Assessment of Vessel Requirements for the U.S. Offshore Wind Sector

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U.S. Offshore Wind: Removing Market Barriers

Grant Opportunity

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The Douglas-Westwood LLC Project Team
February 28, 2013

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Executive Summary

Douglas-Westwood was commissioned by the US Department of Energy (DOE) to investigate the anticipated demand for various vessel types associated with offshore wind development in the United States through 2030, as well as to assess related market barriers and mitigating policy options. This Report contains our findings. It is intended to provide guidance on all vessel-related aspects of offshore wind installation to a wide range of audiences, including federal and state-level government agencies, research institutions, prospective project developers, installation companies, vessel operators and shipbuilders, as well as the general public.

To develop scenarios of potential vessel demand, Douglas-Westwood, in conjunction with Navigant Consulting and the National Renewable Energy Laboratory (NREL) and in cooperation with the Department of Energy (DOE), established detailed rollout scenarios for four US offshore wind regions, respectively Atlantic Coast, Great Lakes, Gulf Coast and Pacific Coast. Rollout scenarios were based on DOE-provided offshore wind capacity targets by region in three sets of variations, reflecting several possible rates of wind farm installation and differing levels of technology advancement prior to 2030. The highest growth scenario reflects the potential for 54 GW of capacity installed by 2030 in alignment with the *National Offshore Wind Strategy* issued in 2011 by DOE and the Department of the Interior.

The resulting scenarios used throughout this Report are referred to as the High Growth – High Technology (HH) scenario, the Medium Growth – High Technology (MH) scenario, and the Low Growth – Low Technology (LL) scenario. These scenarios inform our views of the vessel requirements in the US offshore wind sector through 2030. Each scenario falls into two phases: Phase 1 covers 2013 to 2020, while Phase 2 covers 2021 to 2030. The rollout scenarios are discussed in detail in Chapter 7 of this Report.

Deployment Scenarios		54GW by 2030 (HH) High Growth- High Tech Scenario		28GW by 2030 Moderate Growth with High Technology Adoption (MH)		10GW by 2030 - Low Growth - Low Tech Scenario (LL)	
		2020	2030	2020	2030	2020	2030
Total Capacity Deployed by Milestone Date (in GW)		7	54	4	28	1	10
Regional Distribution							
	Atlantic Coast	4	28	2	12	1	8
	Great Lakes	1	6	0.5	4	0	1
	Gulf Coast	1	5	0.5	4	0	1
	Pacific Coast	1	15	0.5	8	0	0

Table 1: Summary of Rollout Scenarios
Source: Douglas-Westwood, Department of Energy, NREL, Navigant

Demand Scenarios by Region

In the High Growth (HH) case, we expect 7 GW of installed offshore wind capacity nationally by 2020, and 54 GW by 2030. Within this case, the Atlantic Coast leads with 4 GW in 2020 and 28 GW in 2030. Virtually all projects in advanced stages of planning are on the East Coast, and thus all scenarios see this region both developing fastest and reaching the highest installed capacity.

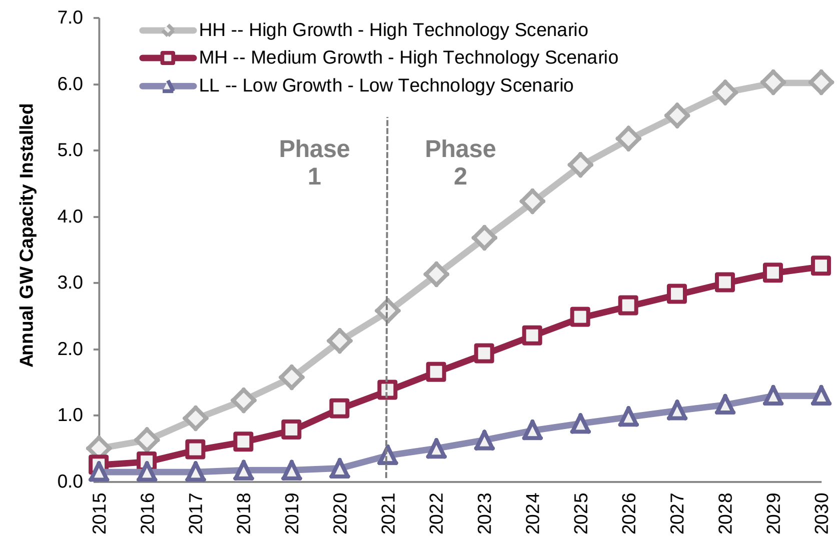


Figure 1: Annual Installation Rate in Each Scenario – US Total
Source: Douglas-Westwood, NREL

The Great Lakes region also has a formidable wind resource, but the pace of development will likely be slower than in the Atlantic Coast, as demographic factors are somewhat less favorable and other renewable options are also available. Further, the Great Lakes region must accommodate the constraints of the St. Lawrence Seaway as well as the wave and icing conditions prevailing on the lakes in the winter. Finally, much of the shallow water area of Lake Michigan and Lake Huron is close to shore, and thus the opportunity to use fixed platform wind turbines out of sight of land is limited. Indeed, floating turbines may ultimately prove to be the best solution for the region. Our High Growth scenario sees 1 GW of total installed capacity by 2020 and 6 GW by 2030 in the Great Lakes region.

Key Findings

The US Gulf Coast has a rich history of offshore development, primarily associated with the oil and gas sector. This legacy provides considerable experience and assets required for fixed and floating platform design, construction and maintenance. These capabilities can be readily applied to the offshore wind sector.

The wind resource in the Gulf of Mexico is generally inferior to the East Coast or the Great Lakes. At the same time, the region is more prone to hurricanes. Furthermore, the region has ample alternatives to offshore wind. Texas, with nearly 11 GW of lower cost, onshore wind capacity, leads the nation by far. Our High Growth scenario sees 1 GW of installed capacity in the Gulf Coast by 2020, and 5 GW by 2030.

The Pacific Coast is characterized by a rapidly dropping shelf, with water depths quickly exceeding the limits of fixed platforms. The region also suffers from NIMBY issues (NIMBY is an acronym for "Not in My Back Yard") which will limit the ability to put turbines near shore. The northwest of the region is amply served by hydropower, limiting the need for more expensive offshore wind alternatives. On the other hand, California is a leader in renewable energy policy, and offshore wind should find support there, if a suitable technology can be developed. Overall, the Pacific Coast would be an ideal location for floating turbines—a technology which is both promising and progressing, but not yet proven. However, if such floating technology proves to be cost effective on a large scale, then offshore wind could become a competitive alternative power source for California. Our High Growth scenario for the Pacific Coast sees 1 GW offshore wind capacity installed by 2020 and a total of 15 GW installed by 2030.

These scenarios inform our views of the need for offshore wind vessels. We present the results of our vessel demand forecasting exercise in detail in Chapter 9, and provide a brief overview of the results below. We note that the scenarios should not be interpreted as forecasts. This Report takes no position on the likely pace of offshore wind development; rather we look at the vessel-related implications of a given set of potential development paths.

Vessel Requirements under Each Demand Scenario

The rollout scenarios combined with three potential vessel strategies drive the anticipated vessel requirements (expressed in annualized vessel equivalent numbers) for a range of vessel types in various offshore wind capacity development scenarios. The related model and the underlying assumptions are covered in Chapter 8 and in Appendix 2.

Our vessel demand forecast for the High Growth scenario (where total US offshore wind capacity will reach 54 GW by 2030) represents the high end of our estimates. In this scenario, the United States, overall, will require about 19 construction vessel equivalents and almost 400 various survey, service and maintenance vessel equivalents by 2030. Within the construction vessel category, about half of the vessels are heavy lift and cable-lay vessels throughout the forecasting period. The number of turbine installation vessels (jackup vessels and purpose-built turbine installation vessels – TIVs – combined) will reach 4.9 vessel equivalents by 2020, 7.8 vessel equivalents by 2025 and 9.1 vessel equivalents by 2030 in the high case scenario.

Vessel demand expressed in vessel equivalents will likely mean more vessels in reality. This is due to the fact that vessel equivalent numbers assume full utilization of the vessel fleet within the given seasonal and weather windows. In real life, scheduling problems, logistical constraints, the variability of activity and the macroeconomic and financing environment keeps utilization rates below the theoretical maximum level. Our estimates indicate that the actual number of installation vessels employed in the US in the High Growth scenario may be 50 to 100% above the vessel equivalent numbers calculated by our model. In addition, another 15 to 20 jackup vessels or TIVs may be employed as heavy maintenance vessels (see Box 1).

The offshore wind capacity foreseen in the Medium Growth scenario (28 GW by 2030) generally represents a view better aligned with the European experience and the pace of US power generation capacity additions in the respective regions in recent times. In this scenario, we anticipate the construction vessel fleet to gradually ramp up to 8.2 vessel equivalents by 2030, of which nearly 40% will be heavy lift and cable-lay vessels throughout the projection period.

In the Medium Growth scenario, the number of turbine installation vessel equivalents (jackup vessels and TIVs combined) will gradually ramp up from 2.9 in 2020 to 4.4 in 2025 and 4.8 in 2030. We anticipate that over 200 vessels of other vessel types will also be needed to support the US offshore wind industry in this scenario. More than four fifths of these will be personnel transfer and other supply vessels employed both during the construction and during the operation and maintenance phase of offshore wind projects. Some, and possibly most, of the 20 anticipated heavy maintenance vessels foreseen by 2030 in the O&M vessel category will likely be retired or older generation jackups and TIVs.

Key Findings

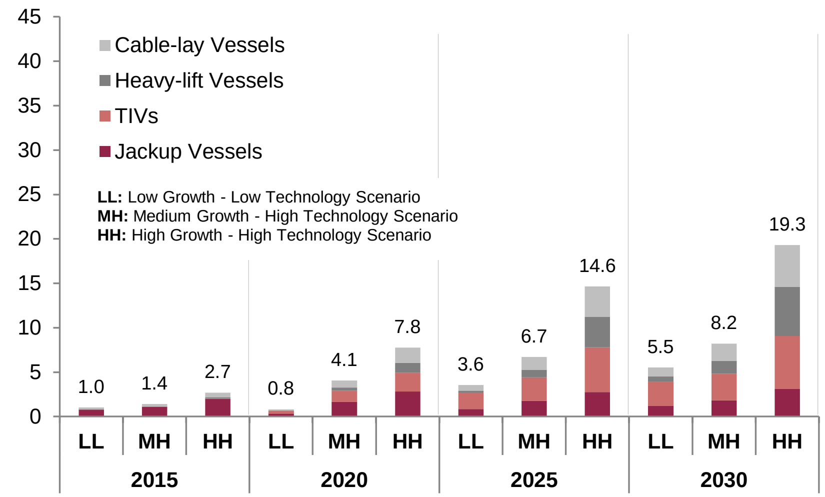


Figure 2: Annual Construction Vessel Requirements in the US under the "US TIV" Installation Strategy
Source: Douglas-Westwood

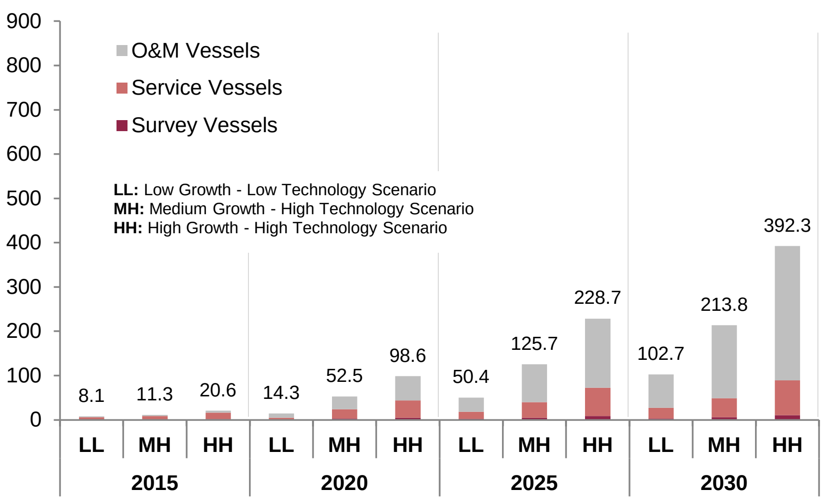


Figure 3: Annual Other Vessel Requirements in the US under the "US TIV" Installation Strategy
Source: Douglas-Westwood

A detailed overview of our modeling results in various scenarios and installation strategies is presented in Chapter 9 of this Report. We provide further background on our modeling methodology in Appendix 2 and in-detail modeling results in Appendix 3. In this summary, we present the results of the "US TIV Strategy", which foresees the construction of US-flagged turbine installation vessels as the primary means to satisfy turbine installation vessel requirements in the United States. We also analyze vessel requirements in two other installation strategies. The "US Jackup Strategy" assumes that turbine installation will mainly be carried out with low specification US-built jackups with feeder barge support, whereas the "European TIV Strategy" anticipates a higher participation of European installation vessels in US wind farm construction projects. These installation strategies are discussed in detail in Chapter 8.

The critical shortage in US vessel capabilities lies in the installation vessel category, particularly in turbine installation vessels (jackups and TIVs). Today, the US has only one specialized turbine installation vessel, the RD MacDonald, which is only partially completed as of the writing of this report. The evolution of the future turbine installation vessel fleet in the US will have to start from this modest foundation. There are no US-flagged cable-lay vessels. These are available globally, but cable-lay vessels have been in high demand recently. Other vessel types are assumed to be readily available or possible to construct in a short period of time. These include tugs, personnel transfer vessels and various supply and construction barges.

Key Findings

Box 1

Cross Check: The European Installation Fleet versus Our Model Forecasts

Model predictions do not always align with reality. Competitive pressures, logistical constraints, the variability of activity, and the macroeconomic and financing environment often mean that forecast quantities can vary from observed values. As a means to cross check our vessel forecasts, we compare these to the actual European installation fleet and the pace of turbine installation there. To this end, we have run our model with past and projected European offshore wind capacity additions, and calculated theoretical vessel equivalent requirements for Europe in a similar fashion as we did for the US.

Our analysis indicates that in the early phase of offshore wind development, there appears to be a large mismatch between calculated vessel equivalent numbers and the actual size of the available vessel fleet. At the end of 2008, there were about 14 installation vessels in the European vessel fleet which were used in offshore wind projects at some point in their lifetime. Only two of these vessels were purpose-built TIVs as late as 2008. Offshore wind installation often required improvised solutions, and many of these vessels were generic offshore construction vessels used mainly in port, bridge, or oil & gas-related construction projects. Importantly, many of these vessels were employed only at one or two offshore wind projects and not on a continuous basis.

By 2011, the vast majority of new installation vessel additions were purpose-built TIVs, and this trend is expected to continue going forward. It may be therefore more accurate to compare only the actual TIV fleet to model results for the post 2011 period. Between 2011 and 2014, actual TIV and calculated installation vessel numbers are more or less in line with each other in Europe. The notable jump in the size of the actual European TIV fleet in 2012 (with a total of eight new TIV deliveries in 2012 alone) reflects the anticipation of a rapid increase of installation vessel demand, as projected by our model, from 2013 onwards. The apparent overcapacity that will develop in the 2012- 2014 period will likely be absorbed only around 2018, providing that new vessel capacity additions slow down significantly after 2014.

We can reasonably assume that TIVs will dominate European offshore wind installation projects after 2011, and for practical purposes, only count purpose-built TIVs as actual installation vessels in Europe. In this case, our calculations indicate that the available installation vessels in Europe will install 24 full turbines sets per year on average in the 2011-2014 period. It is important to emphasize that this number includes the installation of foundations, transition pieces and turbine components alike. Overall, the average 24 turbine sets per installation vessel rate corresponds to an effective utilization rate of around 60%. Our comparable model estimate for the US indicates that an installation vessel equivalent will install an average 49 full turbine sets per year over the 15-year period between 2015 and 2030.

If we try to estimate the actual number of installation vessels to be used in the US based on the observed European installation rate (i.e. 24 turbine sets per available installation vessel), then the actual US vessel numbers are expected to be roughly twice as high as the vessel equivalent numbers calculated by our model. The 9.1 installation vessel equivalents in the US will likely mean approximately 18 actual specialized installation vessels in the water.

Part of the future heavy maintenance fleet will also likely be jackups or TIVs, probably older generation or retired units. This will further add to the number of offshore wind-qualified vessels operating in the US market. However, there is not enough reliable information in Europe about maintenance practices to determine what the exact ratio might be. As the cumulative offshore wind capacity increases, the number of jackup vessels or TIVs which are primarily employed in maintenance operations may easily match or even exceed the number used mainly for installation work in the post-2020 period, thus an additional 15-20 installation vessels of some sort may be used for maintenance by 2030.

Key Findings

Cross Check: The European Installation Fleet versus Our Model Forecasts (continued)

When comparing model estimates for vessel requirements in the US and Europe, the numbers look very similar on the basis of annual turbine installations per vessel equivalent. On average, one installation vessel equivalent will be required for every additional 49 turbine sets installed annually in the US between 2015 and 2030, according to our model. The corresponding model estimate for Europe suggests that one installation vessel equivalents would on average install 51 full turbine sets annually in the 2008-2020 reference period. At the same time, the calculated European and US numbers are considerably different on a vessel equivalent per installed capacity (MW) basis. The average annual megawatt capacity addition per installation vessel equivalent is increasing from 142 to 250 MW between 2008 and 2020 in Europe, while the same coefficient is increasing from 245 to 455 MW per vessel equivalent between 2015 and 2030 in the US.

This difference can be explained by the considerably larger average turbine size in the US over the projection period, which results in larger installed capacity by vessel, when applying the same installation efficiency rates in the US and Europe. It is important to note that US average turbine size projections are based on NREL technology assumptions, whereas European turbine size assumptions are derived from visible trends in the market. These trends indicate that even as 5 and 6 MW turbines are slowly gaining ground in Europe, the 3.6 MW turbine size will remain predominant in new installations in the next few years. The larger average project size in the US also explains part of the difference, as vessels spend less time with repositioning and more with actual capacity installation than they do in the case of Europe. We excluded the Pacific Coast region from both calculations, as floating turbines are expected to be predominant in this region. These may not require specialized installation vessels.

In conclusion, the actual number of jackups and TIVs will likely be higher in a given rollout scenario than the calculated vessel equivalent numbers suggest. This is due to the fact that vessel equivalent numbers assume full utilization within the pre-defined seasonal and weather windows.

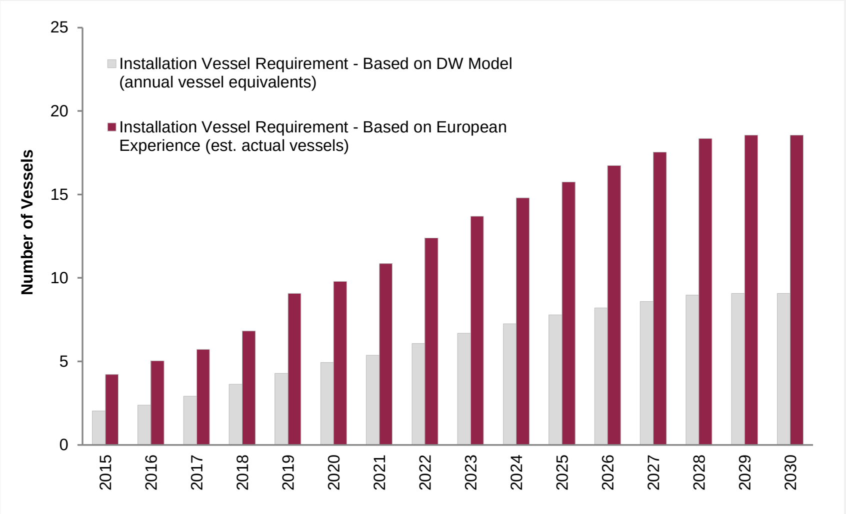


Figure 4: Jackup and TIV Demand in the US – Modeled vs. Estimated Actual Units

Source: Douglas-Westwood

In real life, operational difficulties, unplanned maintenance and logistical problems regularly occur, which can deteriorate vessel efficiencies to well below theoretical levels. Moreover, competitive considerations also affect vessel orders. As a result, full utilization of the installation vessel fleet has been and may continue to be elusive, even in the relatively mature European market. To date, only a few purpose-built installation vessels can operate in a more or less continuous fashion in European waters, moving from one project to the other.

In our rule of thumb estimate, the actual number of specialized offshore wind vessels built in the US might be 50-100% higher than vessel equivalent numbers suggest, if we only consider installation activities, and do not take maintenance-related vessel requirements into account.

Key Findings

Cross Check: The European Installation Fleet versus Our Model Forecasts (continued)

US - High Case*	2015	2020	2025	2030
Annual Installed Capacity (MW)	500	1,525	3,425	4,125
Cumulative Installed Capacity (MW)	500	6,000	19,125	39,000
Average Turbine Size (MW)	4.9	6.4	8.9	9.1
Average Project Size (MW)	361	500	779	831
Annual Number of Turbines Installed	103	238	383	451
Installation Vessel Equivalents (Model)	2.0	4.9	7.8	9.1
Heavy Maintenance Vessel Equivalents (Model)	0.0	6.0	18.0	39.0

** Excluding Pacific Coast Region*

Europe - Actual and Projected	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Annual Installed Capacity (MW)	373	577	883	874	1,166	3,105	2,800	3,100	3,400	4,200	5,100	6,400	6,900
Cumulative Installed Capacity (MW)	1,495	2,072	2,955	3,829	4,995	8,100	10,900	14,000	17,400	21,600	26,700	33,100	40,000
Average Turbine Size (MW)	2.8	2.7	3.0	3.6	4.0	4.0	4.0	4.1	4.2	4.3	4.4	4.5	4.6
Average Project Size (MW)	69	60	155	199	271	250	250	292	333	375	417	458	500
Annual Number of Turbines Installed	133	218	294	243	292	350	475	601	763	969	1,232	1,566	1,992
Installation Vessel Equivalents (Model)	2.6	4.3	5.5	4.6	5.4	14.5	13.1	14.1	15.0	18.1	21.4	26.2	27.6
Heavy Maintenance Vessel Equivalents (Model)	0.0	0.0	1.0	2.0	3.0	6.0	9.0	12.0	16.0	20.0	25.0	31.0	38.0
Actual OW-Suited Installation Vessel Fleet	14.0	18.0	20.0	24.0	34.0	37.0	39.0	n/a	n/a	n/a	n/a	n/a	n/a
of which Purpose-Built TIV	2.0	4.0	4.0	7.0	15.0	18.0	20.0	n/a	n/a	n/a	n/a	n/a	n/a
Annual OW-Suited Installation Vessel Additions	3.0	4.0	2.0	4.0	10.0	3.0	2.0	n/a	n/a	n/a	n/a	n/a	n/a
of which Purpose-Built TIV	1.0	2.0	0.0	3.0	8.0	3.0	2.0	n/a	n/a	n/a	n/a	n/a	n/a

Purpose-built TIV fleet in Europe is approximately 60% larger than calculated vessel equivalents.

Table 2: Key Offshore Wind Sector Characteristics in the US and Europe
Source: Douglas-Westwood

Summary of Findings

1. The conditions leading to the development of a large fleet of dedicated offshore wind turbine installation vessels in Europe are presently absent in the US.

Generous feed-in tariff-based support schemes, aggressive renewable energy targets, and a willingness of major utility players to invest in large renewable projects have ensured a steady flow of large-scale offshore wind projects in Northern Europe. This in turn has spurred European ship owners to invest in a new generation of highly sophisticated, purpose-built turbine installation vessels. By contrast, the US system—based heavily on state-level programs and incentives, more lightly capitalized developers, and negotiated power purchase agreements seeking to minimize renewable energy costs—has slowed the development of the US offshore wind industry.

2. The European experience provides critical insights about installation methods and vessel-specific requirements for potential American developers, installers and shipbuilders alike.

The construction of offshore wind installations has more or less become a standardized and streamlined process as the industry has matured in Europe. Installation requires the concerted operation of a number of specialized vessel types at various project phases. The European experience informs US expectations, and permits us to define the most important vessel types involved in this process, including their specific technical and operational parameters and critical components, such as jackup legs, dynamic positioning and heave compensation systems, which are essential for efficient installation operations. The average installation rates and costs which European operators were able to achieve, provide a useful reference for prospective US developers and vessel operators alike. (See Chapter 3 for more details on average dayrates by various vessel types and Chapter 8.3 for more details on vessel economics in various installation strategies).

3. The Jones Act is not an insurmountable obstacle, but it will likely increase cost and may cause delays in future US offshore wind projects.

The Jones Act does not prevent foreign-flagged vessels from engaging in offshore wind farm construction in US waters, but it does prevent foreign vessels from loading cargo and personnel in US ports and then transporting these to a US offshore wind farm construction site. Therefore, foreign-flagged installation vessels will have to be supported by various Jones Act-compliant feeder barges and other support vessels when operating on US wind farm projects. The Jones Act will not present an insurmountable obstacle to the development of the US offshore wind industry, but it will likely increase costs and delay installation in some cases.

4. A large fleet of advanced construction vessels is available in Europe for contracted work in the US, but the limitations resulting from the Jones Act represent a major obstacle for their deployment overseas.

This Report catalogues the vessels available for the construction of offshore wind installations on both sides of the Atlantic. A significant number of installation vessels in Europe could potentially participate in future offshore wind projects in the United States. Some of the established European installation companies are actively investigating US offshore wind market opportunities, but a confluence of factors is holding these companies back at the moment. The most important obstacles are excess demand for vessels in Europe, the lack of a visible US project flow, and the operational difficulties imposed by the Jones Act.

Key Findings

5. US shipyards lack the experience in building specialized turbine installation vessels and could only build them at a significant cost premium over more competitive Asian shipyards.

US shipyards are aware of the potential that lies in offshore wind turbine installation. Most of the major yards have tracked the industry for years. However, US shipbuilders have no experience in building advanced, purpose-built turbine installation vessels (TIVs). In all likelihood, these yards will be capable of constructing such vessels in the future, should the need arise, but they can only do so at a high cost premium compared to Asian yards. Estimates vary, but a US-built TIV would likely cost 60% to 200% more than a comparable vessel built in an Asian shipyard. This cost premium would likely be reflected in expected dayrates as well, thereby burdening the economics of future US offshore wind projects with an incremental cost of about $20-40 million per 100 turbines installed, roughly $50,000 per MW of installed capacity, or 0.2 cents per kWh.

6. The offshore wind turbine installation fleet will evolve gradually from lower cost, more basic vessels to larger, more expensive and sophisticated ones.

More basic solutions will likely dominate in the initial phases of development, mainly relying on the modest fleet of existing US vessels over the course of the first few projects. These vessels have only limited capabilities, both in terms of deck space and lifting capacity. The long mobilization time and the higher dayrates of advanced European TIVs make the use of these vessels in US offshore wind projects a distinctly high-cost proposition, even before considering the difficulties resulting from the Jones Act. Nevertheless, these will be used if US solutions are unavailable. Over time, as the US industry evolves, the European experience suggests that US vessel owners will have an incentive to construct their own fleet, which will grow more complex and sophisticated as the flow of projects becomes larger and more predictable. (See Chapter 8.3 for more details on vessel economics in various installation strategies).

7. Long-term vessel demand appears manageable, even in the most aggressive rollout scenario.

The results of our modeling exercise indicate that the projected demand for various vessel types associated with the construction and maintenance of offshore wind installations can be met by a number of means, including US newbuilds, use of contracted European vessels, and reliance on non-specialized US vessels. Our model suggests that the US turbine installation vessel fleet would have to grow progressively and reach a total of 9-10 vessel equivalents by 2030 to achieve the 54 GW of installed capacity foreseen in the High Growth scenario. This 9-10 vessel equivalents will likely mean more actual vessels in practice (see Box 1). Notwithstanding, even the most aggressive expansion of US offshore wind will require only about one specialized installation vessel equivalent be constructed per year, not a large number by any standard. To the extent these will be newbuild units constructed in the US, the economic benefits will likely be concentrated around Gulf Coast shipyards located in the coastal areas between Florida and Texas. Supply chain benefits related to vessel kitting, local services and O&M support will be distributed more evenly among US offshore wind regions.

Key Findings

Industry Drivers and Policy Considerations

In this section we examine certain key factors relevant to the creation of a US offshore wind installation and support fleet. These are factors that decision makers and policy makers should take into account if seeking to stimulate offshore industry growth but should not be construed as recommendations. Offshore wind remains a capital intensive, logistically challenging business.

The success of the business globally has depended on the willingness of governments to absorb learning curve costs through explicit support mechanisms such as renewables obligations and feed-in tariffs as well as policies addressing the kinds of issues identified below. All industry-related investments and policies involve costs and benefits, and we take no positions here on their inherent desirability.

1. Government Support for Offshore Wind

The economics of offshore wind installation, whether services or vessels, are ultimately driven by the viability of the offshore wind sector itself. This in turn is a function of the general system of support and preferences provided by the Federal and state governments to the sector, as has demonstrably been the case in the development of the land-based wind energy industry. Such support includes production tax credits (PTCs), investment tax credits (ITCs), grants and loan guarantees on the Federal level and favorable tax rates, financial incentives, renewable energy credits or standards, and real estate-linked preferences on the state and local level. All of these mechanisms have enhanced the viability and growth of the wind industry and, in the specific case of offshore wind, will in turn ultimately determine the demand for installation ships and other offshore wind vessels.

2. Visibility and Predictability Stimulate Investment

Certain vessel types used in offshore wind turbine installation (especially the most sophisticated purpose-built TIVs) are specialized vessels with limited applicability in other sectors, such as in offshore oil & gas. Therefore, vessel operators need a high level of certainty that their vessels will be sufficiently utilized over a long period of time in order to invest in such specialized assets.

European industry trends, notably in the U.K. and Germany, have shown that a government commitment to support a series of projects of sufficient scale to ensure multiple years of work for vessel owners is the single best way to stimulate investment in newbuild vessels. In the US, New Jersey has made significant strides in seeking to approve a single project in excess of 1 GW, representing three seasons of installation and component manufacturing work. This type scale of commitment would be consistent with the European model in providing visibility and predictability for the entire supply chain, including vessel operators. Other states might consider such an approach, possibly pooling projects with neighboring states to achieve greater critical mass overall.

3. Fostering Supply Chain Development

Since 2008 several consortia have developed design concepts for US-constructed turbine installation vessels in anticipation of rapid industry growth. However, due to the lack of incentives coupled with uncertainties about national policies, only a single US-based marine construction firm, Weeks Marine, has placed its faith in the industry and decided to proceed with the construction of the first purpose-built US installation vessel, the RD MacDonald. Tax policies and power purchase agreements in Denmark, the UK and Germany effectively rewarded such initiative, by increasing the incentive for proactive investment in the industry, rewarding early market entry and creating a competitive advantage for early movers.

4. Jones Act Rules

There are presently no US flagged vessels that could readily install 6 MW turbines in deeper waters, as would be required for the Block Island demonstration project, for example. As a consequence, developers may require a foreign-flagged TIV to mobilize from Europe to the United States in order to install the latest generation offshore wind technology. In addition to a steep mobilization cost—as much as $7-10 million just for transit —such a vessel would be prohibited by Jones Act rules from installing, in US waters, turbines that were loaded aboard it in a US port. These restrictions also prevent lower cost Asian-built vessels from operating freely in US waters, thereby limiting the most favorable economic scenarios for offshore wind developers. Jones Act waivers have historically been granted under certain circumstances, and may be considered in the case of offshore wind, although there is currently no movement in that direction.

Key Findings

5. Shipyard Competitiveness

The US has at least four large, and perhaps twenty, smaller yards which could construct offshore wind installation vessels. However, the US shipyards lack experience in the offshore wind industry and fabrication is much more expensive in the US than in Asian yards. Our industry surveys indicate that US-built vessels would cost 60-200% more than comparable Asian-built vessels. This is in part due to higher labor costs in the US, but more importantly, to a lack of TIV construction experience and a less developed supply chain. A large Korean yard like Samsung, for example, might construct 50 to 75 large vessels in a normal year, whereas the typical yard in the US would build only 2 to 4 large commercial vessels during the same period.

Creative strategies are needed in order to enable US shipyards to reduce costs and gain experience while complying with Jones Act constraints. For example, some yards have increased their competitiveness while meeting domestic content requirements using "ship-in-a-box" strategies which see modular components of vessels constructed in Asian yards, with these modules assembled in the US. Reducing the premium of US yards to 25-40% over their Asian peers with such strategies might prove sufficient to bridge the gap and enable developers to utilize US-built TIVs.

6. Capturing Value with Local (Ex-Shipyard) Final Assembly

It is highly unlikely that new shipyards would be built in offshore wind states purely for the construction of turbine installation vessels. Less than twenty TIVs are forecast to be needed through 2030, thus representing perhaps one newbuild order per year—not sufficient to prompt the establishment of new shipyards in offshore wind states. However, a substantial amount of vessel kitting can be accomplished outside the yard. Thus, while hull construction will likely be limited to established shipyards, the value of certain final assembly may be captured locally.

7. Communicating Opportunities to Components Suppliers

Major equipment used on TIVs includes engines, cranes, navigation, heave compensation, jacking systems and dynamic positioning systems. Given the relatively small number of TIVs anticipated to be built in the US in this decade, it is unlikely that component suppliers would establish a plant in a given state purely for this purpose.

However, such suppliers do make investments from time to time, and a linkage to an offshore wind project could be a reason to choose a given state as an investment destination. Making leading suppliers aware of investment support for a given jurisdiction could encourage inward investment.

8. Infant Industry Issues

The structure of the offshore wind industry in the United States is quite different from that in Europe. In the US, power purchase agreements are negotiated on a case-by-case basis, with considerable effort on the purchasing party's side to minimize per kilowatt hour power costs. At the same time, most US wind farm projects are being promoted by independent developers like Cape Wind, Fishermen's Energy, and Deepwater Wind. None of these has the capitalization of a major European utility like Dong or E.On. US developers also have to lock in power rates before they have full confidence in installation and operating costs. Thus, the US system tends to minimize power prices, depends on lightly capitalized developers, and puts cost-containment pressures on developers and a supply chain which have never constructed an offshore wind farm before in the United States.

