DOE

MARKET RESEARCH STUDY

CRANES FOR WIND TURBINES

August 2023

This project was funded by the Department of Energy, an agency of the United States Government, through a contract for Phase 0 Outreach and Assistance for the Small Business Innovation Research/Small Business Technology Transfer Programs Office. Neither the United States Government nor any agency thereof, nor any of its employees, nor the contractor, nor any of their employees, makes any warranty, expressor implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Prepared by Dawnbreaker® • 2117 Buffalo Road • Rochester, NY • 14624 • (585) 594-0025 • www. dawnbreaker.com

Table of Contents

1.0 Introduction

Wind turbines are expected to be taller, larger and louder whether based on land or offshore. This conclusion is based on two reports from Lawrence Berkeley National Laboratory (LBNL) and the National Renewable Energy Laboratory.[1,2] In the 2023 analysis of land-based turbines LBNL concludes that wind turbine heights are expected to be 60% taller in this decade, than the 122 meters that was common between 2011 and 2020.[3] This same trend is seen with offshore wind, where towers are both taller and the turbines more powerful. These predictions have many implications for the challenges facing the wind turbine industry.

This report focuses on one challenge – the ability and availability of cranes needed to hoist these towers whether on land or offshore, as well as their availability for maintenance. While it is natural that offshore wind cranes would be designed to withstand extreme weather conditions, these offshore cranes must also offer a far larger lifting capacity compared to onshore cranes.[4] Given that the challenges are different in both environments, this report is divided into two sections – the first focused on cranes designed for off-shore tower and turbine installation and maintenance, while the second section focuses on cranes needed for land-based installation/maintenance of taller turbines.

Offshore Wind Cranes

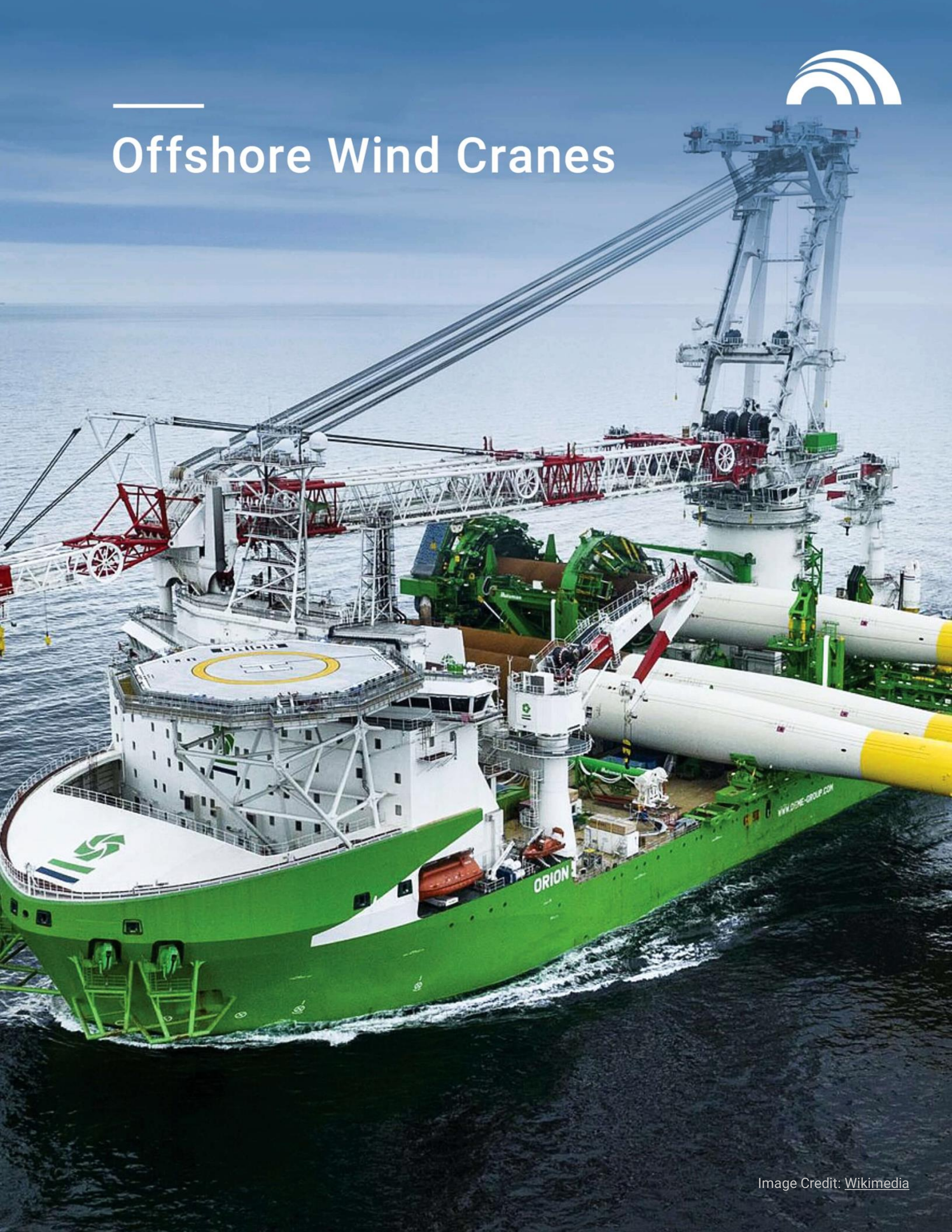


Image Credit: Wikimedia

2.0 The Growth of Offshore Wind and the Cranes used to Build Them

Although the discussion of offshore windfarms has been ongoing for many years, the actual number of Operating Wind Farm Projects is limited. China has 134 fully commissioned wind projects, the United Kingdom has 43, and the United states has two.[5] Globally, many other windfarms are in various stages of preparation. The ForeSee database provides insight into all of these projects and their stage of development in the permitting, construction and commissioning processes.

Table 1: The Number of Offshore Wind Farm Projects by Country and Stage of Permitting/Development

Country	Offshore Wind Farm Projects	# Projects Operating	Construction has progressed to connect turbines	In Build Phase	Consented or applied for Consent
Belgium	16	12	0	0	0
China	413	134	4	14	14
Denmark	122	15	0	1	3
France	46	2	0	4	4
Germany	188	29	1	1	4
Ireland	73	1	0	0	1
Japan	173	12	0	3	3
Netherlands	132	11	3	1	1
Taiwan	141	4	5	2	2
United Kingdom	223	43	1	3	11
United States	187	2	0	2	24
Vietnam	139	29	1	4	5

Source: Data from TGS 4Coffshore

The first U.S. offshore windfarm was installed off the coast of Block Island, Rhode Island in 2016.[6] This five-turbine, 30 MW project was developed by Deepwater Wind, now Ørsted US Offshore Wind. Envisioned initially as a larger project, this initiative replaced the diesel generators that previously provided power to residences on this island.

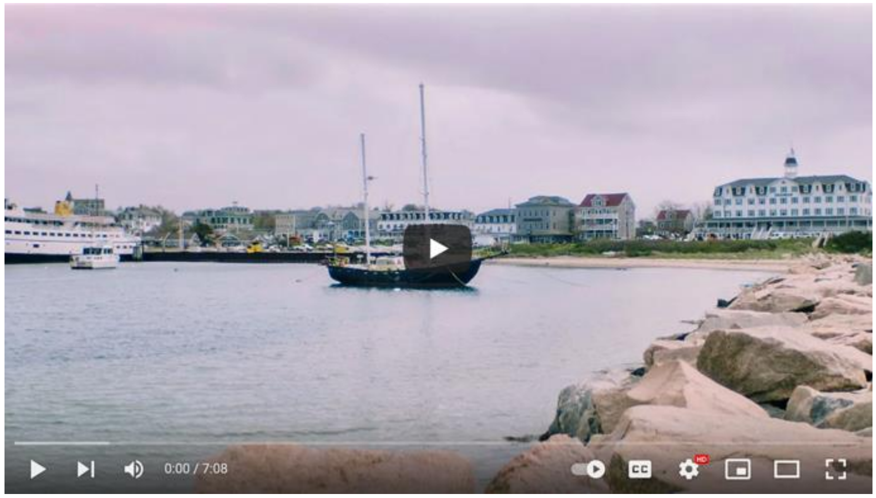


Figure 1: The First U.S. Offshore Windfarm on Block Island Rhode Island
Click here to see video

There are two types of offshore wind farms installed today: **(1) Fixed Bottom Wind Farms and (2) Floating Wind Farms**. Most of the early offshore wind farms were fixed bottom, but that trend is beginning to change as an increasing number of floating windfarms are anticipated globally. The reason for this is that 80% of global offshore wind resource potential is found in deep waters (>60 m). This is too deep for fixed-bottom offshore wind turbines and water at this depth requires floating wind turbines in order to efficiently harness deep water wind. While floating wind contributes only a small percent of the cumulative offshore wind capacity at this time, the market is still in its early stages. According to a 2022 publication by Carbon Trust, the following floating windfarms are currently fully commissioned and tend to scale from one to multiple turbines in numerous phases.

Table 2: Fully Commissioned Global Floating Wind Projects

Project	Country	First Power	Total capacity	Turbine Rating
Hywind I	Norway	2009	2.3 MW	2.3 MW
Sakiyama 2MW Floating Wind Turbine	Japan	2016	2 MW	2 MW
Hywind Pilot Park	United Kingdom	2017	30 MW	6.0 MW
Floatagen Project	France	2018	2MW	2 MW
Kinkardine - Phase I	United Kingdom	2018	2 MW	2 MW
IDEOL Kitakyushu Demo	Japan	2018	3 MW	3 MW
Kinkardine - Phase 2	United Kingdom	2021	48 MW	9.5 MW
TetraSpar Demonstrator - Metcentre	Norway	2021	3.6 MW	3.6 MW
CTGNE Yangjiang Shapa - Phase III	China	2021	5.5 MW	5.5 MW

Source: Data from Carbon Trust[7]

The short video of Hywind Scotland provides insight into the magnitude, weight and complexity of the installation process and introduces the importance of heavy lift cranes.

Figure 2: Full Story of Hywind Scotland – the World's First Floating Windfarm
Click here to see video

Analysts predict that global floating wind installations are to increase rapidly in the coming years due to the development of many 100.0 MW to 500.0 MW projects. Main growth markets that are called out include France, the UK, the United States, South Korea, Ireland, Japan, Norway, Colombia, and Italy. Looking towards the future, floating wind turbines are expected to account for 16.5 GW by2030.[8] The actual rate of growth will depend on navigating – supply chain issues, securing substantial financial investment and support to develop or modernize both port infrastructures as needed, as well as manufacturing facilities.[9]

The following figure details the projected installed floating wind capacity predicted by Frost & Sullivan analysts for the 2022–2030-time frame.

