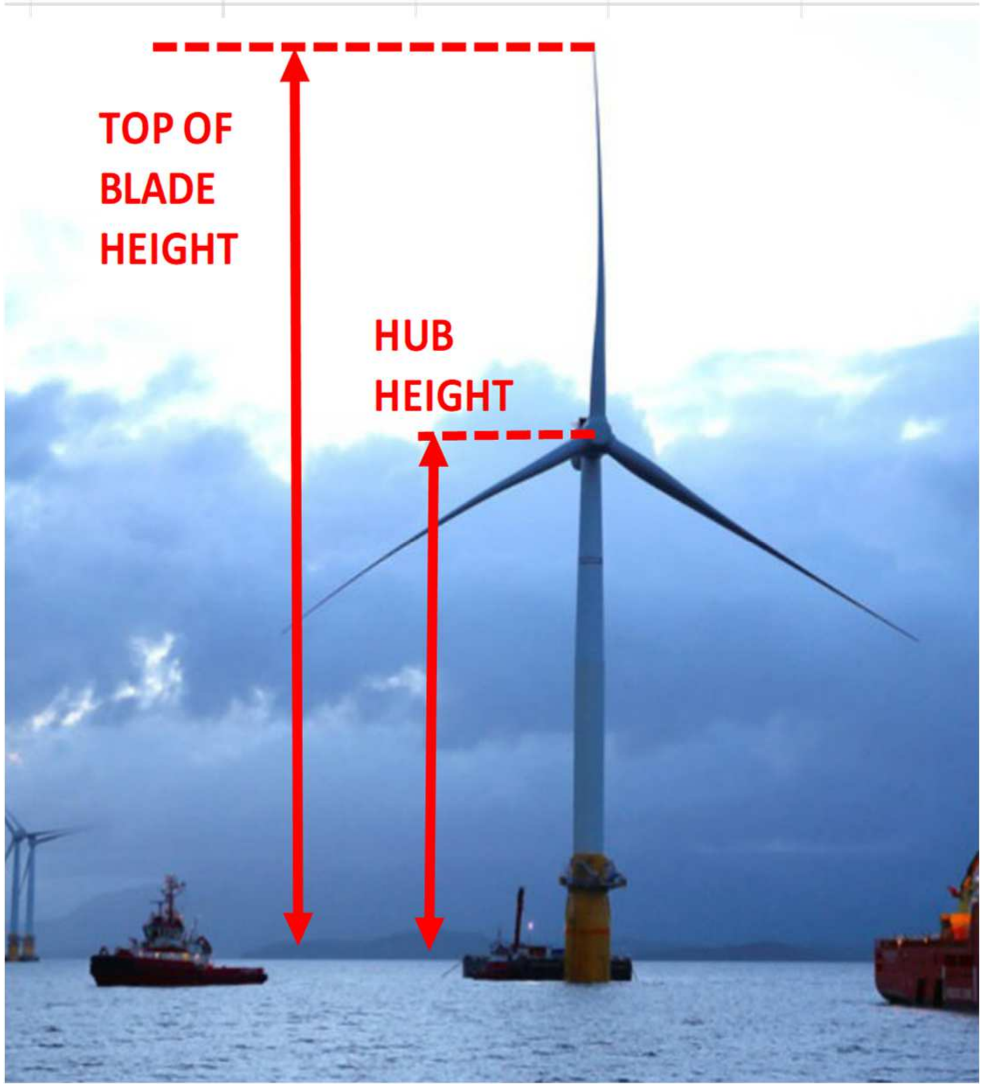


TURBINES

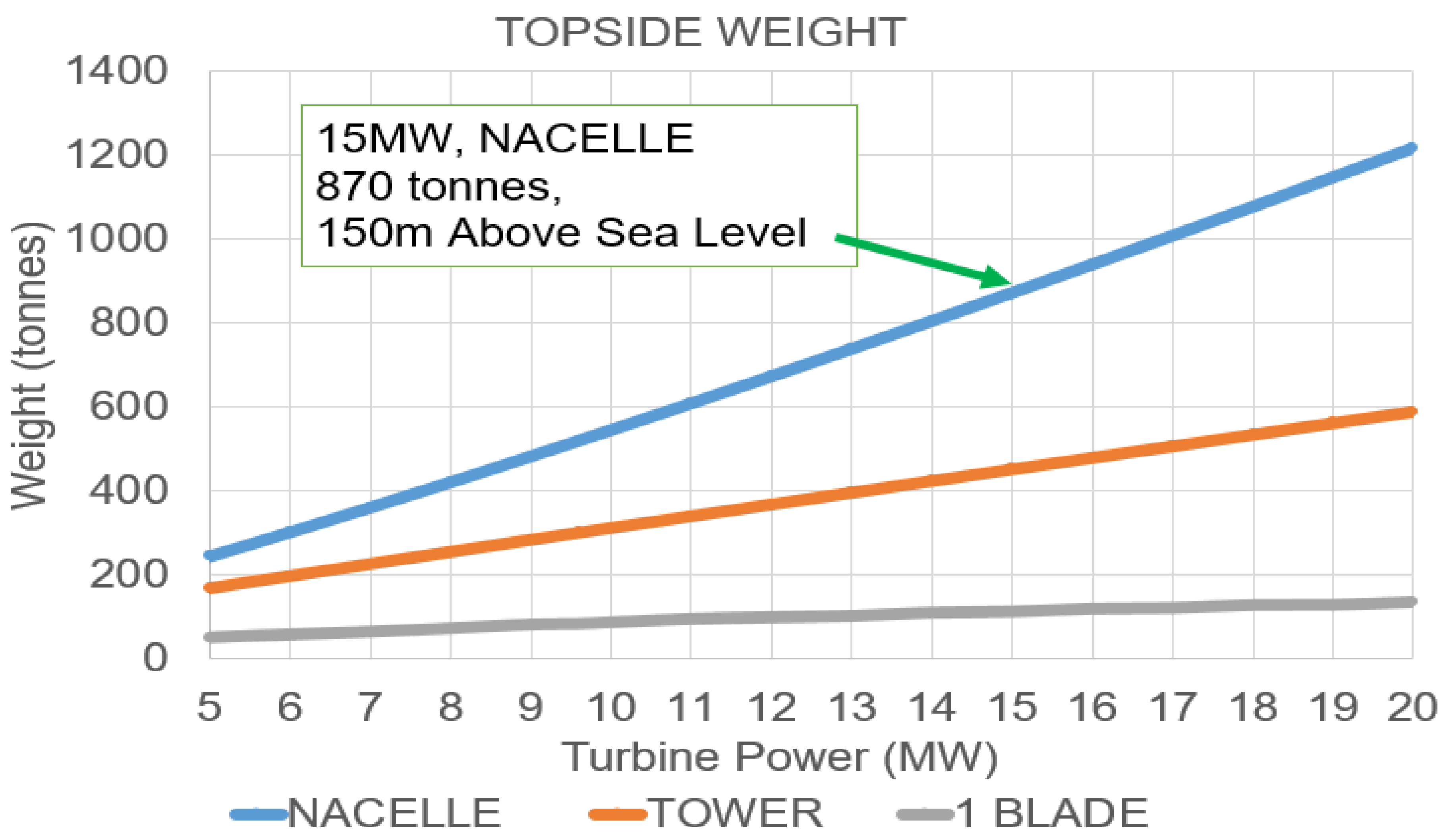
BLADE HANDLING, ref[13]

AIR DRAFT Ref[13]

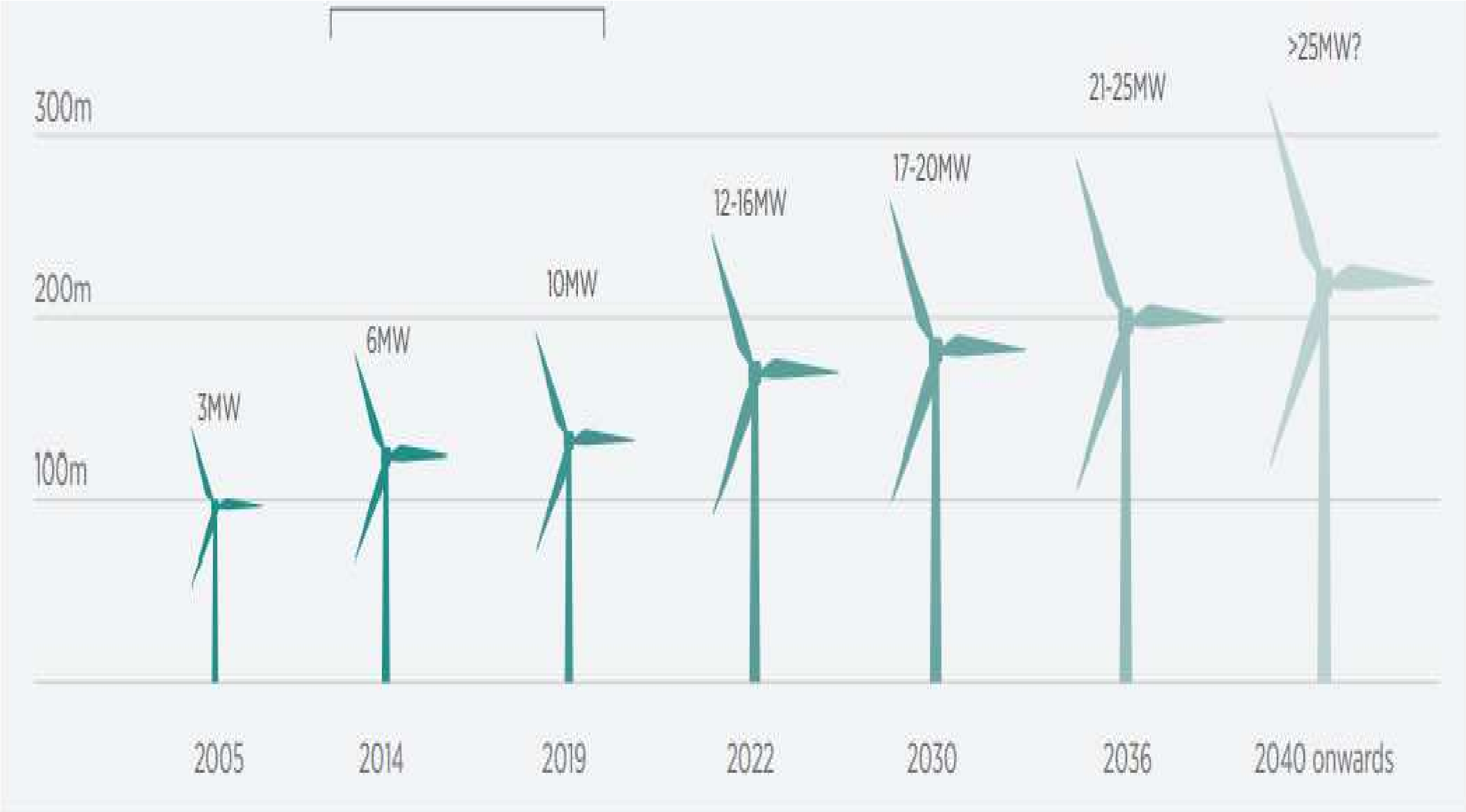
TURBINE CAPACITY	BLADE LENGTH	HUB HEIGHT	TOTAL HEIGHT	LOCATION
		ABOVE WATER		
MW	m	m	m	
2	43.3	68.8	113.2	
3	52.8	80.1	133.9	
5	67.6	97.4	166.2	
6	73.8	104.6	179.8	
8	84.9	116.3	202.6	Hywind Tampen
9.6	92.7	124.1	218.3	Kincardine
10	94.6	126.1	222.2	
11	99.1	130.6	231.2	
12	103.3	135.8	241.7	Dogger 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 Ref[13]