This combination of factors may lead to an overly ambitious attempt to minimize installation costs, and do so by using lower cost vessels and less efficient installation strategies. This would imply a higher risk of delays or cost overruns. Cost-side pressure may also increase the risk of financial failure for some developers. Such an event could potentially undermine confidence in the industry as a whole, and would certainly reduce the appetite for vessel construction and related supply chain investment.

Opportunities for US and International Companies

Offshore wind provides opportunities for vessel owners and operators, as well as for service companies and vessel constructors, including shipyards and components providers. Visible projects on the East Coast—Cape Wind, Block Island and Atlantic City at the time of writing —should provide opportunities for both US and European installers (see Chapter 1.2 for a detailed overview of current US offshore wind projects). Cape Wind will generate work for US offshore construction companies. Block Island, to the extent 6 MW turbines are used, may well require the support of European TIVs. In both cases, at least one additional feeder barge will be required. As the industry develops over time, both US and European installers will see additional opportunities.

Jones Act-compliant support services, including personnel transfer vessels, tugs, and supply vessels will by definition be required to assist in installation, and later, for field maintenance services. These companies will tend to be local or regional, and may be established as start-ups or new business lines for fishing fleets, ferry services or other offshore providers.

To date, one installation vessel has been constructed in the United States. Incremental vessel orders will most likely depend on the fate of the RD MacDonald, the first vessel constructed. Assuming this vessel finds gainful employment, others may be encouraged to order additional vessels. Large US-built TIVs are more likely to enter service when a clear flow of offshore wind projects emerge.

The choice of whether to contract a European TIV or commission the construction of one in the United States depends materially on the construction cost differential between the US and Asian yards. The cost premium to Asian yards is estimated at 60-200%. The lower bound is achieved by relying on Asian yards to build modules which are later incorporated into the vessel in US yards, the so called "ship-in-a-box" strategy. The larger the foreign share recognized as complying with the Jones Act, the more competitive the US yards will be for the balance of the work.

The US has no flagged cable lay vessels. While cable lay is exempt from the Jones Act, large scale, on-going power cable installations may beg the question of why this is so. To the extent that ordinary Jones Act conditions come to be applied to cable lay operations, the industry will require a few cable lay vessels, providing opportunities for US shipyards.

Optimizing the foreign portion of vessels qualifying for domestic content provisions will be key in balancing cost considerations with new orders for US shipbuilders.

Small yards will benefit from US offshore wind regardless of cooperation with Asian yards. Feeder barges, workboats and personnel transfer vessels must all be Jones Act-qualified; thus they will be US-built, providing opportunities for US manufacturers.

Foreign manufacturers and those from non-coastal states may find the demand for vessel components and systems insufficient to warrant investment in a new facility in offshore wind states purely to meet offshore wind demand. Notwithstanding, such companies should be aware that a number of states with offshore wind potential also have specific programs designed to incentivize the establishment of a local offshore wind supply chain. These incentives may create an opportunity to establish a manufacturing facility intended to serve both offshore wind and other markets.

Floating turbines have potential for manufacture in a number of regions. Perhaps the Great Lakes represent the most significant opportunity. Large installation vessels cannot transit the St. Lawrence Seaway. Thus, the Great Lakes would face three options. A large, dedicated TIV could be constructed in the region; however neither the region's shipbuilding capacity nor the flow of projects can assure sufficient work for what may prove a $300 million vessel. Alternatively, the region may limit itself to shallow water sites and turbines of perhaps 4 MW nameplate capacity. This would allow the use of Seaway compatible installation vessels like the RD MacDonald.

In addition, the Great Lakes could turn to floating turbines, which could be constructed in the region with existing expertise in manufacturing and metal work. Such turbines would be able to capitalize on the Lakes' great depths and eliminate the need for specialized installation vessels. Thus, for the Great Lakes, the best opportunity may ultimately lay in floating offshore wind turbines.

Floating wind turbines may also provide opportunities for West Coast yards like San Diego's NASSCO. Such turbines can be constructed in the unused sections of drydocks, thereby permitting the simultaneous construction on other vessels in the same dock. Principle Power's floating turbine was built sharing a single drydock with another vessel under construction.

Key Findings

Opportunities for US and International Companies				
Stakeholder Group	**Opportunity**	**Participants**	**Rationale**	**Supportive Policy Options**
US Vessel Operators and Installers	Installation services for offshore wind turbines, foundations, and transition pieces	Primarily incumbents - contractors in Northeast, Gulf Coast and in the Great Lakes region	Turbine installation requires experienced contractors	No special policy support required
US Installation Vessel Owners	Need for specialized installation vessels	Primarily incumbents - operators in Northeast, Gulf Coast; utilities may be involved in later stages	Vessels cost $50-300 million, owners must have large balance sheets or vessel expertise	Reward early entrants with grants or tax breaks
Non-US Installation Vessel Owners	Need for specialized installation vessels exceeding current US capabilities	Primarily European incumbents - major installation companies like MPI and A2Sea	Timely installation of 6 MW turbines in 60+ ft water depths may require European TIVs	Support wind farm developers with rates that cover the cost of using European TIVs
Non-US Cable Lay Vessel Operators	Need for specialized cable lay vessels for wind farm power cables	Primarily European incumbents	No US-flagged vessels are available - existing fleet has plenty of work in Europe	Insure Jones Act does not prevent employment of these vessels in the US
US Cable Lay Vessel Operators	Potential need for US-flagged cable lay vessels	US power and telecom cable lay companies like Tyco	Steady stream of future projects may justify the construction of US-flagged cable lay vessel(s)	Reward early entrants with grants or tax breaks
US Shipyards - Large Vessels	Need for US installation and possibly cable lay vessels	Established yards only	Relatively small number of TIVs and other large vessels does not warrant new yard construction	Optimize "ship-in-the-box" percentage requirements to encourage US construction
US Shipyards - Personnel Transfer and Support Vessels	Need for US-built barges and personnel transfer vessels to support wind farm installation	Smaller yards as well as repair and maintenance facilities	Barges and support vessels must be US-built to meet Jones Act requirements	No special policy support required, but grants and tax breaks can encourage early movers
US Components Suppliers	Installation and other major vessels will require major components, such as cranes, jacking systems, DP	Primarily incumbents - major players like NOV, Caterpillar, Wartsila and others	Small number of required components is unlikely to justify greenfield investments	Capture those manufacturers looking to establish facilities for reason beyond just offshore wind
US Floating Turbine Supply Chain Players	Alternative, pre-asssembled turbine support structure not requiring installation vessels	Primarily shipyards and metal goods producers	Floating turbines can largely eliminate dependence of specialized installation vessels	Government R&D support for floating turbine technology
US Service and O&M Players	Support services for installation and field maintenance	Existing and start-up companies - including fishing and ferry boat operators	Barriers to entry are relatively low, smaller / local companies can easily enter the market	General entrepreneurial and investment support programs

Table 3: Opportunities for Various Stakeholders in the US Offshore Wind Supply Chain
Source: Douglas-Westwood

US Offshore Wind Development Scorecard

US Offshore Wind Development Scorecard Vessel-Related Aspects														
		Pre-Construction Phase			Construction Phase								Post-Construction Phase	
		Survey Vessel Availability			Construction Vessel Availability				Support Vessel Availability				O&M Vessel Availability	
		Environmental Survey Vessels	Geophysical Survey Vessels	Geotechnical Survey Vessels	Installation Vessels	Heavy Lift Vessels	Cable Lay Barges (near-shore)	Cable Lay Vessels (open ocean)	Tugs	Feeder Barges / Jackup Barges	Generic Barges / Offshore Supply Vessels	Personnel Transfer Vessels	Heavy Maintenance Vessels	Personnel Transfer Vessels
2013	**Atlantic Coast**	Green	Green	Green	Yellow	Yellow	Red	Orange	Green	Red	Green	Yellow	Yellow	Yellow
	Great Lakes	Green	Green	Green	Red	Red	Red	Orange	Green	Red	Green	Yellow	Red	Yellow
	Gulf Coast	Green	Green	Green	Yellow	Green	Red	Orange	Green	Red	Green	Yellow	Yellow	Yellow
	Pacific Coast	Green	Green	Green	Red	Yellow	Red	Orange	Green	Red	Green	Yellow	Red	Yellow

Legend		
	Red	No vessels available meeting Jones Act requirements
	Orange	Vessels in short supply, but available on global market
	Yellow	Work around with existing vessels feasible
	Green	Vessels readily available

Key Findings

The scorecard above provides a snapshot of our most important findings related to the current availability of various vessel types along the offshore wind supply chain in the four potential US offshore wind regions. The scorecard is intended to highlight key bottlenecks, which can potentially hinder the development the US offshore wind industry, and to track progress towards the elimination of these obstacles on a regular basis.

Survey Vessels

The availability of survey vessels will be primarily a function of scheduling and price, neither of which should pose a material obstacle to the development of the offshore wind industry in the US. Survey vessels are assumed to be widely available across the US, as these vessels are used for a wide range of activities, including for scientific and naval research as well as for seismic studies for the offshore oil and gas industry.

Environmental surveys and relatively unsophisticated bathymetric analysis, the assessment of water depth and seabed conditions, can be completed by various vessel types equipped with sensors or by autonomous underwater vehicles (AUVs). Such sensors and AUVs are comparatively affordable and readily available on the market. Geophysical surveys encompassing seismic surveys of the seabed can be conducted by the US geophysical fleet, which is primarily employed in the oil and gas sector. Geotechnical surveys involving core samples can also be accomplished using any kind of fixed platforms with drilling equipment welded to the deck. Core sampling is routinely conducted in coastal waters for projects like bridge or dock construction, and the existing fleet could, in all likelihood, be augmented by the jackup drilling fleet in the Gulf of Mexico, part of which is currently stacked and idle.

Construction Vessels

The most problematic areas in the offshore wind supply chain lie in the construction vessel category. Offshore wind farm construction is carried out by a number of specialized vessel types, which either have to be built domestically or contracted from the global marketplace, once offshore wind development reaches a meaningful scale in the US.

The critical shortage in US vessel capabilities lies in the installation vessel category, particularly in turbine installation vessels. Today, the US has only one dedicated turbine installation vessel, the RD MacDonald, which has relatively modest capabilities and was only partially completed as of mid-2013. The Atlantic Coast and Gulf Coast regions have a certain degree of access to installation solutions, which can be suitable in the early stages of offshore wind development. The RD MacDonald was primarily designed to serve the Atlantic Coast and the Great Lakes regions. Additionally, the Atlantic Coast is the best-positioned to mobilize European installation vessels, if it becomes necessary. This would likely entail extra costs and operational difficulties arising from Jones Act restrictions. The Gulf Coast region has a large fleet of offshore installation vessels, primarily serving the oil and gas industry. Improvised installation solutions based on the existing fleet, such as retooled jackup barges or heavy lift vessels, will likely be able to meet some or all of the installation vessel demand in the Gulf Coast region, which is projected to be relatively modest in any scenario. Vessel access to the Great Lakes is limited by the size of the locks along the St Lawrence Seaway system. The region will therefore have to rely on smaller installation vessels and turbine sizes, or develop its own installation vessel fleet. Both solutions can prove challenging for project economics. In the Pacific Coast, only floating platform solutions appear feasible on a commercial scale. These can be assembled in a port and floated to the installation site using tugboats. In this case, the challenges related to the availability of installation vessels do not apply. However, certain floating platform designs may require specialized installation vessels, such as the PelaStar support barge, which was developed specifically for the installation of the PelaStar tension leg platform (see Chapter 9.6).

The Atlantic Coast, the Gulf Coast and the Pacific Coast regions have varying degree of ready access to heavy lift vessels. A large number of heavy lift vessels are serving the offshore oil & gas industry in the Gulf of Mexico, these vessels can also be deployed to offshore wind-related installation projects both in the Gulf Coast and in the Atlantic Coast. The Pacific Coast region appears to be amply served by the region's own heavy lift vessel fleet, which can be deployed to offshore wind projects as well. Heavy lift vessel access to the Great Lakes system is problematic due to the size limitations along the St. Lawrence Seaway. This means that the region will either have to use smaller substations, which can be lifted with "Seawaymax" sized heavy lift vessels, or build a large heavy lift vessel that will most likely be "locked in" to the Great Lakes system.

Douglas Westwood

Key Findings

There are no US-flagged cable lay vessels in operation today. Foreign-flagged cable-lay are generally available in the global marketplace, although cable-lay capacity is increasingly tight, which may cause bottlenecks in offshore wind construction projects in the future. Cable-lay barges are used in shallow waters near the shore, where large cable-lay vessels are not practicable. These tend to be smaller, domestic-built vessels. Such cable-lay barges are currently not available in the US, but existing barges could be adapted without great difficulty.

Service Vessels

Service vessels will have to US-built and US crewed due to Jones Act requirements. Tugs, non-fixed barges and improvised personnel transfer vessel (PTV) solutions are readily available. Jackup barges will be needed for offshore wind construction; more optimized PTV solutions will likely develop over time.

Tugs are readily available in the US and they will be used in other applications when not employed in offshore wind work. As a result, there will be no exclusive offshore wind tug fleet in the US.

To the extent the turbine installation vessels remain in the field, they must be supported by feeder barges which ferry turbine components from the staging port to the wind farm site. Turbine manufacturers require that these vessels be stabilized prior to the removal of turbine components. This may be accomplished by using a jackup barge. There are currently no suitable jackup barges in the US, thus at least one would likely be required prior to the inception of any offshore wind projects. We anticipate that such barges will be constructed in timely fashion to support US wind industry. The transport of most foundation types does not require fixed barges. Such non-fixed vessels are readily available in the US.

A wide range of vessel types can be applied as PTVs, including some of the current fishing fleet and even certain pleasure craft. We assume that personnel and supply vessels of some sort will be available for offshore wind-related operations in the US. Initially, these will most likely be general purpose or multiuse vessels enlisted to support offshore projects. As the offshore wind industry matures in the US, purpose-built vessels optimized for wind installation are likely to emerge.

Operation & Maintenance Vessels

O&M vessels will have to US-built and US crewed due to Jones Act requirements. Retired installation vessels will most likely be used for heavy maintenance work over time; improvised PTVs are readily available and will increasingly specialize over time.

Wind farms will require access to maintenance vessels with the ability to replace heavier components, such as turbine blades. No such vessels exist today in the US; during the first several years of project deployment, existing wind farms will most likely turn to the installation vessel fleet when major maintenance must be conducted on operating turbines. As a result, the same regional characteristics apply to heavy maintenance vessels as in the case of installation vessels. Later on, as economies of scale are attained, a dedicated maintenance fleet is likely to emerge. Lower spec early generation installation vessels may be retired to maintenance duty over time, as larger and more capable vessels displace them from construction projects. We assume that maintenance vessels will be available as needed, with the caveat that installation vessels may play this role for some time.

PTVs used during the O&M phase are the same type of vessels used for construction support. PTVs are used to transport maintenance crews to the wind farm site for planned maintenance operations and to carry out smaller repairs. A wide range of vessel types can be applied as PTVs for offshore wind O&M support. Initially, these will likely be general purpose or multiuse vessels. As the offshore wind industry matures in the US, purpose-built PTVs optimized for offshore wind operations will likely appear.

Part 1

Overview of the Vessel-Related Aspects of the Offshore Wind Industry

Overview of the Vessel-Related Aspects of the Offshore Wind Industry

Introduction

Only a handful of Western European countries (and to a lesser extent China) have so far developed significant amounts of offshore wind power generating capacities. Understanding the policy frameworks under which offshore wind has developed in these countries provides useful guidance for US policymakers and project developers alike. In Chapter 1, we examine the European installation experience and review the current state of the US offshore wind industry.

Offshore wind projects in Northern Europe have progressively grown both in size and complexity over time. This has led to the emergence of standard installation methods and to the development of an increasingly specialized vessel fleet. We analyze these methods and provide a detailed overview of the offshore wind farm installation process in Chapter 2. We analyze the main vessel types used in offshore wind installation in detail, and catalogue the available vessel fleet in the most important vessel categories in Chapter 3. We take a detailed look at some of the key vessel components, such as jackup legs, cranes and dynamic positioning, which are critical for successful installation operations in Chapter 4.

The Jones Act will likely present the most important constraint for the operation of installation vessels in US waters, and it may also have an impact on the development of the US offshore wind installation vessel fleet. We provide an overview of the Jones Act and highlight some of the most important rules governing vessel certifications and classifications in Chapter 5.

Market participants along the offshore wind industry supply chain will play a key role in the development of a domestic installation vessel fleet. We surveyed a number of US shipyards and interviewed several installation companies both in the US and Europe to find out, whether the US vessel supply chain can adapt flexibly to the future needs of offshore wind industry. We present the results of these surveys in Chapter 6.

A2SEA Sea Worker Installing a Siemens Turbine in London Array
Source: Siemens

Chapter 1

Development of the Offshore Wind Industry to Date

1 Development of the Offshore Wind Industry to Date

1.1 The European Installation Experience

The Origins of the European Offshore Wind Industry

The development of the offshore wind industry began in northwestern Europe in the early 1990's, but offshore wind projects gained meaningful scale only from the early 2000's. The first commercial offshore wind farm was inaugurated in 1991 in Denmark, an early pioneer in offshore wind development. The Vindeby project consisted of eleven 450 kW turbines with a total capacity of 4.95 MW. Until about 2001, the European offshore wind sector developed slowly, with only a handful of pilot-scale projects near the shore, featuring less than 1 MW turbines. The early stage of development was concentrated in Denmark, the Netherlands and Sweden.

The Middelgrunden project in Denmark, which was completed in 2001, is recognized as the first utility-scale project with 20 turbines and a total installed capacity of 40 MW. Offshore wind capacity addition on a truly commercial scale started in 2002-2003 with the inauguration of two 100+ MW projects in Denmark, namely the Horns Rev 1 and the Rodsand 1 wind farms with 160 MW and 166 MW installed capacity, respectively. This temporary peak was followed by several years of relatively slow activity and distinctly small projects. Offshore wind capacity additions only started to pick up again from 2007, when the adoption of the EU's climate and energy package provided enough confidence for utility investors to commit multiple billion dollars to offshore wind megaprojects.

The post-2007 boom saw the construction of increasingly large wind farms like the Horns Rev 2 project (209 MW) in Denmark in 2009, and a series of UK megaprojects, such as Sheringham Shoal (317 MW), Walney (367 MW), Greater Gabbard (504 MW) and the London Array (630 MW) wind farms, all completed in 2012.

Today, Europe remains the unchallenged global leader in offshore wind. As of the end of 2012, China and Japan are the only countries outside of Europe with existing commercial offshore wind capacities. The European dominance in offshore wind resulted from a combination of factors, namely a strong domestic manufacturing base, generous renewable support schemes at the national level, ambitious renewable energy targets, a very good wind resource and a vibrant supply chain around the offshore oil & gas industry in the North Sea.

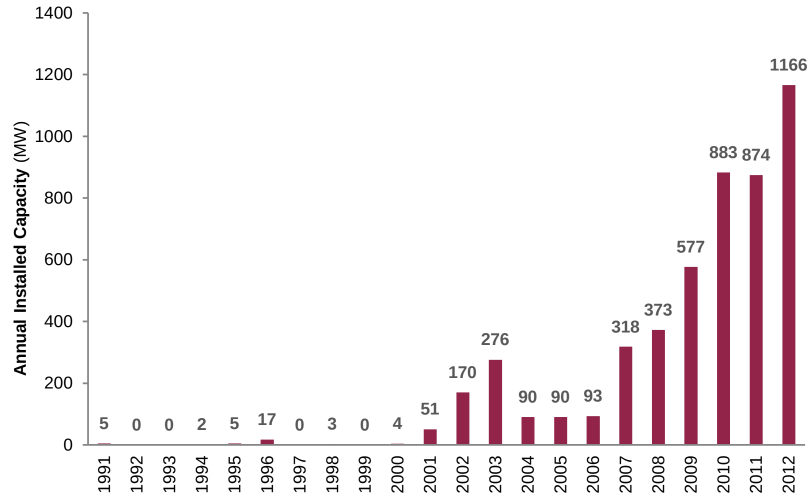


Figure 5: Annual Offshore Wind Capacity Additions in Europe
Source: EWEA

Manufacturing Traditions

Industrial equipment manufacturing has strong traditions and a very robust industrial base in Germany and in Scandinavia. This, coupled with world-class R&D, led to the emergence of wind turbine manufacturing champions, such as Germany's Siemens and Denmark's Vestas. These companies built their dominant market positions in onshore-based wind installations, but over time, as the offshore wind industry developed, they were able to translate their market leadership into dominant positions in offshore wind turbines as well. As a result, 97% of all offshore wind turbines installed in Europe to date were manufactured by just four German and Danish companies, 86% of the total by Siemens and Vestas alone.

1 Development of the Offshore Wind Industry to Date

In Germany's case, support for offshore wind is not only part of the country's climate policy, but also an important part of industrial policy, given the dominance of German companies in high-end equipment manufacturing. In this respect, offshore wind stands in a stark contrast to solar panels. German companies (most notably Q-Cells, which went bankrupt in 2012) initially achieved considerable success in the solar business, but later lost competitiveness to low-cost Chinese competitors, and solar subsidies are now regarded by some as supporting the outsourcing of German jobs to China.

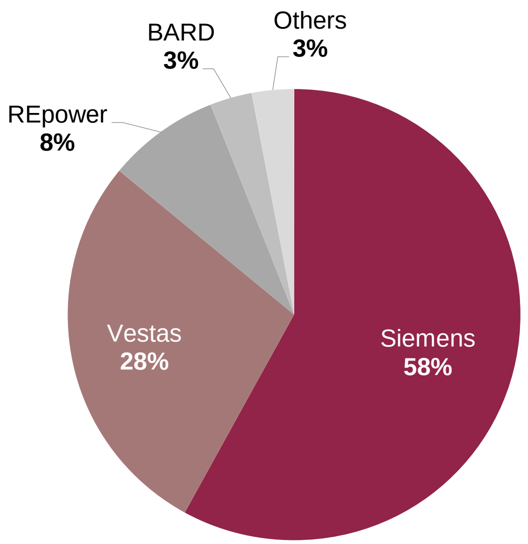


Figure 6: Cumulative Market Share of Offshore Wind Manufacturers
Source: EWEA

Support Schemes and Targets

The relatively high share of renewables in the European power system is due to the generous support schemes that sprung up in the late-1990's and early-2000's in individual EU member states. Renewables received another strong boost with the adoption of the EU's climate and energy package in 2007, which went into force in 2009.

The package established the so-called 20-20-20 set of targets, mandating a 20% reduction of greenhouse gases from 1990 levels, a 20% reduction in energy consumption and 20% share of renewables in energy consumption, all by 2020. The package broke down the 20% renewable target to member state level, and required each member states to develop national policies to reach the target, including elaborate support schemes to support renewables.

These support schemes are typically feed-in tariff systems, but some member states also use more market-oriented support policies based on tradable green certificates (somewhat similar to the renewable portfolio standards in the US). Nevertheless, both types of support schemes differentiate between various sources of renewable energies, providing higher tariffs (or more green certificates) for higher-cost sources, such as offshore wind. It is a widely-held view among European policy-makers and industry sources that the renewable target is the only hard target in the 20-20-20 framework, whereas the energy efficiency and the greenhouse gas reduction targets are going to be difficult to attain.

After Germany's decision to phase out nuclear power entirely by 2022, the importance of renewable power generation, including offshore wind, has increased further. Germany is set to overtake the UK as the largest market for new offshore wind capacity additions in 2013-2014, and 38% of all new offshore wind turbines are expected to be erected in German waters over the next two years, according to the European Wind Industry Association (EWEA).

The North Sea Wind Resource and the Oil & Gas Sector

The third factor behind the large-scale deployment of offshore wind in Europe lies in the North Sea. On the one hand, the North Sea region has an excellent wind resource. On the other hand, the region is home to one of the world's most developed offshore oil & gas infrastructures, with abundant capabilities along the entire offshore wind supply chain, including shipping, cable-laying, offshore construction, heavy lifting and personnel transfer to offshore installations. As a result, the first offshore wind projects could rely entirely on the existing offshore supply chain and the large-scale deployment of offshore wind capacities could begin before specialized turbine installation vessels appeared on the scene in the latter part of the last decade.

1 Development of the Offshore Wind Industry to Date

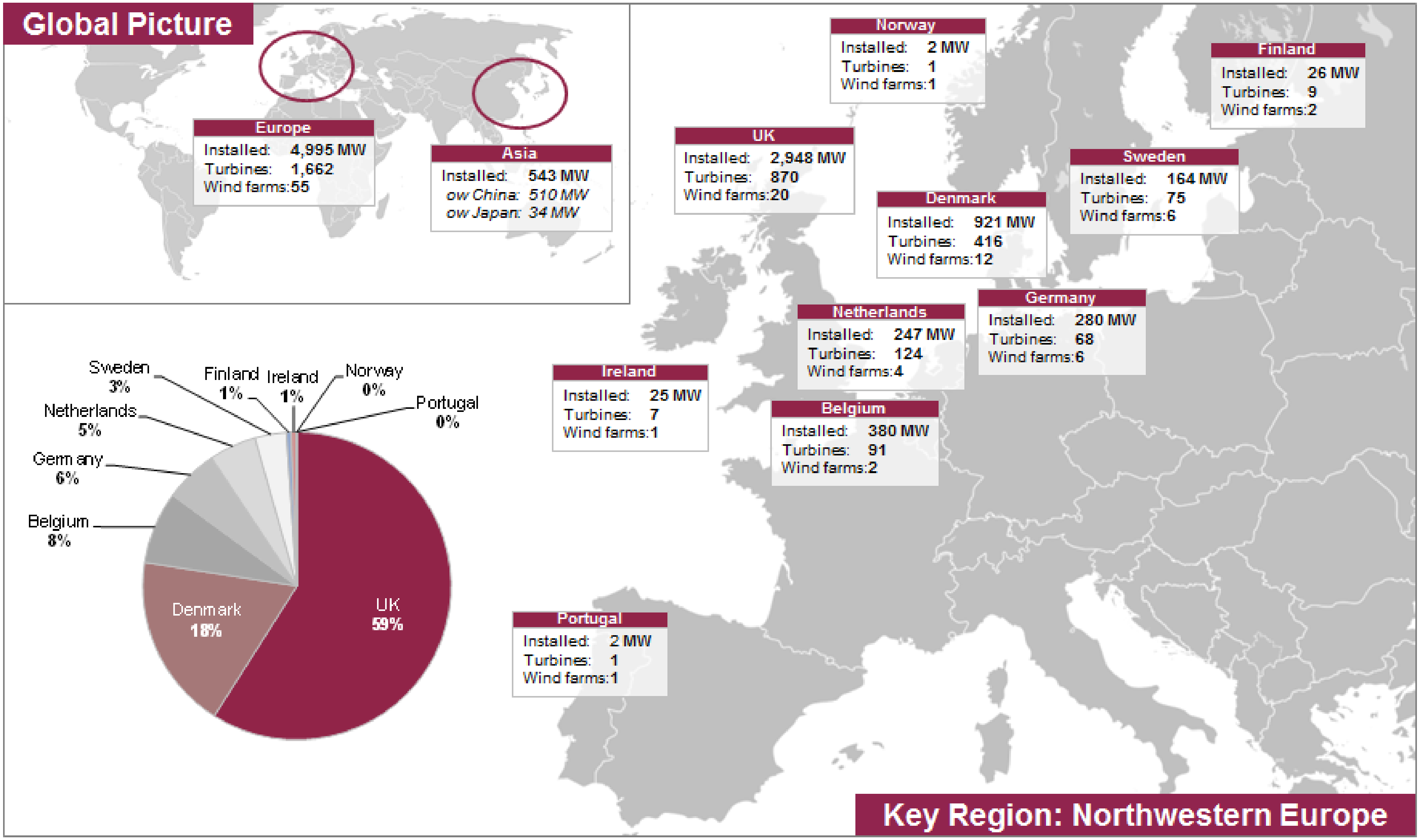


Figure 7: Cumulative Installed Offshore Wind Capacity through 2012 – Europe and Asia
Source: Douglas-Westwood

1 Development of the Offshore Wind Industry to Date

Lessons from the European Installation Experience

Specialized Vessel Capacity Follows Visible Project Flow

Meaningful offshore wind capacity additions started around 2002-2003 in Northern Europe with the construction of two large offshore wind farms (Horns Rev 1 and Rodsand 1) in Denmark. This early take-off, however, was followed by a multiyear slowdown in offshore wind activity. European utilities only started to sanction truly large-scale offshore wind projects after the adoption of the EU climate and energy package in 2007.

The introduction of specialized jackup vessels and purpose-built turbine installation vessels to the market coincided with these waves of activity. The first wave saw in 2002 the conversion of two A2Sea vessels, the Sea Energy and the Sea Power, to specialized offshore wind installation operations. Both of these vessels worked on the Horns Rev 1 project and a host of other smaller wind farms. The first purpose-built turbine installation vessel, the MPI Resolution was also built around this time. It was completed in 2003 and initially worked on a series of smaller North Sea projects, including the North Hoyle and Scroby Sands wind farms, both with a 60 MW installed capacity. It is interesting to note that Europe had about 100 MW of installed capacity by the time the first A2Sea vessels were converted to offshore wind installation. Previous wind farms were installed by vessels “borrowed” from the North Sea oil & gas industry.

The second, larger wave of offshore wind projects from 2007 boosted demand for more sophisticated purpose-built TIVs, and a new generation of installation vessels started to hit the market from around 2009. The pace of capacity additions accelerated further from 2010, and as many as 11 purpose-built TIVs were delivered or entered service in the 2010-2012 period, with at least another four vessels currently under construction at the time of writing.

Most of these vessel additions were made in anticipation of a continuously growing project flow in Europe in the balance of this decade. The consensus view within the European offshore wind industry is that the rapid acceleration of installation activities in recent years is just the beginning of the “take-off” phase of offshore wind development. The European Wind Energy Association estimates that only those projects currently under construction will constitute 1,400 MW of new capacity addition in 2013 and 1,900 MW in 2014. E.On Climate and Renewables, one of the leading operators of offshore wind farms across Northern Europe, estimates that 40,000 MW of offshore wind capacity will be installed in Europe by 2020, which will require annual installed capacity volumes to increase by 30% each year between 2012 and 2020.

The European experience suggests that the chicken and egg dilemma playing out between wind farm projects and the specialized installation vessels required for their construction can be resolved once a stable and visible flow of relatively large projects is in place. In such an environment, vessel operators can and will ramp-up their installation vessel fleets with little hesitation.

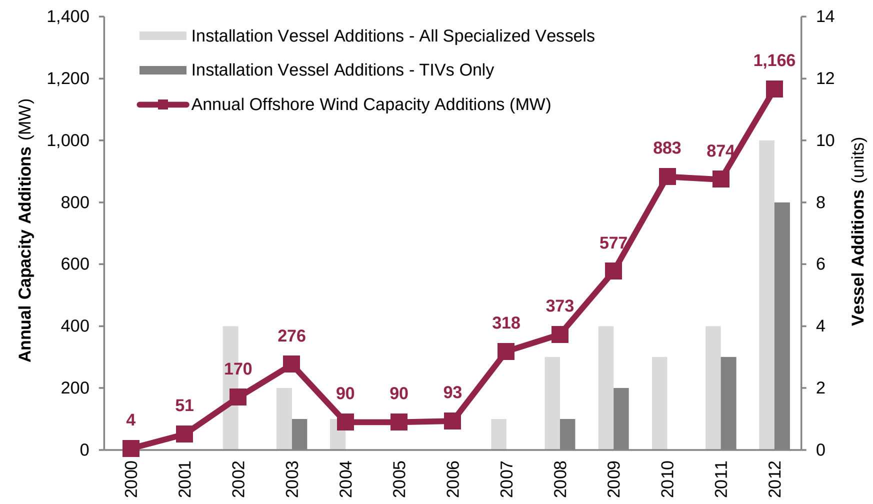


Figure 8: Offshore Wind Capacity and Specialized Vessel Additions in Europe

Source: EWEA, Douglas-Westwood

Tendency towards Market Concentration, but not Among Vessel Operators

An interesting characteristic of the European offshore wind market is the high level of concentration along most parts of the supply chain. As already discussed above, turbine manufacturing is heavily concentrated in the hands of a few German and Danish players, most notably Siemens and Vestas. The manufacturing of foundations is similarly concentrated with only three players (Bladt from Denmark, Erndtebrucker Eisenwerk in Germany and SIF Group/Smulders in the Netherlands) accounting for 76% of all foundations installed in 2012. The manufacturing of high-voltage array and export cables is dominated by five players, Nexans (US), JDR (US), Prysmian (Italy), ABB (Switzerland) and NKT (Denmark), accounting for a total of 78% of the array cables and 95% of export cables installed during 2012.

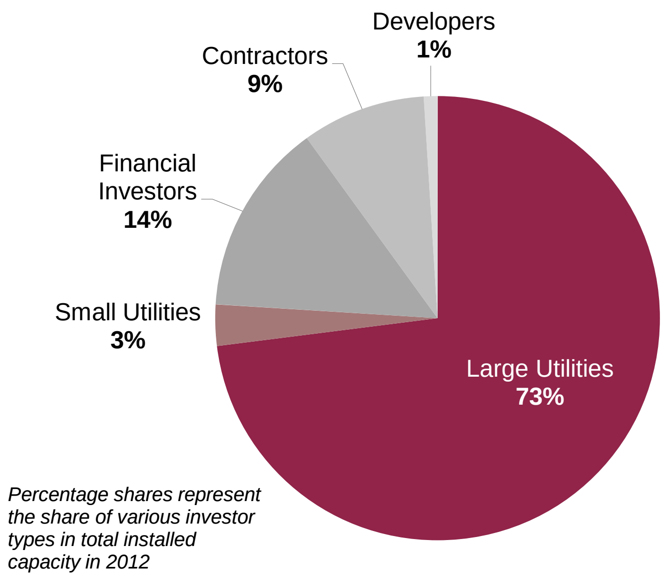


Figure 9: Offshore Wind Investments in Europe in 2012 by Investor Type
Source: EWEA

The vast majority of European offshore wind assets are operated by large utilities, which is a markedly different industry structure than that taking shape in the US, one that is dominated by small project-specific developers. In Europe, a total of 73% of installed offshore wind capacity was added by large utilities in 2012, and at the end of 2012, about 71% of the cumulative stock of offshore wind generating capacity was in the hands of only six major European power companies, namely Dong (Denmark), Vattenfall (Sweden), E.On (Germany), RWE (Germany), Scottish & Southern Energy (UK) and Centrica (UK).