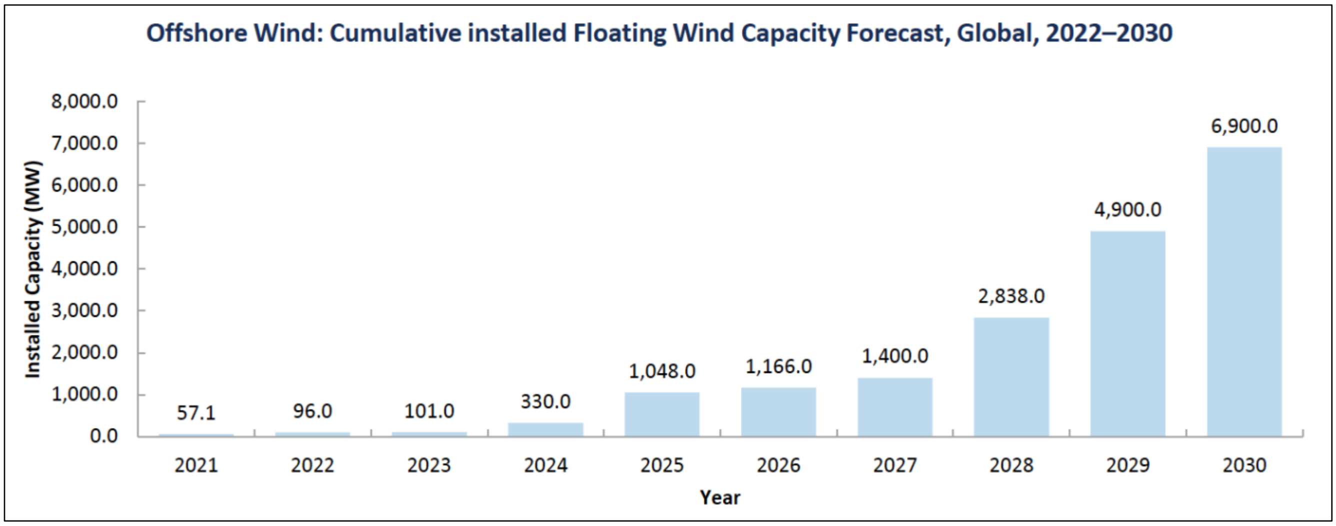


Figure 3: Offshore Wind: Cumulative installed Floating Wind Capacity Forecast, Global, 2022–2030
Source: Reprinted with permission from Frost & Sullivan[10]

Currently, there are three types of floating foundations for floating offshore wind turbines. These include the following:

- **Spar:** A Spar floating foundation is constructed of concrete, steel, or a hybrid combination. The Spar floating foundation is a cylinder that floats vertically in the water.
- **Tension Leg Platform (TLP):** A TLP floating foundation is constructed of steel and consists of multiple columns and pontoons. The TLP's mooring system requires vertical-tensioned tendons that offer stability to this type of structure.
- **Semi-submersible:** A semi-submersible floating foundation is constructed of either concrete, steel, or a hybrid combination. This type of floating foundation consists of multiple pontoons and columns and a hull that is submerged.

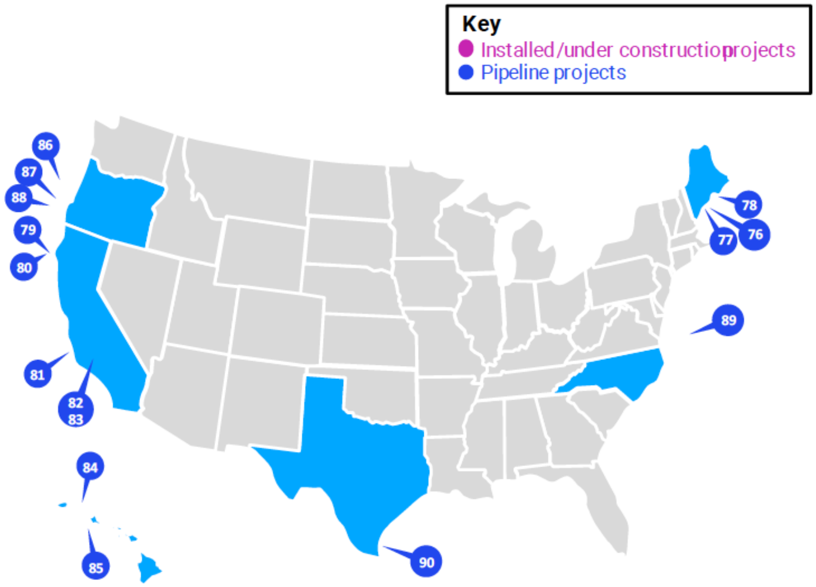
The following figure illustrates these three types of floating foundations. They are, from left to right: Spar floating foundation, Tension Leg Platform (TLP), and Semi-submersible.

Figure 4: Illustration of floating foundation types (NREL 2022)
Key, left to right: spar, semi-submersible, TLP
Source: U.S. Department of the Interior, Bureau of Ocean Energy Management (BOEM), January 2023[11]

2.1. United States Market: Floating Offshore Wind

As of July 2022 reporting, although the U.S. has yet to deploy any demonstration projects, the forecast for floating offshore wind up to 2030 remains very high. In 2022 "The President set a bold goal of deploying 30 gigawatts (GW) of offshore wind by 2030, enough to power 10 million homes with clean energy, support 77,000 jobs, and spur private investment up and down the supply chain."[12]

There is an increasing focus on floating offshore wind in the U.S., with most of the interest coming from the west coast – as seen in the figure below. California and Oregon both have set targets of 3 GW floating offshore wind by 2030. Additional states such as North Carolina and Maine, while they have set OSW targets, there is "nothing specific to floating wind."[13]



Project	MW
Maine	
76. Aqua Ventus	12
77. Maine Research Array	144
78. Future Floating *	450 - 1500
California	
79. Redwood	150
80. Humboldt WEA *	1600
81. Morro Bay *	700-1000
82. Lompoc/CADEMO	60
83. Castle Wind *	1000
Hawaii	
84. Oahu Northwest *	400
85. Oahu South *	400
Oregon	
86. Coos Bay *	10,000
87. Bandon *	2,800
88. Brookings *	3,400
North Carolina	
89. Central Atlantic E *	1000
Texas	
90. Gulf of Mexico *	2000

** = call areas*

Figure 5: Map of American floating offshore wind projects in the pipeline
Source: 4COffshore; Carbon Trust, July 2022[14]

As the projects mentioned in this figure are in the planning stage, one can readily assess the 2023 status by conducting a quick search using the projects name. The following links to sample articles relate the three largest projects mentioned in this figure: Maine: Future Floating; California: Morro Bay and Oregon: Coos Bay.

- Maine: "The Future of wind energy in the U.S. is floating turbines as tall as 30 rock"[15]
- California: "Morro Bay Wind Energy Area"[16]
- Oregon: "Oregon governor, lawmakers call for offshore wind pause"[17]

3.0 Installation and Maintenance of Offshore Wind Turbines (OWT)

The increase in turbine size, the height of the towers and the distance from the shore of both fixed and floating offshore wind installations have given rise to a number of challenges. Cranes, often referred to as "heavy lifting devices" are needed to assemble and install the wind tower (whether fixed or floating). The amount of weight cranes must lift and the heights to which they need to be raised have resulted in many new designs.

In looking at the process of assembling and installing offshore wind, it is useful to consider what equipment is needed quayside or on the vessel used to transport, position and aid in the final assembly of the wind tower at its designated location. In a 2023 publication from the National Renewable Energy Laboratory (NREL), it was suggested that “Port operations will still require forklifts, gantry cranes, and heavy-load carriers to transport components, and large gantry cranes or quayside mounted ring or crawler cranes will be needed to join the columns and trusses and then integrate the wind turbine. Quayside infrastructure will likely require heavy-lift wharfs to accommodate these operations. Requirements may be reduced if the floating platforms are assembled on semisubmersible barges.”[18]

What is emerging is an increase in modifications to cranes installed on the transport vessels themselves. Contractors are working to develop next-generation wind turbine installation vessels that can realize lifts on offshore windfarms within “the next few years.” These heavy lift vessels (HLVs) will permit lifts weighing up to 1300 tons and achieving heights of approximately 120m above sea level, with a horizontal reach of 35m.[19] Companies such as **Cadeler** have commissioned turbine installation jack-up vessels with a carrying capacity of 17,600 tons. “Each vessel should be able to transport and install seven complete 15-MW turbine sets.”[20] Other companies specializing in designing and manufacturing cranes to be mounted on ships serving the wind industry include Liebherr. The HLC 295000 has a lifting capacity of 5,000 tons. Huismann also makes a family of cranes for this application including pedestal mounted cranes and leg encircling cranes. Jack-up boats which have been prevalent in the wind operations and maintenance market are increasingly challenged by these factors.[21]

3.1. Crane Typologies

The World Forum Offshore Wind (WFO) organization suggests that the [crane] lifting function associated with operation and maintenance of offshore wind farms be classified in the following manner, while referring to fixed of floating offshore wind systems:

“• **Fixed-to-fixed lifting operation,** e.g. from a jack-up vessel to a bottom-fixed offshore
wind turbine

● **Fixed-to-floating lifting operation.** e.g. from a jack-up vessel to a floating offshore wind turbine (FOWT) at harbor or from a heavy lift crane at the quayside to the FOWT

● **Floating-to-fixed lifting operation,** e.g. from a heavy lift vessel to a bottom-fixed Turbine

● **Floating-to-floating lifting operation**, e.g. from a heavy lift vessel to a FOWT."[22]

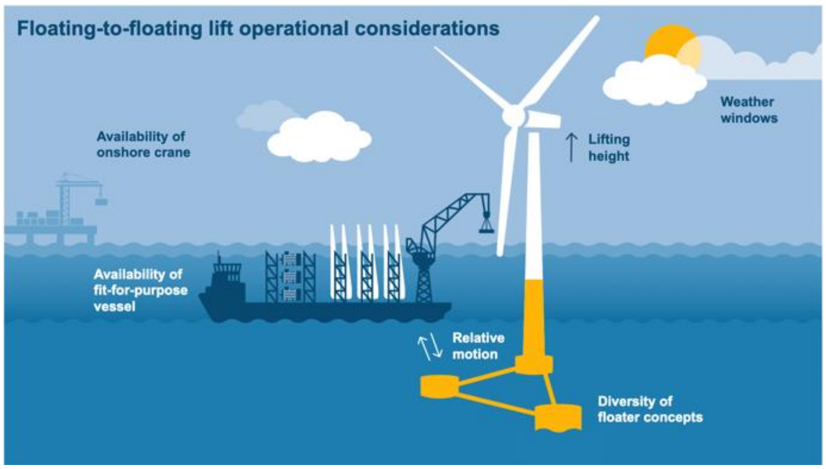


Figure 6: Lifting needs when transferring from one floating entity to another
Source: World Forum Offshore Wind[23]

The following figure also from the WFO report represents a variety of add-on cranes. This includes two major categories: Tower-based and Platform-based cranes. The tower-based example depicts two types of cranes: Self-hoisting and self-climbing.

Figure 7: Tower-based and Platform-based Add-on cranes
Source: WFO[24]

The following short video provides a demonstration of a self-hoisting crane.

Figure 8: A self-hoisting crane demonstration
Click here to see video

3.2. Operations and Maintenance Needs for Cranes

Operations and maintenance (O&M) is one of the top issues in bottom-fixed offshore wind farms, as it serves to reflect the challenges experienced by wind farm owners in reducing OpEx (operating expense) due to "variable vessel charter costs" and environmental constraints on accessibility. (To clarify, the environmental constraints involve floating turbine and maintenance vessel motion/movement.)