TURBINE SIZE **Ref[13]**



FOWT COSTS

Cost comparisons:
Fixed offshore wind is more expensive than onshore wind
Floating wind is 50% more expensive than fixed offshore wind
Floating wind major maintenance very expensive

Types
Numerous technologies. No clear winning concept yet. Semi-sub in steel is the better short-term solution.

Uncertainties;
- Insurability will be important factor for projects seeking finances
- Supply Chains need commitments from Developers to invest in facilities.
- No reliable CAPEX references available yet.
- No O&M references for business cases.
- Volatility of raw material costs, inflation, financing uncertainties.

PORTS - SUPPLY CHAIN (Ref [19])

15MW turbine

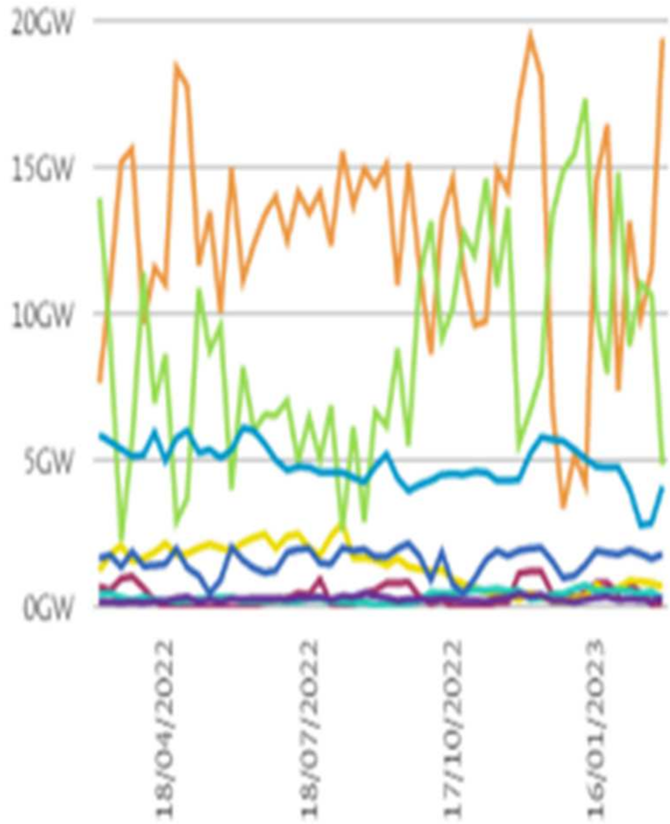
- Complete size of a given floater is around: 100 x 100 x 25m
- Complete weight of steel floater is around: 2,500 ~ 4,000 tons
- Addition weight of moorings 1000tonnes in 100m of water
- Complete weight of a concrete floater is around: 17,000 –27,000 tons