Interestingly, however, this high level of concentration is not typical among the operators of offshore wind installation vessels. We have identified a total of 17 European companies that either regularly employ specialized vessels for offshore wind turbine installation or have at least one such vessel under construction. Nine of these companies own and operate more than one vessel specialized in turbine installation. The large number of players is due to the widespread presence of a multitude of shipping operators around the North Sea, and the considerable overlap between offshore wind installation and other offshore construction activities, particularly in the oil & gas sector.

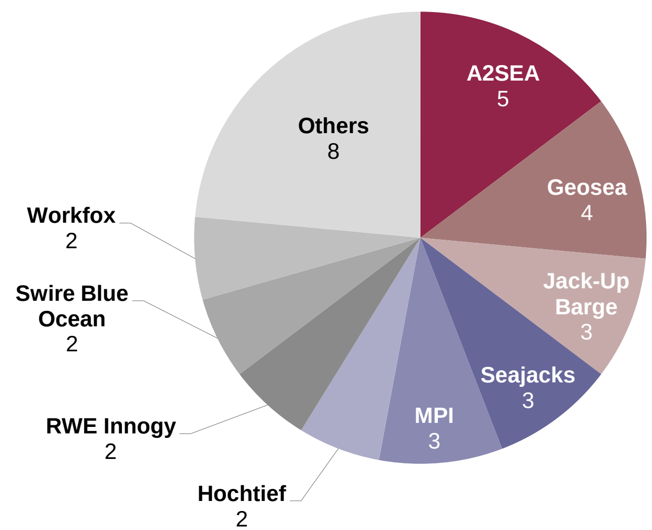


Figure 10: Leading European Offshore Wind Installation Vessel Operators
Source: Douglas-Westwood

1 Development of the Offshore Wind Industry to Date

Several of the major operators of offshore installation vessels (for example, Workfox, Geosea and Jack-Up Barge BV) primarily focus on servicing the oil & gas industry with their relatively versatile fleet of jackup barges. Offshore wind represents a lucrative opportunity for these companies to extend their activities. Other operators, notably MPI and Seajacks, focus primarily on offshore wind, but nevertheless offer services with their more specialized vessels to the oil & gas industry as well. These include platform maintenance and decommissioning services, among others. Hochtief's Odin jackup vessel, which was primarily designed for offshore wind projects, was also used in various other marine construction operations, including the pile driving work during the expansion of the Bremerhaven container terminal in Northern Germany.

Outlook and Challenges Ahead

The most recent statistical records indicate that the average project size, the average turbine size, the average water depth and the average distance from shore have been generally on a rising trend. However, the EWEA does not expect the average turbine size to increase much further from the current 4 MW level over the next one or two years, due to the continuing popularity of the 3.6 MW turbine model by Siemens. Vessel operators also reckon that moving beyond the current 6-7 MW maximum turbine size would require a new generation of TIVs or purpose-built feeder barges, which can accommodate considerably larger components, particularly turbine blades.

The move towards deeper waters may also hit a hard ceiling in the near future, as monopile foundations continue to dominate in the European offshore wind market and still account for three quarters of new installations. According to major European vessel operators, the continuing appeal of monopiles is due to their significantly lower cost compared to more sophisticated tripod or jacket type foundations, as well as to the complexity associated with the installation of more advanced foundation types.

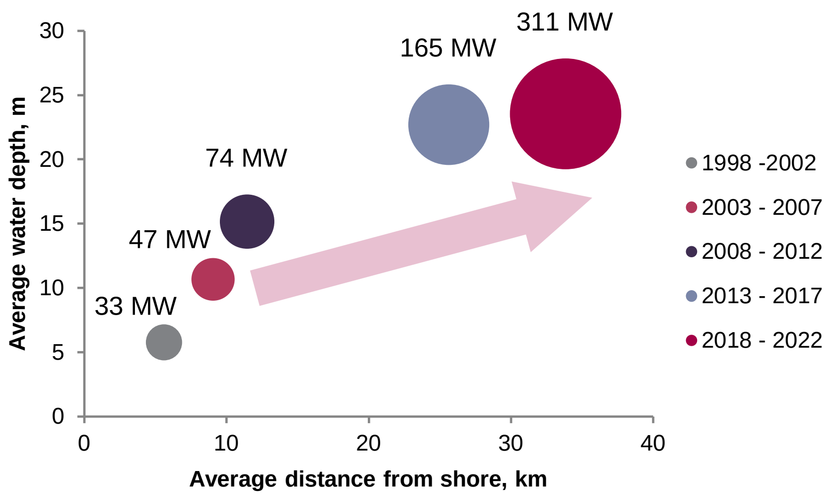


Figure 11: Growing Trend in Average Water Depth and Distance from Shore
Source: Douglas-Westwood

The maximum water depth suitable for monopile foundations is around 35 m (115 ft). A number of industry experts believe that average water depths will not increase much beyond this limit, until more cost efficient alternative foundation types are discovered, or monopiles suitable for deeper waters are developed.

1 Development of the Offshore Wind Industry to Date

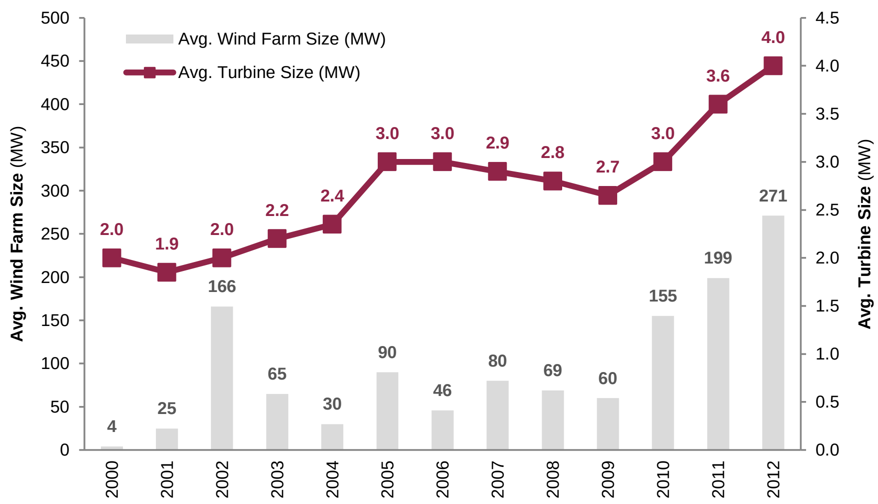


Figure 12: Average Wind Farm and Turbine Size in Europe
Source: EWEA

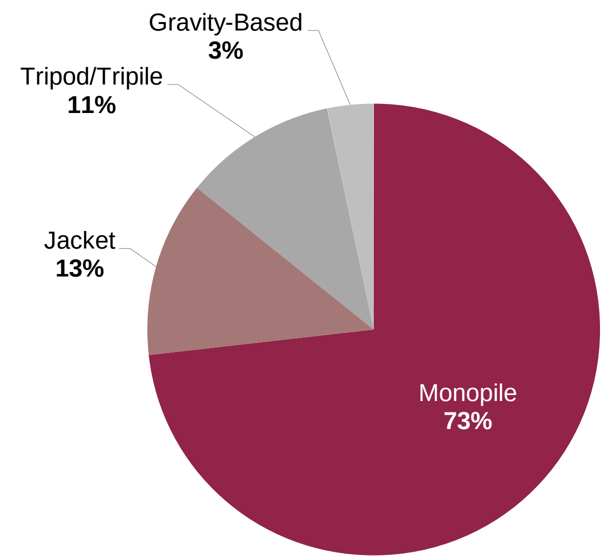


Figure 13: Foundation Types Installed in Europe in 2012
Source: EWEA

Turbine manufacturing and installation vessel availability appear to be no constraint on continuing growth in offshore wind capacities in Europe. However, bottlenecks have started to emerge in transmission in recent years, both in cable manufacturing and in existing power grids.

The manufacturing of high voltage export cables is heavily concentrated among a handful of players (see above), and they would have to expand capacities quite rapidly to keep up with growing capacity additions, which is not at all assured.

Bottlenecks in onshore transmission capacity are also becoming a problem, especially in Germany, where the national transmission grid would require considerable upgrades and expansion to accommodate additional power from intermittent wind sources from the north of the country and to deliver it to southern and western load centers.

It is a sobering reality that the cost of offshore wind power has not come down significantly with the rapid expansion of installed capacities in Europe. Increasing water depths and the growing distance from shore are in fact pushing the cost of offshore wind investments higher, while the cost efficiency improvement from larger turbine size will be limited by the difficulties associated with the installation of turbines larger than 6 MW.

It is important to note, that the average load factor in Europe is around 35% (ca. 3,100 hours/year). Given the exceptional wind resource, the mature nature of the industry and a considerable move away from shore in recent years in Europe, it would be optimistic to expect superior performance for early North American projects. Some US project developers anticipate load factors of close to 50% for announced projects.

1.2 Overview of Current Offshore Wind Projects in the US

Turning to the US market, we note that the country presently lacks “steel in the water”, but a number of projects continue to advance.

Probable Offshore Wind Projects in the US									
Project	**State**	**Developer**	**Distance from Shore**	**No. of Turbines**	**Turbine Size**	**Planned Capacity**	**Planned Const. Start**	**Planned Completion**	**Project Cost***
Cape Wind	MA	Energy Management Inc.	6 nm	up to 130	3.6 MW	up to 468 MW	2014	2015	$2,500 mn
Block Island	RI	Deepwater Wind	3 nm	5	6 MW	30 MW	2014	2014	$250 mn
Atlantic City	NJ	Fishermen's Energy	3 nm	5	5 MW	25 MW	2014	2014	$200 mn

** Latest available data*

Table 4: Probable Offshore Wind Projects in the US

Source: Douglas-Westwood based on public sources as of February 2013

Cape Wind

Cape Wind is the only commercial-scale offshore wind project in the United States under late stage development. The project envisions a maximum of 468 MW consisting of 130 x 3.6 MW wind turbines. The turbines are to be installed in federal waters on Horseshoe Shoals in Nantucket Sound, 5.6 nautical miles from Cape Cod. Some local residents remain concerned over the location of the project, claiming that the project will ruin scenic views and reduce property values.

The project has been in development since 2001. The project’s developer currently anticipates construction to start in 2014 and last about 18 months. The project has received all permits necessary for construction start.

Cape Wind is being developed by Energy Management Inc. (EMI), a New England based energy company with 38 years of experience in energy conservation, pollution control and gas-fired power plant operation. Various sources estimated the project’s total cost at about $2.5 bn.

The project has secured two separate 15-year power purchase agreements (PPA) with local utilities. National Grid agreed in May 2010 to purchase 50% of Cape Wind’s power production at 18.7 cents per KWh, rising by 3.5 cents per KWh each year. The PPA was challenged in court, but was upheld in December 2011 by the Massachusetts Supreme Judicial Court. In November 2012, Cape Wind signed a similar 15-year PPA with NSTAR, a subsidiary of Northeast Utilities, for 27.5% of Cape Wind's power output.

Block Island

The Block Island offshore wind farm is a 30 MW demonstration-scale project in Rhode Island consisting of 5 x 6 MW turbines. The project also includes the construction of a new substation on Block Island, as well as a 34.5 kV submarine transmission cable from the wind farm to Block Island and from there on to the shore, connecting the island to the mainland grid for the first time. The project site is approximately 3 nautical miles from Block Island in state territorial waters. The project developer is Providence-based Deepwater Wind, which expects construction to start in 2014 at the earliest. The total cost of the demonstration project, including the wind farm and the transmission cable, is estimated at $250 million by the project’s developer.

Deepwater Wind submitted the final state and federal permit applications for Block Island in October 2012. The company was expected to have obtained the federal lease for the project by early-2013 at the time of writing. The US subsidiary of the UK-based power company National Grid PLC signed a 20-year power purchase agreement (PPA) for the entire output of the wind farm. The PPA has been approved by the Rhode Island Public Utilities Commission, and the Rhode Island Supreme Court upheld the contract in July 2011.

The price of the power from the Block Island wind farm is capped at 24.4 cents per KWh for the first full year of commercial operation, which escalates at 3.5% each year. However, the purchase price is subject to a number of adjustment clauses, for example, the first year price may be reduced if capital costs are lower than the amount set in the PPA. Under the contract, Deepwater Wind must absorb any construction cost overruns.

1 Development of the Offshore Wind Industry to Date

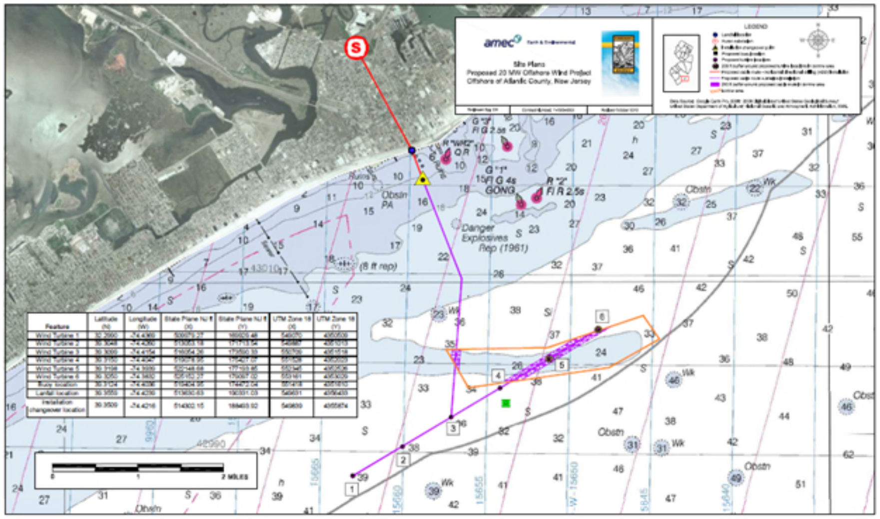
Atlantic City

The Atlantic City wind farm is a demonstration-scale project initiated by Fishermen's Energy, an offshore wind developer sponsored and financed by the East Coast commercial fishing industry. The project consists of 5 x 5 MW turbines. The wind farm's proposed location is just 2.8 miles from the New Jersey coast in state waters. Water depth is 40 ft (12 m) at the site. The construction of onshore installations was expected to commence in 2013 at the time of writing, while the offshore construction and commissioning was foreseen in 2014.

Fishermen's Energy had completed all geotechnical surveys and secured all federal and state permits necessary to proceed with the construction of the project by mid-2012. The company was reported to be in the process of selecting contractors for the project at the time of writing, with a stated preference for New Jersey vendors, as far as practicable.

The demonstration project is expected to cost more than $200 mn. The associated infrastructure includes underground cables and an onshore substation, which will be installed 25 to 70 ft underground, below Atlantic City's Tennessee Avenue. The staging area for workers and equipment will be various Atlantic City docks and harbors, including the Tennessee Avenue beach, Gardner's Basin and the docks at Rhode Island Avenue.

New Jersey has been highly supportive of offshore wind development. The state enacted the Offshore Wind Economic Development Act in 2010, which calls for at least 1,100 MW of wind energy to be produced in the state. NIMBYism is also less of an issue in Atlantic City than it is in New England. The project's developer appears to be keen to showcase the project to Atlantic City visitors, and the wind farm's visibility from the shore was considered a plus during site selection.



Overview of the Atlantic City Wind Farm
Source: Fishermen's Energy

1 Development of the Offshore Wind Industry to Date

Advanced Technology Demonstration Projects Supported by the Wind Program of the U.S. Department of Energy

In addition to the projects noted above, a number of other initiatives are also under way in the US. In December 2012, the US Department of Energy awarded funding for seven offshore wind pilot projects totaling $168 million over six years. These projects are to promote or demonstrate large cost reductions over existing offshore wind technologies and develop viable and reliable options for offshore wind installation in the United States.

Under the program, each project will receive an initial funding of up to $4 million for initial engineering, design and permitting during a one year period. The DOE will then select up to three of the seven pilot projects for follow-on phases and provide up to $47 million for each selected projects to proceed with siting, construction and installation. The targeted start of commercial operation for the selected projects is no later than 2017. The final grant amount is subject to Congressional appropriations. The seven projects selected for the first phase of funding are listed below.

DOE Demonstration Projects Selected for First Phase Funding						
Project	State	Developer	Distance from Shore	No. of Turbines	Turbine Size	Planned Capacity
Cleveland	OH	Lake Erie Energy Development Co.	7 nm	9	3 MW	27 MW
Boothbay Harbor	ME	Statoil North America	12 nm	4	3 MW	12 MW
Monhegan Island	ME	University of Maine	2 nm	2	6 MW	12 MW
Atlantic City	NJ	Fishermen's Energy	3 nm	5	6 MW	30 MW
Virginia Beach	VA	Dominion Power	20 nm	2	6 MW	12 MW
Port Isabel	TX	Baryonyx Corp.	5 nm	3	6 MW	18 MW
Coos Bay	OR	Principle Power Inc.	8-13 nm	5	6 MW	30 MW

Table 5: DOE Demonstration Projects Selected for First Phase Funding

Source: Department of Energy

Port Isabel, TX

Baryonyx Corporation, based in Austin, Texas, plans to install 3 x 6 MW turbines in state waters near Port Isabel, Texas. The project will demonstrate an advanced jacket foundation design and integrate lessons learned from the oil & gas sector on hurricane-resistant facility design, installation procedures, and personnel safety.

Atlantic City, NJ

Fishermen's Atlantic City wind farm plans to install 5 x 5 MW turbines in state waters 3 nautical miles off the coast of Atlantic City. The project will result in an advanced bottom-mounted foundation design and innovative installation procedures to mitigate potential environmental impacts. (See above for further details.)

Cleveland, OH

Lake Erie Development Corporation, a regional public-private partnership based in Cleveland, Ohio, plans to install 9 x 3 MW turbines on "ice breaker" monopile foundations designed to reduce ice loading. The project will be installed on Lake Erie, 7 nautical miles off the coast of Cleveland.

Coos Bay, OR

Seattle, Washington-based Principle Power plans to install 5 semi-submersible floating foundations outfitted with 6 MW direct-drive offshore wind turbines. The project will be sited in deep waters 8 to 13 nautical miles from Coos Bay, Oregon. Principle Power's semi-submersible foundations will be assembled near the project site in Oregon, helping to reduce installation costs.

Boothbay Harbor, ME

Statoil North America of Stamford, Connecticut plans to deploy 4 x 3 MW wind turbines on floating spar buoy structures in the Gulf of Maine off Boothbay Harbor at a water depth of approximately 460 ft (140 m). These spar buoys will be assembled in harbor to reduce installation costs and then towed to the installation site.

Monhegan Island

The University of Maine plans to install a pilot floating offshore wind farm with 2 x 6 MW turbines on concrete semi-submersible foundations near Monhegan Island. These concrete foundations could result in improvements in commercial-scale production and provide offshore wind projects with a cost-effective alternative to traditional steel foundations.

Virginia Beach, VA

Dominion Virginia Power of Richmond plans to design, develop, and install 2 x 6 MW turbines off the coast of Virginia Beach on innovative "twisted jacket" foundations that offer the strength of traditional jacket or space-frame structures but use substantially less steel.

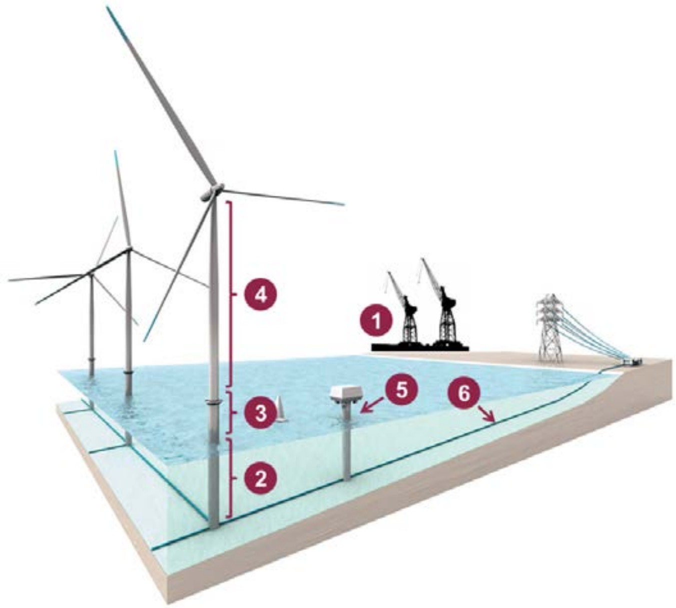
Chapter 2

Installation Methods

2 Installation Methods

Port Logistics
1

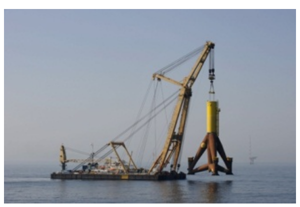
- To the extent possible, turbine components have to be pre-assembled onshore.
- In the construction phase, staging ports need to be able to accommodate the pre-assembly and storage of foundation and turbine components.
- In the O&M phase, service ports have to enable quick loading of spare parts and 24/7 departure to the wind farm site.



Cable Laying Operations
6

- Array cables connect wind turbines with each other and the substation, export cables connect the substation to the onshore grid.
- Both array and export cables are installed by specialized cable-lay vessels.
- Offshore cables are typically buried under the seabed, either via trenching and burial, or via less costly rock dumping.

Foundation Installation
2



- Method depends on foundation type. The most widely-used monopiles are driven into the seabed by large pile hammers, often by the same vessel used for turbine installation.
- Much heavier gravity-based and tripod-type foundations require vessels with heavy lifting capability.
- Floating turbines are pre-assembled onshore and towed to the site by tugs.

Transition Piece
3

- The transition piece is connecting the most widely-used monopile foundations with the turbine tower.
- They are typically installed by the same vessels as turbines themselves.
- Other foundation types are already fitted with transition pieces prior to installation (e.g. tripods), or do not require transition piece at all (e.g. jackets, gravity-based structures).

Turbine Installation
4

- Turbine installation can take several forms. Smaller turbines can be installed in one piece by heavy lift vessels.
- The largest turbines are assembled piece by piece, typically by using purpose-built TIVs.
- Medium-sized turbines are typically assembled by using either the “bunny-ear” or the “rotor star” configurations (pictured).

Substation Installation
5

- Substations are pre-assembled onshore and installed at the site as a single unit, typically by a heavy lift vessel, or by a jackup vessel with heavy lifting capabilities.
- Substation foundations are also heavier than those used for turbines.
- Larger wind farms have multiple substations (roughly one for each 250 to 400 MW of installed capacity).

Figure 14: Overview of the Offshore Wind Farm Installation Process
Source: Douglas-Westwood

2 Installation Methods

An understanding of vessel characteristics and requirements is driven by the nature of installation activities. We review offshore wind installation process in this section.

2.1 Foundation Installation

A growing number of contractors have advanced installation vessels, which are capable of installing both the foundations and the turbines. However, foundation and turbine installation work is still predominantly carried out by different vessels on a given project. Generally, foundation installation can be carried out by a wider variety of construction vessels, such as derrick barges, in addition to more specialized jackups and TIVs.

The method varies, depending on the foundation type. The most important foundation types assessed below are monopiles, tripods, jackets and gravity-based structures.

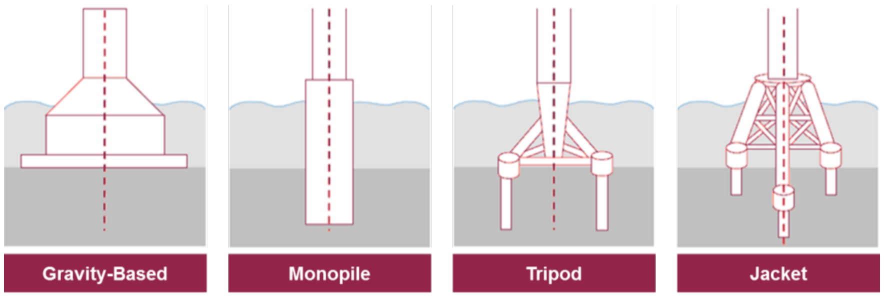


Figure 15: Widely-Used Offshore Wind Turbine Foundation Types
Source: E.On

Monopiles are hammered into the seabed using jackup vessels or newer self-propelled turbine installation vessels (TIVs). Monopiles are either transported in a vertical position or floated to the site, where they are upended. The monopile is accurately located using a gripping tool and driven into the seabed using a pile hammer. A pile hammer can exert a force of 300 tons or more with each blow. Monopiles are typically driven to a depth of 30 meters (100 ft) into the seabed.

Deepwater structures, especially tripods, are heavier than monopiles, thus the installation of these require higher spec jackup vessels with large crane and storage capacity. Tripods and jackets require multiple small “pin piles” to be driven into the seabed. Piles can be installed before or after the placement of the structure; pre-piling requires a piling guide. Tripod and jacket structures are fabricated with sleeves at each corner, allowing them to be located accurately over the pin piles. The interface between the substructure and the pin pile is then grouted.

Prior to installation of gravity-based structures (GBS), seabed preparation is carried out to ensure a level site. GBS are typically installed from a crane barge. GBS can be installed extremely quickly provided the supply logistics are efficient, with separate installation and transportation vessels. GBS can also be floated to site before being installed.

Stable sea conditions are required for support structure installation and increased downtime is therefore to be expected with projects further offshore and in deeper waters. Thorough seabed surveys are necessary on the foundation site to insure efficient installation.

Contract lead times have varied greatly from project to project, but a support structure installation period of 9 months was reported for the installation of the 100 monopiles at Thanet. The 54 monopiles at Lynn and Inner Dowsing were installed in around 3 months. Experience from the most recent offshore wind projects shows that installation rates have averaged one support structure every two days.

Foundation installation also includes the installation of transition pieces. The transition piece joins the foundation to the turbine tower. These are maneuvered into place by crane and a structural grout is applied in the annular gap between the transition piece and the support structure. Transition pieces can be installed at a rate of over one per day but around 1.5 days per transition piece is standard across a project.

2 Installation Methods

Case Study: Belwind, Belgium, 165 MW

As part of a $360 million Engineering, Procurement and Construction (EPC) contract to provide balance of plant on the Belwind project, Van Oord sourced and installed 56 monopiles and transition pieces. The monopiles weighing between 300 and 500 tons were transported from the manufacturing site to the logistics base at Zeebrugge, Belgium. Transition pieces were transported from Aalborg, Denmark to Zeebrugge.

The monopiles were installed from Ballast Nedam's Svanen HLV, the largest floating crane in the world with a lifting capacity of 8,200 tons. The monopiles were lifted using the Svanen's grab hook and were located to an accuracy of 1cm using GPS technology. The monopiles were driven around 110 ft (34 m) into the seabed, an operation taking approximately 3 hours.

Installation of the 56 monopiles was completed between September 2009 and February 2010. The transition pieces were transported three at a time to the site and fitted over each monopile by the JB114 jackup platform. The transit time from Zeebrugge to the offshore site located about 26 nautical miles from the port was around six hours. At the site, the jackup's 230 ft legs were extended and the platform elevated. The JB 114's crane lifted the transition piece and slid it over the monopile with an overlap of 23 ft. About 70 square feet of concrete was poured in the annulus between transition piece and monopile. Installation of the 56 transition pieces was completed in 5 months between October 2009 and March 2010.

HLV Svanen
Source: Ballast Nedam

2.2 Wind Turbine Installation

Wind turbine installation involves transporting the wind turbines to the site in their main components and then installing them upon the support structure using a combination of jackup vessels and/or crane barges. Wind Turbine installation methods have undergone a number of development stages.

Main Characteristics of Various Turbine Types														
	Hub Height meters		Blade Length meters		Rotor Diameter meters		Tower Weight tons		Nacelle Weight tons		Towerhead Weight* tons		Total Assembly tons	
	Low	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
3 MW Class	65	84	44	55	90	113	73	130	70	85	130	160	210	290
3.6 MW Class	75	90	52	59	107	120	180	180	125	125	220	230	400	410
5 MW Class	85	95	60	62	122	126	285	450	280	320	430	440	710	890
6 MW Class	85	105	75	75	126	154	220	280	200	320	360	480	610	760
8 MW Class	105	120	80	80	164	164	400	450	350	430	450	550	850	950
10 MW Class	120	125	67	90	164	190	500	600	n/a	n/a	500	625	1,000	1,125

** Towerhead weight includes the weight of the nacelle, the blades and the hub.*

Table 6: Indicative Size and Weight Dimensions of Various Turbine Classes
Source: Douglas-Westwood Based on Industry Sources

Stage 1

Early wind farm installations employed barges and pontoons that were used as work platforms in offshore sectors like port construction or bridge building. The units were not self-propelled and had to be moved from site to site. Not all units had jack-up capabilities. The units could not transport components and separate transport vessels were needed to deliver components to the site.

Example: Odin

Stage 2

This stage saw the development of both barges and vessels tailored towards offshore wind installation. Not all units were newbuild vessels, but these units were retrofitted to meet the industry's needs. The barges had permanent cranes and DP capabilities, although most of them remained non-self-propelled. Both self-propelled and non-self-propelled vessels lacked the traditional vessel hull design, and operated more similarly to work platforms. By this stage, both the barges and the vessels had jack-up capabilities, but could not transport components. As in the previous stage, transport vessels were employed to deliver components to the site. Wind turbine installation typically took place in the summer months in the early stages, but season and weather windows have become less limiting to construction activities in subsequent stages.

Example: Thor (barge) and Windlift 1

Stage 3

This stage includes the new turbine installation vessels (TIVs) like the Pacific Orca designed by Knud E Hansen. This stage embodies the latest developments and technologies in turbine installation. The vessels have traditional vessel hulls, looking and operating like vessels. They have a large deck area that is used to transport components and used as work space while the vessel carries out the installation.

The vessels have jack-up and DP capabilities, fixed cranes and sometimes a helipad. Self-propelled, they can attain speeds of up to 13 knots, reducing transfer times considerably. In addition, once the vessel is jacked up, it is able to carry out operations in harsher weather conditions. Overall these vessels reduce installation times, create larger weather windows for operations, and reduce transport times.

Example: Pacific Orca

2 Installation Methods

Stage 4 – Next Generation Concepts

It is not yet clear what would be the predominant turbine installation method in the future beyond Stage 3, but a number of interesting concepts have emerged in recent years, which can be indicative of the directions of future development.

Single-Lift Installation

IHC Merwede, in collaboration with W3G Marine, has designed a new turbine installation vessel concept "Windlifter", which would transport and install fully assembled wind turbines in one lift onto pre-installed foundations. This would reduce the number of tasks to be performed during offshore turbine installation, and thereby improve operational efficiency as well as safety during the installation process.

Windlifter Concept
Source: Windlifter.nl

The installation of fully pre-assembled turbines in one piece is not unprecedented. For example, the two 5 MW turbines at the Beatrice Demonstrator Project in Scotland were installed by a heavy lift vessel (Rambiz) in 2006 and 2007. However, the simultaneous transportation of multiple large pre-assembled turbines (four of them in the case of the IHC Merwede concept) and their installation at commercial scale projects is not feasible with the current TIV fleet.

Windlifter Concept – Mechanical System to Skid the Turbines into Position
Source: Windlifter.nl

The "Windlifter" concept is different from currently used TIVs in a number of important ways. The Windlifter has no jackup legs, no heave compensation and no onboard cranes either, thus it is not limited by water depth or crane height. Instead, the concept is using an X-BOW hull line design to provide stability, and a relatively simple modular mechanical system to skid the turbines from the vessel onto the foundation.

2 Installation Methods

Floating and "Tip-Up"

Floating turbines are not yet deployed in a commercial scale, but these represent a promising future solution for deepwater locations, where fixed foundations are not feasible. The most extensively tested floating design is using a single cylindrical spar buoy as floating support structure, which is moored to the seafloor with catenary cables. The floating spar buoy design has already been tested in a full-scale demonstration project, notably Hywind, deployed 7.5 miles from the Norwegian coast at a water depth of 720 ft (220 m). The Hywind project was developed by Statoil; Siemens supplied the 2.3 MW turbine.

Hywind's Spar Buoy Foundation is Being Towed to the Installation Site
Source: Nordicenergysolutions.org

Generally all floating turbine designs are at least partially pre-assembled onshore and towed to the site by tugboats. The installation of spar buoy type turbines is slightly more complicated due to the fact that they have to be upended, and the turbine installed at the installation site. The Hywind project used a relatively unsophisticated crane barge (Eide Lift 6), but more specialized vessel designs may be developed for "tip-up" operations, if spar buoy-type floating turbines become widely used.

A Norwegian start-up WindFlip has already developed an interesting concept, which would use the same vessel for towing and "tip-up". WindFlip would use a lightweight barge to float the turbine horizontally to the site, and then erect it by letting in water at one end, with the device still attached. Once the structure is moored to the seafloor, the vessel fills with air, returns to a horizontal position and proceeds with the installation of the next turbine.

The WindFlip concept would allow developers to install spar buoy-based floating turbines without using crane barges, and the vessel's 8 knot transit speed would allow a somewhat shorter shuttle times between the staging port and the installation site compared to a feeder barges towed by tugs.