The main feature of a jack-up vessel is its ability to elevate itself above the water surface using a system of legs.

As part of the Phase III Summary report published by Carbon Trust,[25] the Heavy Lift Maintenance (HLM) and Tow-to-Port (TTP) studies were reviewed. Their objective was to examine two alternative strategies for performing large component exchange on floating wind turbines. These were: 1) Heavy lift maintenance (HLM) where operations were done from a floating platform within the wind farm array; and 2) Towing the turbines to shore for port-side maintenance (TTP). It was expected that jack-up vessels would not be viable due to water depth for the exchange of large components within a floating offshore wind farm. It was more likely that component exchanges would be performed either by a floating crane vessel or alternative temporary crane solutions able to use lower cost vessels. As is often discussed, the ever-increasing size of next generation turbines is creating a demand for new, larger turbine installation vessels. The downside of this is that "given the expected high cost of using these large, heavy-lift dynamic positioning (DP) vessels for maintenance work, there is considerable interest in understanding alternative solutions that can perform component exchange operations utilizing smaller vessels."

When addressing heavy lift and maintenance (HLM), the problem is that many of the existing fleet of heavy lift vessels (HLVs) are unable to lift to the hub height of a 10MW offshore wind turbine. Beyond that, a consideration must be acknowledged that over the course of a wind turbine's lifetime (even more notably when looking at a large wind farm and its many turbines) the large(r) components (e.g., such as rotor blades, transformers, generators, etc.) will require repair and possibly replacement. Unique to floating offshore maintenance are the challenges associated with motion – between the lift vessel and floating turbine – that result in extreme demands on the dynamic positioning (DP) system and other motion-compensation systems (in addition to weather restrictions when occurring).

> "Floating offshore maintenance has previously been performed within the oil and gas industry, but it is noted that many of the existing heavy lift vessels (HLVs) would be unable to lift to the hub height of a 10MW turbine (approximately 112m above sea level), although they would have adequate weight capacity."[26]

Another factor to consider is that for the typical floating offshore wind farm, it is expected that "large component exchange will require at least 1-2 lifts annually, but the requirement for heavy lift component replacement might be significantly increased due to serial component failures, fatigue damage, extreme events etc. In particular, blade leading-edge erosion may lead to the requirement to replace a large number of blades within the design lifetime of 25-30 years."[27]

3.3. Temporary Vessel-mounted Cranes, Turbine-mounted Cranes

It is anticipated that several options will become available that will assist more readily with major component replacement. These include **temporary vessel-mounted cranes, turbine-mounted cranes, and traditional heavy lift vessels.** Nacelle cranes (whether permanently or temporarily installed) will have smaller lifting capacities as compared to external cranes. For this reason, the components may need to be broken down into sub-components and this "incurs time, pre-lift preparation and the requirement for reassembly in the nacelle." When using external cranes, it requires the use of a dynamic positioning (DP) vessel which brings with it unique challenges that include motion compensation systems, safe handling zones, vessel availability, equipment transfer, and possibly a need for assistance from an offshore service vessel (OSV) if the external crane vessel has limited deck space. *As a result, advances in crane design that enable heavier and higher lifts will benefit both fixed and floating wind platforms and even may offer the* *capability for heavy lifting, at height, without the requirement of HLVs or larger deck area OSVs*.

Figure 9: A Self-hoisting crane improves wind turbine maintenance
Click **here** to see video

4.0 Offshore Crane Innovations

As noted earlier, contractors are working to develop next-generation wind turbine installation vessels that can realize lifts on offshore windfarms within "the next few years." These Heavy Lift Vessels would permit lifts weighing up to 1300 tons and achieving heights of approximately 120m above sea level, with a horizontal reach of 35m. *Also under development are innovative technologies, such as climbing cranes, that are "expected to facilitate offshore maintenance without the use of HLVs, which may enable cost reductions."* [28]

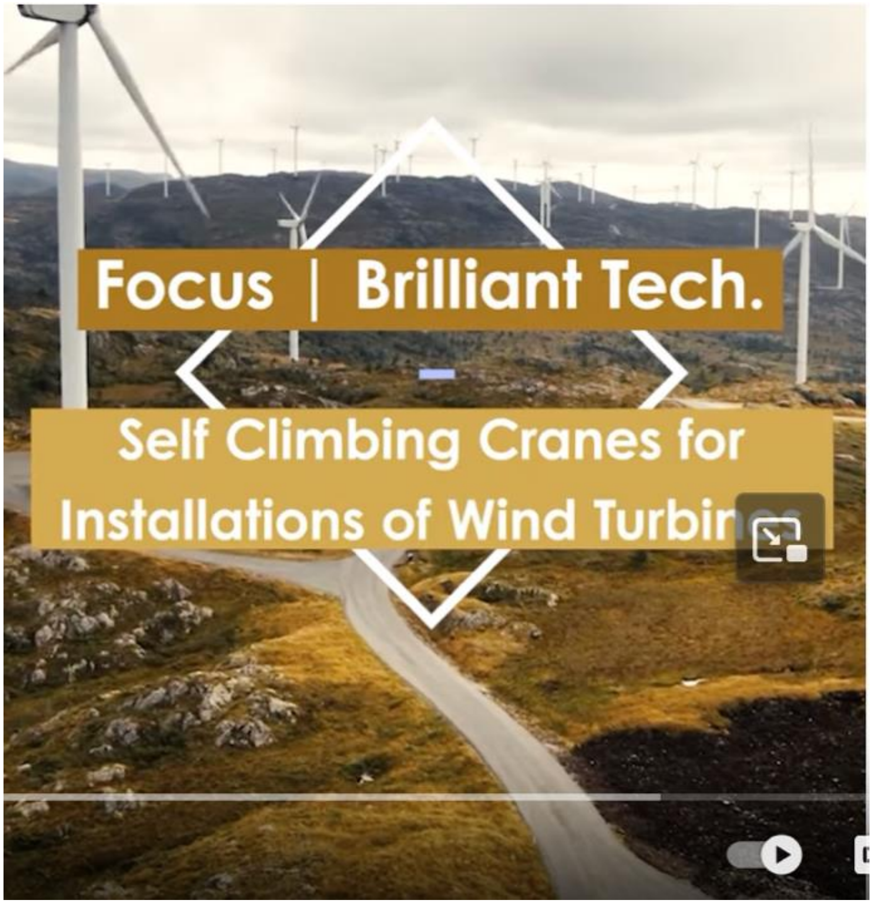


Figure 10: Self-Climbing Cranes
Click here to see video

4.1. Turbine-mounted Cranes and Vessel-mounted Cranes

Alternative HLM technologies are at different stages of technology readiness levels (TRL) and are in need of further development at this time. The different HLM technologies reviewed by the Floating Wind JIP (FWJIP) are representative of a wide range of technology maturity levels. It was on this basis that the following development needs were noted for each technology type.

Turbine-mounted Cranes

According to the study conducted by Carbon Trust further development requirements for turbine-mounted cranes were found to include the following:

- "Refinement of procedures to transfer cranes between the service vessel and floating turbine.

- Engagement with turbine OEMs in order to define acceptable fixing positions and possible tower reinforcement.
- Further development of lifting procedures, including considering whether a lay-down area is required at the tower base or whether components can be lifted directly to/from an attending vessel.
- Review of safety issues related to personnel working in/on a moving nacelle."[29]

The Anson self-climbing crane is an example of a turbine-mounted crane.

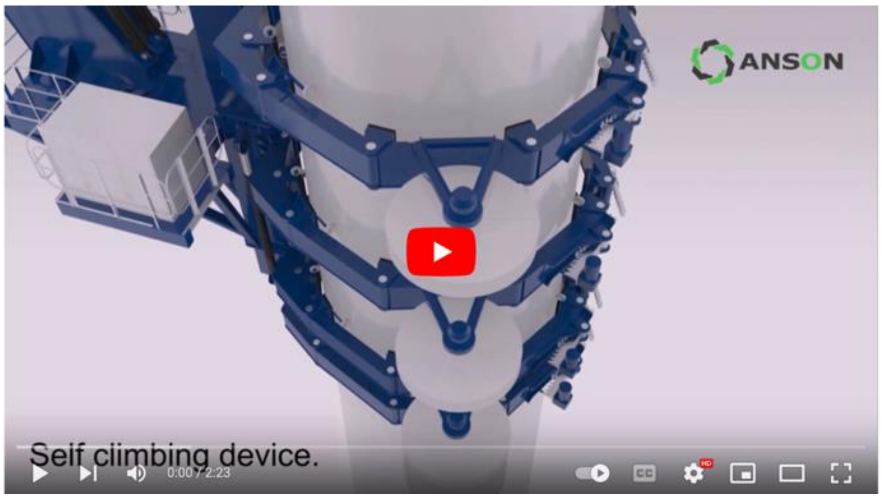


Figure 11: Self-climbing device by Anson
Click here to see video

Vessel-mounted Cranes

Further development needs for vessel-mounted cranes were found to include the following:

- "Development of the motion-compensation systems to achieve successful integration of DP and crane boom systems and acceptable crane hook motions relative to the moving nacelle of a floating wind turbine.
- Demonstration of the integrated vessel and motion-compensation systems."[30]

A particularly notable statement in the report is that,

> "***The combination of lift height, capacity and reach necessary for port side maintenance are only met by a limited number of cranes worldwide***. *Since very few onshore mobile cranes are able to operate at heights required by these operations (up to 150m-200m), an increase of market availability of such cranes might be required, as* ***these are currently very costly (approximate cost €10k/day) – [$11,123 USD] – and their limited availability could be a bottleneck for future maintenance***."[31]

A possible alternative would be to charter jack-up vessels for port-side maintenance instead of using very large and costly onshore cranes – if – seabed properties were adequate within the within the port for jack-up operations. When in the elevated position, cranes onboard jack-up vessels can more easily achieve the required lifting heights.

5.0 Installing Offshore Wind Turbines (OWT)

Integral to offshore wind installations are wind turbine installation vessels (WTIVs). According to GWEC Market Intelligence's Global WTIVs database 2022, China and Europe operate the majority of jack-up and heavy-lift vessels that are used for offshore wind turbine installation. There is no shortage of WTIVs expected globally until 2026. However, in the U.S. at this time (as of 2023 reporting) there are only two "tailor-made" Jones Act compliant WTIVs under construction. In order to avoid bottlenecks in production, "plans for new WTIVs will have to be executed in the next two or three years," if the Biden Administration's 30 GW target for offshore wind by 2030 is to be met. The U.S. wind industry is considered "a successful example of onshoring

The Jones ACT may be a bottleneck for offshore wind turbine construction

manufacturing." To explain … "Strong growth beginning in the 2000s attracted core equipment providers to establish US facilities. These major component manufacturers brought their supply chains with them."[32]

The installation of an offshore wind turbine (OWT) essentially involves assembling various parts of a wind turbine ultimately to be connected to the grid. When it is an offshore wind turbine, its installation is classed a marine operation that incurs with it, various challenges. These challenges include the following, among others: "marginal installation equipment on the market," environmental weather conditions, and the safety risks that come with lifting operations. Any OWT installation requires installation vessels. These vessels are chosen by weighing various factors such as market availability, allowable budget for installation tasks, and wind turbine technologies (i.e., size and number of components).