The port infrastructure should account for

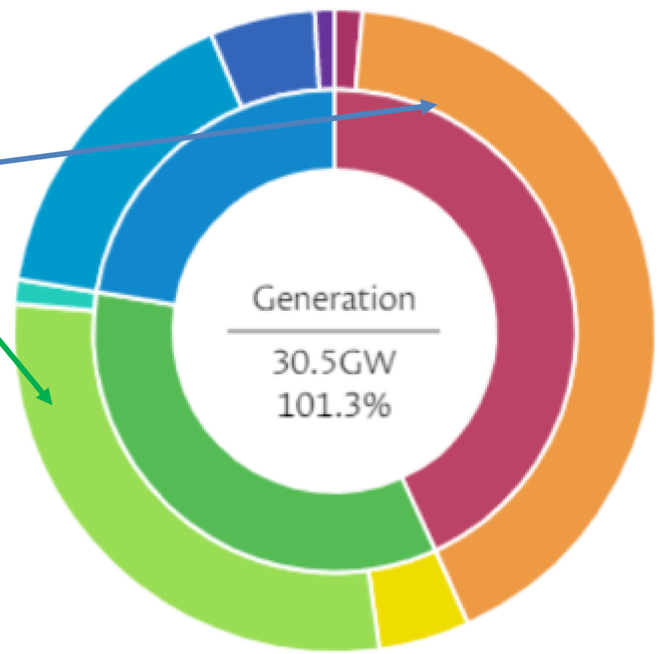
- Strong Bearing capacity for storage and assembly of components
- Bearing capacity of 25-50 tonne/sqm for WTG assembly operations
- Quay length of 500 meters
- Draft at quay and along channel should be no less than 10-12 meters

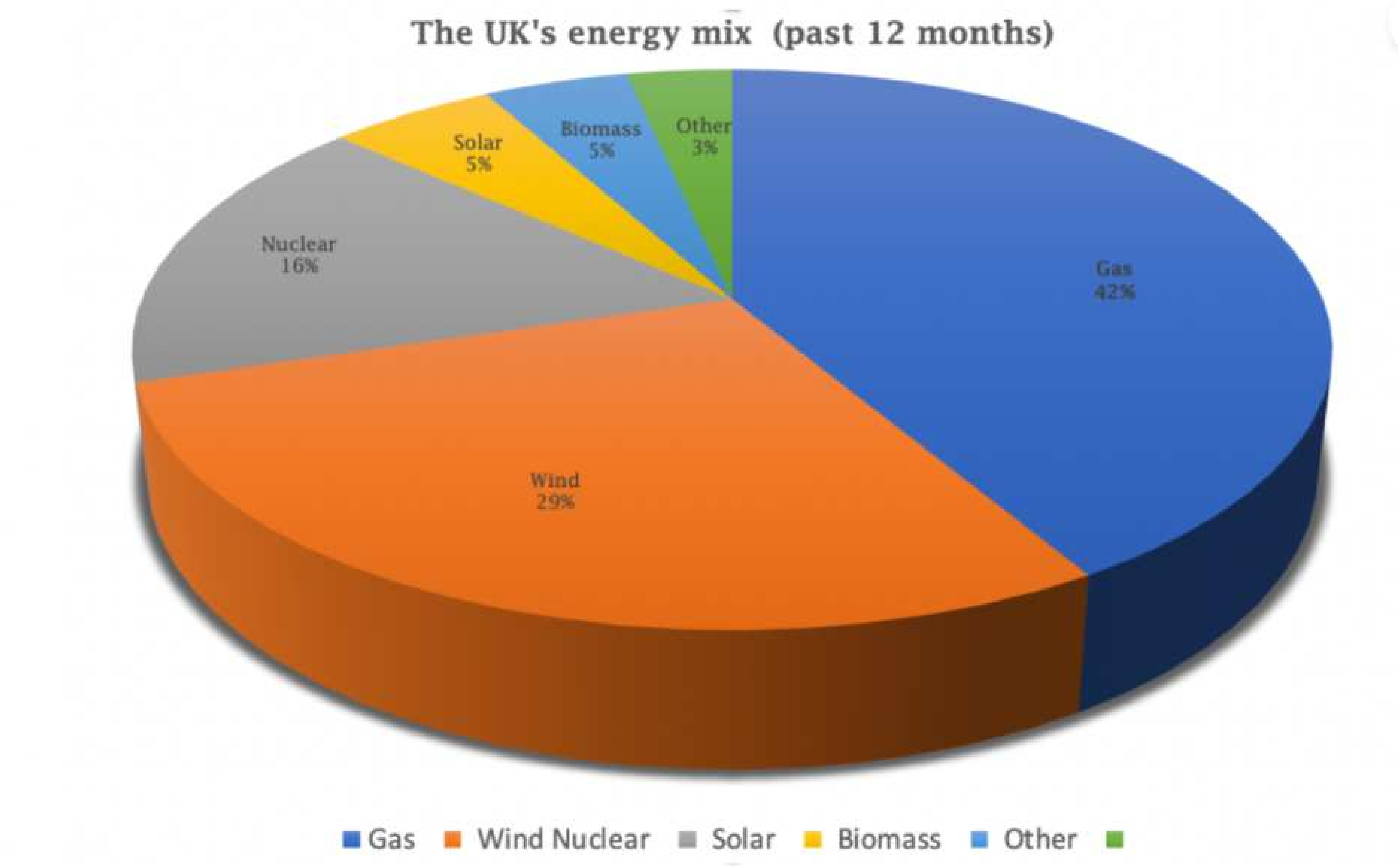
ELECTRICITY GENERATION

GB ELECTRIC 2022, Ref[21]