WindFlip Concept
Source: Windflip.com

No Lift Installation

Principle Power's patented WindFloat floating substructure design was the second commercially tested floating concept after Hywind. The WindFloat foundation improves dynamic stability by dampening wave and turbine induced motion using a tri-column triangular semisubmersible platform. The wind turbine is positioned on one of the three columns. After being towed to the installation site, the WindFloat platform is anchored with a conventional catenary mooring system consisting of four lines.

2 Installation Methods

The WindFloat prototype was installed in October 2011 by Principle Power about 5 km (3 miles) offshore of Aguçadoura, Portugal in approx. 45 meters (150 ft) of water. The project's developer was Portuguese utility EDP; the WindFloat platform was fitted with a Vestas V80 2.0 MW offshore wind turbine. The installation was the first offshore wind turbine deployment worldwide which did not require the use of any heavy lift equipment offshore.

The entire system was assembled and pre-commissioned onshore at the Lisnave drydock facility in Portugal. The structure was then towed to the installation site located some 350 km (200 miles) from the assembly location. The installation was performed by the Bourbon Liberty 228 anchor handling vessel, which was assisted by three other tugboats in the procedure.

The Bourbon Liberty 228 Anchor Handling Vessel Installing Principle Power's WindFloat Turbine
Source: Renewable Energy Magazine

Key Features of Current Turbine Installation Practices

Specialist installation vessels have become the norm in offshore wind turbine installation. Purpose-built vessels have the capability of transporting up to ten complete wind turbines from the staging port to the construction site and installing them piece-by-piece. The current fleet of high specification installation jackups is able to operate in depths of around 100 ft. Newbuilds are being designed to operate in water depths of 200 ft or more.

More standard jackup vessels and crane barges have also been able to perform the work, albeit at usually a less rapid rate. These lower specification vessels, often from other offshore sectors, will be unable to handle larger wind turbines coming to market in the future due to their limited crane height and lifting capabilities.

Current market rates for wind turbine installation vessels (per day equivalent) are around $150,000, with installation costs varying due to a number of technical and commercial factors. Technical factors include water depth, distance from shore, seabed conditions, support structure type, component weight, number of wind turbines and weather conditions. Commercial factors affecting price include the availability of vessels, the amount of risk associated with ground conditions and weather, and the contracting strategy adopted with the installation contractor. Increasingly vessel operators have been able to command higher day rates given the current lack of vessels in the market.

Commissioning of the wind turbines takes place in phases for larger offshore wind farms. Each turbine is energized, commissioned and tested individually and in groups to ensure functionality. Poor weather conditions can severely affect the length of the commissioning phase.

Contract lead times have varied from project to project. The installation of 100 wind turbines at Thanet was started in January 2010 and completed in July 2010 (see case study), whilst the 54 wind turbines at Lynn and Inner Dowsing were installed in a five month period. Installation timelines can be compressed through employing multiple vessels; UK Round 3 projects are forecast to utilize three or more high specification vessels on long-term contracts.

2 Installation Methods

In general, work on recently installed offshore wind farms indicates that one wind turbine can be installed per day in optimal conditions and circumstances. With transportation time and weather downtime factored in, 2.5 days per wind turbine is a more realistic overall view. Larger wind turbines will require longer installation periods. With project sizes increasing, offshore wind project could tie up an installation vessel for an entire year. The largest projects already require more than one vessel. Indeed, many operators will not contract for multiple projects because of the risk of run-over from one project to another.

Case Study: Thanet, UK, 300 MW

MPI Offshore installed 100 Vestas V90 (3 MW) wind turbines using the vessel MPI Resolution, which had been transferred from installing transition pieces. Completion of the transition piece installation program was taken over by A2Sea's vessel Sea Jack.

The MPI Resolution is a purpose designed wind turbine installation vessel, able to carry nine complete wind turbines including full height towers. Vestas also designed a stacking system to allow for transport of 27 blades and quick load-out. This large storage capacity made it possible to move from turbine to turbine in as little as 18 hours.

Nacelles, blades and towers were pre-assembled at Dunkirk, France before transportation to the site. On this project, blades were installed one at a time as opposed to the so-called 'bunny ears' arrangement. The 'bunny ears' configuration occupied excessive deck space and required a challenging vertical lift, being more exposed to gusts of wind.

MPI Offshore installed the 100th and final wind turbine at Thanet in July 2010, five weeks ahead of schedule. From start to finish including weather, loading days and transit, the wind turbine installation phase lasted 198 days according to Vestas, the wind turbine contractor for Thanet. Actual wind turbine installation duration at the site was estimated to be 100 days.

MPI Resolution
Source: MPI Offshore Limited

2 Installation Methods

2.3 Cable-Lay (Array and Export) Operations

Array cables connect wind turbines with each other and the substation, while export cables connect the substation to the onshore grid. Both array and export cables are installed by specialized cable-lay vessels using the reel-lay method. The cable is typically manufactured dockside and spooled onto a reel or carousel on the lay vessel. Once the vessel reaches the installation site, the line is progressively unwound, straightened and paid out in a J-curve through the vessel moon pool or over the stern and down to the seabed.

The same vessels are sometimes used for both array and export cable installation although there appears to be increasing divergence in the market. Export cable-laying vessels will typically have larger carousels to allow the storage of larger spools. Large cable-lay vessels can carry between 5,000-9,000 tons of cable, but the supply of such high-spec vessels is currently very tight globally, and other sectors, such as telecommunications, are also competing for the capacity of these vessels.

ABB-Manufactured Offshore Cable on a Cable-Lay Vessel
Source: Offshoreenergy.dk

Export cable-layers aim to minimize the numbers of splices that have to be made in the offshore environment, consequently carousels and turntables are getting larger. For example, a carousel capacity of 7,000 tons would allow for up to 45 miles of cable to be laid. With unit weight increasing for high-voltage cabling and projects moving further from shore, there is likely to be a need for larger carousels and turntables.

Offshore cables are typically buried under the seabed to protect them against fishing gear or vessel anchors. This is either done via the trenching and burial method, or via less costly rock dumping. Trenching and burial is a costly and time-consuming method requiring a dedicated marine spread. Depending on the seabed soil type, trenching operations are performed by ploughs, jetting machines or, on hard soils, cutters. Burial may be effected by backfilling the trench with the excavated soil, although trenching without backfill is usually adequate for on-bottom stability and protection. Burial affords a higher degree of protection than trenching, but at a higher cost. The rock dumping method simply covers the cable with a layer of gravel or rock.

Cable-laying can be carried out using either a one-stage or two-stage process. In the one-stage approach, cable is simultaneously laid and buried using a cable plough. In this method, the plough is towed either by the cable-lay vessel or a tug. In the two-stage process, the cable is laid on the seabed and then buried by a separate vessel equipped with a trenching ROV.

Fixed burial depths – such as the 10 ft burial depth required in UK waters – can present a significant challenge for contractors. Time and costs associated with ploughing operations rise significantly as burial depth increases. To date, some contractors have been unwilling or unable to enter the market under these circumstances. A shallower burial depth of 5 ft, which is the minimum burial depth in New Jersey state waters, for example, means that high power air jets can be used, which is both quicker and less expensive. Operators noted that cable detection becomes very difficult in burial depths of above 10 ft, which makes underwater cable repairs costlier and more complex.

2 Installation Methods

The construction of a landfall is a complex matter and it is essential that contractors have a good understanding of the issues involved. Landfall locations with high waves and rocky seabed conditions will obviously be more difficult and expensive than sites with sandy shores in benign environments.

The most common landfall construction technique is to pull the cable ashore using a winch mounted on the beach. To protect the cable, a combination of land equipment and marine dredgers may be used to dig a trench across the beach through the tidal zone (using cofferdams to prevent the tide from filling it in again) and out to the lay barge. The cable is pulled ashore in this trench, usually with temporary buoyancy modules attached to ease its passage.

A typical third generation cable-lay barge has a draft of about 40 ft and it may only be able to get within 1.0 to 2.5 miles of the shore, depending on the inclination of the seabed. To minimize the length of cable that must be pulled from the ship to shore, the shore approach section of a line is typically perpendicular to the beach. A perpendicular approach also enhances the stability of the line as it minimizes the destabilizing effect of cross currents caused by wave refraction in shallow water. Even so, the shore approach sections of most cables are buried for protection purposes.

Once the cable is installed, the trench is filled in, and the lay barge completes its offshore installation operations. Landfall trenches are typically 10 ft deep to ensure that the cable is adequately protected against future erosion.

Horizontal directional drilling (HDD) is a commonly used alternative landfall option in environmentally sensitive or densely populated coastal areas. In case of the Atlantic City Phase 1 project, Fishermen's Energy, the project's developer is planning a HDD landfall. The shore landing point in this case would be about 2,500 ft from the onshore interconnection point and about 1,500 ft from the high water mark near the Atlantic City boardwalk. Water depth at the shore landing point is about 6 meters (20 ft). Large cable-lay vessels, which typically have a draft of about 6-7 meters (20 ft), can approach the shore within 2 km (1.1 nautical miles) in case of the Atlantic City project, where water depths are about 15 meters (50 ft). Between the shore landing point (about 1,500 ft from the shore) and the operating limit of the large cable-lay vessel (1.1 nautical miles from the shore), a smaller cable-lay barge will have to carry out the cable-laying operations. In case of the Atlantic City Phase 1 project, this can be a simple New Jersey-based barge fitted with a small carousel.

Case Study: Sheringham Shoal, UK

Sheringham Shoal is a 317 MW offshore wind farm project located about 9 miles off the UK east coast and commissioned in 2012. A trio of installation vessels was used to lay the export cables to carry electricity to shore for the project. Contractor Visser & Smit managed the operation. The 180 ft *Atlantic Guardian* vessel was utilized to clear the cable route of debris and obstacles in preparation for export cable installation. These preparatory activities are important as they reduce potential delays for more expensive cable-lay operations.

Team Oman Cable-Lay Vessel
Source: Scira Offshore Energy

With the export cable route cleared, the 280 ft *Team Oman* arrived on site. The *Team Oman* (formerly *Team Sea Spider*) is a dynamically positioned vessel with 5,000 ton deck load capacity. The vessel arrived on site with cables in September 2010 and underwent final modifications prior to the start of the job.

The cable-lay started from shore and worked towards the offshore site. The cables were manufactured by Nexans in Norway and comprised a bundle of power and optical cables. The two cables for Sheringham Shoal were both over 12.5 miles in length with a unit weight of 77kg (170 lb) per meter.

The third installation vessel was the 260 ft diving support vessel (DSV) *VOS Symphony*. The TM03 trenching system from marine engineering firm TravOcean was operated from this vessel. The cable was trenched and placed in a single operation.

2 Installation Methods

2.4 Offshore Substation Installation

Substation installation typically takes place after the support structure installation phase and cabling work has been carried out, but prior to the installation of the wind turbines. The substation is manufactured onshore before being transported to the project's staging area.

A large heavy lift vessel is required to position the substation onto the jacket structure. Crane ratings must be the order of 900 tons to 3,000 tons to handle the lifting requirements of substation modules. These challenging installation requirements limit the number of installation assets that can be used to heavy lift vessels, such as Seaway's vessel *Stanislav Yudin*, and semi-submersible crane vessels.

The supply of these specialist vessels is limited and costs are extremely high. These vessels are in high demand for offshore oil and gas construction and decommissioning work.

Offshore Substation Installation
Source: Vattenfall

Case Study: Thanet, UK

Seaway Heavy Lifting (SHL) was contracted by Thanet Offshore Wind Limited to transport and install the Thanet Offshore Substation. The original schedule was for final installation in December 2009 but this was extended to February 2010 in order to allow the substation fabricator to fully commission and test the facilities prior to installation.

The 820 ton offshore substation jacket was transported by Seaway's *Stanislav Yudin* vessel from the fabrication site in Newcastle, UK. The 1,460 ton topsides were transported by cargo barge from Lowestoft, UK. With the jacket placed on the seabed, four 33m x 72" x 60 ton piles were driven to 21m penetration depth using an IHC S-600 piling hammer. After leveling, the piles were grouted and final jacket leg cut-off was made. All installation activities were completed in just 15 days. Substation installation typically lasts longer, about 5-8 weeks, when transportation time and weather downtime is also factored in.

Chapter 3

Vessel Types

3 Vessel Types

Introduction to Vessels

From ensuring timely construction to O&M activities, vessels play an important role in the overall success of offshore wind farms. An offshore wind farm project has several phases from development to decommissioning that have specific vessel needs. Irrespective of the phase, all vessels employed in the offshore wind sector can be categorized as either construction vessels or support vessels.

Construction Vessels

Construction vessels include the following main vessel types:

- Jackup vessels / Jackup barges
- Purpose-built turbine installation vessels (TIVs)
- Heavy lift vessels / Derrick barges
- Cable-lay vessels

Support Vessels

Within the support vessel category, the main vessel types are:

- Survey vessels
- Transport barges / Feeder barges
- Tugs
- Personnel transfer vessels (PTVs)
- Heavy maintenance vessels

Some of the vessels are phase-specific while some can be used in multiple phases. In this section, we assess the role vessels play in the offshore wind industry.

Windcat PTV Operating in High Waves
Source: Windcat

Heavy Lift Vessel Stanislav Yudin Installing a Substation At the Anholt Wind Farm
Source: Windcat

3 Vessel Types

A Detailed Look at Vessel Roles by Project Stage

The following tables provide an overview of vessel operations at each phase of offshore wind project development, using a 100 turbine wind farm project as an example. The "time" and "cost" columns provide an estimate of net vessel time required (which includes operational and weather-related downtime) and dayrate ranges in each phase of the project lifecycle based on current European rates.

PHASES	APPLICATIONS	TIME	COST
Environmental surveys	A wide range of offshore surveys are required to assess project impacts. Data is gathered over long periods, typically more than one year. Environmental survey results feed into the Environmental Impact Assessment (EIA), which must be carried out for every offshore wind farm project. The primary surveys to be carried are as follows: **Benthic environmental surveys:** Assessment of species living on the seabed and in the sediments in the vicinity of the proposed offshore wind site. Physical sampling is carried out at various sites and is backed up with less invasive techniques, including video surveillance. **Pelagic environmental surveys:** Assessment of open water species including fish in the vicinity of the proposed offshore wind site. The experience of local fishing vessels can be especially useful. **Ornithological environmental surveys:** Visual and radar surveys are undertaken at the proposed site for a period of a year or more to identify bird species, estimate populations, observe flight patterns, and feeding areas. **Sea mammal environmental surveys:** Marine and aerial surveys to assess the prevalence of cetaceans, seals and other sea mammals in the vicinity of the proposed offshore wind site. **Coastal process surveys:** The likely effects of the proposed offshore wind project on coastal erosion and sediment transfer need to be analysed. This may inform the location of onshore infrastructure in some cases.	**ca. 15 – 20 weeks vessel time for a 100 turbine development, but extended over 2 years**	**$10,000 to $15,000 per day**
Geophysical surveys	Geophysical work covers numerous areas including seabed bathymetry (depth data), seabed features, stratigraphy (geological layering) and analysis of hazardous areas. Geophysical work accounts for approximately 20% of the costs of seabed surveying. Due to the relatively shallow water requirements for offshore wind (less than 100 ft), small and relatively low-cost vessels can be used to perform this task.	**ca. 12 – 20 weeks for a 100 turbine development**	**$20,000 to $25,000 per day**

3 Vessel Types

AREA	APPLICATIONS	TIME	COST
Geotechnical surveys	Geotechnical site investigation surveys are undertaken prior to construction to allow detailed design and installation procedures to be developed for foundations, array cables, export cable routes and jack-up operations. Geotechnical work accounts for approximately 80% of the costs of seabed surveying. This type of work requires larger, more stable vessels with highly skilled operators on-board. Due to the specialised nature of this work, it is considered more difficult for new entrants to access this market. Geotechnical investigations may include, but not be limited to the following tasks: **Sample boreholes** at proposed foundation locations and along cable routes, investigation to a depth of 50 meters (165 ft) or more for foundations, and 5 meters (16 ft) or more for cable routes may be required. **Sample penetration tests** at proposed foundation locations and along cable routes. **Core samples** from the upper stratigraphy of the seabed are taken using a specialist tool. **Plough trials** along the export routes. **Investigation of specific obstructions** identified during the geophysical investigations.	**ca. 8 – 20 weeks for a 100 turbine development**	**$50,000 to $100,000 per day**
Logistics	Due to the cost implications of project delays, efficient logistics strategies are essential. Installation strategies vary on a project by project basis with the two main options being installation from logistics ports (staging areas) or installation from point of manufacture. Self-propelled jack-ups can typically carry payloads of 4,000 tons or more but may be constrained by the physical dimension of components with wind turbine blades exceeding 60 meters (200 ft) in length. Installation barges have higher storage capabilities and have often been used for transporting components. On the other hand, installation barges have narrower weather windows. Wind turbine sub-components and balance of plant items are usually transported from a geographically dispersed group of suppliers to a project logistics base or to a wind turbine assembly hub. Large projects, which are becoming increasingly common, require dozens of shuttle trips for foundation structures, wind turbine towers, nacelles, and blades. In Europe, the supply chain is focused around the North Sea rim, with the majority of foundations being shipped from Denmark, the Netherlands and Belgium. Assembly hubs for wind turbine manufacturers are developing on the continent in Denmark and Germany with Esbjerg and Bremerhaven being key centers. For the Greater Gabbard project, the components (nacelles, blades and towers) for 140 wind turbines were shuttled from the assembly hub at Esbjerg in Denmark to Harwich in the UK in 36 shipments. This contract was carried out using BBC Chartering's Konan vessel.	**Each shipment can carry 4 complete wind turbines** **25 shipments for a 100 turbine development**	**$150,000 to $270,000 per day when utilizing an installation vessel**

3 Vessel Types

AREA	APPLICATIONS	TIME	COST
Foundation installation	The method varies depending on foundation type. Monopiles are driven into the seabed using jackup vessels or newer self-propelled turbine installation vessels, whereas gravity-based structure (GBS) foundations are typically installed by using crane barges. Experience from recent offshore wind projects shows that foundation installation rates typically average one every 2.0-2.5 days. GBS foundations can be installed at a faster rate providing the supply logistics are efficient, with separate installation and transportation vessels. The piling involved with monopiles requires longer installation times per foundation. Installation rates have typically been very efficient with only minor problems reported. A faster installations rate is possible, if multiple vessels are employed at the same time. This practice will likely become more widespread, as project sizes increase. Transition pieces can theoretically be installed at a rate of over one per day, but around 1.5 days per transition piece is standard across a project. The relatively wide dayrate range indicates that foundations can be installed by a wider range of vessel types, including older generation jackup barges as well as more expensive modern TIVs and heavy lift vessels.	**Installation of 100 structures at Thanet was completed in just 35 weeks. Normally, each structure is installed in ca. 1.5 to 2 days**	**$150,000 to $310,000 per day**
Turbine installation	To date, turbine installation offshore has been undertaken using principally the same method as foundation installation. This involves taking the turbines to the site in their main components (tower sections, nacelle often with two blades attached), and then installing them upon the foundation using a combination of jackup vessels, crane barges and/or purpose-built TIVs. Specialist installation vessels have become the norm. These have the capability of transporting up to ten complete turbines from the load-out location to the construction site and installing them piece-by-piece. More standard jack-up vessels and crane barges are able to perform the work, albeit usually at a less rapid rate.	**Installation of 100 wind turbines at Thanet was completed in 25 weeks** **Each turbine is installed in approx. 1 day (gross)**	**Early TIV: $150,000 to $200,000 per day** **Modern TIV: $200,000 to $270,000 per day**

3 Vessel Types

AREA	APPLICATIONS	TIME	COST
Cable-laying (array and export)	Cables are laid using the reel-lay method. The cable is typically manufactured dockside and spooled onto a reel or carousel on the lay vessel. Once the vessel reaches the installation site, the line is progressively unwound, straightened and paid out in a J-curve through the vessel moon pool or over the stern and down to the seabed. Depending on their location, cables may need to be protected against fishing gear, dropped objects or vessel anchors. Thus, it is common practice to install some form of protection on cables which are routed across fishing grounds, or in areas where there are high levels of vessel activity – particularly near offshore platforms or busy shipping lanes. The main methods of cable protection are: **Trenching and burial** **Rock dumping** (coverage with gravel or rock) Trenching and burial is a costly and time-consuming method requiring a dedicated marine spread. Depending on the seabed soil type, trenching operations are performed by ploughs, jetting machines or, on hard soils, cutters. Burial may be effected by backfilling the trench with the excavated soil, although trenching without backfill is usually adequate for on-bottom stability and protection. Burial affords a higher degree of protection than trenching, but at a higher cost. Cable installation has generally been undertaken using barges equipped with a carousel, tensioners and haulers. The array cables at the Thanet wind farm were installed using a more sophisticated DP2 (dynamically positioned) vessel. These DP vessels allow faster setup and installation times. DP2 vessels can also remain on station in higher sea states in comparison to barges. The same vessels are sometimes used for both array and export cable installation although there appears to be increasing divergence in the market. Export cable-laying vessels will typically have larger carousels to allow the storage of larger spools.	**Array: surface lay – one array cable per day (12 hours); simultaneous burial can take 1.5 days.** **Export: 7 miles a day (500m/hour, ploughing) is possible a more typical rate is 3 miles per day (200m/hour, ploughing)**	**Array: \$100,000 to \$160,000 per day** **Export: \$100,000 to \$250,000 per day**
Substation installation	The substation is manufactured onshore before being transported to the project's staging area. A large crane vessel is then required, either a shear-leg crane or other heavy lift unit, to position the substation onto its foundation. This installation typically takes place after the foundations and cabling work have been carried out and prior to the mounting of the turbines. Crane ratings must be the order of 900 tons to 3,000 tons to handle the lifting requirements of substation modules.	**ca. 5 – 8 weeks installation time for a 100 turbine development**	**\$250,000 to 310,000 per day**

3 Vessel Types

AREA	APPLICATIONS	TIME	COST
Personnel transfer vessels (PTVs)	Personnel transfer vessels (PTVs) are essential tools in the operation and maintenance (O&M) phase of a project. They enable the rapid transfer of maintenance personnel to offshore wind turbines. Vessels can typically carry 12 personnel. The same PTVs are used during the construction phase. Based on existing projects, typically one PTV is required for every 10 turbines through the construction phase and for every 25 turbines through the O&M phase. Vessels are generally contracted on long-term leases. Two year construction support contracts and five year operational support contracts are typical. Larger projects will require three or more PTVs on long-term contracts in the operational phase. While there have been individual cases of project owners operating their own vessels, project owners are generally not interested in owning and managing a fleet of support vessels. The majority of the market is still made up of small operators with a fleet of three or fewer vessels. So far there has been little in the way of consolidation of these smaller players, with contractors often using these companies for shorter contracts and hiring for spot work. Vessel design is typically based on a 15-20 meter (50-65 ft) hull, capacity for 10-15 passengers and operating ranges of between 50 to 70 nautical miles. These vessels are able to operate in swells of up to 2 meters (7 ft), although 1.5 meters (5 ft) appear the upper limit for safe personnel transfer. Future vessels are likely to be based around a 25-30 meter (80-100 ft) hull and have capacity for between 15 and 25 passengers.	**Offshore construction phase: 2 years for a 100 turbine development** **Operational phase: 20 years plus**	**$2,000 to $4,000 per day**
Heavy maintenance vessels	Installation and repair vessels are typically chartered for major repair and overhaul work, which cannot be completed by PTVs. The majority of larger projects will aim to charter vessels for at least a week to perform any necessary major repair/overhaul work. Due to the high demand, these vessels will be chartered in advance of requiring their services; otherwise projects are left exposed to "spot rates" which can fluctuate depending on demand, making budgeting difficult. The indicated rates refer to a case where heavy maintenance and repair work are carried out by early-generation turbine installation vessels. However, remodelled jackup vessels, crane barges or liftboats can also be used for the same purpose, probably at lower rates.	**Pitch mechanism replacement programme on 25 turbines at Burbo Bank – MPI Resolution was chartered for 3 – 5 months**	**$140,000 to $200,000 per day**

3 Vessel Types

In this chapter, we provide an overview of each vessel type that play an important role in offshore wind construction, operation and maintenance. We also use these broadly defined vessel types in later parts of the Report, when breaking down our future vessel demand estimates in the US offshore wind industry by vessel type.

3.1 Survey vessels

Survey vessels are used for a wide range of activities, including for scientific and naval research as well as for seismic studies for the offshore oil & gas industry. Typically, three types of surveys are required before an offshore wind project can commence to the construction phase.

Environmental surveys can be completed by vessels equipped with sensors or by autonomous underwater vehicles (AUVs), both of which are readily available on the market.

Geophysical surveys are seismic surveys of the seabed. These surveys are undertaken prior to construction, and they are necessary for the planning of installation procedures, cable routes and jack-up operations, among other functions. Geophysical work covers numerous areas including seabed bathymetry (depth data), seabed features mapping, stratigraphy (geological layering) and analysis of hazardous areas. Due to the relatively shallow water requirements for most current offshore wind projects (less than 100 ft), small and relatively low-cost vessels can be used to fulfil this work.

Geotechnical work requires larger, more stable vessels with highly skilled operators. Geotechnical investigations typically includes the drilling of sample boreholes at proposed foundation locations and cable routes, penetration tests for foundation installation and jackup operations and plough trials for cable-lay operations. Geotechnical surveys involving core samples can be accomplished with dedicated geotechnical survey vessels, but they can also be completed by using any fixed platform with drilling equipment welded to the deck.

MV Highland Eagle Geotechnical Survey Vessel
Source: GEMS Group

Fugro Searcher Offshore Survey Vessel Designed for Geophysical Research
Source: Fassmer Group

3.2 Jackup Vessels

Until recent years, jackup vessels had been the most common vessel type used for turbine installation. Various jackup vessels and barges with jackup capabilities are also routinely used in the installation of foundations and transition pieces at offshore wind projects. Jackup vessels are self-propelled or towed floating platforms that can be raised and lowered at an offshore location by means of mechanized jackup legs.

Jackup vessels are either self-propelled or towed barges. They are primarily used for offshore or portside construction. These units have typically four or more legs, depending on size.

Rendered Image of a Jackup Barge in Operation
Source: Offshorewind.biz

Liftboats

Liftboats are a specific variant of jackup vessels primarily used in the US Gulf of Mexico. Liftboats are typically three-legged, self-propelled jackup units, which are widely used for offshore construction activities, particularly in the oil & gas sector. Liftboats are generally not well suited for the installation of large offshore wind turbine components due to their limited deck space and low crane capacity. The relatively low crane height of liftboats is somewhat compensated by their longer jackup legs compared to more “conventional” jackup vessels. Hercules Offshore is the largest operator of liftboats worldwide with over 60 vessels in its fleet. The maximum crane load in Hercules’ fleet ranges between 15 and 200 tons, but only two of its liftboats can handle loads of over 100 tons, which is necessary for the installation of most components of a 3.6 MW or larger turbine. The typical deck area in Hercules’ fleet ranges between 1,000 and 5,000 square feet (between 92 and 460 square meters), only three vessels have decks larger than 5,000 square feet.

Nevertheless, at least one liftboat, KS Drilling’s Titan 2 vessel is known to have participated in the installation at a commercial-scale offshore wind farm in the UK. (See case study below). The vessel was acquired by Hercules Offshore from its previous owner, KS Drilling in 2013, and subsequently renamed Bull Ray. The Titan 2 currently commands a dayrate of around $65,000 and is deployed in West Africa, servicing the offshore oil & gas sector.

Liftboats Engaged in Offshore Construction in the Gulf of Mexico
Source: Alliance Liftboats

3 Vessel Types

Case Study: Liftboats in Offshore Wind Turbine Installation

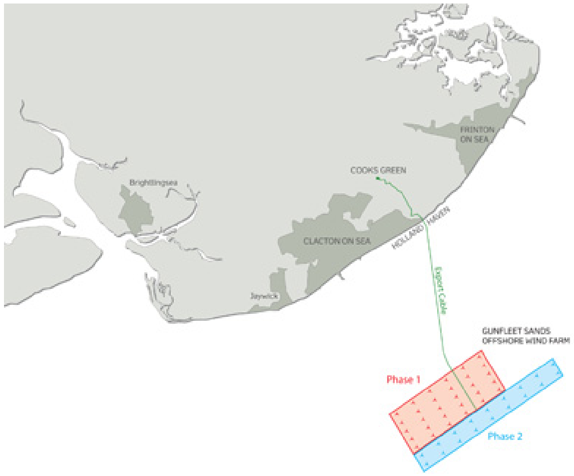
Gunfleet Sands 1 & 2

The Gunfleet Sands offshore wind farm project (phase 1 and 2) is located 7 km (4 nautical miles) south of Essex County in the UK in the Thames Estuary. The first two phases of the project consist of 48 Siemens turbines, each with a 3.6 MW capacity. Construction started in March 2008, the first turbines were installed in April 2009, turbine installation was completed in January 2010 and the wind farm was fully commissioned by June 2010. The wind farm was developed by Danish utility DONG Energy; Marubeni Corporation acquired a 49.9% stake in the project in 2011.

Under a contract with Siemens, the Titan 2 liftboat, owned at the time by KS Energy Services, participated in the turbine installation at the Gunfleet Sands project in 2009 and 2010. The Titan 2 installed 29 of the 48 turbines at the wind farm, the remainder of the turbines were installed by A2Sea's Sea Worker jackup vessel.

The 3.6 MW Siemens turbines were mounted on top of monopile foundations, which were installed by Furgo Seacore's Excalibur vessel. The turbine towers were installed in 2 pieces, nacelles and turbine blades were installed one-by-one. Each tower weighted a total of 193 tons. The hub height was 75.5 meters (250 ft) and the nacelle weighted 138 tons at each turbine. The Titan 2 has two Seatrax 10520 leg cranes, each with a 200 ton capacity. The blades were 52 meters (170 ft) long and weighted 16 tons each. Water depths at the wind farms site were up to 15 meters (50 ft), well below the Titan 2 maximum operational water depth of 67 meters (220 ft).

Titan 2 Vessel Installing a Turbine at the Gunfleet Sands Project
Source: Dee Marine Ltd.



Overview of the Gunfleet Sands 1&2 Offshore Wind Project
Source: DONG Energy

3 Vessel Types

3.3 Turbine Installation Vessels (TIVs)

TIVs are self-powered vessels with jackup capabilities, purpose-built for offshore wind farm installation and O&M activities. Modern TIVs are typically 90 meters (295 ft) or more in length, with a beam of 40 meters (130 ft) or more.

The most modern of these vessels are designed with the capability to transport as many as ten complete wind turbines, although a move beyond the current 5-6 MW turbine size in the future would stretch the storage capabilities of even the largest contemporary TIV, such as the A2Sea *Sea Installer*, which is 132 meters (430 ft) in length and 39 meters (130 ft) in breadth. Next generation 10 MW turbines will have blades in excess of 80 meters (260 ft) in length, and tower heights of close to 100 meters (330 ft).

TIVs are equipped with at least one crane, are DP rated, and designed to carry foundations and turbines on board. These vessels have 4 to 8 jackup legs. Newer TIVs are larger, and they have higher crane capacity, reach, and deadweight tonnage. A substantial fleet of both self-powered jackup barges and purpose-built turbine installation vessels have been delivered in recent years.