5.1. The Impact of Jones Act on Access to WTIVs

The Jones Act is extremely significant due to its implications impacting the offshore wind industry. Under the Jones Act, any and all vessels carrying merchandise between any two points in the U.S. must, in fact, be built and also be registered in the United States. Wind developers are planning a number of offshore wind projects along the East Coast in the United States. Due to the rules set down by the Jones Act, two approaches to using vessels to install offshore wind energy projects in the U.S. are under consideration by the stakeholders involved.

One approach involves the scenario where a wind turbine installation vessel (WTIV) that is compliant with the Jones Act would do two things: 1) carry components from a U.S. port to the site; and 2) install the turbines. This is reasonable since WTIVs have a large deck, legs that enable the vessel to lift out of the water, and a tall crane that can lift and place turbines. As of December 2020, stakeholders told the Government Accountability Office (GAO) that, at that time, there were no vessels compliant with the Jones Act that were capable of serving as a WTIV. The figure below illustrates the mechanics of the Jones Act as it applies to offshore wind under this first scenario.

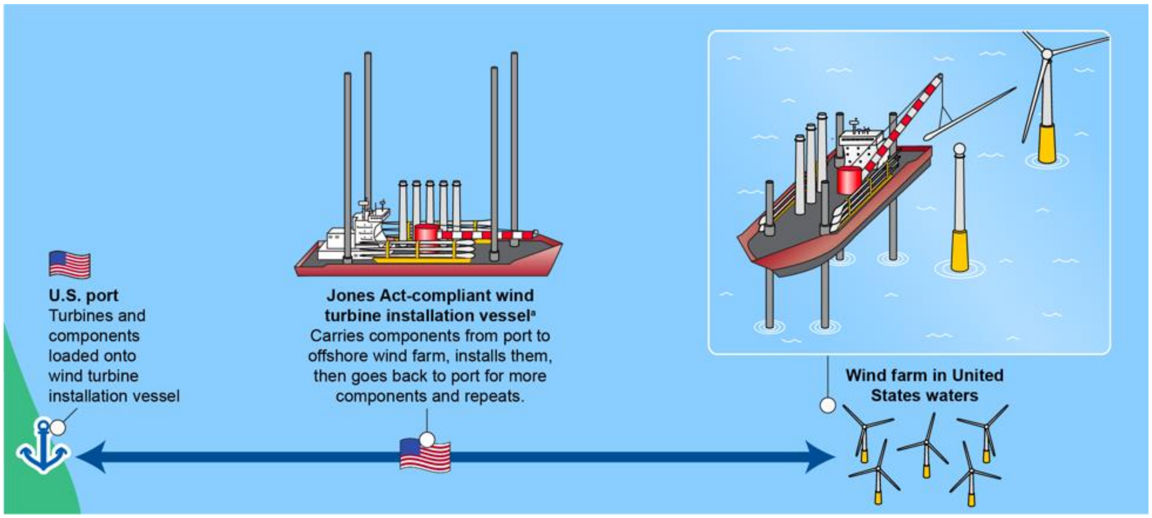


Figure 12: Example of Offshore Wind Installation in U.S. Waters Using a Jones Act-compliant Installation Vessel
Source: GAO, December 2020[33]

A second approach involves the scenario where a foreign-flag WTIV would install the turbines with the components that had been carried to the site from U.S. ports by feeder vessels compliant with the Jones Act. "While some potential feeder vessels exist, stakeholders said larger ones would probably need to be built to handle the large turbines developers would likely use." The outcome of one or the other of the two scenarios is that "Either approach may lead to the construction of new vessels that comply with the Jones Act." The figure below illustrates the mechanics of the Jones Act as it applies to offshore wind under this second scenario.

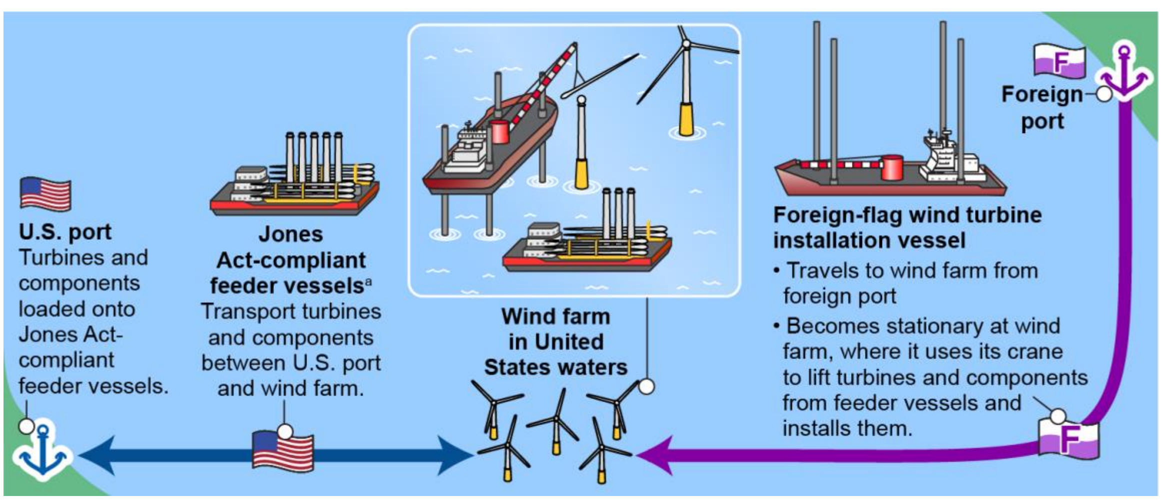


Figure 13: Example of Offshore Wind Installation in U.S. Waters Using a Foreign-Flag Installation Vessel and Jones Act-compliant Feeder Vessels
Source: GAO, December 2020[34]

Irrespective of which scenario is selected by the developer, "a project would most likely need a single WTIV for its construction phase. While the amount of time it takes to complete a project's construction varies based on the size of the project and the installation approach used, project developers said they generally expected each project to require an installation vessel for several months, out of a work season that lasts from spring through fall." Of particular significance is the statement made by GAO that, "According to a range of stakeholders [GAO] interviewed, *developers could not use this approach currently, or for the next few years, as there are no Jones Act-compliant vessels with sufficient capacity to function as a WTIV to install the larger turbines that offshore wind developers plan to use*."

Table 3: Comparison of Largest Identified Jones Act-Compliant Jack-Up Vessel with Foreign-Flag Vessels Used to Install U.S. Offshore Wind Projects as of May 2020

	Name	Crane capacity (U.S. tons)	Clear deck area (square feet)
Largest identified Jones Act-compliant jack-up vessel[a]	*Robert*	500	15,403
Foreign vessel used in 2016 to install turbines for Block Island Wind Farm (RI)	*Brave Tern*	882	34,445
Foreign vessel used in 2020 to install turbines for Coastal Virginia Offshore Wind	*Vole au Vent*	1,654	38,050

Source: GAO, December 2020[35]

At the time of publication (December 2020), GAO reported that Dominion had announced plans to build a Jones Act-compliant WTIV and a Dominion spokesperson told GAO that "the vessel will cost about $500 million and take about 3 years to build." GAO's response to that statement was that "this vessel alone would likely not be able to meet the WTIV needs of the U.S. offshore wind market if all proposed projects proceed as scheduled." The outcome is that even if a Jones Act-compliant WTIV were to become available, some of the wind developers may opt to use the second scenario where a foreign-flag WTIV would install the turbines with the components that had been carried to the site from U.S. ports by feeder vessels compliant with the Jones Act.

The challenges identified by offshore wind stakeholders are associated with constructing and using Jones Act-compliant vessels for offshore wind installations. (This does not preclude the fact that other challenges are not being addressed by various federal programs.) Notably, stakeholders stated that "obtaining investments in Jones Act-compliant WTIVs — which may cost up to $500 million — has been challenging, in part due to uncertainty about the timing of federal approval for projects." Stakeholders believe that when a wind project is approved, that is when investors are more likely to pursue investments in the necessary vessels. Additional challenges include potential port infrastructure limitations to using Jones Act-compliant vessels, however, still "offshore wind, offshore wind developers and state agencies have committed to make port investments."[36]

The vessels used in offshore installations, while the expectation is that these will be in sufficient supply for China, this is not the case for Europe that may see shortages towards the end of this decade, unless investments are put into place prior to 2027. *The United States, due to its required adherence to the restrictions laid out by the Jones Act, is put in the position that unless it moves to action to build new vessels, the U.S. will struggle to meet the Biden Administration's target of 30 GW of offshore wind by 2030*.[37]

5.2. Offshore Installation Vessels: Estimated Cost, Lead Time, and Demand

The following table lists vessel types involved with offshore wind installations and the estimated costs, lead times, and demand for these vessels in order to ensure that 30 GW of offshore wind energy is deployed by 2030, as per the U.S. national goal. It is important to note that wind turbine installation vessels do not necessarily have to be compliant with the Jones Act if a "feeder barge installation strategy" is employed. However, building wind turbine installation vessels domestically makes it more likely these home-built vessels will most likely be dedicated to projects in the United States.[38]

Table 4: Vessel types involved with offshore wind installations

Vessel Type	Estimated Cost	Estimated Construction Time	# Existing	Estimated Peak Demand to 2030
U.S.-dedicated wind turbine installation vessel	$250–$500 million	3 years	0 (1 under construction)	5
Cable lay vessel	$250 million	3 years	0	4
Feeder barge/vessel	$150–$200 million new, $10–$20 million retrofit	Depends on design	20 jack-ups, 44 barges	10
Service operation vessel	$50–$100 million new, $10–$50 million retrofit	2-3 years	0 (2 under construction, multiple oil and gas vessels which could be adapted)	13+
Crew transfer vessel	$5–$10 million	1- 2 years	3	58
Scour protection vessel	$200 million	3 years	0 (1 under construction)	2
Heavy lift vessel	Depends on design		18	Depends on installation strategy
Anchor handling tug supply vessel	$100 - $200 million	2 years	Limited supply	2

Source: NREL, 2022[39]

5.3. Permitting and Construction Timelines

Globally, the time it takes to move offshore wind projects *from their early development stage to full commissioning typically takes up to nine years.* In breaking down this nine-year time frame, "the bulk of this time is spent in the permitting and consenting stage, with timelines stretching even further when there are barriers or delays in the permitting process." Once permitted, large scale offshore wind projects can be constructed quite quickly – typically in a span of two years – contingent to the scale (size) of the project.[40]

6.0 Innovations

This section provides an introduction to the innovations in crane design being made to accommodate the unique challenges of the production, transportation and installation of on-shore and off shore wind turbine systems comprised of the tower, the rotor and the nacelle. It is unclear from the literature how many of these innovations are currently deployed. For that reason, efforts have been made to qualify if the innovations are under development or deployed. For the reader who would like an introduction to the 15 most common types of cranes, before looking at the innovations, and overview can be viewed at this link and includes: (1) mobile cranes, (2) tower cranes, (3)crawler cranes, (4) overhead cranes, (5) floating cranes, (6) truck mounted cranes, (7) telescopic cranes, (8) rough terrain cranes, (9) harbor cranes, (10) aerial cranes, (11) hydraulic cranes, (12) carry deck crane, (13) stacker crane, (14) railroad crane and (15) gantry cranes.