Generation by type	GW	%
Fossil fuels	13.2	43.7
Renewables	10.5	34.9
Other sources	6.8	22.7
Generation by source		
Coal	0.42	1.4
Gas (orange0	12.74	42.3
Solar	1.40	4.7
Wind (light green)	8.72	29.0
Hydroelectric	0.38	1.2
Nuclear	4.92	16.3
Biomass	1.61	5.4
Other	0.30	1.0
Imports and exports		
Belgium	0.04	0.1
France	−1.02	−3.4
Ireland	0.03	0.1
Netherlands	0.17	0.6
Norway	0.37	1.2
Storage		
Pumped storage	0.01	0.0





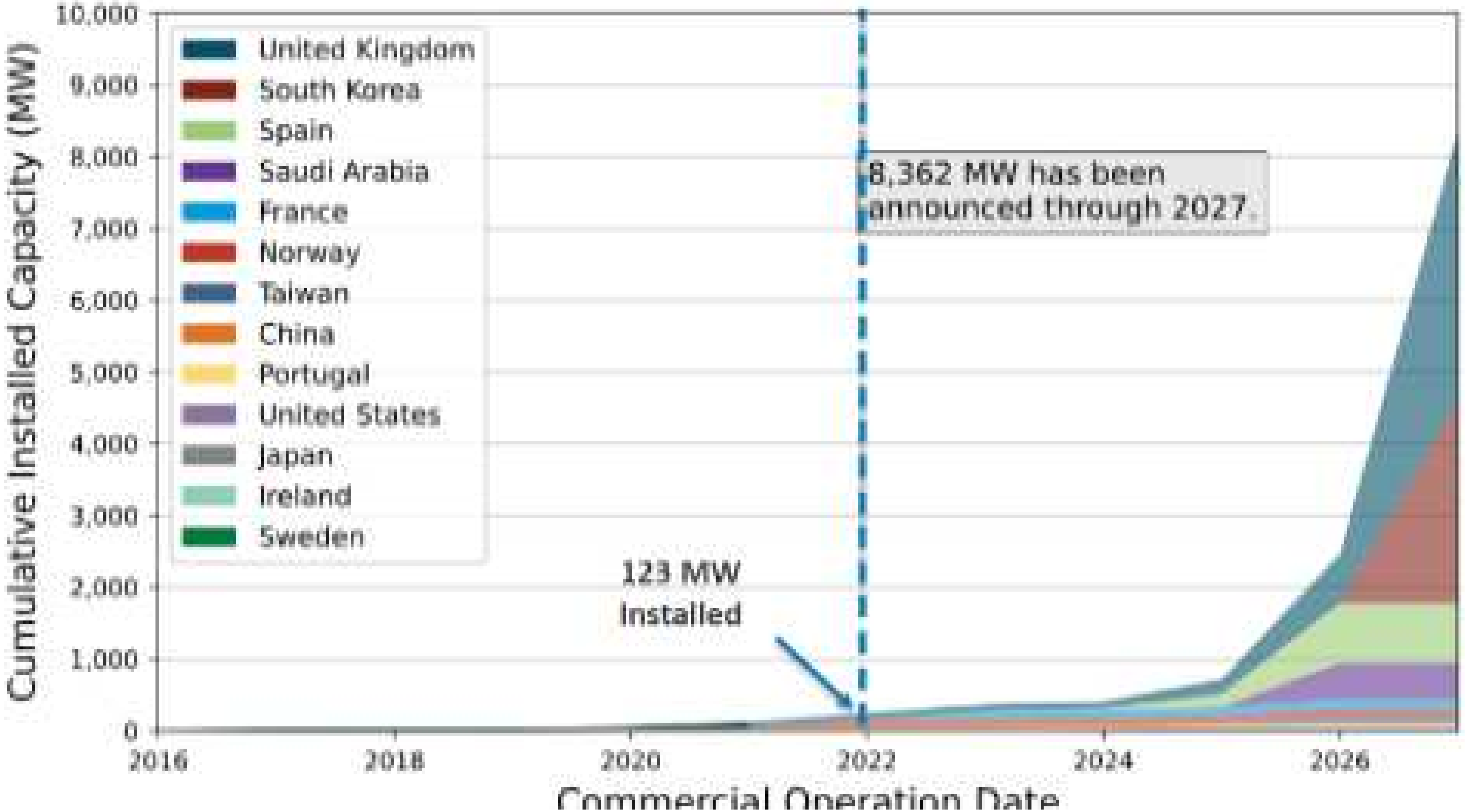
Wind is becoming an increasingly significant factor in the UK's energy mix (Source: grid.iamkate.com)

WORLD FLOATING WIND Ref[1]

Globally Floating Offshore Wind will grow from a low 15 km2 today to more than 33,000 km2 by 2050.