TIV at Sheringham Shoal
Source: World Maritime News

3 Vessel Types

Owner	Vessel Name	Vessel Type	Status	Flag	Yard	Year Built	Length (m)	Breadth (m)	Draft (m)	Water Depth (m)	Cargo Area (m2)	Pay Load (t)	Main Crane Load (t @ m)	Crane Height (m)	Speed (knots)	Legs	Accommodation (people)	Dynamic Positioning
A2SEA	Sea Power	Semi-Jackup	Operational	Denmark	-	1991/2002	92	22	4.3	24	1,020	2,386	230 t @ 15 m	-	7.8	4	16	None
A2SEA	Sea Energy	Semi-Jackup	Operational	Denmark	-	1990/2002	92	22	4.3	24	1,020	2,386	110 t @ 20 m	-	7.8	4	16	None
A2SEA	Sea Jack	Jackup Barge	Operational	Denmark	-	2003	91	33	5.5	30	2,500	2,500	800 t	-	-	4	23	None
A2SEA	Sea Worker	Jackup Barge	Operational	Denmark	-	2008	56	33	3.6	40	750	1,100	400 t @ 17 m	-	-	4	22	None
A2SEA	Sea Installer	TIV	Operational	Denmark	Cosco (China)	2012	132	39	5.3	45	3,350	5,000	800 t @ 24 m	102	12.0	4	35	DP 2
Bard	Wind Lift 1	Jackup Barge	Operational	Germany	Western Shipyard (Lithuania)	2010	102	36	3.5	45	-	2,600	500 t @ 31 m	121	-	4	50	DP 1
Besix	Pauline	Jackup Barge	Operational	St. Vincent & G.	IHC Merwede (Netherlands)	2002	48	24	2.5	30	-	1,500	200 t	-	-	4	-	-
DBB Jack-Up Services	MV Wind	Jackup Barge	Operational	Denmark	Rupelmonde (Belgium)	1995/2010	55	18	2.4	25	-	-	1,200 t	100	-	4	-	DP 2
Geosea	Neptune	Jackup Barge	Operational	Luxembourg	IHC Merwede (Netherlands)	2012	60	38	3.9	52	1,600	1,600	600 t @ 26 m	-	7.7	4	60	DP 2
Geosea	Goliath	Jackup Barge	Operational	Luxembourg	Lemants (Belgium)	2008	56	32	3.6	40	1,080	1,600	400 t @ 15 m	-	-	4	12	DP 2
Geosea	Vagant	Jackup Barge	Operational	Netherlands	IHC Merwede (Netherlands)	2002	44	23	4.2	30	-	1,000	-	-	-	4	10	None
Geosea	Buzzard	Jackup Barge	Operational	St. Vincent & G.	De Biesbosch (Netherlands)	1982	43	30	3.0	40	-	1,300	-	-	-	4	8	None
Gulf Marine Services	GMS Endeavour	Jackup Barge	Operational	Panama	Gulf Marine Service WLL (UAE)	2010	76	36	6	65	1,035	1,600	300 t	-	8.0	4	150	DP 2
Fugro Seacore	Excalibur	Jackup	Operational	Vanuatu	HDW Kiel (Germany)	1978	60	32	2.8	40	-	1,352	220 t @ 14 m	64	-	8	50	None
HGO InfraSea Solutions	Innovation	TIV	Operational	Germany	Crist Gdyna (Poland)	2012	147	42	7.3	50	-	8,000	1,500 t @ 32 m	120	12.0	4	100	DP 2
Hochtief	Thor	Jackup Barge	Operational	Germany	Gdansk (Poland)	2010	70	40	8.3	50	1,850	3,300	500 t @ 20 m	-	-	4	48	None
Hochtief	Odin	Jackup Barge	Operational	Germany	Crist Gdyna (Poland)	2004	46	30	5.5	35	-	900	300 t @ 15 m	-	-	4	40	None
Jack-Up Barge	JB-114	Jackup/Heavy Lift	Operational	Bahamas	Labroy Shipping (Singapore)	2009	56	32	3.0	40	-	1,250	300 t @ 16 m	-	-	4	-	None
Jack-Up Barge	JB-115	Jackup/Heavy Lift	Operational	Bahamas	Labroy Shipping (Singapore)	2009	56	32	3.0	40	-	1,250	300 t @ 16 m	-	-	4	-	None
Jack-Up Barge	JB-117	Jackup/Heavy Lift	Operational	Bahamas	Labroy Shipping (Singapore)	2011	76	40	3.9	45		2,250	1,000 t @ 22 m	-	-	4	-	None
KS Drilling	Titan 2	Jackup Barge	Operational	Panama	Semco Shipyard Lafitte, LA (US)	2007	52	35	2.9	40	-	-	176 t @ 12 m	-	7.0	3	-	-
MCI	LISA A	Jackup	Operational	Panama	Kaiser Swan, Portland (US)	1977/2007	73	40	4.0	33	1,000	950	425 t @ 18 m	80	-	4	40	None
Master Marine	NORA	Jackup	Operational	Cyprus	Drydocks World Graha (Indonesia)	2012	118	50	7.4	50	2,500	7,200	750 t @ 29 m	-	8.0	4	260	DP 2
Muhibbah Marine	MEB JB1	Jackup Barge	Operational	Germany	HDW Howaldswerke (Germany)	1960/1995	49	31	3.0	ca. 30	748	-	272 t @ 14 m	-	-	8	20/60	GPS
RWE Innogy	Victoria Mathias	TIV	Operational	Germany	Daewoo (South Korea)	2011	100	40	4.5	40	-	4,200	1,000 t @ 21 m	110	7.5	4	60	DP 2
RWE Innogy	Friedrich-Ernestine	TIV	Operational	Germany	Daewoo (South Korea)	2012	109	40	-	40	-	4,200	1,000 t @ 21 m	110	6.4	4	60	DP 2
Seajacks	Seajacks Kraken	TIV	Operational	Panama	Lamprell (UAE)	2009	76	36	3.7	41	900	1,550	300 t @ 16 m	-	8.0	4	90	DP 2
Seajacks	Seajacks Leviathan	TIV	Operational	Panama	Lamprell (UAE)	2009	76	36	3.7	41	900	1,550	300 t @ 16 m	-	8.0	4	90	DP 2
Seajacks	Seajacks Zaratan	TIV	Operational	Panama	Lamprell (UAE)	2012	81	41	5.3	55	2,000	3,350	800 t @ 24 m	-	9.1	4	90	DP 2
Swire Blue Ocean	Pacific Orca	TIV	Operational	Cyprus	Samsung H. I. (South Korea)	2012	161	49	6.0	70	4,300	6,600	1,200 t @ 31 m	118	13.0	6	111	DP 2
Swire Blue Ocean	Pacific Osprey	TIV	Operational	Cyprus	Samsung H. I. (South Korea)	2012	161	49	5.5	70	4,300	6,600	1,200 t @ 31 m	118	13.0	6	111	DP 2
Workfox	Seafox 7	TIV	Operational	Isle of Man	Labroy Shipping (Singapore)	2008	75	32	3.4	40	700	1,120	280 t @ 22 m	-	-	4	113	None
Workfox	Seafox 5	TIV	Operational	Isle of Man	Keppel Fels (Singapore)	2012	151	50	10.9	65	3,750	6,500	1,200 t @ 25 m	-	10.0	4	150	DP 2
MPI / Vroon	MPI Resolution	TIV	Operational	Netherlands	Shanhaiguan (China)	2003	130	38	4.3	35	3,200	4,875	600 t @ 25 m	95	11.0	6	70	SDP-11
MPI / Vroon	MPI Adventure	TIV	Operational	Netherlands	Cosco (China)	2011	139	41	5.5	40	3,600	6,000	1,000 t @ 26 m	105	12.5	6	112	DP 2
MPI / Vroon	MPI Discovery	TIV	Operational	Netherlands	Cosco (China)	2011	139	41	5.5	40	3,600	6,000	1,000 t @ 26 m	105	12.5	6	112	DP 2
Weeks Marine	RD MacDonald	Jackup Barge	Operational	US	Jacksonville, FL	2012	79	24	4.4	22	955	2,300	680 t @ 43 m	46	-	8	-	-
Fred. Olsen Windcarrier	Brave Tern	TIV	Operational	Malta	Lamprell (UAE)	2012	132	39	6.0	45	3,200	5,300	800 t @ 24 m	102	12.0	4	80	DP 2
Fred. Olsen Windcarrier	Bold Tern	TIV	Under constr.	Malta	Lamprell (UAE)	2013	132	39	6.0	45	3,200	5,300	800 t @ 24 m	102	12.0	4	80	DP 2
Hochtief	Vidar	TIV	Under constr.	Germany	Crist Gdyna (Poland)	2013	137	41	6.3	50	3,400	6,500	1,200 t @ 28 m	-	10.0	4	90	DP 2
Van Oord	Aeolus	TIV	Under constr.	Netherlands	Sietas (Germany)	2013	139	38	5.7	45	-	6,500	900 t @ 30 m	120	12.0	4	74	DP 2
Seajacks	Seajacks Hydra	TIV	Under constr.	-	Lamprell (UAE)	2014	-	-	-	48	900	3,350	400 t	-	-	4	90	DP 2
DBB Jack-Up Services	Wind II	TIV	Under constr.	-	Nordic Yards (Germany)	2014	80	32	-	45	-	-	-	-	-	4	-	DP 2
Inwind	INWIND Installer	TIV	Concept	-	-	-	101	68	4.5	65	3,500	4,500	1,200 t @ 25 m	105	-	3	90	DP 2
Gaoh Offshore	Deepwater Installer	TIV	Concept	-	STX (South Korea)	-	140	40	6.5	50	6,000	10,450	1,600 t @ 20 m	105	10.0	4	120	DP 2

Table 7: Current and Planned TIVs and Jackup Vessels Available for Offshore Wind Turbine Installation as of End-2012

Source: Douglas-Westwood

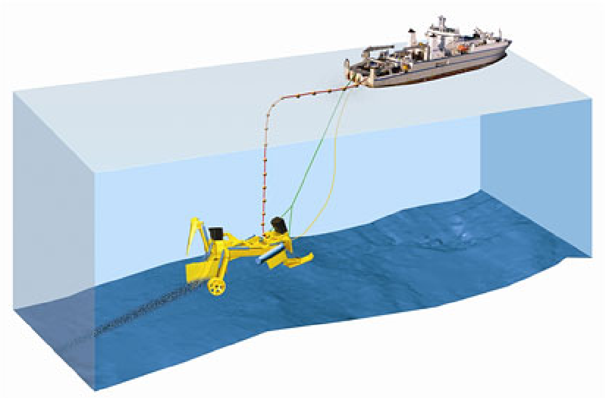
3 Vessel Types

3.4 Cable-Lay Vessels

Cable-lay vessels are used to lay cables underwater for power transmission, telecommunications, or other purposes. Most cable lay vessels are equipped with Dynamic Positioning (DP) and Dynamic Tracking (DT) systems. They are generally large vessels which cannot be used in shallow waters. Most vessels can lay one or two cables at a time. They are also capable of repairing and joining cables as needed. Some newer cable-lay vessels can maintain speeds of more than 14 knots while laying cable. Cable-lay barges are used in shallow waters near the shore, where large cable-lay vessels are not practicable.

In shallower waters, particularly in areas where fishing is prevalent, it is desirable to bury underwater cables to prevent damage from anchors and fishing gear. Trawling and other bottom-fishing methods can completely sever an underwater cable. Burial is either done via the “trenching and burial” method, where the cable lay vessel pulls an underwater plow and buries the cable into the furrow, or the simpler rock dumping method, where the cable is only covered by a layer of rocks.

There are no US-flagged cable lay vessels in operation today, but cable-lay vessels are available in the global marketplace. Cable-lay capacity is becoming increasingly tight at present, which may cause bottlenecks in offshore wind construction in the future.



Cable-Laying Operation Using an Underwater Plow
Source: Gadget.co.nz

Cable Lay Vessel Normand Cutter
Source: ISB Offshore

Cable Lay Vessel North Ocean 105
Source: MB 50

3 Vessel Types

Operator	Name of Ship	Length (m)	Breadth (m)	Draught (m)	Deadweight (tons)	Service Speed (knots)
Alcatel Submarine Networks	PETER FABER	78.36	13.42	3.81	2,200	-
Alcatel Submarine Networks	LODBROG	142.94	23.52	7.38	5,970	14.5
Alda Marine SPAS	ILE DE SEIN	140.36	23.4	8.016	9,820	15.4
Alda Marine SPAS	ILE DE BREHAT	139.7	23.4	8.02	10,000	15.4
Alda Marine SPAS	ILE DE BATZ	136.4	23.4	8	10,000	15.4
Alda Marine SPAS	ILE DE RE	143.4	20.52	7.23	4,500	15
ASEAN Cableship Pte Ltd	ASEAN EXPLORER	141.93	23	8	9,650	14.5
ASEAN Cableship Pte Ltd	ASEAN RESTORER	131.4	21.8	6.3	5,235	16
ASEAN Cableship Pte Ltd	ASEAN PROTECTOR	70	24.4	3.5	3,788	-
Boskalis Westminster NV	SAMSUNG	100	-	-	4,300	-
Brunei Shell Petroleum	AJANG HARAPAN	74.982	18.288	4	2,919	-
COG Offshore AS	VIKING FORCADOS	87.95	24.4	3.29	3,375	8
E-Marine PJSC	NIWA	144.79	21.6	8.071	7,900	15
Emirates Telecommunications	SAMA	93.4	15.5	3.75	3,300	-
Emirates Telecommunications	ETISALAT	72.525	13.2	4.5	1,417	13
EWS Oil Field Services	ELNUSA SAMUDRA I	45.3	9	2.04	-	-
France Telecom Marine	RENE DESCARTES	144.5	22	7.4	8,208	15
France Telecom Marine	RAYMOND CROZE	107.02	17.81	6.26	2,800	15
France Telecom Marine	LEON THEVENIN	107.83	14.8	6.25	3,220	15
Global Marine Systems Ltd	WAVE VENTURE	141.5	19.38	6.1	5,012	12.5
Global Marine Systems Ltd	WAVE SENTINEL	137.5	21	6.014	4,552	12
Global Marine Systems Ltd	CABLE INNOVATOR	145.5	24	8.517	10,557	12
Global Marine Systems Ltd	PACIFIC GUARDIAN	115.02	18	6.318	3,544	12
Global Marine Systems Ltd	C. S. SOVEREIGN	130.7	21	2.508	7,417	9
Global Marine Systems Ltd	CABLE RETRIEVER	131.4	21.8	6.5	5,235	12

Table 8: Selected Foreign-Flagged Cable-Lay Vessels
Source: Knud E Hansen

3 Vessel Types

Operator	Name of Ship	Length (m)	Breadth (m)	Draught (m)	Deadweight (tons)	Service Speed (knots)
IT International Telecom Inc	IT INTERCEPTOR	114.03	18.51	6.001	3,000	15.83
IT International Telecom Inc	IT INTREPID	115	18	6.318	3,523	13.5
Italmare SpA	TELIRI	111.5	19	6.513	3,400	14.5
Kokusai Cable Ship Co Ltd	KDDI OCEAN LINK	133.16	19.6	7.415	6,270	15
Kokusai Cable Ship Co Ltd	KDDI PACIFIC LINK	109	20.5	7.513	6,597	13
KT Submarine Co Ltd	SEGERO	115.38	20	7.805	6,409	15
Louis Dreyfus Armateurs SAS	ILE D AIX	151.54	21.6	7.8	8,373	11
Maersk Supply Service AS	MAERSK RESPONDER	105.5	20	9.1	7,958	14
Maersk Supply Service AS	MAERSK RECORDER	105.5	20	9.1	7,919	14
Mercurius Shipping	MERCURIUS	61.3	10.8	3.27	-	13
Nico Middle East Ltd	TEAM OMAN	86.1	24	4.5	4,800	10
North Sea Shipping AS	ATLANTIC GUARDIAN	103.49	18	6	3,538	14.4
NTT World Engineering Marine	SUBARU	123.33	21	7.018	6,843	13.2
P&O Maritime Services UK Ltd	EUROPEAN SUPPORTER	105.6	22	6.791	7,000	18
Prysmian Power Link Srl	GIULIO VERNE	128.54	30.48	5.374	10,569	10
Sarku Engineering Services Sdn	SARKU CLEMENTINE	74.9	18.29	4	2,806	9
SB Submarine Systems Co Ltd	CS FU AN	141.5	19.38	6.1	4,975	11
SB Submarine Systems Co Ltd	CS FU HAI	105.5	20	9.1	7,959	14
Seabulk Offshore Dubai Inc	HEIMDAL	136.7	19.4	6.162	6,204	16
Seaworks AS	FJORDKABEL	26.83	-	-	-	-
Siem Offshore AS	SIEM CARRIER	83	19	6.31	4,688	11
Stabbert Maritime Holdings LLC	OCEAN ECLIPSE	112.02	20.52	6.839	4,835	13
Stemat BV	STEMAT SPIRIT	90	28	4.92	6,209	10
Subsea 7 MS Ltd	ACERGY DISCOVERY	120.47	19.5	6.514	4,645	12

Table 8: Selected Foreign-Flagged Cable-Lay Vessels (continued)
Source: Knud E Hansen

3 Vessel Types

Operator	Name of Ship	Length (m)	Breadth (m)	Draught (m)	Deadweight (tons)	Service Speed (knots)
TranSM	C/S VEGA	74.25	12.51	4.512	877	13.5
Transoceanic Cable Ship Co LLC	RELIANCE	139.15	21	7.8	10,301	13.9
Transoceanic Cable Ship Co LLC	DEPENDABLE	140	21	7.8	7,800	13.9
Transoceanic Cable Ship Co LLC	RESPONDER	139.15	21	8.4	10,144	13.9
Transoceanic Cable Ship Co LLC	RESOLUTE	139.2	21	8.4	10,277	13.9
Transoceanic Cable Ship Co LLC	DECISIVE	140	21	7.8	10,077	13.9
Transoceanic Cable Ship Co LLC	DURABLE	140	21	7.8	10,096	13.9
Transoceanic Cable Ship Co LLC	GLOBAL SENTINEL	145.66	21.6	8.07	8,527	15
Tyco Marine SA	TENEO	81	14	5.7	1,563	14.5
Zhoushan Electric Power Co	ZHOU DIAN 7	73.75	15	3.5	1,520	11

Table 8: Selected Foreign-Flagged Cable-Lay Vessels (continued)
Source: Knud E Hansen

Case Study: Cable-Lay Vessels

Neptune Project

Neptune Project Overview
Source: Neptune

In a recent example, an Italian-flagged cable-lay vessel was employed to lay a power transmission cable across the Hudson River from New Jersey to New York. The Neptune project provides up to 660 MW of electric power from the PJM system in New Jersey to the LIPA grid on Long Island via a 500 KV, direct current (DC) cable. The Neptune project includes no overhead transmission lines. All transmission cables are buried either under water (for approximately 50 miles of the total distance) or underground (approximately 15 miles of the total distance).

Prysmian manufactured and installed the 65 mile long cable link. Underwater, the three cables were bundled and buried 4 to 6 ft under the seabed using a vessel specially designed and outfitted for this purpose. Both the land cables and the submarine cables were manufactured in Europe (Italy, France and Netherlands).

The link had to be installed in two sections due to the differing coastal and environmental conditions. Prysmian employed the Italian-flagged Giulio Verne vessel in the deeper areas, and a cable-lay barge in the shallower sections.

Hudson Project

Cable Lay Vessel Giulio Verne
Source: Shipspotting

Additionally, in May 2011 Prysmian was awarded $175 million contract to lay the underground and submarine power link between New York City and New Jersey transmission grid. They will be responsible for the design, manufacturing, supply and installation of both the land and submarine cables for the 7.5 mile route. Completion is scheduled for mid-2013.

The submarine cables will be installed using the Italian flagged Giulio Verne at river bottom depths ranging from 10 to 15 ft. The Giulio Verne is equipped with a hydro plow machine designed by Prysmian. The submarine cables will be manufactured in Prysmian's Arco Felice plant in Italy. The cable will be loaded on the vessel in Europe and sailed over to the cable-lay site.

3.5 Heavy Lift Vessels

Heavy lift vessels are designed to transport and lift large, heavy or oddly shaped cargoes that cannot be handled by conventional transport vessels. Heavy lift vessels are widely used in the offshore oil & gas industry, and they are also extensively deployed to support offshore wind installation projects in Europe. The installation of substations at offshore wind farms usually requires a heavy lift vessel. Certain offshore wind projects used heavy lift vessels for foundation and turbine installation work as well. For example, Ballast Nedham's heavy lift vessel Svanen installed foundations and turbines at the Egmond aan Zee wind farm in the Netherlands, and the Rambiz heavy lift vessel (operated by Scaldis Salvage and Marine Contractors) installed jacket foundations and fully pre-assembled 5 MW turbines at the Beatrice Wind Farm Demonstrator project.

Heavy lift vessels fall under two main categories: construction semisubmersibles, whose primary purpose is to transport large cargoes; and heavy lift crane vessels (or heavy crane barges), whose primary purpose is to lift large cargoes either portside or at offshore locations.

Construction Semisubmersibles

These vessels are designed with flat open hulls capable of supporting large structures, such as oil platforms and vessels, on board for transport. The open design allows oddly shaped structures that are wider than the vessel itself. The vessel is able to partially submerge itself so that the cargo can be floating above its hull. When ballasts back up, the cargo is lifted into its hull. The operation is reversed for unloading the cargo.

Heavy Lift Vessels

These vessels are built to load, carry and unload large and heavy loads. Generally these vessels have more than one crane on board. In the offshore wind sector, heavy lift vessels are primarily used for the installation of substations and heavier foundation types, such as jackets. Heavy lift vessels are also occasionally deployed to install monopile foundations and various turbine components, but these tasks are more often performed by various jackup vessel types.

Semi-Submersible Heavy Lift Vessel Transporting an Offshore Platform
Source: Dockwise

3 Vessel Types

Heavy Lift Vessel with a Load of Turbine Blades
Source: Pbase

Heavy lift vessel category also includes various self-propelled or non-powered heavy crane barges, sometimes these are referred to as derrick barges. These are fitted with large cranes which generally have high reach and load capacity.

Heavy Lift Vessel Rambiz
Source: Londonarray.com

3 Vessel Types

Operator	Name of Ship	Length (m)	Breadth (m)	Draught (m)	Deadweight (tons)	Service Speed (knots)	Safe Working Load (tons)
BigLift Shipping BV	HAPPY SKY	155	26.5	9.5	18,680	16	900
BigLift Shipping BV	HAPPY STAR	155	26.5	9.5	18,680	16	900
Jumbo Shipping Co SA	BRODOSPLIT 473	153	27.4	8.1	14,000	17	1,100
Jumbo Shipping Co SA	BRODOSPLIT 474	153	27.4	8.1	14,000	17	1,100
Kahn Scheepvaart BV	JUMBO JAVELIN	145	26.5	7.5	12,870	17.2	600
Kahn Scheepvaart BV	FAIRPARTNER	143	26.5	7.5	11,350	16.5	600
Kahn Scheepvaart BV	FAIRPLAYER	145	26.5	6.5	13,278	16.5	900
Kahn Scheepvaart BV	JUMBO JUBILEE	145	26.5	8.1	13,017	17	900

Table 9: Key Characteristics of Selected Foreign-Flagged Heavy Lift Vessels
Source: Knud E Hansen

3.6 Tugs

Tugs are required at several stages of the offshore wind supply chain. The main purpose of a tug is to tug or tow vessels, barges, or cargo. Tugs have powerful engines and are capable of towing weights of up to 5-10 times their own weight. Unencumbered, a tug can achieve a cruising speed of about 8 to 12 knots, and about half as much when towing a barge at the open ocean. A tug's power is generally stated by its engine's horsepower and bollard pull. Operationally, pulling is easier than pushing for a tug, especially over long distances. Majority of tugs have two-stroke engines since these engines have faster revolutions than four-stroke engines. Power produced by a tug depends on several factors like engine size, engine type, propeller size, and shape and size of the tug boat.

Smaller tugs (harbor and river tugs) have engines that produce 500 – 2,500 KW (ca. 680-3,400 horsepower) and a power-to-tonnage ratio of 4 to 9.5. Larger ocean going tugs have engines that produce up to 20,000 KW (ca. 27,200 horsepower) and have a power-to-tonnage ratio of 2.2 to 4.5. In comparison, a cargo vessel has an approximate power-to-tonnage ratio of 0.35 to 1.2.

There are three major tug categories based on the primary operation area. Ocean-going tugs are capable of operating in open seas. Harbor tugs operate primarily within a harbor, assisting larger vessels in entering and exiting the port. Many of these tugs are equipped with powerful fire-fighting equipment as well. River tugs are used to move barges up and down rivers. Due to their special structure, river tugs cannot operate safely in open waters. River tugs have less powerful engines than their counterparts operating in harbors and the open seas.

The ocean-going tug category is the most relevant for the offshore wind industry. There are a number of tug types within this category.

Standard Tug

Standard tugs are the most common ocean-going tug type, covering all generic tow boats, which are used for towing cargo on a hawser.

Notch Tug

These tugs can be secured in a notch of a barge. The barge is specifically designed to fit with the tug and once together, both operate as one vessel. This configuration is stable only when the barge is loaded. When the barge is empty, the tug has to tow the barge on a hawser.

Top: Harbor tug towing a container ship
Source: gcaptain

Right: River tugs transporting a log boom on the Fraser River
Source:123RT

Five Harbor Tugs Assist an Ocean Going Tug with Mooring a Platform
Source: towingline.com

3 Vessel Types

Integrated Tug Barge (ITB)

Like notch tugs, ITBs are specialized units of a tug and a barge, which are connected to operate as one unit. Unlike notch tugs, ITB tugs cannot operate independently from the barge. Once connected, the ITB operates like a small vessel. ITBs were originally developed to get around the numerous coast guard requirements for small cargo vessels, but they are not widely used today. The main reason for the low popularity of ITBs is that Coast Guard regulations require them to meet small vessel requirements (e.g. for crewing and identification lights in the harbor), thus the advantage of using an ITB versus a small cargo vessel is negligible. The last ITB was built in the 1980's.

Articulated Tug Barge (ATB)

ATBs have evolved from ITBs. Like notch tugs and ITBs, ATBs are connected to a barge by a notch in the stern. Unlike a notch barge, tugs in ATBs can push the barge irrespective of the barge's load. Unlike ITBs, where the tug and barge are locked together in a rigid connection, ATBs have an articulated or "hinged" connection system between the tug and barge. This allows movement in one axis, or plane, in the critical area of fore and aft pitch. No such movement is possible with an ITB unit.

Anchor Handling Tug Supply Vessel (AHTV)

These are the most powerful tugs and are typically used to tow offshore platforms to and from sea, or anchor vessels in position out at sea. They are also used as cargo supply vessels or to transfer personnel out to offshore platforms and wind farm sites. Like standard tugs, AHTVs are not connected to or specially built for a barge. AHTVs can operate in rough sea states and maintain higher speeds compared to cargo vessels or a tug and barge combination.

For the offshore wind sector, we only consider ocean going tugs with high bollard pull. Employed for both the construction and the O&M phase of offshore wind farms, various tug types can be used in different ways in the offshore wind industry. Standard tugs are typically used to tow jackup barges to and from the wind farm site, and from one turbine to the other within the construction site. Various tugs are also used to tow supply barges to the wind farm site. Standard tugs can also to tow monopiles (without a barge) to wind farm locations, but using a tug to perform this task has certain limitations. The tug will not be able to sail faster than 4 to 8 knots and the distance of the wind farm from shore cannot exceed 50 nautical miles. AHTS type tugs can also be used to transport supplies, monopiles, transition pieces or personnel to the wind farm.

Aerial View of an ATB
Source: Crowley Marine

Aerial View of AHTS
Source: Marineinsight

3.7 Barges

A barge is flat bottom boat used to transport heavy bulk cargoes as well as in offshore construction. Barges are either ocean-going or river barges, and they are typically non-self-propelled vessels. Barges are either construction or transport barges.

Construction Barges

Construction barges are used in offshore construction projects, including in offshore wind installation. These barges typically have cranes on board, either permanently-mounted, or temporary ones that are loaded on board for a specific operation. Barges that house derrick cranes are often called derrick barges. Jackup barges (discussed in section 3.2) would technically fall under the broader category of construction barges. Similarly, large, ocean-going barges with sizeable cranes can be categorized as heavy lift vessels (discussed in section 3.5). For the purposes of this report, particularly in the assessment of US vessel requirements, we categorized jackup barges as “Jackup Vessels”, and heavy crane barges as “Heavy Lift Vessels”. Both types are included in the “Construction Vessels” category. The “Barges” vessel type throughout our assessment means transport barges (see below) as well as more generic crane barges (such as the Chesapeake 1000 or the E.P. Paup) that are suitable for offshore construction, but not specialized for turbine installation. The requirements for these more generic barge types are assessed under the “Service Vessels” header in later parts of this Report.

Transport Barges

Transport barges are built to transport heavy cargo. Their open design makes the loading and unloading of large-sized and unusually-shaped cargoes relatively easy. Barges are a comparably cheap option to transport supplies and wind turbine components from a staging port to the offshore wind installation site.

Compared to supply vessels and TIVs, transport barges are much slower and more sensitive to bad weather. These vessels are sometimes stabilized using spuds or jackup legs, but simpler barges are often not stabilized at all. At the same time, they are less expensive to build, cheaper to charter and generally have much higher availability than supply vessels or TIVs.

Barges can play an important role in offshore wind farm construction, particularly when the wind farm is relatively close to shore. One or more so-called feeder barges can be shuttled to ensure a continuous supply of turbine components for specialized installation vessels (jackups or TIVs), which are operating at the installation site. This way, installation vessels can operate more efficiently, as the shuttling between the staging port and the installation site is done by low-cost transport barges, rather than advanced TIVs.

As the offshore wind industry matures in Europe and Asia, a new fleet of barges tailored to the offshore wind industry’s needs is being developed. These barges are specially designed to transport turbine parts and have cranes that can be used for both loading and unloading.

Wind Feeder – Artist Rendition
Source: Port Feeder Barge

3.8 Offshore Supply Vessels

Platform supply vessels or offshore supply vessels (OSVs) are used to transport cargo, supplies, and crew from the staging port to an offshore oil platform or to a wind farm site.

Most supply vessel lengths range from 65 to 350 ft. Cargo is loaded both above and below deck for improved stability. Supply vessels are designed to maintain high speeds even in harsh weather conditions. Many supply vessels have deck cranes that increase loading and unloading efficiency.

Supply vessels are sometimes retrofitted to complete a specific task. Many have firefighting capabilities and are able to assist with oil spill clean-up. Dynamic positioning is becoming indispensable, as these vessels need to navigate in close proximity to offshore structures. Most contemporary supply vessels are equipped with a DP system.

Total crew and personnel on supply vessels depend on the size and task. Smaller vessels have a crew of 3 to 4, while larger ones can accommodate a crew of up to 30 people. Typically a supply vessel can travel at a speed of 16 to 22 knots. When wave heights reach 1.5 to 2.0 meters (5 to 7 ft), a supply vessel has to reduce speed by only about 10-15%.

Supply vessels provide a vital service to oil platforms and, depending on demand, can achieve high day rates. When being used in the offshore wind sector, a typical OSV can transport two monopiles and several nacelles at a time.

Although OSVs are routinely used in the European offshore wind sector due to the widespread availability of these vessels around the North Sea oil & gas industry, they are less likely to be used in US offshore wind operations, especially in the early stages of development. OSVs can be considered as high-end alternatives to simpler transport barges, and they are especially suitable for deepwater sites. OSVs are dynamically positioned, whereas barges are either anchored or have jackup capabilities, limiting their operational water depth. Given the availability of cheaper barges and the relatively shallow waters in most potential offshore wind sites in along the Eastern Seaboard, it is not very likely that new OSVs will be built to support the offshore wind industry in the Atlantic Coast or even that existing OSVs will be chartered from the Gulf of Mexico for this purpose. For these practical considerations, we excluded OSVs from our vessel demand modeling exercise (any potential demand for OSVs is included in the *Barge* category).

Offshore Supply Vessel Offloading Supplies at Platform
Source: Offshore Energy Today

OSV Offloading Supplies at Platform, Assisted by Deck Crane
Source: Triplex Offshore Energy Today

3 Vessel Types

3.9 Personnel Transfer Vessels

Personnel transfer vessels (PTVs) are required during both the installation and the operation & maintenance phase of offshore wind projects. During the installation phase, PTVs supply crew changes and supplies to the installation vessels. During maintenance operations, PTVs transport maintenance crews and assist heavy maintenance vessels with personnel transfer and other supplies.

Current vessels are typically based on a 15-20 meter (50-65 ft) hull length with capacity for 10-15 passengers, and ranges of between 50 and 70 miles. In the future, vessels are likely to be based around 25-30 meter (80-100 ft) hull lengths, and have capacity for 25-30 passengers. These vessel designs are already being marketed in the UK as a solution for the longer ranges and wider operating windows that will be required in Round 3 developments. In order to further widen operating windows, several personnel access solutions are being marketed, including the Ampelmann Offshore Access System.

Vessels are generally contracted on long-term leases with 5 year operational support contracts possible. The majority of the market is made up of small operators with a fleet of three or fewer vessels. To date, there has been little in the way of consolidation among the PTV operators. Growth in this market is expected to be rapid. Some estimates suggest that the number of PTVs will have to triple over the next five years to support the rapidly accelerating installation rate in Europe, and to assist maintenance operations at a growing fleet of offshore wind turbines worldwide.

A number of small to medium sized companies provide personnel access services as well as specialized equipment to the offshore wind sector in Western Europe. Companies currently active in the sector are Windcat Workboats, Offshore Wind Power Marine Services, Turbine Transfers, North Sea Logistics, Ocean Wind Marine, Northern Offshore Services and MPI workboats. A number of other companies currently not active in the offshore wind sector could easily enter the market, if Northern European offshore wind installation continues to expand as foreseen.

Motion Stabilized Personnel Transfer Vessel
Source: Windcat

Marine co Shaman Personnel Transfer Vessel
Source: Admen

3 Vessel Types

3.10 Heavy Maintenance Vessels

Turbines require maintenance and repair subsequent to their installation. This can range from regular checks and the maintenance of the technical equipment to extensive repair work and upgrades, such as the replacement of blades or gear box parts.

Routine maintenance and regular checks on the electrical equipment will likely involve PTVs (or helicopters in remote sites equipped with a helipad). More substantial repair work, however, requires similar vessels to those used for turbine installation. These operations will likely be carried out by retired or older generation installation vessels.

As the first offshore wind farms reach the end of their lifetimes, decommissioning and repowering operations will also become necessary at an increasing scale. These works will likely be carried out by similar heavy maintenance vessels, notably, low spec jackups and retired, older generation TIVs, in the future.