6.1. ENERCON Climbing Crane | Onshore Wind

The Lagerwey Climbing Crane is said to be the world's first self-climbing crane for the construction of wind turbines. The company invented and developed this crane in order to accommodate the trend, in place currently, to build higher and higher turbines – also potentially located in challenging locations. The ability to achieve this is due to the following capabilities: the crane's limited size, easy transport, quick set-up time – that this crane is slated to offer advantages for constructing wind turbines. Also, when using the LCC140 [LCC = Lagerwey Climbing Crane] another advantage is that this crane requires a "considerably smaller permanent crane installation site" when compared to using conventional crane types in these scenarios. The crane climbs by way of the skids attached to the crane.

Figure 14: Climbing Crane – LCC140
Source: Click here to see video

Property	Metric
Transport	11 trucks
Total weight	270 tons
Assembly time **Disassembly time**	One working day One working day
Mast length **Boom length**	33 meters 46 meters
Boom range	32 meters
Max. hoisting weight	140 tons (net weight)
Crane construction area	approx. 500m2 (location dependent)
Design & Certification	CE (EN13001) & TUV Type Examination A multitude of Safety, Electrical, Hydraulic and various other EN norms are applied
Operation	Radiographic and/or from computer
Auxiliary crane	400 ton, depending on situation at site

Due to its limited size and relatively low weight, this climbing crane can be transported to the desired site by eleven trailers. Also, roads do not need to be adapted at the construction site for transporting the crane – in most cases. For the most part, the regular requirements for transporting wind turbine components are suitable. Its limited permanent crane installation site is approximately 500m2. The advantage this offers is saving limited square meters that are essentially quite precious to a site. Due to these features, this climbing crane is able to work in areas where large cranes cannot, also where the cost of using regular cranes could be avoided. The crane has a short assembly and disassembly time and can be transported on short (i.e., regular) trucks.

> "The connection of the Climbing Crane with the tower reduces the risk of crane instability during lifting operations. This makes working with the Climbing Crane safer. *The "Blade-beam" specially developed for the LCC140 makes it possible to lift blades without having to use steering lines. This makes lifting the blades much more manageable and also possible in small locations where the use of steering lines is not possible*."

It is important to realize that each wind project and each wind location is unique, with its own unique challenges. Per Lagerway, "*However, the rule of thumb is; the higher the turbine, the more advantage the Climbing Crane will give you on both crane costs and the costs for the permanent crane installation site*."[41] The first ENERCON wind energy converter has been installed with the Climbing Crane LCC140 prototype – April 14, 2021 – for onshore wind.

6.2. Mammoet's WTA (Wind Turbine Assembly) Lifting System

As wind developers pursue stronger wind flows, what is happening is that onshore wind hub heights are growing beyond the reach of conventional crawler cranes. A potential solution is Mammoet's new WTA (wind turbine assembly) lifting system that "allows theoretically infinite hub heights and paves the way toward emissions-free turbine erection." How this works is the WTA assembles wind turbine generators by attaching itself to the tower directly and then climbs to each lift location by using a series of clamps to self-assemble itself and move on. This crane is able to assemble tower sections, hubs, and nacelles, and has a lifting capacity of 150 tons. "Its innovative concept means that the WTA can keep working when conventional crawler cranes can't." Further, this crane can operate at wind speeds up to 20m/s, thereby reducing downtime during construction. The following figure shows the Mammoet WTA as compared to the Liebherr LG 175, which is a lattice boom mobile crane used for onshore wind energy installation projects.[42]

Figure 15: Comparison of Mammoet WTA and Liebherr LG 1750 Lattice Boom Mobile Crane
Source: Mammoet News

Since the WTA (wind turbine assembly) has a significantly reduced footprint and is much smaller and lighter than any type of crawler crane, it can lessen the need for groundwork on site. *"The system's small size means quicker and more cost-effective mobilization. While a conventional crawler crane can require up to 50 truckloads to reach the site, the WTA gets there with just nine."*

Further advancements and subsequent advantages include …

> "With no boom laydown requirement, much fewer components, and a lower total weight, the WTA is also faster from pad to pad. In fact, *relocation time is reduced by approximately 50%*, compared to using crawler cranes. It, therefore, shaves weeks off wind farm construction schedules. *Powered entirely by electricity, it also opens the door for a 100% emissions-free journey from the factory to the first Megawatt – with transport to the site via electric or hydrogen-powered truck, on-site maneuvers via ePPU-enhanced SPMT and carbon-free WTA lifting*."

The WTA system is design-ready and was slated for market release during Q2 2023.[43]

Mammoet Onshore Efforts can be seen here.
Mammoet Offshore Efforts can be seen here.

6.3. WindSpider Self-erecting Crane

In December 2022, RWE Renewables (RWE) published a press release announcing its recent signing of a Letter of Intent (LoI) with WindSpider. RWE reportedly is “exploring how innovation can make the installation and operation of its wind farms even more efficient, in order to further drive down costs. For bottom-fixed and floating offshore wind projects, the availability of specialized cranes could become a bottleneck. That is why RWE has recently signed a Letter of Intent (LoI) with WindSpider.” The rationale behind this partnership – “Similar to its position in bottom-fixed offshore wind, RWE is aiming to become a leader in floating wind and to have one gigawatt of the technology in operation or under construction by 2030.”[44]

According to the WindSpider website, its WindSpider crane system is ready for the next generation 20MW+ wind turbines. Claims for their crane solution for 1200+ metric ton & 200+ meter height includes reducing installation and maintenance cost by more than 50% and that the system is scalable, flexible and modular.[45]

The WindSpider crane is a self-erecting solution the uses the tower of the wind turbines as part of the crane when performing installation, maintenance, re-powering, and decommissioning of wind turbines. How this is done:

> “The WindSpider attaches to the tower and moves up and down using mast sections. At each step upwards, the WindSpider lifts the next or wanted section of the tower or turbine, including the rotor blades, in place. When it’s all done, the WindSpider reverse the process back to the starting point at the base and is lifted off. As WindSpider is part of the wind turbine tower there are no relative movements between the WindSpider crane and wind turbine when lifting components.”

Windspider products include WindSpider Pro and WindSpider Lite.

WindSpider Pro, as seen below, is used for installation. WindSpider Pro offers the lifting capacity to install or replace all parts of an offshore wind turbine (including the nacelle). This can be used onshore or offshore, for fixed or floating turbines. This WindSpider Pro series “Eliminates the need for large and expensive jack-up vessels, and hence increased availability.”

Figure 16: WindSpider Pro
Source: WindSpider[46]

WindSpider Lite, as seen below, is used for maintenance. It has a lifting capacity of 150 metric tons, can repair or replace turbine components (e.g., blades, gearbox, etc.) and it is termed a "Solution fit for bottom fixed and enables maintenance offshore for floating offshore wind."[47]

Figure 17: WindSpider Lite
Source: WindSpider[48]

6.4. Roundabout Solution to the Jones Act for the U.S. Market from Offshore Drilling Design Group in Collaboration with Crane Manufacturers

Riviera Maritime Media hosted the webinar "Taking the strain: cranes and lifting equipment for offshore vessels" in mid-September of 2022. Various spokespersons representing various groups involved with offshore applications attended this webinar, presenting various options and potentially new solutions to the problems encountered with offshore wind and the limitations currently in place by the Jones Act for the American offshore wind market.

Responding to recurring concerns regarding the problems associated with the ever-increasing height of cranes, a spokesperson from the US-based design group Friede & Goldman (NB: better known for its offshore oil drilling rig designs) spoke to this design group's latest innovation. Called the BargeRack, it is said to be "a solution to the complexities of the Jones Act-mandated feeder system for installing offshore wind turbines. And it is different from other windfarm installation vessels." The group's claim is that their design would lower wind turbine installation costs in the United States. This BargeRack design is pictured in the Figure below.

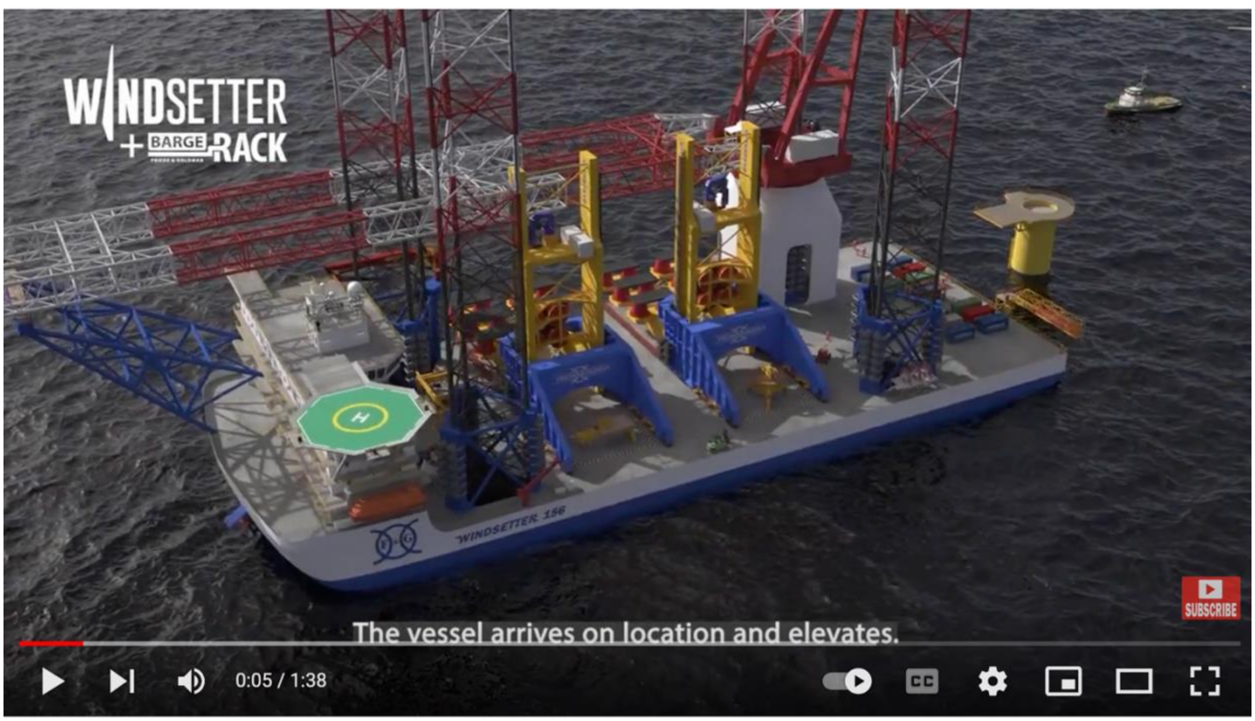


Figure 18: Friede & Goldman's BargeRack Design
Source: Friede & Goldman[49] Click here to see video

Friede & Goldman stated the Jones Act is "a major preoccupation" for the group. As explained previously in this report, for context here – the Jones Act defines a bottom-fixed turbine foundation as a port. According to this definition, internationally flagged ships (i.e., such as wind turbine installation vessels) are permitted only to operate at a project site by lifting components off a feeder vessel, under the provision these vessels *remain stationary*. Therefore, components must be shipped to the site by a US-flag, US-built feeder vessel.