Floating wind			
Today		0.1GW	
Predicted 2027	world	8.3GW	
Predicted 2050	world	250.0GW	(16,000 of 15MW turbines)

CUMULATIVE FLOATING WIND Ref[22]



FOWT Challenges   Ref[20]

a. To reduce FOWT costs, sustained mass production is needed
c. Commercial FOWT will use >15MW turbines
d. Probably visual impact when fitted out inshore.
e. Spar and TLPs to stay offshore for in place major maintenance

Port With Manufacture Ref[28]

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 water 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 fixed-bottom wind turbines.

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)

> 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 ATTENTION

ANY QUESTIONS

Email ac1080@Exeter.ac.uk

ABBREVIATIONS

FOWT	floating offshore wind turbine
HTV	heavy transport vessel
Km	kilometre
M	metre
SPMT	self propelled modular transporter (trailer)
T	(metric) tonnes
WTG	wind turbine group

REFERENCES

1. ‘www.dnv.com, accessed 28 April 2022
2. ‘www.wison.com, accessed 28 April 2022
3. ‘www.menon.no, accessed 28 April 2022
4. ‘www.equinor.com, accessed 28 April 2022
5. ‘www.principlepower.com, accessed 28 April 2022
6. ‘www.saipem.com, accessed 28 April 2022
7. ‘www.trivane.com, accessed 28 April 2022
8. ‘www.hexicon.eu, accessed 28 April 2022
9. ‘‘www.deme.com’, accessed 16th Feb. 2022
10. ‘www.xwind.com accessed 1st June 2022
11. ‘www.bw-ideol.com, accessed 19th June 2022
12. ‘www. saitec-offshore.com, accessed 28 April 2022
13. ‘www.vestas.com, accessed 28 April 2022
14. BSEE, Bureau of Safety and Environmental Enforcement (USA), 2022
15. US Department of Energy, 2023, *Josh Bauer/NREL*
16. ‘www.ibedrola.com , 2023
17. ‘www.vrhof.com, and ‘www.aecton.com 2023
18. ‘www.NREL.com, 2023
19. ‘www.bluefloat.com, 2023
20. ‘www.mainstreamrenewablepower.com, 2023
21. ‘www.iamkate.com, 2023
22. ‘www.energy.gov, 2023
23. ‘www.sbm.com, 2023
24. ‘www.floatingwindfarm.weebly.com, 2023
25. ‘www. everaxis.com, 2023
26. ‘www.roll-group.com, 2023
27. ‘www. Fukushima-Forward.jp, 2021
28. ‘www.moffatandnichol,.com, 2023
29. ‘www.jmu.jp, 2023