Maintenance Crew Arriving at and Offshore Wind Farm
Source: Renewbl.com

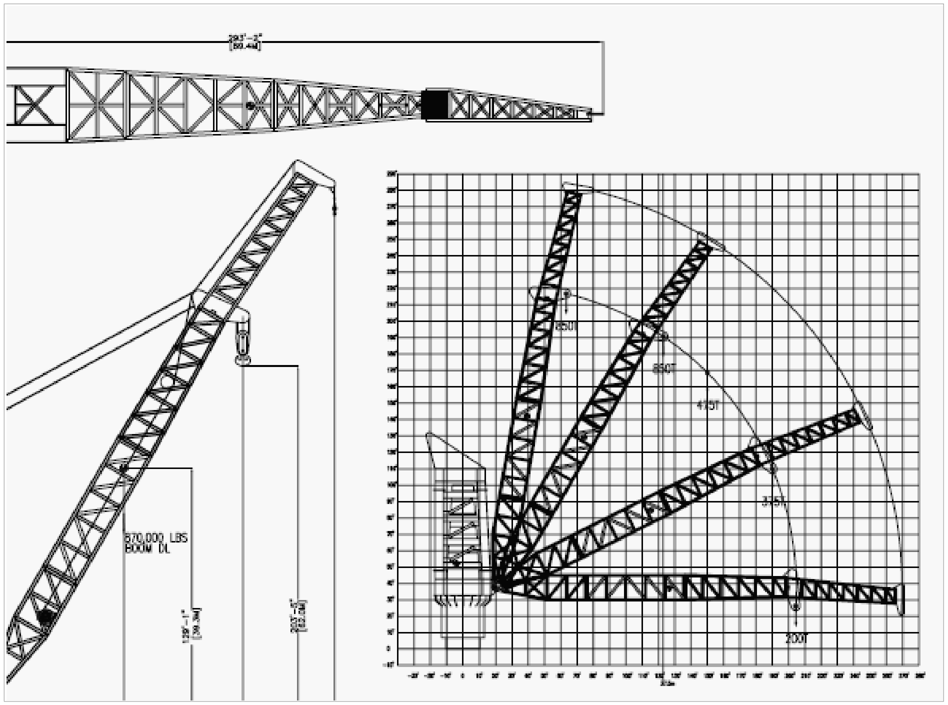
Rotor Repair Work at an Offshore Wind Turbine
Source: Alpha Energy

Indicative Specifications of Offshore Wind Vessels

Offshore Wind Vessel Indicative Specifications														
	Length Range		Breadth Range		Draught Range		Deadweight Range		Speed Range		Max. Wave Height		Max. Wind Speed	
Vessel Type	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
	[m]	[m]	[m]	[m]	[m]	[m]	[MT]	[MT]	[kn]	[kn]	[m]	[m]	[m/s]	[m/s]
New Generation Purpose-Built Vessels (TIVs)	75	160	30	50	3.4	10.9	3,300	8,000	6	13	2.5	3.5	15	25
Newbuild Jackups	40	100	20	40	2.4	8.3	900	3,300	7	8	1.5	2.5	20	30
Heavy Lift Vessels	100	180	25	70	3.6	13.5	1,100	22,000	6	17	1.0	2.0	15	25
Cable-Lay Vessels	25	150	10	30	2.0	9.1	900	11,000	8	18	-	-	-	-
Offshore Supply Vessels (OSVs)	45	110	10	25	3.8	6.7	800	6,000	12	17	-	-	-	-
Personnel Transport Vessels (PTVs)	20	70	5	15	0.9	3.6	10	700	16	36	0.5	1.5	10	20
Tugs	20	50	5	15	3.2	6.3	200	1,100	11	16	-	-	-	-
Barges	25	100	10	25	2.5	3.6	1,400	3,300	-	-	1.0	2.0	15	25
Survey Vessels	15	160	5	30	1.2	8.0	10	6,500	6	21	-	-	-	-

Notes
1) This is an indicative list.
2) The results from the vessel search have been filtered to reduce the overall amount of data to a workable fleet list representing the most suitable assests for
3) Only ships with an IMO number are included in the results. This applies to all passenger vessels >100 GRT, and all cargo vessels >300 GRT.
4) Only operational vessels are included in the results, under construction or planned units are specifically excluded.

Table 10: Indicative Specification of Selected Offshore Wind Vessel Types
Source: Knud E Hansen



Chapter 4

Vessel Components

4 Vessel Components

4.1 Jackup Legs

Jackup legs on jackup vessels or barges are subject to extreme forces in volatile conditions, especially during the jacking up and jacking down process. A stuck or broken jackup leg can destabilize the entire vessel. As a result, proper design and manufacturing of the jackup legs is vital. Jackup legs can be differentiated based on a number of characteristics, notably by the number of legs, type of legs, method of seafloor stabilization and type of elevating device.

Number of Legs

Depending on its size, a jackup typically has four or six legs. A four legged jackup is the most common, but the newer turbine installation vessels (TIVs) are equipped with six legs. According to Knud E Hansen, designer of the new Pacific Osprey and Pacific Orca, more legs increase the cost of the vessel, but provide substantially more stability and allow the vessel to continue operations in harsher weather. As wind farms move further away from shore, TIVs need to be able to work in harsher weather or face a reduced operational window.

Types of Legs

Open Truss legs

Open Truss legs are made of tubular steel sections that are crisscrossed like an electrical tower. Open truss legs are more expensive, but these legs are strong and able to maintain stability in deeper waters and harsh weather conditions.

Columnar Legs

These legs are made of large steel tubes and are easier and cheaper to manufacture. At the same time, they are less stable than the open truss legs and limit the vessel's ability to work in deep waters and harsher weather conditions.

Open Truss Jackup Legs
Source: Liebherr

Columnar Jackup Legs
Source: Seajacks

Seafloor Stabilization

When the vessel or platform is jacked up in position, the entire weight of the vessel/platform is borne by the legs. Ensuring that the legs are properly grounded on the ocean floor is vital. If the legs are not properly grounded, (e.g. one or more legs "punch through" the ocean floor during the jacking-up process), then the vessel will be destabilized. A tilted vessel can result in a kink in the leg or prevent the vessel from lowering back to the water. To minimize this risk, jackup legs are fitted with either a mat or spud cans.

Mats

When the jackup is needed to work in areas where the ocean floor is soft, the legs are fitted with a mat. When the vessel is jackup in position the mat is lying on the ocean floor from which the legs (connected to the mat) extend up to the vessel/platform.

4 Vessel Components

Spud cans

These act like shoes and are attached to each leg. Made of steel, the spud cans are cylindrical in shape with a spike and cleats that push into the ocean floor, making the legs stable.

Elevating Devices

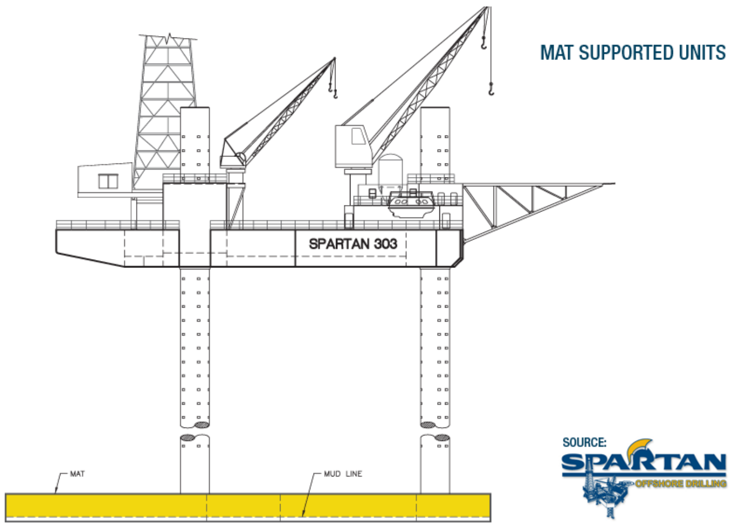
The technology used to take the jackup legs up and down is the elevating device. There are two devices that are seen in existing jackup vessels or platforms.

Hydraulic Cylinders with Stationary and Moving Pins

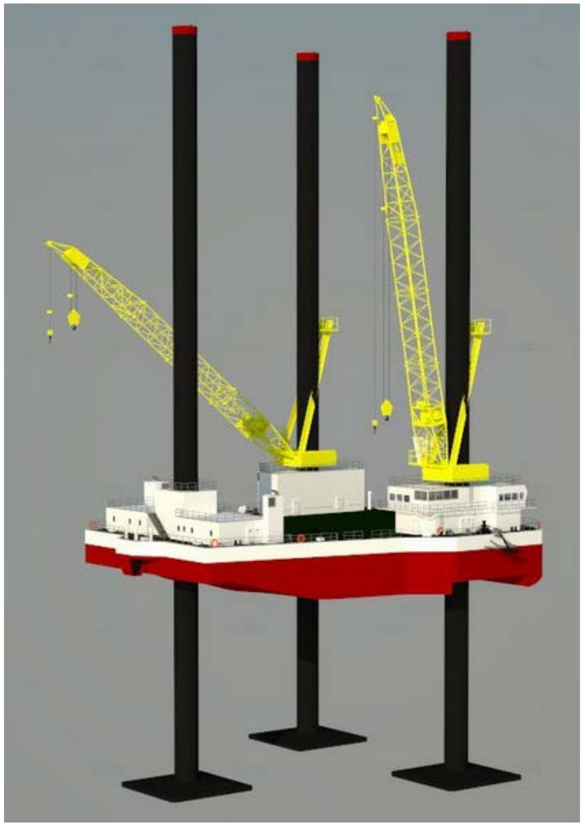
The hydraulic cylinder extends and retracts along the jackup legs climbing up and down the legs when jacking up or down.

Rack with Two Pinion Gears

The gears are turned to move the legs up and down. Most of the newer jackups use this technology.



MAT Supported Jackup Legs
Source: Spartan



Jackup Design with Columnar Legs and Spud Cans
Source: Alibaba.com

4 Vessel Components

4.2 Dynamic Positioning

Dynamic positioning (DP) is a computer system, which can automatically control the vessel's position using its main engines, bow thrusters, propellers, and rudders. Inputs to the computer system come from wind sensors, gyrocompasses, and other special devices like vertical reference units. The DP system can be set to certain coordinates or navigate the vessel in relation to another vessel. Using DP makes the use of anchor handling tugs redundant.

DP systems are rated DP0, DP1, DP2, and DP3. The difference between these ratings is the level of redundancy; the higher the rating, the higher the redundancy. This means that, if one system fails, there is a back-up thruster with an independent power unit to take over. DP3 systems are primarily used for drilling rigs. Supply vessels and crew transfer vessel tend to use DP1 systems. Deep water supply vessels that are 220 ft (67 m) or longer, construction vessels, and ROV support vessels are equipped with DP2.

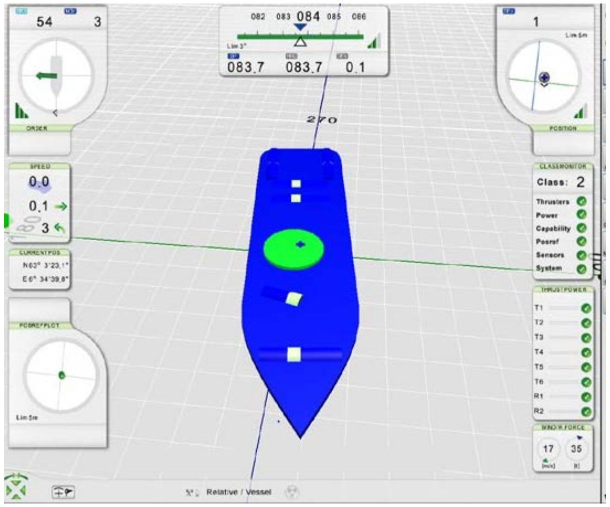


Diagram Showing the DP System of the Olympic Octopus
Source: ShipTechnology.com

DP systems are widely used in the offshore oil and gas industry for pipelay, cable-lay and survey activity.

DP systems can be retrofitted to a vessel and, until recently, required the vessel to go in to a drydock. A Texas-based company has launched a turnkey modular DP system that does not require drydock installation. By using a package system approach, additional thrusters with independent power sources are installed on the vessel. These thrusters are deployed when the vessel needs to use DP. Since DP systems are expensive and time consuming to install, this faster and less expensive method allows more vessels to be fitted with DP systems.

Portable Dynamic Positioning System
Source: Thrustmaster

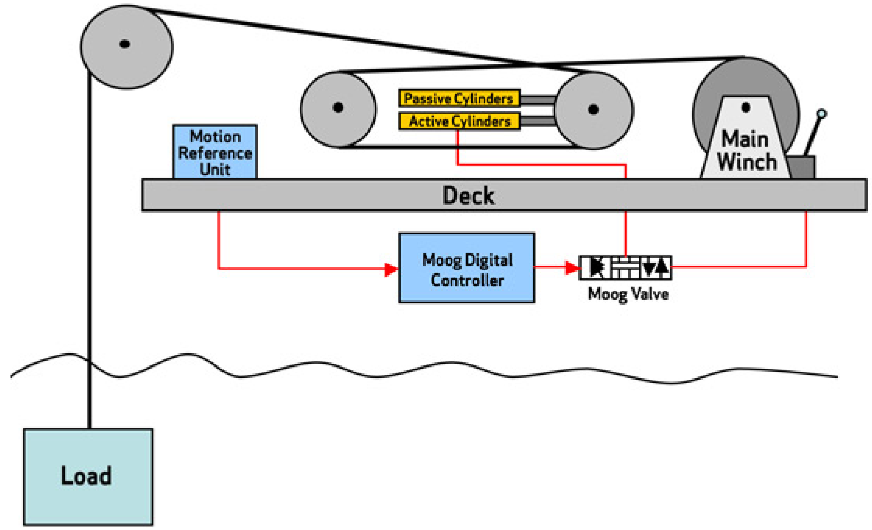
4 Vessel Components

4.3 Heave Compensation

While dynamic positioning controls the horizontal motion of a vessel, active heave compensation systems are designed to adjust for a vessel's vertical motions.

When using heave compensation, the vertical movement of the vessel is electronically monitored and the crane winch is automatically controlled to compensate for vertical motion. The crane cable is continuously paid out or reeled in to allow the load to hover above the seabed. The operator of the winch can then generate command signals to the winch drum which are superimposed on the automatic compensation function. This permits the operator to precisely control slow and accurate movements relative to the seabed.

Heave Compensated Barge Installing a Transition Piece
Source: Barge Master



Functional Schematic of a Heave Compensation System
Source: MovingYourWorld

In offshore construction, heave compensation and jacking-up a construction vessel serve a similar purpose. Once the vessel is jacked-up, the vessel is not affected by the water movement during operations. When a vessel cannot jack up, either because it does not have the capability or due to sea conditions, heave compensation is vital to improve operational efficiency.

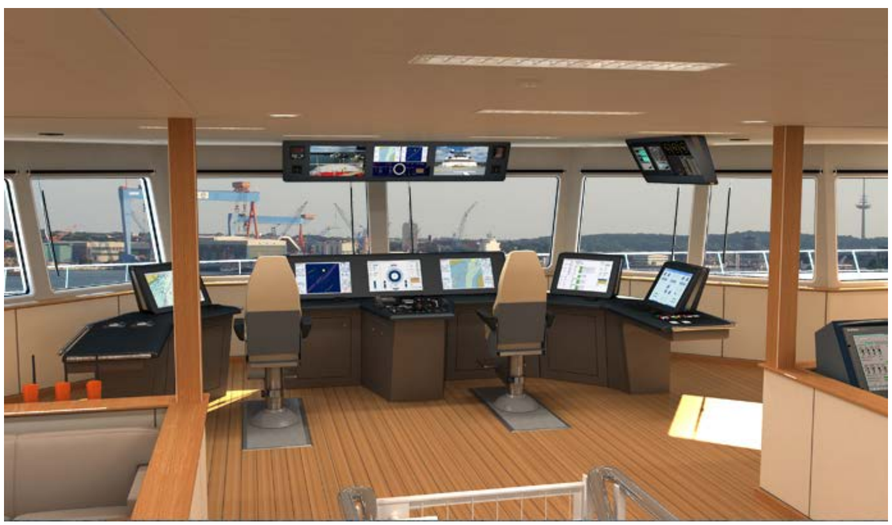
4.4 Navigation

Navigation systems that are used on modern vessels are called electronic chart display and information systems, or ECDIS. The navigation system has three main features.

Before the vessel leaves port, the navigation system is used to plan the ship's voyage. It sets out the route that the vessel should sail using an internal electronic navigational chart. If the planned route has potential hazards, the system issues an alert.

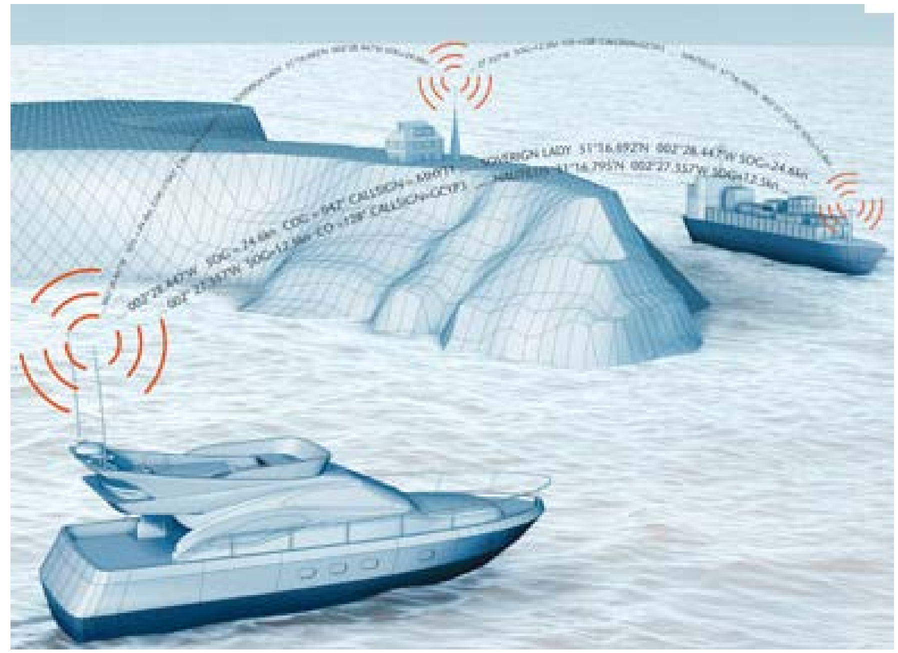
Once the vessel leaves port the system monitors the vessel's actual route. Using vessel specifications entered in the system, the system issues warnings if the vessel exceeds the allowance for danger. For example, if the vessel is turning at a rate that is not safe for the vessel's stability or entering waters that are lower than the minimum vessel draft.

During the voyage, the system automatically plots the position of the other ships within its radar range. For each vessel detected, the system provides details on current distance from the ship. Using the ship's route and speed information, the system issues an alert if any other vessels are on a possible collision path with the vessel.



Navigation System Interface Installed on the Bridge of the Ship
Source: Raytheon Anschutz

In 2000, the International Maritime Organization (IMO) adopted a new requirement for all ships to carry an automatic identification system (AIS). The AIS provides information about the ship to both coastal authorities and other vessels in the area. The AIS is like the black box on a plane and can provide information about the ships journey ex-post. It also allows navigation systems to use the information to detect possible collisions and issues.



AIS Systems Sharing Information
Source: IMO

4.5 Cranes

The height and reach of a crane on an offshore wind vessel is critically important. As turbine technology improves, the size of the turbines is also increasing. Taller towers and larger nacelles require cranes to have a higher reach and be able to carry larger tonnage. Over the last few years many dedicated offshore wind vessels like the MPI Resolution have fitted larger cranes on deck to accommodate the growing size of wind turbines.

Whether the crane is loaded onto a vessel or it is permanently mounted, the crane should have an upward reach of 125 meters (410 ft) with a load capacity of 600 to 1000 tons.

Rambiz Installing a Wind Turbine at the Beatrice Wind Farm
Source: Scaldis

It is common to see derrick cranes with a lattice boom on offshore wind construction vessels. It was not until 2010 that a telescopic crane was successfully used for offshore wind turbine installation. Compared to the lattice boom crane, the telescopic crane requires less deck space and has a lower center of gravity because of a completely retractable boom.

In 2010, a Liebherr telescopic crane was permanently mounted on the MV Wind jackup barge. The vessel was chartered by A2Sea for heavy maintenance operations the Egmond aan Zee wind farm in the Netherlands. Since the crane was originally not designed for offshore wind installations, it had to be modified to use electric power sourced from the vessel versus a diesel engine.

MV Wind Installing a Nacelle Using a Lattice Boom at a Dutch Wind Farm
Source: Alternative Energy Newswire

4 Vessel Components

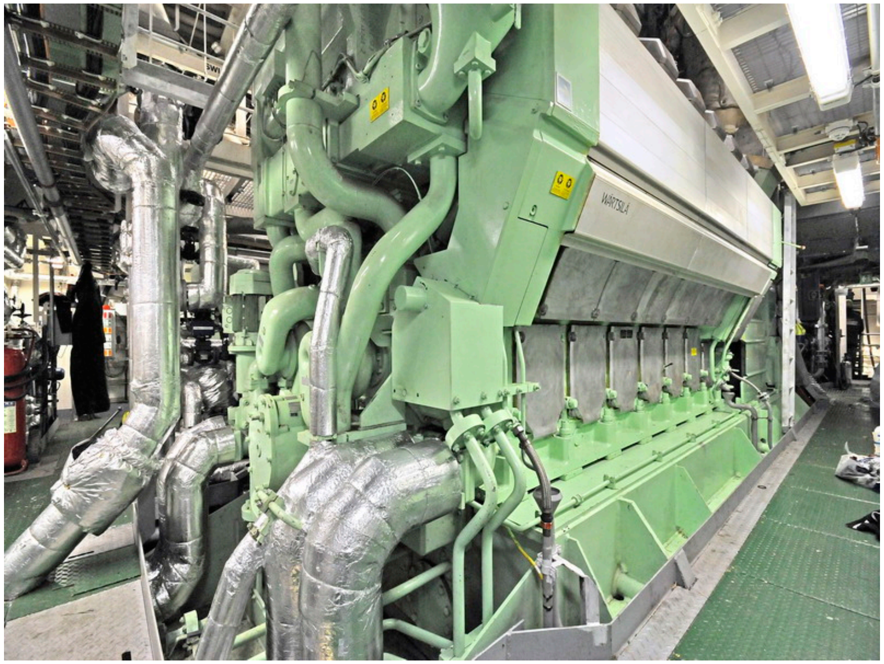
4.6 Power

Power on a vessel is provided by the main and the auxiliary engines. The main engines are used to propel the ship while the auxiliary engines are the power source for all other needs and activities on the vessel. The engine room houses the main and auxiliary engines along with generators, air compressors, feed pumps, gearboxes and fuel pumps.

The main engines are typically two stroke diesel engines that can run on both diesel and heavy fuel oil. The main engines power the propellers and are often called the propulsion engines. It is important to note that the main engines do not power the thrusters. The thrusters, which are mainly used when the vessel needs to maneuver in tight spaces, are powered by electric motors controlled from the vessel's bridge. The motion of both the propellers and thrusters are reversible by hydraulic motors that rotate the blades up to 180 degrees.

Compared to the main engines, the auxiliary engines are typically smaller and faster four-stroke engines. Auxiliary engines are of various sizes depending on what they are powering. Larger auxiliary engines are used to drive electrical generators that support the vessels electrical systems. Most vessels have three or more generators that have more power than is needed, but this ensures smooth operations during planned or emergency engine repairs. Auxiliary engines require constant care and have their own cooling systems, fuel systems and lubrication system, among others.

Diesel engines can be classified on the basis of speed (slow, medium, and high-speed), working principle (two vs. four stroke) and arrangement of cylinders (vertical vs. radial).



Engine Room in an Offshore Supply Vessel
Source: Maritimepropulsion.com

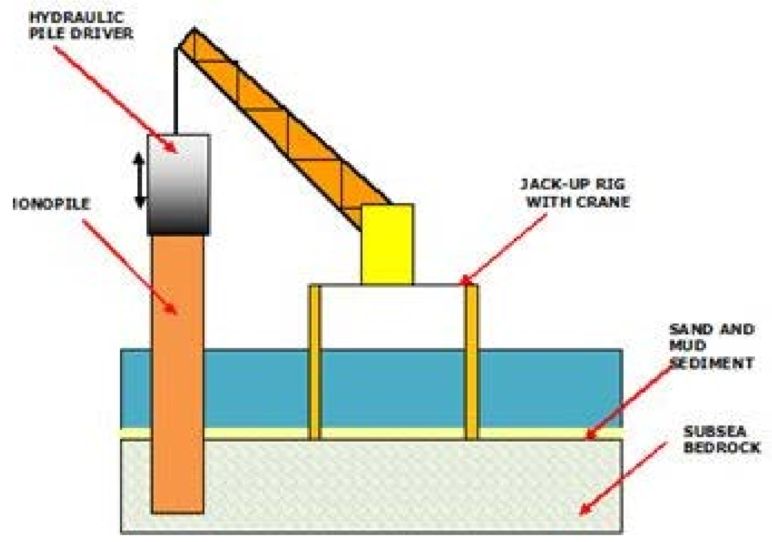
4 Vessel Components

4.7 Hammer

A pile hammer is a hydraulic, diesel or air operated pile driver hammer used to drive foundation structures deep underground. The pile hammer is used for both onshore and offshore construction.

Diesel pile hammers are powered by large two-stroke diesel engines. The weight is the piston operating within the cylinder. To start the pile driving, the weight is lifted using the crane. The pile hammer and the crane are attached by cable. As the weight is lifted, air is drawn into the chamber. When the weight is released, the air compresses and heats up to the diesel’s ignition point. At this point diesel fuel is injected into the cylinder, creating the energy that drives the weight back up. The pile driver can also be operated on hydraulics. This is more efficient and environmentally friendly than diesel fuel-driven hammers.

For offshore wind farm construction, the monopile is initially positioned on the seabed. Once in position, the pile driver (attached to a crane) hammers the monopile into the seabed to ensure a stable foundation for the turbine.



Drawing of Monopile Installation Using Pile Hammer
Source: Bright Hub

Chapter 5

Regulations and Certifications

5 Regulations and Certifications

5.1 The Jones Act

Overview

The Jones Act, more formally known as the Merchant Marine Act of 1920 (P.L. 66-261) regulates waterborne commerce in US waters and between US ports. The relevant sections of the Jones Act, 46 U.S.C. §55102 and 19 C.F.R. §4.80(b)a, deal with cabotage, that is, with transportation of goods between two US ports. The Jones Act requires that such goods be carried in US-flagged vessels constructed in the United States, owned by US citizens, and crewed by US citizens or permanent residents.

Relevance for Offshore Wind

For purposes of the US offshore wind industry, the issue is whether only US flagged vessels can participate in the transportation, installation, servicing or maintenance of offshore wind farms in US waters. Of particular concern are turbine and foundation installation vessels, since these are the most complex, expensive and scarce vessels types related to offshore wind installation. Other types of vessels, for example, tugs and barges, are plentiful in the US, and therefore the Jones Act represents no binding constraint for the industry.

A key consideration for the Jones Act is whether goods and services are "transported" in US waters. The notion of "transported" is interpreted to mean that a vessel with goods on board changes location. Thus, the moving of turbine components from a US port to an offshore wind farm site qualifies as "transporting" for the purposes of the Jones Act. However, the transference of goods by crane or hose from a supply vessel to a stationary vessel or vice versa is not considered transportation under the Jones Act. For example, foreign-built offshore drilling rigs operating in the Gulf of Mexico are deemed to meet Jones Act requirements, even though their activities involve the handling of goods, notably crude oil, gas, and related produced water—as long as the rig maintains a fixed position while the goods are on board. Such rigs would fail to meet Jones Act requirements, were they to move from a fixed position with oil, gas or produced water on board. In theory, therefore, a Korean-built rig carrying gravel from the site of a completed well to a new drilling location in the US Gulf would be in violation of the Jones Act. But as a practical matter, the law accommodates commercial realities, and virtually all floating drilling rigs operating in US waters are foreign-built.

This interpretation of the Jones Act also extends to the offshore wind industry. Any vessel transporting a turbine, foundation or other components from a US port to an offshore wind site in US waters must be US flagged (or "coastwise qualified" in Jones Act terminology), as an offshore wind installation site is considered to be a port.

A European-flagged, Asian-built turbine installation vessel (TIV) would not be eligible to mobilize from Europe, load turbines in a US port, and install them in US waters.

However, the same European vessel could mobilize from Europe to US waters and install turbines brought to it from a US port by a US-flagged vessel, for example a barge or tug. The use of a crane in the process would not violate the Act.

Feeder Barge Transporting Turbine Components
Source: Wikimedia

5 Regulations and Certifications

This interpretation was confirmed by a ruling of the US Customs and Border Protection (CBP) dated May 27, 2010 (HQ H105415), which established that using a foreign vessel and crew for drilling, monopile driving or installation activities on an offshore wind project does not, in itself, constitute a violation of the Jones Act. The above-mentioned limitations naturally apply, namely that the vessel cannot load cargo or disembark crew in US ports, thus it has to be supported by feeder barges and other support vessels when carrying out installation activities.

Implications for US Offshore Wind Development

In practice then, the Jones Act is unlikely to constrain the development of the US offshore wind industry, although it will increase costs and delay installation in some cases.

For two visible projects as of this Report—Cape Wind and the Block Island demonstration project—the intended method of installation calls for barges or tugs to ferry turbine components to the designated offshore site. In the case of Cape Wind, installation can in all likelihood be accomplished using only US vessels. (See a detailed case study in Chapter 8.2 entitled 'Case Study: Cape Wind Turbine Installation Strategies').

In the case of Block Island, the situation is more nuanced. The weights and dimensions of the proposed 6 MW turbines during installation may exceed the capabilities of available vessels in the United States. The employment of a specialized European TIV has been mooted as one potential solution, with the turbines components to be ferried to the installation location by US-flagged vessels.

Therefore, in the short to medium term, the Jones Act should not present an insurmountable obstacle to the development of the US offshore wind industry.

In the longer term, the Jones Act may become a more substantial impediment. A US- built TIV may cost twice as much as an Asian-built counterpart, and the most sophisticated of these may exceed $300 million in cost. Should the offshore wind industry take off, the Jones Act may compel developers to rely on more costly or less efficient solutions than those available in Europe. But these concerns are well into the future. For now, the Jones Act should not impede the development of the offshore wind business in the United States, although it may increase project costs by as much as $20-40 million for a 100 turbine development.

Geosea Goliath Loading Supplies from a Support Barge
Source: Geosea

5.2 Certifications

Summary

Federal law specifies the certification requirements for certain vessel types, while other vessels are typically classified and certified by one of the major classification societies. Inspections associated with certification and periodic surveys are carried out by the Coast Guard or one of the classification societies that are authorized to do so by the Coast Guard.

During the operation of the vessels involved in offshore wind-related activities, the BOEM (Bureau of Ocean Energy Management) has overall responsibility to enforce regulations related to safety management, while the Coast Guard is assumed to have jurisdiction over the vessels' operations in general, in conjunction with its mission to ensure marine safety.

Certification requirements, inspection regimes and operational standards are not yet fully defined in the US and further regulatory efforts are needed to provide clarity about requirement, procedures and jurisdictions of federal and state authorities.

The Role of the U.S. Coast Guard

In the United States, the Coast Guard is responsible for developing regulations and standards that govern the safe design and construction of ships and shipboard equipment. Such standards are based on the standards developed by the American Bureau of Shipping, a non-profit classification society, which has been in operation since 1862.

The body of law governing vessel certifications and inspections is Title 46 (Shipping) in the Code of Federal Regulations, usually referred to as CFR 46. Under federal law, the Coast Guard is responsible for inspecting vessels that are registered in the United States or are foreign ships in US waters. The Coast Guard delegates this responsibility to the Officer in Charge, Marine Inspection, who issues Certificates of Inspection for newbuild and foreign vessels, and carries out periodic inspections on vessels in operation. These fall into two categories: safety inspections and security inspections.

Inspections of vessel safety systems include:

- Hull inspection to ensure seaworthiness
- Main/auxiliary power inspection to ensure safe and operable machinery for vessel propulsion and emergency power.
- Boiler inspection to ensure that boiler systems are structurally sound with operable safety devices.
- Electrical systems inspection to ensure satisfactory installation of wiring and equipment.
- Lifesaving systems inspection to ensure satisfactory and adequate means to abandon ship.
- Firefighting systems inspection to ensure fixed and portable devices are suitable for the intended space and type of fire.
- Navigation inspection to ensure adequacy and operation of navigation equipment.
- Pollution prevention inspection to ensure compliance with international regulations and domestic laws.

Inspections of vessel security systems include:

- Verification of security related documents and certificates such as the ship security plan, International Ship Security Certificate and Declaration of Security.
- Ensuring that appropriate training drills and exercises are being conducted.
- Ensuring that the required onboard security procedures are in place.

The Coast Guard has delegated some of its certification and statutory functions to recognized classification societies (namely to the American Bureau of Shipping, Det Norske Veritas, Lloyd's Register, Germanischer Lloyd, and some more limited functions to Bureau Veritas, RINA S.p.A, and ClassNK as well). Certificates issued by these classification societies are recognized as those issued by the Coast Guard.

5 Regulations and Certifications

CFR 46 specifies which vessel types have to be certified and inspected by the Coast Guard or one of the authorized classification agencies. These are:

- Tank Vessels (Subchapter D)
- Passenger Vessels of various sizes (Subchapters H, K, T)
- Cargo and Miscellaneous Vessels (Subchapter I)
- Offshore Supply Vessels (Subchapter L)
- Oceanographic Research Vessels (Subchapter U)
- Certain Bulk and Dangerous Cargo Vessels (Subchapter O)

Uninspected Vessels detailed in Subchapter C, such as towboats, recreational and fishing vessels, are only required to comply with various safety and emergency rules (e.g. with regards to fire protection and lifesaving equipment) under federal law.

The Coast Guard issues Certificates of Inspection (COI) for a period of 1 year for passenger vessels (longer than 65 ft), 2 years for most other vessel categories and 3 years for small passenger vessels (less than 65 ft in length). The annual vessel inspection fees to retain the COI range between $1,000 to $15,000, depending on the vessel types, according to Coast Guard documents.

Inspection Regime during Operations at Offshore Wind Installations

The Energy Policy Act established the BOEMRE (Bureau of Ocean Energy Management, Regulation and Enforcement), the precursor to BOEM and BSEE (Bureau of Safety and Environmental Enforcement), as the lead authority to regulate offshore wind in federal waters. Its jurisdiction begins upon the award of a lease to the developer. Federal waters begin at 3 nautical miles from the coast in most states, except for Texas and the Florida where state waters extend to 9 nautical miles. BOEM (the successor of BOEMRE) is generally responsible for the inspections of vessels engaged in offshore wind installation and maintenance with respect to their safety management system (SMS) and their compliance with the Outer Continental Shelf Lands Act, among others. BOEM's role is defined in Part 585 of CFR 30 (on Renewable Energy and Alternative Uses of Existing Facilities on the Outer Continental Shelf).

In July 2011, BOEMRE and the Coast Guard signed a Memorandum of Agreement, which clarifies their respective roles in offshore wind-related safety regulations. As a general rule, the Coast Guard will continue to regulate and inspect the safety on those vessel types, which it is required to certify and inspect under CFR 46 (e.g. on personnel transfer vessels, and offshore supply vessels), whereas BOEM's regulation for safety management systems will apply to all other vessel types.

The British Wind Energy Association (BWEA) took the first steps in developing detailed guidelines specifically designed for the operation of jackup vessels in the offshore wind industry in 2009. The related document is entitled 'Guidelines for the Selection and Operation of Jack-ups in the Marine Renewable Energy Industry'. The document includes suitability and acceptance criteria, as well as certification requirements for jackup vessels involved in offshore wind operations. Currently there is no such specific guidance or federal regulation in the US, which defines operating standards for jackup vessels engaged in offshore wind turbine installation.