The Friede & Goldman group explains the problem and their solution in this way:

> "The question has always been how to get the components off the barge, the feeder that's coming out. And we [Friede & Goldman] feel like we've come up with a pretty ingenious way to do that by having a rack that is attached to the jack-up. We physically lift the barge up out of the water [which] has several advantages. Number one is that relative motions between the jack-up and the barge are completely eliminated. So, we don't need any expensive motion-compensation equipment. We don't need a fancy deck barge that has 3D motion compensation. We don't need a separate jack-up vessel on location. A big bonus of the concept, he added, is that 'any dumb barge' serves the purpose because all the relevant equipment is on the wind installation vessel. Our goal has been to use the existing barge fleet. The jack-up vessel can be built outside of the United States and does not need to be Jones Act-compliant. So that lowers capex. The barges would need to be built inside the United States but there's plenty of them around already and they're fairly simple to build."

The BargeRack design could handle turbines up to 20 MW. Beyond this BargeRack design, the group is working on solutions to other problems beyond the ongoing increases in size. They are working to reduce the size of the crane boom since "the boom that determines the size of the vessel: Once the vessel gets big, everything gets expensive. And it's just like this never-ending loop of expense. If [Friede & Goldman] can make the boom shorter, [they] can make the vessel shorter and lighter. Everything gets cheaper."

Dutch crane designer Tetrahedron (Rotterdam) is working with Friede & Goldman on the company's unconventional design that will lift wind-turbine components (towers, blades, and nacelles) up to 50m higher than conventional cranes. The Tetrahedron is shaped like a 3D triangle, designed specifically for wind turbines that, "because they are slender, put a premium on height rather than reach. The essential calculations of the static and dynamic loads are done in a few minutes by proprietary software." Tetrahedron is now a five-year startup that is "involved in discussions with several potential customers who would pioneer the technology on an existing jack-up vessel."

A spokesperson from crane manufacturer Huisman states that "What is not diminishing is the demand for new offshore cranes. [The company] reported orders are coming thick and fast for record-breaking cranes. With 305 cranes delivered already, the Netherlands-based manufacturer has 20 cranes on order, of which nine are leg-encircling designs

(LEC) specific for the wind industry. Over 142 of Huisman's cranes to date are electric and [the spokesperson] noted this demand is growing significantly because we're working in the renewable industry. Backing up her observations about rapid development, Huisman's run of orders in 2021 alone include a 1,600 mt LEC for jack-up vessel *Sea Installer* owned by offshore energy specialist DEME, a 2,600 mt LEC for Eneti's new wind turbine installation vessel, and a 2,200 mt LEC for *Charybdis*, Dominion Energy's wind turbine installation vessel. *Almost every contract sets new records*. The Eneti order will result in a crane with a 147-m long boom capable of reaching 170 m above deck. The 2,600 mt lifting capacity means the crane will be able to install the next generation of 20 MW turbines. As a measure of the projected growth of the offshore wind turbine industry, the contract also provides for the option of a second crane that would be installed on another installation vessel."

Additionally, in response to the demand for increasingly powerful cranes, Huisman has doubled the slew-bearing production capacity of its facility in Schiedam, the Netherlands. (This is due to the fact that large-diameter slew bearings are a key component of heavy-lift cranes.)

Of particular note is that the 2,600 mt crane is driven electrically. This allows for crews to more accurately position the crane while at the same time using less energy.[50]

7.0 Trend: Oil and Gas (O&G) Companies Transitioning to Wind Sector

National Oilwell Varco, Inc. (NOV) is an oil and gas (O&G) company that designs, manufactures and sells equipment and components used in O&G drilling and production operations. The company carries a broad portfolio that ranges from "some of the heaviest, largest, and most complex mobile machines on earth (on and offshore drilling rigs, wind turbine installation ships, and FPSOs) to very small precision sensors and measuring devices."[51]

According to the company's 10-K filing for the year ended 12/31/22, the company is taking steps to transition into the wind market. The rationale is that the company would use its expertise in offshore heavy-lift equipment and naval architectural design, coupled with the fact that NOV is a "leading equipment and technology provider for purpose-built vessels used to build, install, and maintain offshore wind towers and turbines." As a result, NOV "promises in development and commercialization of novel products and technologies to improve the efficiencies and economics of land and offshore-based wind, geothermal power generation, and carbon capture and sequestration."

Before discussing the capabilities that enable NOV to transition from primarily oil and gas to wind, first a brief description of a recent acquisition by NOV, its rationale, and its impact on moving into the wind market may be in order. In 2019, NOV acquired a minority interest in Keystone Tower Systems, a company that has developed a patented "*tapered spiral-welding process that enables automated wind tower section production. If perfected, this proprietary process could significantly decrease tower section production times and reduce costs. Additionally, in time the process could enable in-field manufacturing operations, which could reduce costs and eliminate many logistical limitations of transporting the larger-diameter sections necessary for tall tower developments*." As of the time of reporting, Keystone's first commercial line was undergoing testing and commissioning before commercial production would begin within NOV's facility in Pampa, TX.

NOV is developing a "fit-for-purpose" onshore wind tower erection system. Constructing onshore wind towers currently requires large crawler cranes. These large crawler cranes, while they provide mobility at low and moderate hub heights, are found to be "significantly less efficient" when working with high hub heights. NOV's technology, which is "built upon the intellectual property, control systems, and experience developed through mobile desert and arctic drilling rig design, uses a tower crane in conjunction with a unique mobility system. This patent-pending combination creates a structurally-sound, mobile tower crane that is expected to significantly improve the safety, reliability, and efficiency of tall wind tower installation processes."[52]

Fixed Offshore Wind

"NOV has drawn on its expertise in oil and gas jack-up vessel design, robust aftermarket network, and strong reputation in marine equipment design to become the leading global equipment and design provider for offshore wind turbine installation vessels. NOV's comprehensive offerings include designing and manufacturing critical jacking systems, cranes, and mooring equipment; developing and licensing vessel designs; working closely with shipyards to install and commission equipment on wind installation vessels; and aftermarket parts, service, and repair. *The Company expects an upcoming growth period in the global offshore wind installation vessel market, driven primarily by the need for larger vessels required to support the installation of wind turbines with increasingly large rotor diameters, nacelle weights, and hub heights*. *The vessels required to install modern, heavier* *nacelles at higher hub heights are similar to those previously designed by NOV and are relatively consistent across global geographies*.

Additionally, as U.S. fixed offshore wind projects approach final permitting approval, the need for Jones Act-compliant wind installation vessels will become more urgent. As a result, the Company is well-positioned to capture additional orders associated with future newbuild wind installation vessels."

Floating Offshore Wind

The Company believes that the nascent floating offshore wind market presents one of the great renewable resource opportunities of the next decade. NOV is actively developing new products and technologies to support this industry alongside its legacy portfolio, which includes *cranes*, winches, mooring systems, cable-lay systems, ballasting systems, and chain connectors and tensioners. *NOV has developed a patent-pending Tri-Floater semi-submersible floating foundation that requires less steel than competing offerings*. *NOV is also designing several proprietary lifting and handling tools for streamlined turbine component installation*. *Today, the floating offshore wind market sits in the pre-commercial development phase, with industry players focused on proofs of concept and mitigating execution risk*. NOV is working to become a value-added partner capable of meaningfully reducing project execution risk by leveraging the Company's broad and growing portfolio of relevant technology, extensive track record of successfully managing complex marine projects, relationships with global shipyards, and robust global supply chain accustomed to stringent quality and traceability.

Onshore Wind

NOV is developing technology to lower onshore wind's LCOE by economically constructing increasingly tall wind towers. Higher hub heights allow turbines to reach stronger winds, significantly increasing energy capture, lowering energy cost, and expanding the regions where wind projects can be profitably developed. Higher hub heights are also required for larger, more efficient turbines. The combination of larger turbines and steadier, higher winds improves wind farm economics. Consequently, wind turbine size and tower height have been increasing steadily for several years. *NOV's core design and manufacturing competencies for large, industrial capital equipment, including cranes, lifting tools*, and rotating machinery, uniquely position NOV to develop fit-for-purpose wind components and installation equipment to facilitate building onshore wind turbines at higher hub heights."[53]

Marine Construction

This segment "designs, engineers, and manufactures *heavy-lift cranes; a large range of knuckle-boom and lattice-boom cranes*, including active heave options; mooring, anchor, and deck-handling machinery; a full range of jacking systems both for drilling rigs and *wind turbine installation jack-ups; and solutions for installing offshore wind towers and turbines*, pipelay, and construction vessel systems. *Within Marine Construction, GustoMSC provides design solutions for drilling jack-ups and floaters, wind turbine installation jack-ups, and floating offshore wind solutions like the TriFloater*. *Marine Construction serves the oil and gas industry as well as wind energy and other marine-based end markets*. *This business unit also provides aftermarket support, including upgrades of existing equipment, spare parts, repair and field services*."[54]

Rig Technologies

The company's Rig Technologies segment manufactures and supports the capital equipment and integrated systems required for drilling oil and gas wells both onshore and offshore, as well as other marine-based markets that includes *offshore wind vessels*. Equipment and technologies this segment offers to customers include: "substructures, derricks, and masts; *cranes*; jacking systems; pipe lifting, racking, rotating, and assembly systems; fluid transfer technologies, such as mud pumps; pressure control equipment, including blowout preventers; power transmission systems, including drives and generators; rig instrumentation and control systems; mooring, anchor, and deck handling machinery; *major equipment components for offshore wind construction vessels*; and pipelay and construction systems." Further, this segment provides spare parts, repair, and *rentals* as well as remote equipment monitoring, technical and field support and more. It is this segment that *designs and builds equipment for wind turbine installation companies, "where demand is dependent on global investment into offshore wind energy developments*."[55]

8.0 Crane Manufacturers (Onshore and Offshore): Profiles

This section profiles several of the top crane manufacturers, starting with a brief overview which is then followed by a table with links to each respective company's onshore/offshore offerings, wind brochures, specifications, home page, wind page, and video – as available. Huisman, PALFINGER AG, Lagerwey, Konecranes, EAGLE WEST are representative of key players involved in the wind cranes market. Established players (e.g., Huisman, PALFINGER AG, Konecranes) typically offer larger product portfolios and maintain a geographic presence whose reach is worldwide. Lagerwey is a newer entrant to the wind market. [56]

8.1. Huisman Equipment BV (Netherlands)

Huisman Equipment offers turnkey contract manufacturing for a wide array of onshore, offshore and heavy-lift cranes. These cranes are built for durability and possess the ability to lift in extreme environments. The cranes offer a "small space claim, a low center of gravity, and a low own weight." The company stresses that beyond their existing portfolio of cranes that include pedestal mounted cranes (PMC), overhead cranes, offshore wind cranes, subsea cranes, hoist cranes (and additional lifting equipment for construction applications), the company has the proven expertise to provide custom cranes able to perform lifting tasks as needed, by application.[57] Offerings vary by size and type, in accord with requirements necessary for specific applications.

The company develops and manufactures their cranes in-house and has a 35-year legacy in this area, claiming their cranes have become "the standard in the design and construction of heavy lift cranes."[58] Moving forward, the company, due to successful operation of their existing cranes for the offshore wind turbine installations, has rolled out a range of cranes tailored expressly for wind turbine installation. These include Leg Encircling and Pedestal Mounted Cranes.