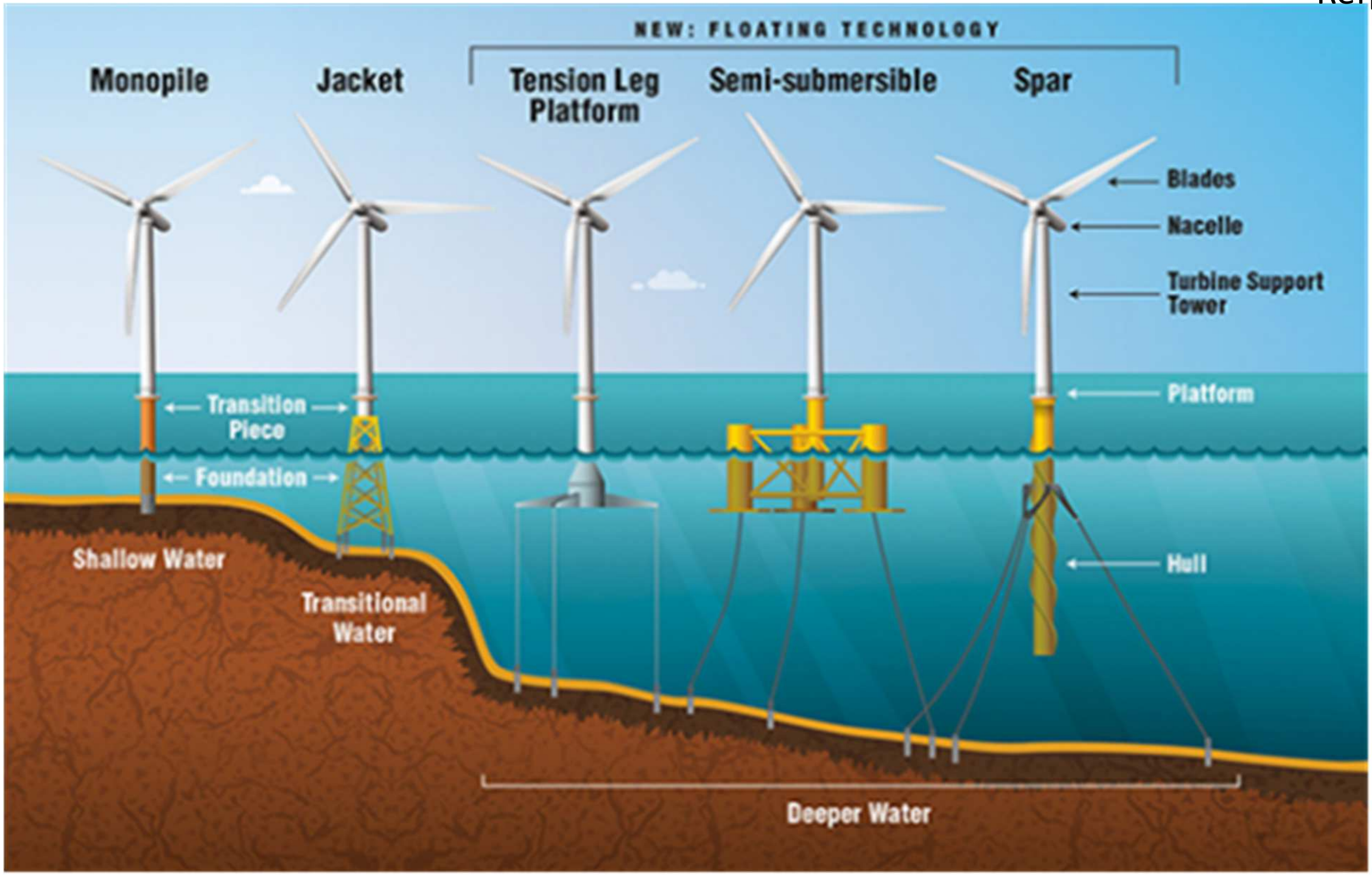
ABSTRACT

Interest in floating offshore wind farms in deep waters is increasing, as an option for marine renewable energy. Existing floating wind projects demonstrate the feasibility of future commercial floating wind farms. To boost the competitiveness of floating offshore wind energy, it is important to identify the major cost drivers during the lifecycle, including the installation phase. Costs will be considered in the presentation into the optimum use of installation vessels. Each type of floating substructure types exhibit quite different characteristics during transportation and installation.

This presentation is a review of the state-of-the-art technical aspects of floating offshore wind turbine installation for different substructures types. An overview is first presented introducing the classification of floating offshore wind turbines, installation vessels, rules and regulations, and numerical modeling tools. Various installation methods and concepts for floating offshore wind turbines are critically discussed, including cable installation, wind turbine substructures and components. Opportunities and challenges of the installation methods of floating offshore wind turbines are identified.

Future developments in technical areas are envisioned in loadout, topside fit out, ocean tow and offshore installation are discussed. This review aims to guide research and development activities on floating offshore wind turbine installation.

Ref[14]


NEW: FLOATING TECHNOLOGY
Monopile
Jacket
Tension Leg Platform
Semi-submersible
Spar
Blades
Nacelle
Turbine Support Tower
Platform
Hull
Transition Piece
Foundation
Shallow Water
Transitional Water
Deeper Water

Engineers Formed 1913

ıish Institute of Engineers invite you to a lecture **Thursday 13th April 2023 6.00pm**

ıapel Lecture Theatre, Penryn Campus, Penryn, Cornwall, TR10 9FE

ɛ welcome - both members and non-members – 6.00pm Tea & Coffee: 6.00pm CIE AGM: 6.45pm Lectuı

s easily accessible via local bus and rail services. Plenty of car parking on site.

ieneral Meeting of the CIE takes place 6.00pm & will be immediately followed by the **Don Dixon Memorial Lectu**

URE: Floating Offshore Wind Turbines – Installation Techniques

ɛntation will investigate construction and installation challenges for the various varieties of floating offshore wind turbi
ɛ the barges, the semi-submersibles, the spars and the tension-leg platforms (TLPs). The aim is for simplification of iı
time spent by personnel offshore and a valuable minimization of risks.

Crowle **Fellow RINA, IMarEST** and **Soc Consulting Marine Engineers & Ship surveyors**

aval Architect with over 50 years experience in design, construction and installation of many marine structures.
growth in offshore wind, Alan has returned to university! Currently studying for a Masters by Research with the University of
ɛnewable Energy team, Alan is investigating optimal techniques for the installation of these massive, ingenious floating
ind turbine structures.

Questions

Q1. Why is floating wind so important?

A1. It is important for climate change that as much electricity as possible is produced from renewable resources, floating wind being one of them.

Q2. How do you expect existing floating construction equipment to be used for floating wind installation?