5.3 Classifications

The vast majority of US and foreign-flagged vessels are built to classification standards, regardless of whether they are required to be certified under CFR 46. Without proper classification, vessels are largely unable to secure insurance coverage or call at international ports. Vessel operators typically obtain such certification from one of the 13 classification societies that are members of the International Association of Classification Societies (IACS). The largest and oldest of these societies are Lloyd's Register of the UK, the American Bureau of Shipping, Bureau Veritas in Belgium, Det Norske Veritas from Norway, and the Germanischer Lloyd based in Germany. Det Norske Veritas and Germanischer Lloyd announced in December 2012 that the two groups will merge to create the 3rd largest certification, inspection and classification association in the world.

Det Norske Veritas was the first classification society to develop a class notation for offshore wind turbine installation vessels (the classification is based on DNV's previous classification for drilling and production vessels used in the oil and gas industry). The rules include general design and construction requirements for turbine installation vessels.

The objective of ship classification is to verify the structural strength and integrity of essential parts of the ship's hull and its appendages, and the reliability and function of the propulsion and steering systems, power generation and those other features and auxiliary systems.

Classification Societies achieve this by developing their own set of rules and by verifying compliance with international and national statutory regulations on behalf of flag administrations.

The classification process begins in the design phase, focusing heavily on the implementation and manufacture of key components and technical specifications. During the construction of the vessel, classification society surveyors attend the vessel to verify that it is built in conformance with its approved design plans and the society's rules. A surveyor will also visit the relevant production facilities of key component suppliers to the vessel to verify that the components conform to the society's rules. The classification society surveyor(s) will also attend sea trials and other trials relating to the vessel and its equipment prior to delivery. If all requirements are met, then the society issues a certificate of classification.

On delivery, the vessel will receive periodic surveys by the society to verify that it is being maintained to the required standard. These surveys generally follow a 5-year cycle of annual, intermediate and special surveys. A class renewal (special) survey is typically held every 5 years, and includes extensive in-water as well as out-of-water examinations.

Chapter 6

Supply Chain and Industry Participants

6 Supply Chain and Industry Participants

6.1 Installation Contractors

The Role of European Installers

European installation companies are actively interested in the US offshore wind market, focusing primarily on the Atlantic Coast region. Some of these companies, such as A2Sea, have also submitted bids for US project work in the past. However, a number of factors have prevented the entry of European installation companies to the US market thus far.

European contractors are absent from the US market for the moment because:

- High-paying work is readily available in Europe
- There are only very few visible projects in the US for the moment
- Jones Act makes working in the US challenging and complex
- European contractors lack experience in operating in the US.

The most important of these obstacles relate to the economic, technical and operational implications of the Jones Act, as well as the uncertainty regarding future projects. Compliance with the Jones Act would prevent European purpose-built TIVs from operating in their most efficient fashion in US waters, as they would have to be served by US-flagged feeder barges and support vessels throughout the entire construction season. This would also pose considerable technical and operational challenges, as the need for frequent sea-to-sea transfers would render installation operations more sensitive to weather-related factors, such as sea state changes.

As a consequence of reduced efficiency and high dayrates of European TIVs in US waters, project economics would also suffer. Furthermore, the lack of a more or less predictable and constant project flow might render the utilization rate of European TIVs unsustainably low between major projects, and thereby prevent such vessels to venture the Trans-Atlantic crossing in the first place.

European contractors can reasonably be expected to enter the US market at some point in the future:

- On a consulting basis supporting US construction companies in the initial phases of development
- On a one-off basis, when other solutions are unavailable (e.g. possibly in case of Block Island)
- On a seasonal or semi-permanent basis, when the project stream becomes significantly more visible.

US vessel operators have also expressed keen interest in entering the offshore wind installation market, but to date, only one company, Weeks Marine has invested in specialized offshore wind installation capabilities. However, potential US offshore wind installation players understand that offshore wind may become a significant source of revenue for them, if the US offshore wind industry takes off as envisioned in some of our modeling scenarios. As a result, they have typically been monitoring the market for the last several years.

6.2 Major Installation Companies

In this section, we highlight selected offshore construction and support companies active or expressing an interest in offshore wind.

Domestic Installers

Weeks Marine

Weeks Marine, Inc. is one of the leading marine constructions, dredging and tunneling organizations in the United States and Canada. The Heavy Lift, Salvage and Marine Transportation Division of Weeks Marine, Inc. specializes in providing one-stop waterborne services. It is able to accomplish this by using its fleet of floating equipment, including tug boats, floating cranes, and deck barges. Its pedestal mounted floating cranes allow for full rotation which offers the most efficient system for repeat cycle tasks, such as the loading or unloading of vessels. The capacity and reach of these cranes also make them the most effective cranes for heavy lifts from ocean carriers. Additionally they are well suited for working in narrow ship channels where shear or stiff leg designs may be hampered by limited swing space or swift water currents. Weeks Marine is the only operator that invested in specialized offshore wind installation capabilities, namely the RD MacDonald jackup vessel.

Cal Dive International

Cal Dive International provides manned diving, derrick, pipelay and pipe burial services to the offshore oil and gas industry. Its services include saturation, surface and mixed gas diving, enabling it to provide a full complement of diving in water depths of up to 1,000 ft Cal Dive provides surface and mixed gas diving services in water depths typically less than 300 ft through surface diving vessels.

Manson Construction Co.

Manson Construction is a privately-owned Seattle-based marine construction and dredging specialist. The company has several large derrick barges that are suitable for various heavy installation activities. The company expressed interest in participating in US offshore wind construction projects in the future. The company’s E.P. Paup vessel has a 1,000 ton lifting capacity and it is the most suitable in Manson’s fleet for the installation of offshore wind turbine components.

Donjon Marine Co., Inc

Donjon Marine provides shipbuilding, dry docking, ship repair, barge construction, vessel conversion, repowering, maintenance, steel fabrication, steel assembly, and other related services through the Great Lakes region and beyond. The company's floating heavy lifting equipment includes the 1000 ton capacity floating boomable shear leg Chesapeake 1000 which is based in Port Newark, NJ. Donjon's certified heavy lift derrick barge fleet is used in a number of ways from cargo lifts to providing services in support of its salvage, construction and demolition activities.

Orion Marine

Orion Marine Group, Inc. is a leading heavy civil marine contractor providing a broad range of turn-key solution marine construction and specialty services along the Gulf Coast, the Atlantic Seaboard, West Coast, Canada, and the Caribbean Basin. Its marine construction services include marine transportation facility construction, dredging, repair and maintenance, bridge building, marine pipeline construction, as well as specialty services. Its specialty services include salvage, demolition, diving, surveying, towing and underwater inspection, excavation and repair. The Company is headquartered in Houston, Texas. Orion Marine has historically expressed an interest in offshore wind construction.

Hercules Offshore

Hercules Offshore is a global provider of offshore contract drilling, liftboat and inland barge service. Its fleet of jackup rigs is the fourth largest in the world and the largest in the US Gulf of Mexico. In addition, it owns and operates the largest liftboat and inland barge drilling fleets in the world. Its diverse fleet is capable of providing services such as oil and gas exploration and development drilling, well service, platform inspection, maintenance and decommissioning operations in shallow water markets.

6 Supply Chain and Industry Participants

International Installers

MPI

MPI Offshore is one of the leading offshore wind turbine installation companies in Europe, operating a fleet of large wind turbine installation vessels, notably the MPI Adventure, the MPI Discovery and the MPI Resolution.

The MPI fleet of installation vessels has the lifting and large load capacity, plus the ability to provide a stable platform in hostile marine environments, to provide an effective, competitive solution for the commissioning, decommissioning and maintenance of platforms and pipelines and the transportation of platforms and components.

A2Sea

A2SEA is an offshore wind farm installation and services company based in Fredericia, Denmark. The company is specialized on transport, installation, and servicing of offshore wind farms. In addition to Denmark, the company has subsidiaries in the United Kingdom and Germany.

A2SEA maintains and operates its own fleet of specially designed vessels and equipment. Since installing turbines on Horns Rev, the World's first commercial scale wind farm in 2002, its vessels have gone on to install more than 700 wind turbines and 300 foundations. It has worked across northern Europe from the Baltic to the Irish Sea.

A2Sea is owned by Danish utility DONG Energy (51%) and Siemens (49%). Siemens is also the designated turbine manufacturer for the Cape Wind and Block Island projects, and the company may be an important vendor of offshore wind turbines for future projects as well. Siemens' ownership in the installation company may provide A2Sea with opportunities to participate in US offshore wind projects in the future.

6.3 Shipyards

US Shipyards and Offshore Wind

Like the contractors, US shipyards are also aware of the potential that lies in the US offshore wind installation market. Almost without exception, they have actively investigated market opportunities and a number of US shipyards have provided quotes on installation vessels in recent years.

However, the expertise of US shipyards primarily lies in naval vessels, liners and other vessel types associated with the Hawaii trade, tankers for the Alaska crude trade, offshore supply vessels for the Gulf of Mexico. At the same time, US shipyards admit to lacking experience in building TIVs or jackup barges for offshore wind turbine installation.

In all interviews, shipyards indicated that they are capable of building such vessels, if required, but their cost base to do so will likely be 60-200% higher than that of their Asian competitors. So far, only one specialized offshore wind installation vessel has been constructed in the US: BAE Systems built the hull of Weeks Marine's RD MacDonald vessel at its yard in Jacksonville, Florida.

Our assessment of US shipyards suggests that there are no physical obstacles preventing US shipyards from constructing purpose-built offshore wind installation vessels in the future, but these will be considerably more expensive than their Asian-built counterparts, and learning curve effects will take years to materialize.

Options to reduce construction cost by partially constructing installation vessels in Asia, but certifying them as US-built vessels under current domestic content regulations, merit further investigation. Our interviews with shipyards suggest that this so-called 'ship-in-the-box' shipbuilding model is already widely used in other segments of the shipbuilding industry, and would be applicable to TIVs as well.

Based on our surveys and interviews, we conclude that economic considerations would tend to drive shipbuilding activities towards non-unionized southern shipyards along the US Gulf Coast.

At least a handful of large yards, and perhaps 20 yards in total could build US installation vessels. However, it is unlikely that any new shipyards would be constructed purely to build the modest number of US-built TIVs which might be needed in coming years.

Notwithstanding, the outfitting of vessels can be completed outside the yard setting. For example, the installation of legs and other equipment on the RD MacDonald was completed at Weeks Marine's yard in Camden, New Jersey.

On the East Coast, the yard of greatest interest would be Aker Yards in Philadelphia. The yard sits across the Delaware River from Camden/Paulsboro, New Jersey, the likely staging area for any New Jersey-based wind projects. Although formally in Pennsylvania, Aker's proximity to New Jersey would allow employment and other benefits to be captured, in part by New Jersey.

6.4 Major Shipbuilders

Large Shipbuilders

These companies operate (or used to operate) fully developed, large shipyards building large naval combatants and/or deep-draft, oceangoing merchant ships.

	Shipbuilder	Location	State
ACTIVE	General Dynamics - Bath Iron Works Corporation	Bath	ME
	General Dynamics - Electric Boat Company	Groton	CT
	General Dynamics - NASSCO	San Diego	CA
	Huntington Ingalls - Newport News Shipbuilding	Newport News	VA
	Huntington Ingalls - Ingalls Shipbuilding	Pascagoula	MS
	Huntington Ingalls - Avondale Shipyards	New Orleans	LA

Table 11: Active Large Shipyards in the United States
Source: shipbuildinghistory.com

General Dynamics - Bath Iron Works Corporation

Part of General Dynamics Marine Systems, Bath Iron Works is a full service shipyard specializing in the design, building and support of complex surface combatants for the U.S. Navy.

GDBIW operates two major manufacturing work sites in the West Bath-Brunswick area. Its shipbuilding takes place at its yard on the Kennebec River, bordering Washington Street at the south end of the city of Bath, Maine. Facilities at the main plant include a 750 ft drydock, three shipways, three wharves, an outfitting pier, four level-luffing cranes, and covered facilities for pre-outfit and assembly.

General Dynamics - Electric Boat Company

Electric Boat is the prime contractor and lead design yard for the US Navy's Virginia-class attack submarines. Virginia is the first class of US ships produced for post-Cold War missions and has been designed to be more cost-effective and perform a wider range of mission capabilities than previous classes. The company's construction counterpart is Huntington Ingalls-Newport News Shipbuilding in Virginia.

6 Supply Chain and Industry Participants

General Dynamics NASSCO

General Dynamics NASSCO has been designing and building ships in San Diego's industrial corridor since 1960 and it is the only full service shipyard on the West Coast of the United States. Today, General Dynamics NASSCO has locations on both the West Coast and the East Coast of the US. The company specializes in the design and construction of auxiliary and support ships for the US Navy as well as oil tankers and dry cargo carriers for commercial markets. It is also a major provider of repair services for the US Navy, with capabilities in San Diego, Norfolk, and Jacksonville. General Dynamics NASSCO is one of three shipyards in the Marine Systems group of General Dynamics Corporation (NYSE: GD). General Dynamics, headquartered in Falls Church, Virginia, employs approximately 90,000 people worldwide.

Huntington Ingalls - Newport News Shipbuilding

Newport News Shipbuilding is a shipbuilding company, located in Newport News, VA. It builds some of the most advanced ships in the world, and is an expert in nuclear propulsion, naval design and manufacturing. It is the sole designer, builder and refueler of nuclear-powered US Navy aircraft carriers, and it is one of two providers of nuclear-powered U.S. Navy submarines. With 21,000 employees, it is the largest industrial employer in Virginia.

Spanning more than 550 acres, at the mouth of the Chesapeake Bay, Newport News shipyard sits on 2.5 miles of waterfront property along the James River. Its facilities range from manufacturing facilities to drydocks and piers. In the latest expansion, it added "Big Blue," a gantry crane capable of lifting 1,050 tons. The crane is one of the largest in the Western Hemisphere.

Huntington Ingalls - Ingalls Shipbuilding

For more than 70 years, with more than 18,000 employees, Ingalls Shipbuilding facilities have pioneered the development and production of technologically advanced, highly capable warships for the surface Navy fleet, U.S. Coast Guard, U.S. Marine Corps, and foreign and commercial customers. Ingalls Shipbuilding in Pascagoula, with 800 acres and 11,000 employees, is the largest manufacturing employer Mississippi and a major contributor to the economic growth of the state.

Huntington Ingalls - Avondale Shipyards

Avondale Shipyard is the largest private manufacturing employer in Louisiana with about 4,800 employees and representing nearly $1 bn of economic impact to the state.

Throughout more than seven decades of continuous operation Avondale has produced more than 300 ships and vessels and amassed unmatched experience in designing, engineering, constructing and maintaining a diverse group of military and commercial vessels.

Medium-Sized Shipbuilders

These companies generally operate (or used to operate) well developed, mid-sized to large shipyards capable of building mid-sized to large merchant ships, mid-sized to large naval vessels, offshore drilling rigs and high-value, high-complexity smaller vessels.

The group consists of 20 shipyards owned and operated by only 11 companies. This group includes those shipbuilders which constitute what is now known as the "second tier" of the U.S. shipbuilding industry. Some are more active than others, but all are potential players in the offshore wind supply chain.

	Shipbuilder	Location	State
ACTIVE SECOND-TIER SHIPBUILDERS (20)	Aker Philadelphia (formerly Kvaerner Philadelphia)	Philadelphia	PA
	Austal USA	Mobile	AL
	BAE Systems Southeast - Alabama (formerly Atlantic Marine Alabama)	Mobile	AL
	BAE Systems Southeast - Florida (formerly Atlantic Marine Florida)	Jacksonville	FL
	Bollinger Lockport	Lockport	LA
	Bollinger Marine Fabricators (formerly McDermott SB)	Amelia	LA
	Fincantieri USA - Bay Shipbuilding (formerly Christy Corp.)	Sturgeon Bay	WI
	Fincantieri USA - Marinette Marine	Marinette	WI
	Keppel O. & M. USA (AMFELS) (formerly Marathon LeTourneau)	Brownsville	TX
	LeTourneau Technologies (formerly Marathon LeTourneau)	Vicksburg	MS
	North American Shipbuilding	Larose	LA
	La Ship (formerly North American Fabricators)	Houma	LA
	Gulf Ship	Gulfport	MS
	Tampa Ship (formerly Tampa Bay SB)	Tampa	FL
	Signal International (formerly Texas Dry Dock)	Orange	TX
	Signal International (formerly Friede Goldman Offshore)	Pascagoula	MS
	Vigor Industrial (formerly Todd Pacific Shipyards)	Seattle	WA
	VT Halter Marine Pascagoula (formerly Halter Pascagoula)	Pascagoula	MS
	VT Halter Marine Moss Point (formerly Halter Moss Point)	Moss Point	MS
	VT Halter Marine Escatawpa (formerly Moss Point Marine)	Escatawpa	MS

Table 12: Medium-Sized Shipyards in the United States
Source: shipbuildinghistory.com

6 Supply Chain and Industry Participants

Aker Philadelphia

Aker Philadelphia Shipyard ("APSI") is a leading US commercial shipyard constructing Jones Act-compliant vessels for the US market. It possesses a state-of-the-art shipbuilding facility and has earned a reputation as the preferred provider of oceangoing merchant vessels. Depending on its backlog, the yard has a workforce of up to 1,200, consisting of its own employees and subcontractors. Aker Philadelphia Shipyard is currently in the process of constructing two product tankers. Both vessels are scheduled for delivery through 2013, securing the yard's shipbuilding backlog in this period.

Aker Philadelphia Shipyard's facilities and equipment were installed new between 1998 and 2000. The shipyard was designed with the specific intent of reducing materials handling operations and is based on experience from state-of-the-art Aker Yards shipyards in Europe.

Austal USA

Austal is a global defense contractor. The company designs, constructs and maintains innovative platforms such as the Littoral Combat Ship (LCS) and the Joint High Speed Vessel (JHSV) for the United States Navy, as well as an extensive range of patrol and auxiliary vessels for defense forces and government agencies globally. Austal also designs, installs, integrates and maintains sophisticated communications, radar and command and control systems.

Austal's primary facilities comprise a defense shipyard in Henderson, Western Australia; a defense shipyard in Mobile, Alabama; and a commercial shipyard in Balamban, Philippines. Austal's US facility is a full-service shipyard offering design, construction and high-speed vessel service and repair.

BAE Systems Southeast

BAE Systems Southeast Shipyards owns and operates three strategically located shipyards along the U.S. Gulf Coast and East Coast. Its Gulf of Mexico facility is located in Mobile, Alabama, while BAE Systems Southeast Shipyard's East Coast facilities are located in Jacksonville, Florida. BAE also leases space at the naval station in Mayport, Florida.

BAE's Mobile facility offers dry docking and heavy lift capacity for the large vessels trading in the Gulf of Mexico region and the Caribbean. The company's Gulf Coast facility can accommodate vessels of up to 46,400 ton displacement.

Situated at the edge of the Intracoastal Waterway, BAE Systems Southeast Shipyard Jacksonville, LLC is 301 nautical miles from Fort Lauderdale. The Jacksonville specializes in mega-yacht repairs and refits, as well as commercial and U.S. Navy ship repairs and conversions, marine fabrication and industrial fabrication and assembly. The hull of the RD MacDonald was constructed in this yard.

Bollinger Shipyards

Bollinger Shipyards provides new construction, repair and conversion products and services to the commercial offshore energy and marine transportation markets from its US Gulf of Mexico facilities. Family owned and operated since 1946, Bollinger maintains ten ISO 9001 certified shipyards and a fleet of 28 drydocks for shallow draft and deepwater vessels.

The Lockport New Construction facility has delivered oceangoing tugs, docking tugs, offshore supply vessels, liftboats, derrick barges, deck barges and multi-purpose support vessels. Its indoor fabrication shop area has a total of 461,000 square feet, with full overhead cranes support and a variety of production support services.

Fincantieri USA - Bay Shipbuilding

Located in Sturgeon Bay, WI, Bay Shipbuilding Co. (BSC) is a leader in the construction of OPA 90-compliant vessels, dredges and dredging support equipment (scows, deck barges, tugs, etc.), along with bulk cargo self-unloading solutions. This division of Fincantieri Marine Group specializes in large ship construction projects.

Among its recent contracts, BSC has completed a state-of-the-art 17 cubic yard backhoe dredge, a 24 inch self-contained cutterhead dredge, a 5,000 cubic meter double-trailing drag arm suction dredge and a 7,100 cubic yard split-hull dump scow.

Fincantieri USA - Marinette Marine

Marinette Marine Corporation was founded in 1942 along the Menominee River in Marinette, Wisconsin to meet America's growing demand for naval construction. MMC has designed and built more than 1,500 vessels. Its portfolio includes the U.S. Navy's Littoral Combat Ship, the improved Navy Lighterage System, mine countermeasure vessels and ocean tugs, as well as U.S. Coast Guard icebreakers, buoy tenders and response vessels.

6 Supply Chain and Industry Participants

Keppel O & M USA (AMFELS)

Keppel AmFELS's Brownsville's shipyard in Texas has newbuilding expertise ranging from jackup and semisubmersible rigs to floating production systems, drilling barges and other specialized vessels. The shipyard is backed by a sheltered waterfront area, a drydock and modern steel-processing plant. It is also able to undertake a wide variety of fabrication work at its comprehensive facility including that of wind turbines.

North American Shipbuilding

North American Shipbuilding (NAS) was founded in Larose, Louisiana in 1974. Designing and constructing vessels for ECO (Edison Chouest Offshore) has garnered many notable achievements for NAS, including the construction of the first US Antarctic icebreaking research vessel the largest and most powerful anchor handling vessel in the US fleet, the first dynamically-positioned vessel in the US, the world's first floating production system installation vessel and the largest water throw capacity vessel in the US fleet.

LaShip

ECO's largest shipyard to date, LaShip in Houma, Louisiana, is a modern facility. LaShip is equipped to accommodate a wide range of new construction projects, as well as repairs, conversions and refits. Construction is currently underway on several new well stimulation vessels at LaShip, along with a 360 ft Arctic ice class anchor handling tug supply vessel.

Gulf Ship

Located on 37 acres in Gulfport, Mississippi, Gulf Ship has established itself as a world-class shipbuilder since its inception in April 2006. Among Gulf Ship's many achievements is the ongoing construction of ECO's versatile true tractor tugs, supporting LNG receiving terminals along the Louisiana and Texas coasts.

Tampa Ship

Tampa ship LLC specializes in conversions, general repair and overhaul of a wide range of vessels, including product tankers, container ships, general cargo vessels, drill ships and rigs, offshore supply vessels, bulk carriers, passenger/cruise ships, LPG and LNG carriers and reefer ships.

Tampa Ship is the only commercial shipyard between Pascagoula, Mississippi and Hampton Roads, Virginia equipped with four large graving docks and extensive crane capabilities.

Signal International

Signal International Inc. is a leading Gulf of Mexico provider of marine and fabrication services, including: new construction; heavy fabrication; offshore drilling rig and ship overhaul, repair, upgrade and conversion.

Signal has four shipyards in the US, one in Mobile, Alabama, and one in Orange, Texas and two in Pascagoula, Mississippi. New constructions are conducted in Signal's facilities in Mississippi and Texas. Signal is also able to take on drilling rig conversions and upgrades, ship refurbishment and repair.

Vigor Industrial

Vigor Industrial provides leading shipyards and industrial facilities throughout the Pacific Northwest and Alaska to handle both small and larger projects. Vigor Industrial companies offer ten drydocks, more than 17,000 ft of dedicated pier space; and more than half a million square feet of covered shop area. Occupying 120 acres, it operates more than 50 cranes including a 600 ton gantry in its Portland buildway. In Seattle, Vigor Marine and Vigor Shipyards build, repair and upgrade vessels on three floating drydocks with up to 18,000 long ton capacity, on six piers, with 12 cranes and in extensive indoor assembly, machine and paint shops.

VT Halter

VT Halter Marine, Inc. is a shipbuilding subsidiary of Vision Technologies Systems, Inc. (VTS). The company has the world's largest capacity for small to medium size ship construction. VT Halter Marine shipyards have delivered over 3,000 vessels to commercial and government clients in 29 countries on 5 continents.

Part 2

Forecast of Vessel Requirements for the US Offshore Wind Industry

Introduction

In Part 2 of our Report, we provide a long-term assessment of potential vessel requirements in the US offshore wind sector through 2030. The basis of this forecast is a series of rollout scenarios, which we developed in conjunction with Navigant Consulting and the National Renewable Energy Laboratory (NREL) and in cooperation with the Department of Energy (DOE).

The highest growth scenario reflects the potential for 54 GW of capacity installed by 2030 in alignment with the *National Offshore Wind Strategy* issued in 2011 by DOE and the Department of the Interior. These rollout scenarios along with a series of technology-related assumptions inform our views of the number of turbines and projects likely to be installed in each scenario. We present these rollout scenarios in detail in Chapter 7.

Jones Act-related restrictions and the limited availability of US-flagged installation vessels in the early phases of development results in only three sensible installation strategies for US developers to pursue, when planning for offshore wind projects in the US. We analyze the logistical challenges as well as the economics associated with each of these strategies in Chapter 8.

We incorporate the rollout scenarios, the three analyzed vessel strategies as well as our estimated vessel efficiency coefficients in a comprehensive vessel demand model to establish the anticipated vessel requirements for a range of vessel types. We present a detailed overview of our modeling results in various scenarios and installation strategies in Chapter 9. We provide further background on our modeling methodology in Appendix 2 and in-detail modeling results in Appendix 3 of our Report.

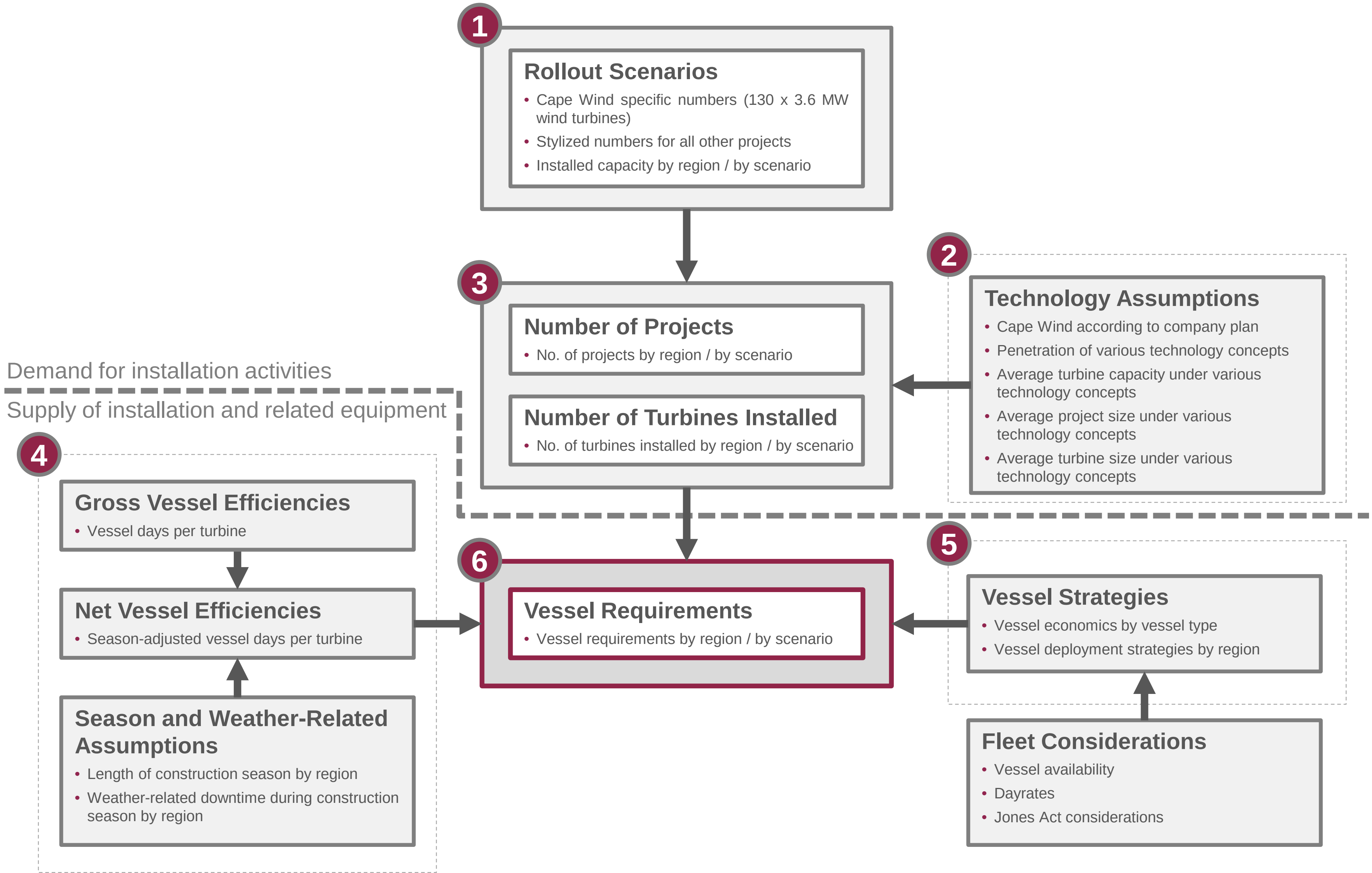


Figure 16: Vessel Demand Model
Source: Douglas-Westwood

Chapter 7
Rollout Scenarios

7 Rollout Scenarios

7.1 US Overview

Deployment Scenarios		54GW by 2030 (HH) High Growth- High Tech Scenario		28GW by 2030 Moderate Growth with High Technology Adoption (MH)		10GW by 2030 - Low Growth - Low Tech Scenario (LL)	
		2020	**2030**	**2020**	**2030**	**2020**	**2030**
Total Capacity Deployed by Milestone Date (in GW)		**7**	**54**	**4**	**28**	**1**	**10**
Regional Distribution							
	Atlantic Coast	4	28	2	12	1	8
	Great Lakes	1	6	0.5	4	0	1
	Gulf Coast	1	5	0.5	4	0	1
	Pacific Coast	1	15	0.5	8	0	0

Table 13: Summary of Rollout Scenarios

Source: Douglas-Westwood, Department of Energy, NREL, Navigant

On the basis of DOE headline offshore wind capacity targets, we and other project team members developed three capacity deployment scenarios for four US regions, namely for the Atlantic Coast, Great Lakes, Gulf Coast and Pacific Coast regions. Our scenarios are based on various rates of offshore wind technology deployment and on three different levels of offshore wind technology advancement. On this basis, we determined offshore wind capacity rollout through 2030 in a High Growth – High Technology (HH) scenario, in a Medium Growth – High Technology (MH) scenario, and in a Low Growth – Low Technology (LL) scenario. We refer to these scenarios as “High Growth”, “Medium Growth” and “Low Growth” scenarios throughout the Report, and use the “HH”, “MH”, and “LL” abbreviations where a short form is necessary (e.g. in tables and charts). Each of these scenarios are detailed below.

The table above provides gigawatt (GW) targets for each scenario on an aggregate and regional basis. The offshore wind deployment scenarios are divided under 3 main categories which are differentiated by the expected demand for offshore wind and technological innovations and absorption rate. Each scenario is further categorized by the four US coasts, namely Atlantic, Great Lakes, Gulf, and Pacific, providing expected targets by coasts for 2020 (Phase 1) and 2030 (Phase 2).

The Douglas Westwood potential roll-out scenario analysis took both a bottom-up and a top-down approach taking into consideration the upper and lower end DOE targets. Using Douglas Westwood’s proprietary database of planned offshore wind projects in the US, we built potential regional scenarios taking into account growth levels and technology. When considering technology, we not only consider current technology and technological improvements like larger blades that result in higher MW per turbine, but also technological innovations and solutions needed to meet coast-specific needs.

Atlantic Coast: Current technology levels are adequate for wind farm development along this coast.

Pacific Coast: This region requires floating turbines and unless floating technology is commercially viable offshore wind farms are unlikely to develop.

Gulf Coast: Since the wind farms are likely to be positioned in hurricane corridors, the turbines will need to be designed to withstand the highest projected hurricane wind and wave loading conditions.

Great Lakes: Many fresh water lakes ice over during the winter, therefore a viable set of solutions is needed to ensure that foundation structures, towers, and turbine operation are not adversely impacted during icing conditions.

7 Rollout Scenarios

Technology assumptions developed by NREL

Metric	Today's Standard Technology	Next Generation Technology	Future Advanced Technology	1st Generation Floating Technology*	2nd Generation Floating Technology
Nameplate Capacity (MW)	3 - 6	5 - 7	7 - 10	2 -5	7 -10
Hub Height (meters)	70 - 90	> 90	> 100	70 -90	> 100
Rotor Diameter (meters)	90 - 130	120 - 170	150 - 225	90 - 110	150 - 225
Water Depth (meters)	10 - 40	10 - 50	10 - 60	> 60	> 60
Monopile Foundations	yes	no	no	n/a	n/a
Jacket Foundations	yes	yes	yes	n/a	n/a
Triple Foundations	yes	yes	yes	n/a	n/a
Gravity Base Foundations	yes	yes	yes	n/a	n/a
Proximity to Staging Area**	< 100 miles	> 100 miles	> 100 miles	< 100 miles	> 100 miles
Proximity to Interconnection**	< 50 miles	> 50 miles	> 50 miles	< 50 miles	> 50 miles
Proximity to Service Port**	< 30 miles	> 30 miles	> 30 miles	< 30 miles	> 30 miles
Project Size (MW)	200 -300	500 - 1,000	> 1,000	5 - 10	> 1,000
Max Nacelle Weight***	215 metric tons (5 MW)	410 metric tons (7 MW)	650 metric tons (10 MW)	215 metric tons (5 MW)	550 metric tons (10 MW)

*Proof of commerical viability (one step from prototype testing)

**Based loosely on staging area distances for planned German installations but recognizing that US installations are likely to be closer to shore

***The nacelle is typically the heaviest component, however heavier lifts may be required depending on the number of tower sections and the installation method (e.g., total turbine lift)

Table 14: Summary of Technology Assumptions
Source: NREL

	Technologies By Scenario	
	High	Low
Today's Standard	×	×
Next Generation	×	×
Future Advanced	×	
1st Generation Floating	×	×
2nd Generation Floating	×	

Table 15: Definition of High and Low Technology (Based on Table 14)
Source: NREL

High Growth Scenario (HH)

In this scenario we assume high growth rates in the offshore wind sector coupled with high technological innovation and adoption. This is an aggressive scenario with 54 GW installed across the US by 2030.