Detailed information on these cranes (and other relevant areas) can be accessed via the links within the following table.

Table 4: Quick Access Table to Information provided by **Huisman**

Huisman							
Home page	Wind page	Offshore Brochure	Onshore Brochure (n/a)	Quayside Cranes page	Pedestal Mounted Cranes	Leg Encircling Cranes	Video

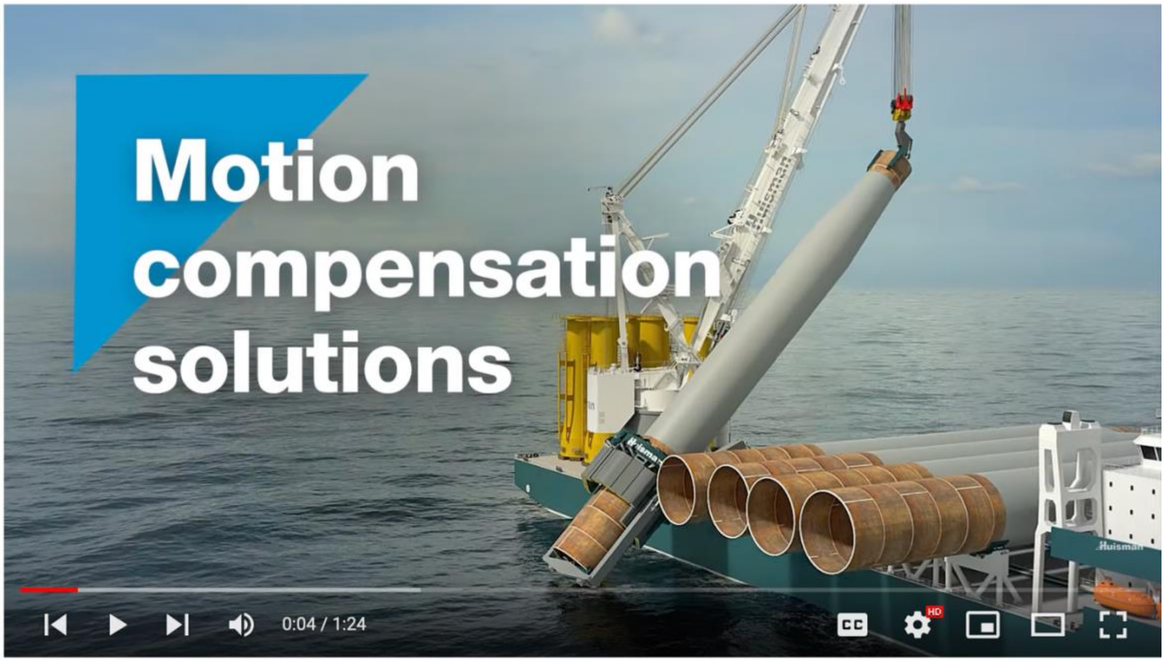


Figure 19: Huismann Motion compensation solutions
Click here to see video

8.2. PALFINGER AG (Austria)

PALFINGER offers a diverse portfolio for the wind industry that includes windmills, transformer stations, wind farm service operation vessels, and wind farm supply vessels. The company offers customized "lifting and handling solutions especially for the wind industry: cranes, lifesaving equipment, winches and handling equipment." PALFINGER has delivered wind cranes for nacelles, platforms, and substations. Through their "lifesaving equipment, winches, and handling equipment" the company offers complete solutions for both onshore and offshore wind farms. Offerings include platform, nacelle, and substation cranes.

When it comes to wind farm support vessels, the company offers complete solutions for both smaller and larger wind farm support vessels. These vary from small marine cranes to larger offshore cranes, with the requisite equipment delivered in accord with the necessary rules and regulations. The types of vessels in this segment include wind farm service operation vessels and wind farm supply boats.[59]

Table 5: Quick Access Table to Information provided by **Palfinger AG**

Palfinger Marine					
Home page	General cranes page	Wind page	Offshore brochure	Onshore brochure (n/a)	Video

Figure 20: Interview with Rupert Reischel, Global Sales Manager Wind Cranes
Click here to see video

8.3. Konecranes (Finland)

Konecranes supplies material handling equipment to the power industry. Its range spans from coal power plants to hydro power plants to wind farms, stating the company offers the cranes and services that accompany these application areas.[60] The company offers electric chain hoists that can be mounted to a jib crane within the wind turbine's nacelle. These hoists are able to raise and lower turbine components for repair or replacement, this "as opposed to accessing the nacelle through the hatch or along the tower." Workshop cranes available from Konecranes include wall console cranes, bridge cranes, jib cranes and manual hoists.[61] Known for the Goliath crane, in addition to this specific crane the company offers "every type of material handling device needed in your shipbuilding operation -- from general-purpose forklift trucks to Electric Overhead Travelling cranes used in welding operations, to outfitting cranes and all the services needed."

Table 6: Quick Access Table to Information provided by **Konecranes**

Konecranes				
Home page	Wind page	Offshore brochure: Shipyard Book*	Onshore brochure (n/a)	Video: Goliath gantry crane

**Shipyard Crane Concepts: Product, Delivery and Service concepts, pp.11-29*
Shipyard Crane Offerings with specifications, pp.43-59

8.4. Liebherr (Switzerland)

In 1970, Liebherr constructed two manufacturing facilities and the North American headquarters in Newport News, Virginia. Today, the company operates four separate companies across the United States. Combined, these companies offer sales and service for twelve product segments through "several company-owned locations and a strong dealer network." Liebherr LR crawler cranes work for onshore installations (whether the terrain is mountainous or flat) and offshore sites.[62] The company's crane portfolio includes maritime, mobile and crawler, and tower cranes.

Links to these offerings are included in the table below where more detailed information will be found and can be pursued for any crane of potential interest.

Table 7: Quick Access Table to Information provided by **Liebherr**

Liebherr							
Home page	Wind page	Wind energy: LR crane product portfolio*	Crawler Cranes by Application	Maritime Cranes	Mobile and Crawler Cranes	Tower Cranes	Video: Liebherr 1800 (with subtitles)

**Ten offerings listed; click on any to see description, specs and image*

8.5. Liftra (Denmark)

Liftra is self-described as "a global corporation recognized by the international wind turbine industry as a specialist within lifting and transportation solutions." The company designs, manufactures, and offers custom solutions that enable "time and cost efficient" wind turbine installation and maintenance for both onshore and offshore sites. With more than twenty years of experience and more than 400 skilled professionals, the company supplies its equipment to 30+ countries worldwide from their locations in Denmark, Spain, China, Poland, Vietnam, Brazil, Australia and the United States.

Liftra has developed compact solutions for onshore and offshore wind turbine installation and maintenance. It is this compact size that reduces CO_2 emissions created during turbine installation and O&M operations. The equipment is designed to enable easier access to remote locations and provide sustainable solutions.[63]

The Liftra Installation Crane enables the installation of turbines with hub heights up to 250 meters "with no need for large, expensive conventional cranes." Notably, the company's LT1500 model is "*mobilized with only 5-8 truckloads, while just 1 truckload is* *needed for transport between turbines on-site. In comparison, the conventional crane method requires 30-40 truckloads for both mobilization and on-site relocation.*"[64] The company does state this about the LT1500 model: "The latest addition to the product family is the pioneering technology of the *LT1500 Liftra Installation Crane, currently under development*.[65]

Liftra offers flexibility regarding ownership and/or operations, allowing for the following options to select from:

- "Full ownership and operation
- Full ownership and external crew
- Full ownership for service contracting
- Interface ownership (For crane base system)
- Rental (Available for selected products)"[66]

Table 8: Quick Access Table to Information provided by **Liftra**

Liftra					
Home page	Solutions and Service providers	Engineering Services	Onshore brochure (n/a)	LT 1500 brochure	Video: LT1500

Figure 21: Liftra Product Showcase 2023
Click here to see video

9.0 Market Size

A question of interest for those looking to enter this market, is how many cranes are used in wind turbine system production, transportation and construction. In other words, how large is the market opportunity. This is not an easy question to address. In an effort to secure some insight, two off-shore wind turbine installers were contacted as well as, ten domestic crane manufacturers, the Material Handling Industry (MHI), the Association of Equipment Manufacturers (AEM) and the Crane Manufacturers Association of America, Inc.

The only useful information garnered was from an overseas off-shore crane manufacturer and installer. This is the information provided.

> *"The standard bottom fixed offshore turbine installation can be divided into two parts, each with a crane setup. The pre-assembly part which is done onshore in a harbor. The tower is upended, assembled, pre-commissioned and made ready for installation. The blades are positioned for loadout. All of this crane work today is made by crawler cranes - normally a setup consisting of a 1350 ton and a 750 ton crawler crane. There could also be some assisting cranes on the side (approximately 200-300 ton class). The offshore installation itself is accomplished by an installation jack vessel with a crane setup consisting of a main crane (1500 to 5000 ton class) and a secondary crane for moving parts on the vessel. The above is for turbines in the range of 8-15 MW."*

The set-up described would be used for each wind turbine system sequentially. Thus, a developer installing more than one off-shore wind turbine in a turbine park, would only need one setup for the job.

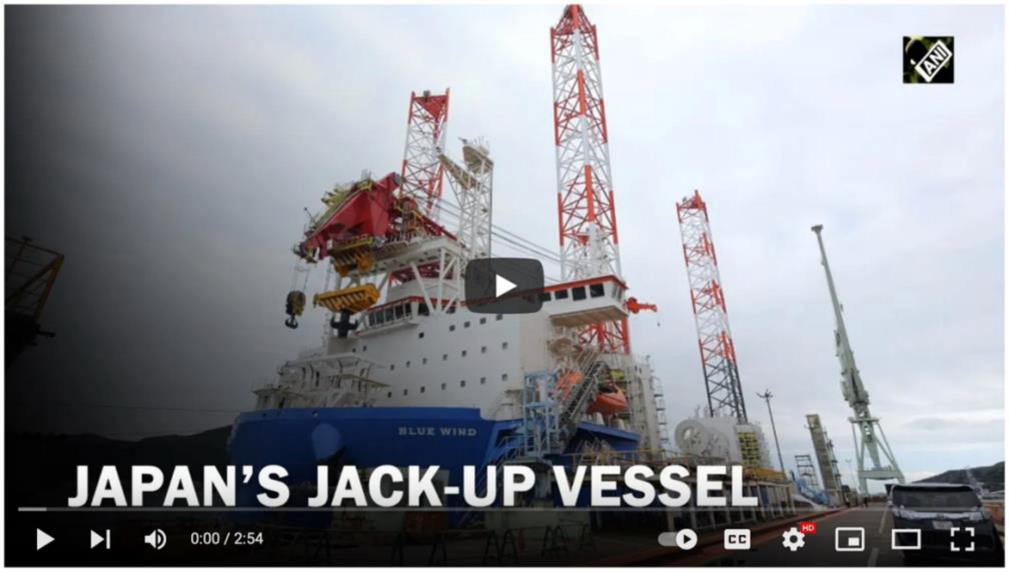


Figure 22: Japan's Jack-up Vessel, 2023
Click here to see video

What is apparent from installments such as Hywind in Scotland is that very large parts are made throughout Europe and then shipped to the installation site. It is therefore reasonable to assume that during the production of towers, rotors and nacelles that cranes of various types are used in production and also in transportation. A quick look at a number of videos regarding the manufacturing process of wind towers, wind rotors, and nacelles indicates that a variety of overhead cranes, hoists and other specialized cranes, large and small – are used during the production process. For this reason, we reached out to domestic crane manufacturers to see if we could quantify the demand. However, when contacting crane manufacturers domestically, the phone is usually answered by Security. No transfer to any knowledgeable parties is then possible. The various associations contacted were also not readily accessible. Thus, we did not receive any additional insight from the additional outreach efforts. Another factor to consider in the future, is that cranes can be purchased or leased. It therefore seems safe to assume that large manufacturers are likely to purchase the cranes needed, while those getting started are more likely to lease.