A2: Large crane vessels such as those operated by Heerema and Saipem will have a part to play in construction of TLPs

Q3. How can heavy maintenance be carried on during operation of Spars and TLPs?

A3: Large crane vessels such as those operated by Heerema and Saipem will have a part to play in the heavy maintenance of TLPs and Spars, but will need to fitted with active heave compensation.

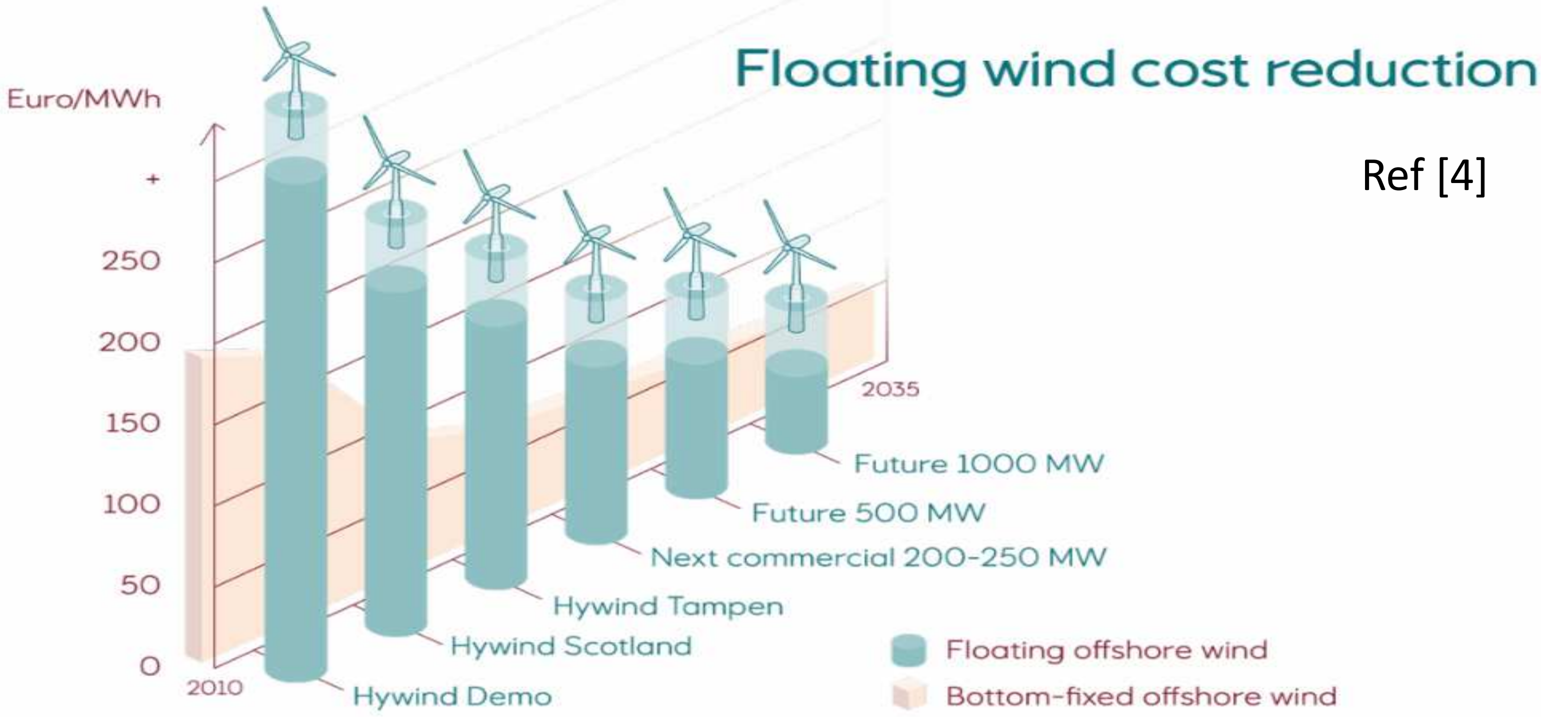
Q4. What new marine vessels are required to install floating wind turbines?

A4. Larger anchor handling tugs which can transport several sets of mooring components and then install them.

Q5. What changes are required in fit-out ports for the inshore construction of floating wind?

A5. The port needs to be within in 3 days sailing time of the offshore wind, at about 3knots maximum, i.e. about 200 nautical miles. A strong quay capable of supporting large mobile cranes. Also water depth alongside the quay of over 0m at low tide is required.

Q6. How is the cost of floating wind turbines expected to reduce?
A6. See the Equinor estimates of future floating wind.



Ref [4]

Equinor says the costs of floating wind are falling as the technology is scaled up (Credit: Equinor)

Q7. Can old oil rigs be used for floating wind?

A7. There may be a role for jack ups to be converted into floating port construction vessels. ClassNK has issued an approval in principle (AiP) for the conversion plan of the medium-sized self-elevating platform (SEP) vessel (*pictured*) for the installation of large wind turbine on a semi-sub floater in port, re[]