Once the various components of the wind turbine system are produced, they need to be shipped whether it is by land or sea. The distribution harbor, as well as the receiving harbor must be prepped with appropriate equipment to receive the number of components.

Figure 23: Transporting 198 wind rubine blades from Italy to the U.S.A.
Click here to see video

In conclusion, more primary market research is required to determine how many cranes of various types may be needed in the future both during production, transportation and construction.

Endnotes

1 Ben Hoen et al, " Effect of land based wind turbine upsizing on community sound levels and power and energy density," *Applied Energy*, Volume 338, 15 May 2023

2 Philipp Beiter et al, "Expert perspective on the wind plant of the future," *Wiley*, 2022

3 Renewable Energy World, "Taller, larger, louder: LBNL looks at future wind turbine trends," *Renewable Energy World, March 24, 2023*

4 MarketWatch, "Wind Cranes report contains company profiles and market share analysis of the top competitors from 2023 to 2030, as well as its predicted CAGR Value of 5.5%," *MarketWatch Press Release*, June 14, 2023

5 Data from Global Offshore Wind Farm Database And Intelligence, Accessed August 1, 2023

6 Jen McCann, "What is the Block Island Wind Farm?" *The University of Rhode Island*, July 8, 2020

7 Carbon Trust, "Floating Wind Joint Industry Programme: Phase IV Summary Report," *Carbon Trust*, July 2022

8 GWEC, "Global Wind Report 2023," *Global Wind Energy Council (GWC)*, 2023

9 Frost & Sullivan, "Growth Opportunities in the Global Offshore Wind Market: Remarkable Cost Reductions, Disruptive Technologies, and Efficient Supply Chain to Drive Offshore Wind Demand," *Frost & Sullivan, Global Energy & Environment Research Team*, November 2022

10 Frost & Sullivan, "Growth Opportunities in the Global Offshore Wind Market: Remarkable Cost Reductions, Disruptive Technologies, and Efficient Supply Chain to Drive Offshore Wind Demand," *Frost & Sullivan, Global Energy & Environment Research Team*, November 2022

11 Matt Trowbridge et al., "California Floating Offshore Wind Regional Ports Assessment," U.S. *Department of the Interior, Bureau of Ocean Energy Management* (BOEM) OCS Study BOEM 2023-010, Prepared under Contract No.140M0121D0008 by Moffatt & Nichol, January 2023

12 The White House, "FACT SHEET: Biden-Harris Administration Announces New Actions to Expand U.S. Offshore Wind Energy," *The White House*, September 15, 2022

13 Carbon Trust, "Floating Wind Joint Industry Programme: Phase IV Summary Report," Carbon Trust, July 2022

14 Carbon Trust, "Floating Wind Joint Industry Programme: Phase IV Summary Report," *Carbon Trust*, July 2022

15 Ella Nilsen, Maine: "The Future of wind energy in the U.S. is floating turbines as tall as 30 rock," *CNN*, May 19, 2023

16 Bureau of Ocean Energy Management, "Morro Bay Wind Energy Area," *Bureau of Ocean Energy Management*, Accessed August 1, 2023

17 Kirk Moore, "Oregon governor, lawmakers call for offshore wind pause," *National Fisherman,* June 14, 2023

18 Matt Shields et al, "A Supply Chain Road Map for Offshore Wind Energy in the United States," *NREL*, January 2023

19 Carbon Trust, "Phase III Summary Report: Floating Wind Joint Industry Project," *Carbon Trust*, 2021

20 Jessica Stump, "Offshore wind market propels demand for heavy-lift vessels," *Offshore*, February 1, 2022

21 World Forum Offshore Wind (WFO), "Onsite Major Component Replacement Technologies for Floating Offshore Wind: the Status of the Industry," *World Forum Offshore Wind*, February 2023

22 World Forum Offshore Wind (WFO), "Onsite Major Component Replacement Technologies for Floating Offshore Wind: the Status of the Industry," *World Forum Offshore Wind*, February 2023

23 World Forum Offshore Wind (WFO), "Onsite Major Component Replacement Technologies for Floating Offshore Wind: the Status of the Industry," *World Forum Offshore Wind*, February 2023

24 World Forum Offshore Wind (WFO), "Onsite Major Component Replacement Technologies for Floating Offshore Wind: the Status of the Industry," *World Forum Offshore Wind*, February 2023
25 Carbon Trust, "Phase III Summary Report: Floating Wind Joint Industry Project," *Carbon Trust*, 2021
26 Carbon Trust, "Phase III Summary Report: Floating Wind Joint Industry Project," *Carbon Trust*, 2021
27 Carbon Trust, "Phase III Summary Report: Floating Wind Joint Industry Project," *Carbon Trust*, 2021
28 Carbon Trust, "Phase III Summary Report: Floating Wind Joint Industry Project," Carbon Trust, 2021
29 Carbon Trust, "Phase III Summary Report: Floating Wind Joint Industry Project," *Carbon Trust*, 2021
30 Carbon Trust, "Phase III Summary Report: Floating Wind Joint Industry Project," *Carbon Trust*, 2021
31 Carbon Trust, "Phase III Summary Report: Floating Wind Joint Industry Project," *Carbon Trust*, 2021
32 Global Wind Energy Council, "Global Wind Report 2023," *GWEC*, 2023
33 GAO, "Offshore Wind Energy: Planned Projects May Lead to Construction of New Vessels in the U.S., but Industry Has Made Few Decisions amid Uncertainties," *United States Government Accountability Office Report to Congressional Committees*, December 2020
34 GAO, "Offshore Wind Energy: Planned Projects May Lead to Construction of New Vessels in the U.S., but Industry Has Made Few Decisions amid Uncertainties," *United States Government Accountability Office Report to Congressional Committees*, December 2020
35 GAO, "Offshore Wind Energy: Planned Projects May Lead to Construction of New Vessels in the U.S., but Industry Has Made Few Decisions amid Uncertainties," *United States Government Accountability Office Report to Congressional Committees*, December 2020
36 GAO, "Offshore Wind Energy: Planned Projects May Lead to Construction of New Vessels in the U.S., but Industry Has Made Few Decisions amid Uncertainties," *United States Government Accountability Office Report to Congressional Committees*, December 2020
37 Global Wind Energy Council, "Global Wind Report 2023," *GWEC*, 2023
38 Source: Matt Shields, "The Demand for a Domestic Offshore Wind Energy Supply Chain," *National Renewable Energy Laboratory (NREL)*, Technical Report NREL/TP-5000-81602, Revised June 2022
39 Source: Matt Shields, "The Demand for a Domestic Offshore Wind Energy Supply Chain," *National Renewable Energy Laboratory (NREL)*, Technical Report NREL/TP-5000-81602, Revised June 2022
40 Global Wind Energy Council, "Global Wind Report 2023," *GWEC*, 2023
41 Lagerway, "Climbing Crane – LCC140," *Lagerway*, Accessed July 11, 2023
42 Samuel Barber, "AIS Wind Energy acquires Liebherr LG 1750," *Heavy Lift & Project Forwarding International*, January 19, 2023
43 Mammoet, "New onshore wind crane takes step closer to reality," *Mammoet News*, Accessed July 11, 2023

44 Sarah Knauber, “WindSpider: RWE Supports Development of New Self-erecting Crane System for Wind Turbines,” *RWE Renewables*, Press Release, December 16, 2022
45 WindSpider, “Home page,” *WindSpider*, Accessed July 30, 2023
46 WindSpider, “Products,” *WindSpider*, Accessed July 30, 2023
47 WindSpider, “Products,” *WindSpider*, Accessed July 30, 2023
48 WindSpider, “Products,” *WindSpider*, Accessed July 30, 2023
49 Selwyn Parker “Stretching offshore cranes to their limits,” *Riviera Maritime*, September 15, 2021
50 Selwyn Parker “Stretching offshore cranes to their limits,” *Riviera Maritime*, September 15, 2021
51 NOV, Inc., “NOV, Inc., Form 10-K: Annual Report Pursuant to Section 13 or 15(d) of the Securities Exchange Act of 1934 for the Year Ended December 31, 2022,” *U.S. Securities and Exchange Commission*, February 14, 2023
52 NOV, Inc., “NOV, Inc., Form 10-K: Annual Report Pursuant to Section 13 or 15(d) of the Securities Exchange Act of 1934 for the Year Ended December 31, 2022,” *U.S. Securities and Exchange Commission*, February 14, 2023
53 NOV, Inc., “NOV, Inc., Form 10-K: Annual Report Pursuant to Section 13 or 15(d) of the Securities Exchange Act of 1934 for the Year Ended December 31, 2022,” *U.S. Securities and Exchange Commission*, February 14, 2023
54 NOV, Inc., “NOV, Inc., Form 10-K: Annual Report Pursuant to Section 13 or 15(d) of the Securities Exchange Act of 1934 for the Year Ended December 31, 2022,” *U.S. Securities and Exchange Commission*, February 14, 2023
55 NOV, Inc., “NOV, Inc., Form 10-K: Annual Report Pursuant to Section 13 or 15(d) of the Securities Exchange Act of 1934 for the Year Ended December 31, 2022,” *U.S. Securities and Exchange Commission*, February 14, 2023
56 MarketWatch, “Wind Cranes report contains company profiles and market share analysis of the top competitors from 2023 to 2030, as well as its predicted CAGR Value of 5.5%,” *MarketWatch,* Press Release, June 14, 2023
57 Huisman, “Onshore and offshore cranes: Manufacturing onshore and offshore cranes for challenging conditions,” *Huisman Manufacturing*, Accessed July 19, 2023
58 Huisman, “Equipped for Impact: Cranes,” *Huisman Manufacturing*, Accessed July 20, 2023
59 PALFINGER AG, "Wind: Wind Farms | Wind Farm Support Vessels | Crew Transfer Boats | Fenders," *PALFINGER Marine*, Accessed July 18, 2023
60 Konecranes, “Industries,” *Konecranes*, Accessed July 29, 2023
61 Konecranes, "Wind Power Cranes," *Konecranes*, Accessed July 18, 2023
62 Liebherr, “Wind Energy On- or Offshore: Wherever there is a Breeze,” *Liebherr*, Accessed July 18, 2023
63 Liftra, “About Us,” *Liftra,* Accessed July 17, 2023
64 Liftra, “LT1500 - Installation Crane,” *Liftra,* Accessed July 18, 2023
65 Liftra, “Turbine Installation,” *Liftra,* Accessed July 18, 2023
66 Liftra, “Operations,” *Liftra,* Accessed July 18, 2023