The rate of technology adoption is high in this scenario. Floating technology, hurricane proof turbines and de-icing technology will be commercially viable.

Demand and growth are robust in all four coasts. The Atlantic Coast starts off the strongest in Phase 1, but by Phase 2 all coasts enjoy high installation rates.

Medium Growth Scenario (MH)

In this scenario we assume moderate growth rates, but high technological adoption. This scenario is perhaps closest to the European experience. 28 GW of offshore wind is expected by 2030 in the US.

Technology innovation and adoption rates remain high. The industry will have the benefit of both current and future technology, including floating turbines, hurricane proof turbines and de-icing technology.

Demand and installation rates are reduced compared to the High Growth scenario. During Phase 1, demand in the non-Atlantic coasts will be minimal, only picking up during Phase 2. Atlantic Coast demand is the main driver in this scenario.

7 Rollout Scenarios

Low Growth Scenario (LL)

In this scenario we assume lower growth rates and a more gradual pace of technological adoption. By 2030, 10 GW will be installed, the majority of which will be on the Atlantic Coast.

The rate of technology adoption will be slow in this scenario. Phase 1 will only have the advantage of Today's Standard technology, with the next generation of technology being available in Phase 2. Hence the Great Lakes and Gulf Coast will have no activity during Phase 1 and only demonstration-scale activity during the early part of Phase 2. Only a few large-scale projects will come online towards the end of Phase 2. Since floating technology will not be commercially viable, there will be no activity on the Pacific Coast. Most of the activity will be concentrated on the Atlantic Coast where current technology is sufficient.

Demand in this scenario will be comparatively low, and US offshore wind installations only reach current European rates after 2025.

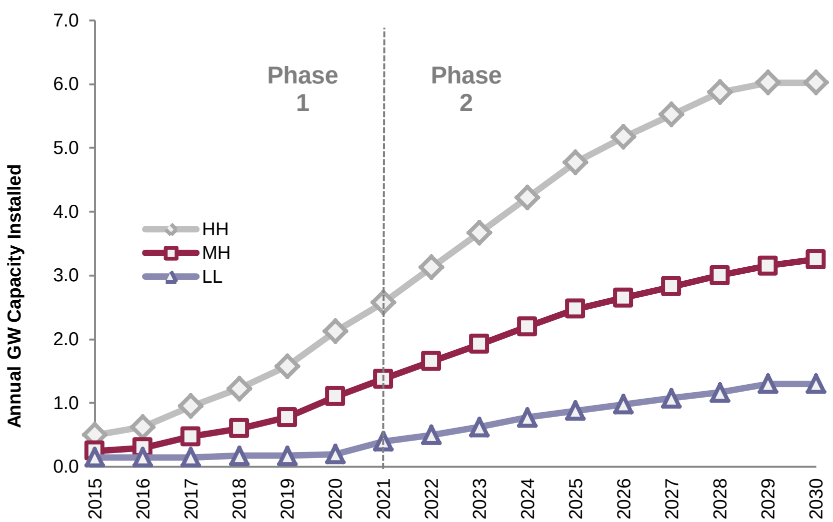


Figure 17: Annual Installation Rate in Each Scenario – US Total

Source: Douglas-Westwood, NREL

7.2 Atlantic Coast

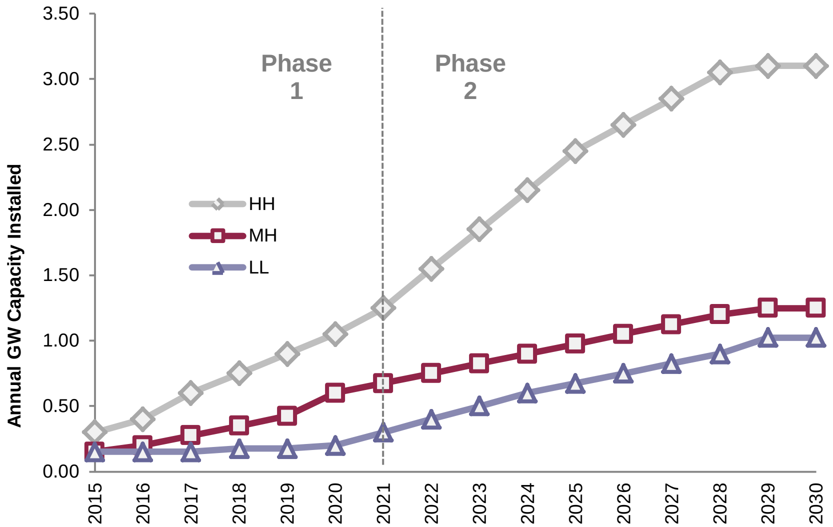


Figure 18: Annual Installation Rate in Each Scenario – Atlantic Coast
Source: Douglas-Westwood, NREL

Key Assumptions

For the Atlantic Coast the scenarios rest on two key assumptions. First, the Atlantic Coast is technologically neutral in a sense that the region is not dependent on technological improvements to achieve rollout targets. Current foundation types and turbine sizes are sufficient to develop the industry and improvements in technology will only increase installation rates. Secondly, electricity demand and the availability of other renewable sources will play an important role in the development of the offshore wind industry on the Atlantic Coast. Hence the primarily driver for the potential installation rates is demand.

Scenario	Start Date	Total GW installed		Max annual GW installed
		Phase 1	Phase 2	
HH	2015	4.0	28.0	3.0
MH	2015	2.0	12.0	1.2
LL	2015	1.0	8.0	1.0

Table 16: Installation Rates in Each Scenario – Atlantic Coast

As per the table above, irrespective of the growth levels and technology, the Atlantic Coast is expected to see offshore wind installation start by 2015.

In the HH scenario, high demand will mean the industry will start off with an aggressive installation rate that will steadily increase during Phase 1. During Phase 2, high demand coupled with increasing turbine sizes is likely to aggressively increase the installation rate, plateauing around 3 GW per year towards the end of Phase 2.

In the MH scenario, demand levels will be more moderate. This will likely mean a lower GW installation in 2015 and a slower increase in the installation rate. In this scenario we anticipate a somewhat linear installation rate plateauing at 1.2 GW per year.

In the LL scenario, both demand and technological adoption is low. Even though the expected GW installed in 2015 is around the same level as in the MH scenario, installation rate during Phase 1 remains flat. By Phase 2, the installation rate picks up with a potentially similar trajectory to the MH scenario, plateauing at 1 GW per year.

7.3 Great Lakes

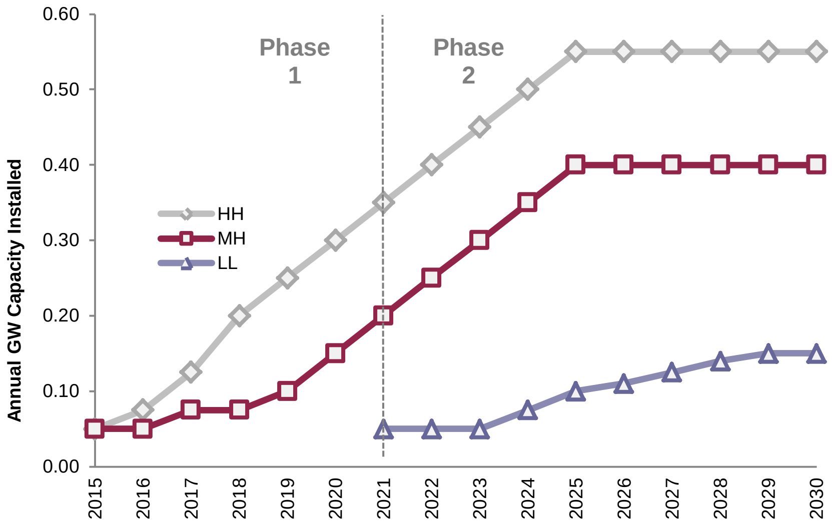


Figure 19: Annual Installation Rate in Each Scenario – Great Lakes Region
Source: Douglas-Westwood, NREL

In the Great Lakes, the possibility of turbines freezing during the winter is a potential issue and commercially viable de-icing or icing mitigation technologies are required for the development of the offshore wind sector in this region. Today there are some solutions for avoiding ice buildup on turbines; these have primarily been implemented in low salinity areas at the North Sea. We expect early installations in the GL region to test and prove icing mitigation technology.

Key Assumptions

The Great Lakes region deployment scenarios are based on the assumption that icing mitigation technology will become commercially viable in the high technology scenarios (HH and MH), but it will not be commercially viable in the low technology scenario (LL).

Since the development of the industry has some reliance on technology, we expect both technology and demand to drive potential roll out scenarios. In both the HH and MH scenarios the roll-out follows a similar trajectory, albeit with a slower start for the MH scenario.

Scenario	Start Date	Total GW installed		Max annual GW installed
		Phase 1	Phase 2	
HH	2015	1.0	6.0	0.5
MH	2015	0.5	4.0	0.4
LL	2021	-	1.0	0.1

Table 17: Installation Rates in Each Scenario – Great Lakes

As per the table above, the two high technology scenarios have projected start dates of 2015. In the low technology scenario installation is project to begin in Phase 2.

In the HH scenario, per year GW installation starts at a modest level, but high demand and high technological adoption results in an increasing installation rate plateauing at 0.5 GW by the middle of Phase 2.

In the MH scenario, installation levels are likely to be similar to the HH scenario, except the yearly increase of installations is expected to remain flat for the early part of Phase 1. By the end of Phase 1, improved technology is likely to influence installation, resulting in higher installation rates, which will plateau at around 0.4 GW by the middle of the next decade.

In the LL scenario, installation activity is not expected to begin until Phase 2. This is primarily due to technological constraints. We expect that slower technological innovation and adoption in the offshore wind sector will push the start date to the early 2020’s. We expect that most of the activity will be demonstration scale through the middle of the next decade.

7 Rollout Scenarios

7.4 Gulf Coast

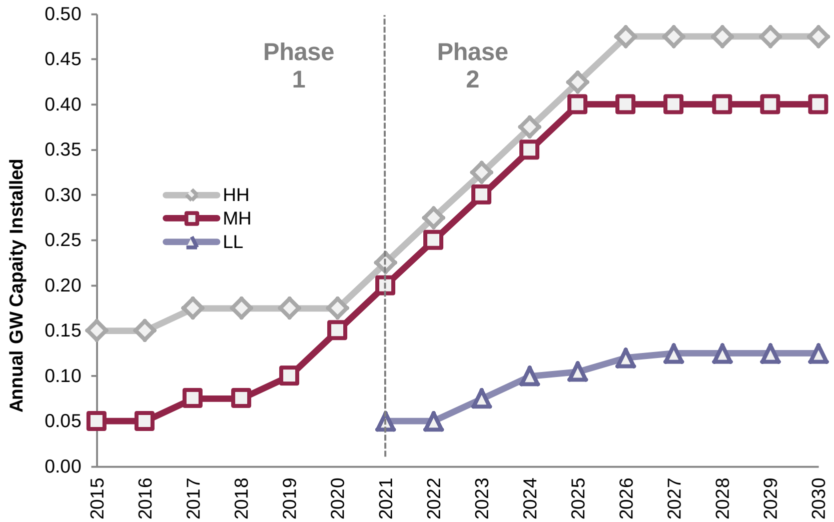


Figure 20: Annual Installation Rate in Each Scenario – Gulf Coast
Source: Douglas-Westwood, NREL

In the Gulf Coast, a commercially viable hurricane resistant turbine technology will be necessary for the offshore wind industry to develop. It is not clear that existing technology would be sufficiently robust to withstand Gulf hurricanes and, as importantly, be insurable against such events.

Key Assumptions

The Gulf Coast projections rely on the assumption that hurricane resistant turbine technology will be commercially viable in high technology scenarios (HH and MH), but such technology will not be available in the low technology scenario (LL).

Since the development of the industry has some reliance on technology, we expect both technology and demand to drive potential rollout scenarios. Potential rollouts follow a similar trajectory in both the HH and the MH scenarios through the middle of Phase 2.

Scenario	Start Date	Total GW installed		Max annual GW installed
		Phase 1	Phase 2	
HH	2015	1.0	5.0	0.5
MH	2015	0.5	4.0	0.4
LL	2021	-	1.0	0.1

Table 18: Installation Rates in Each Scenario – Gulf Coast

As per the table above, the two high technology scenarios have projected start dates of 2015. In the low technology scenario, installation is projected to begin in Phase 2.

In the HH scenario, per year GW installation level starts with the installation of a medium-sized project and the annual installation rate continues at a similar level through Phase 1. By Phase 2, high demand and high technological adoption fuels the industry to a faster installation pace that plateaus at around 0.5 GW per year.

In the MH scenario, moderate demand potentially causes sluggishness during Phase 1. The industry picks up momentum by the end of Phase 1. In early Phase 2 we expect potentially higher installation rates, plateauing at around 0.4 GW per year.

In the LL scenario, the lack of commercially viable hurricane proof technology delays potential projects to Phase 2. We expect most of the activity during the first years of Phase 2 to be test projects. Installation rates and growth remains low during the entire projection period.

7.5 Pacific Coast

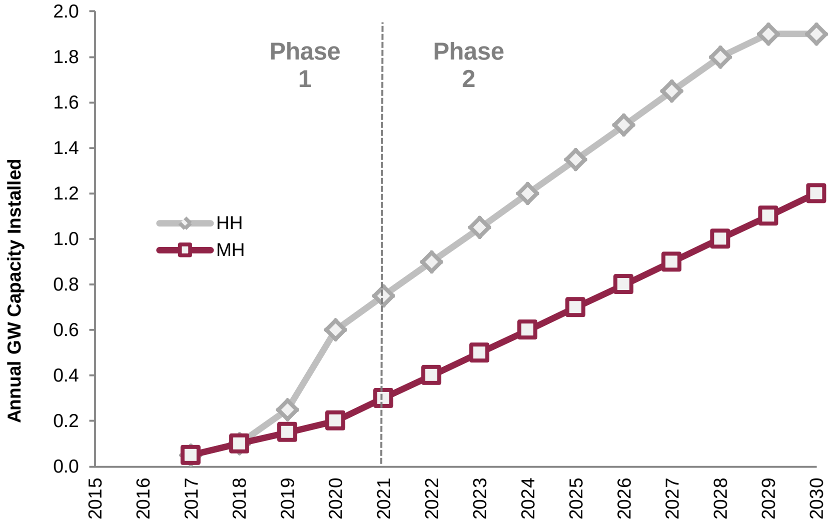


Figure 21: Annual Installation Rate in Each Scenario – Pacific Coast
Source: Douglas-Westwood, NREL

The Pacific Coast is the most reliant on technology. In the Great Lakes region and Gulf Coast, technological innovations are needed to correct for specific weather issues, but wind farms can be installed, if one accepts the risk or downtime associated with these weather patterns. In the Pacific Coast, due to the sharp drop in the seabed very close to the shore line, current foundation types, such as monopiles or tripods, cannot be installed. In the Pacific Coast commercially viable floating foundations are necessity for the offshore wind industry to develop. Today this technology is still in the test phase and there have been no large scale floating offshore wind farms to date.

Key Assumptions

The Pacific Coast scenarios assume that commercially viable floating technology will be available in the high technology scenarios (HH and MH), but it will not be commercially viable in the low technology scenario (LL).

The Pacific Coast will likely follow an all-or-nothing path, where the industry can develop rapidly, once a commercially viable floating technology becomes available. If the floating technology does not develop, there may be no activity at all. Therefore, assuming commercially viable technology as a given, the potential rollout scenarios will depend primarily on demand levels.

Scenario	Start Date	Total GW installed		Max annual GW installed
		Phase 1	Phase 2	
HH	2017	1.0	15.0	1.9
MH	2017	0.5	8.0	1.2
LL	-	-	-	-

Table 19: Installation Rates in Each Scenario – Pacific Coast

The Pacific Coast only has installation activity in the two high technology scenarios. Both scenarios have expected start dates of 2017 and similar installation levels during the first years of offshore wind development.

In the HH scenario, installation levels and the installation rate in the first few years are likely to be low. This is due to the fact that the first few projects featuring floating foundations will likely be test projects. After this initial stage of development, we expect high demand to increase installation rates aggressively, plateauing at around 2 GW per year.

The MH scenario is expected to see a similar rollout in the first few years as the HH scenario, but moderate demand will result in a less aggressive installation rate for the rest of Phase 1 and during the entire Phase 2. By the end of Phase 2, we expect to see installation rates of 1.2 GW per year.

Certain floating turbine designs are expected to be easier to install than turbines with fixed substructures. Unlike fixed foundation turbines, which have to be installed and assembled on site, some floating turbine types, such as Principle Power's *WindFloat* prototype design, can be completed on shore and floated to the installation site. This negates the need for specialized construction vessels needed for fixed foundation wind farms and opens the possibility of a more rapid ramping up of installation than on the Atlantic Coast, for example. It is important to note, however, that this simpler installation of pre-assembled floating turbines relying entirely on tugboats may not be feasible in many cases.

7 Rollout Scenarios

Neither TLP (tension-leg platform), nor spar-type floating substructures can be easily integrated with the turbine at quayside. The main problem with spar structures is the very deep, often more than 60 meter (200 ft) draft of these structures in an upended position, which exceeds the quayside depth of most port facilities in the US. In this case, a special installation method pioneered by the Norwegian *WindFlip* towing and “tip-up” vessel design can provide solutions for pre-assembled floating turbine installation in the future (see Chapter 2.2). The main problem with the portside assembly of TLP floating turbine designs is that these structures are inherently unstable until they are connected to mooring lines. This can be resolved by using specialized towing and installation vessels in the future, such as the *PelaStar* support barge developed by Glosten Associates (see Chapter 9.6).

As of today, only semisubmersible floating turbine designs, such as Principle Power’s *WindFloat*, have proven suitable for full-scale quayside turbine assembly; even though overhead clearance limitations at staging ports can pose challenges in case of these floating turbine types as well.

Chapter 8
Vessel Strategies

8 Vessel Strategies

8.1 Installation Strategies

Based on our conversations with European and US-based installation companies, there appear to be three distinct installation scenarios available to developers when planning fixed platform offshore wind projects in the US. The key limiting factors dictating these strategies are the Jones Act and the limited availability of US-flagged installation vessels in the initial phases of development.

Strategy 1 – US Jackup with Feeder Barge Support

In our first installation scenario, the predominant method for offshore wind turbine installation is the use of US-built jackup vessels for the installation, with turbine components delivered to site by at least one feeder barge. To the extent these vessels are non-self-propelled, tug boats will also be required. In our modeling exercise, we assume that one full-time tug services each non-self-propelled jackup vessel and another services the feeder barge. In this strategy, the installation vessel remains on the installation site, while the feeder barges shuttle between the port and the installation site. The main disadvantage of this approach is the need to use a feeder barge, and a pair of tugs, one each for the jackup vessel and the feeder barge. On the other hand, this strategy still appears to be more cost efficient than mobilizing an advanced European TIV across the Atlantic, as low spec jackup vessels are readily available in the US and their dayrates are comparably lower than that of a European vessel.

Strategy 2 – US TIV with no Feeder Barge Support

Strategy 2 envisions using US-built TIVs. In this approach, a US-built TIV would shuttle between the staging port and the installation site, carrying turbines and other components on board. This strategy would eliminate the need for feeder barges and tugs, but at a higher vessel day rate for the TIV and a time penalty for shuttling between the port and the installation site. At the same time, a modern TIV would have a greater operating window than a barge-and-jackup approach. An advanced TIV (based on the European experience) can operate in significant wave heights of up to 2 meters (7 ft), whereas the operating window of a feeder barge is limited at 1.0-1.5 meter (3-5 ft) wave heights. The key limiting factor, according to operators, is the ability to transfer equipment at sea from a feeder barge. A port-loaded TIV with accommodation facilities can operate independently of support vessels, potentially until its entire load of turbines has been installed.

It should be noted that no advanced TIVs exist in the United States today. The cost of such a vessel might approach $300 million or more and take years to commission and build. Until the offshore wind industry gains traction, such an investment is not highly likely.

At the same time, the RD MacDonald, Weeks Marine's installation jackup, can be used in TIV mode. The vessel can shuttle between the staging port and the installation site loaded with two turbines, but it has to be towed by a tug. In fact, we have modeled our vessel needs in the early years based on this assumption.

Strategy 3 – European TIV with Feeder Barge Support

In the third strategy, we assume that a portion of projects in the Atlantic Coast will be constructed by foreign-flagged TIVs mobilized from Europe to the US Northeast. This may prove not only a theoretical possibility, but also a practical necessity. While the Cape Wind project can be installed using the RD MacDonald, the jackup vessel will probably lack the leg length and crane reach to install the 6 MW turbines for the demonstration project at Block Island, for example. It is not clear that another US vessel exists which could affect such an installation. As a consequence, resorting to a European TIV may prove unavoidable.

Such a TIV would be used in a manner similar to a jackup in Strategy 1. The Jones Act prohibits cabotage, which in this case prevents a foreign-flagged TIV from on-boarding turbines in a US port and subsequently installing these in US waters. The Jones Act does, following practice in the offshore oil and gas industry, allow a foreign-flagged TIV to offload turbines from a US-flagged feeder barge and install these in US waters to the extent that the TIV itself does not travel with the turbines or with other components on board. Therefore, Strategy 3 would see the combination of a relatively low-end European TIV, a US feeder barge and a US tug.

This is a potentially expensive solution. Mobilization from Europe requires at least three weeks each way (we model with a month each way net) at customary dayrates—which at present are elevated due to a relative shortage of rigs in Europe. Further, a Euro TIV is likely to be staffed with at least a few European crew members and have associated administrative overhead. As a result, this is likely to prove a high cost strategy, but during the early years in the industry's development, it may prove inescapable.

8.2 Case Study: Cape Wind Turbine Installation Strategies

We can apply these strategies to Cape Wind or other pending Atlantic Coast projects to illustrate logistics and costs. We emphasize that our analysis is only illustrative. The case study was prepared by Douglas-Westwood using publicly available information sources and general industry data. Cape Wind and other developers may elect strategies which differ, possibly materially, from those presented below.

Please also note that any installation efficiency rates and associated cost estimates in the following case studies refer only to turbine installation. The installation of the foundations and substations would require additional vessel days and incur additional costs. Our interviews with major installation companies suggest that the installation of monopile foundations (the type that is planned for our illustrative Cape Wind project as well) would require a similar installation time and incur similar costs, as turbine installation. Transition pieces take about 40% less time to install compared to both foundations and turbines.

Strategy 1 – RD MacDonald with Feeder Barge Support

As the RD MacDonald is the only available purpose-built offshore wind turbine installation vessel in the United States, we assume that Strategy 1 would depend largely on this vessel. In this strategy, the RD MacDonald jackup is engaged in turbine installation only, while one feeder barge is used to ferry the turbine components for turbine installation. As a consequence, two tugs will be needed in this strategy. One of these would support the RD MacDonald, towing it to the installation site and positioning it within the site. Another tug would support the feeder barge in similar fashion. The feeder barge is anticipated to have jackup capabilities, as the offloading of turbine components will likely require a high degree of stability.

Thus, the process begins when the feeder barge on-loads up to 4 turbines and travels approximately 50 miles from a port, perhaps New Bedford, Massachusetts to the Cape Wind site at Horseshoe Shoals in Nantucket Sound. Transit requires 10 hours. The RD MacDonald hoists the first turbine from the barge and installs it directly on a prepared monopile. Each turbine installation is expected to take 36 hours at the installation site. This process is repeated until only one turbine is left on the feeder barge. This last turbine will be transferred to the deck of the RD MacDonald, and the feeder barge will return to port for a new load. Return transit time to the staging port is 10 hours, followed by 16 hours of loading in the port (4 hours per turbine), and a 10-hour return trip.

During these intervening 36 hours, the RD MacDonald will have installed the turbine left on its deck, and will be ready to install additional turbines by the time the restocked feeder barge returns from the staging port. This process will repeat until all turbines were installed.

Assuming the feeder barge could carry four turbines at each turn, the installation of the 130 Cape Wind turbines alone would take about 4,760 hours. Taking into consideration that sea-to-sea transfer of turbine components from the feeder barge to the deck of the RD MacDonald requires significant wave heights to be no higher than 1.5 meters (this is only the case on 292 days in an average year, or 80.1% of the time in the Northeast United States), the net installation time will be close to 5,960 hours, or 248 days, after adjusting for weather-related factors as well as for the repositioning time for the RD MacDonald. See the case study at the end of this chapter on 'Vessel Utilization in the North Atlantic Coast' for further details.

This estimate assumes perfect execution in every other respect. If we calculate with the more conservative 65% weather uptime during turbine installation (which is more in line with North Sea experience, and also with the actual weather uptime that Weeks Marine experienced during the geotechnical surveys it carried out for the Atlantic City project), then total net installation time for the 130 turbines would increase to about 7,330 hours, or about 305 days. This represents nearly 13 turbines per month, which is at the high end of the 10-14 monthly net installation rate reported as typical by European installers. Given the lack of experience in the industry, an installation rate of around 11 turbines per month is probably more realistic. Installing the 130 Cape Wind turbines could be a year-long project.

Strategy 2 – RD MacDonald as TIV, no Feeder Barge Support

Strategy 2 requires the construction of a US-built TIV. This would require years as well as large up-front investments. As a consequence, this option is neither practical, nor economically compelling at the moment.

However, one could use the RD MacDonald as a TIV in the sense that it carries out both the transport of the turbine components to the site from the staging area as well as the installation of these components without feeder barge support. Since the RD MacDonald is a non-self-propelled vessel, at least one full-time tug would be required to support its operations in this scenario. As in Strategy 1, the staging port is assumed to be approximately 50 miles from the wind farm site. The towing time between the site and the staging area would be 10 hours (each way), with loading again budgeted at 4 hours per turbine. The installation time is estimated at 36 hours for each of the two turbines the vessel would carry.

8 Vessel Strategies

The gross installation time of the 130 turbines planned for Cape Wind would be 6,500 hours, or 271 days. Considering fact that the maximum significant wave height the RD MacDonald can tolerate is 1.5 meters, and that the average wave height remains below 1.5 meters on 292 days (or 80.1%) of an average year in the US East Coast, we estimate that the 130 turbines for the Cape Wind project can, in theory, be installed in 339 days net (i.e. after accounting for weather-related factors) under this installation Scenario. If we use the more conservative 65% weather uptime coefficient, then the total net installation time would be 10,000 hours, or 417 days.

This installation strategy can be a more cost efficient alternative to the feeder barge-supported operating method in Strategy 1 as long as the increase in the total installation time (due to the lack of feeder barge support) in Strategy 2 vs. Strategy 1 remains lower than the dayrate premium in Strategy 1 vs. Strategy 2, which is due to the requirement for an additional feeder barge and a supporting tug in Strategy 1.

Strategy 3 – Low-end European TIV with Feeder Barge Support

In this strategy, the installation of the Cape Wind project's 130 turbines would be carried out by a European TIV mobilized across the Atlantic Ocean for the period of the installation. The vessel would likely be a lower-end TIV with a relatively small deck space. Large deck space would be unnecessary, as the Jones Act would prevent the vessel from loading turbine components in US ports. Furthermore, the Cape Wind project is not particularly challenging, thus the lower dayrates of a simpler TIV would likely be preferred over the somewhat higher installation efficiency of a more sophisticated installation vessel.

In this strategy, the turbine components would be transported to the site by a feeder barge, as in Strategy 1. As before, we assume that the feeder barge could carry four turbine sets on its deck. The installation of the 130 Cape Wind turbines would take the least time in this Scenario, namely 170 to 210 days in total, depending on the weather uptime coefficient (80% vs. 65%).

However, the European TIV would additionally have to travel across the Atlantic, which would add about 30 days each way to the project's overall vessel day requirement. Note that dayrates would have to be paid in full during the trans-Atlantic crossing as well.

As a result of the sharp difference in dayrates and total installation vessel costs, it appears less likely that a European TIV would be preferred over the RD MacDonald as the primary installation vessel in the Cape Wind project. However, for a project like Block Island, which anticipates using 6 MW turbines and jacket foundations in deeper waters, a European TIV might prove the only viable alternative.

8.3 Vessel Economics

Indicative Vessel Economics for Turbine Installation									
Sample Project - Cape Wind	**Unit**	**RD MacDonald as Jackup**		**RD MacDonald as TIV**		**US Purpose-Built TIV**		**Euro TIV**	
Sample Project - Installed Capacity	*MW*	468		468		468		468	
Sample Project - Turbine Size	*MW*	3.6		3.6		3.6		3.6	
Sample Project - No. of Turbines	*units*	130		130		130		130	
Mobilization / Demobilization Time	*days*	-		-		-		2 x 30	
Turbine Installation Time	*hours/turbine*	36		36		24		24	
Staging Port - Installation Site Distance	*nautical miles*	50		50		50		50	
Staging Port - Installation Site Shuttle Time	*hours*	10 (feeder barge)		10 (TIV)		6 (TIV)		10 (feeder barge)	
No. of Turbines Transported by Vessel	*turbines/trip*	4 (feeder barge)		2 (TIV)		4 (TIV)		4 (feeder barge)	
Loading Time in Staging Port	*hours/loading*	16 (feeder barge)		8 (TIV)		16 (TIV)		16 (feeder barge)	
Feeder Barge Support	*yes/no*	One Required		Not Required		Not Required		One Required	
Tug Support	*yes/no*	Two Required		One Required		Not Required		One Required	
Installation Vessel Dayrate	*$/day*	130,000*		130,000*		212,000		169,000	
Barge+Tug-related Dayrate	*$/day*	65,000		0		0		65,000	
Other Administrative Vessel Costs	*$/day*	0		0		0		6,760	
Total Day Rates	*$/day*	195,000		130,000		212,000		240,760	
Weather Uptime	*%*	65%	80%	65%	80%	65%	80%	65%	80%
Installation Period	*days*	305	248	417	339	258	210	210	170
Installation Cost	*$ mn*	60	48	54	44	55	44	50	41
Demobilization Cost	*$ mn*	-	-	-	-	-	-	14	14
Total Vessel-Related Cost	***$ mn***	**60**	**48**	**54**	**44**	**55**	**44**	**65**	**55**

** The RD MacDonald's $130,000 dayrate includes the cost of one tug and an accompanying crewboat as well*

Table 20: Indicative Vessel Economics for Turbine Installation
Source: Douglas-Westwood calculations

We analyze vessel economics under various installation strategies using the Cape Wind project as an illustrative example. The project consists of 130 x 3.6 MW turbine units. The distance between the wind farm site and the staging port (assumed to be New Bedford) is 50 nautical miles.

Our case study indicates that the most cost-efficient solution would be to use an installation vessel in TIV mode without feeder barge support. In our example, the cost of using the RD MacDonald in this way is nearly identical to the cost of using a purpose-built US TIV, as the higher cost of the purpose-built vessel is balanced out by its shorter installation time.

Using the RD MacDonald in jackup mode with feeder barge support allows a faster and more efficient installation than using the vessel in TIV mode, but the total cost of this method is higher due to the high costs associated with the feeder barge support.

Mobilizing a European TIV appears to be the most expensive installation strategy, due to the high cost of the transatlantic crossing, the need to use feeder barge support and other inefficiencies resulting from compliance with the Jones Act

8 Vessel Strategies

The cost advantage of the TIV-based installation strategies vs. the feeder barge-supported operating methods in our illustrative example is mainly due to the high dayrate of a feeder barge ($50,000) and the accompanying tug ($15,000). The high estimated cost of a feeder barge system reflects current market circumstances, and the immature state of the US offshore wind industry. A newbuild feeder barge, which has jackup capabilities and can carry 4 full turbine sets on its deck, is estimated to cost about $25 million, according to industry sources. Prospective US installation companies indicated, that a vessel owner would most likely require at least $50,000 in dayrates for a new $25 million vessel in the early stages of the industry's development, knowing that the vessel may be used only once in the first 5 years of its operation.

It is important to note that the scenarios involving the RD MacDonald are somewhat specific to the illustrative project chosen. Even though the participation of the RD MacDonald is feasible in the case of the Cape Wind project, it may not be feasible in other projects, especially those involving larger turbine sizes. The assessment of the economics of each scenario does not take into account the benefits of earlier project completion, such as the present value of earlier revenue flows.

RD MacDonald as Jackup

We understand the RD MacDonald's dayrates would be anticipated in the range of $120,000-140,000 per day. For the purposes of the illustrative calculations in the table above, we use a dayrate of $130,000 per day. This figure also includes the dayrates of an accompanying tug and a crew boat. However, the dayrate of the feeder barge and its tug, which we estimate at $50,000 and $15,000, respectively, would be additional to the above dayrate number. The feeder barge in our calculations would have jackup capabilities, would be able to carry 4 full turbine sets on its deck and cost about $25 million to build. Thus our final dayrate for the entire fleet participating in turbine installation in this scenario would be $195,000. This results in total vessel-related costs of between $48 million and $60 million, depending on the assumptions used for the weather window.

RD MacDonald as TIV

If the RD MacDonald installs the 130 planned turbines for the Cape Wind project as a self-supplied TIV, then its dayrate remains $130,000. No additional feeder barge is necessary in this scenario. However, the installation of the 130 turbines will take considerably longer, resulting in total vessel-related costs of between $44 million and $54 million, depending on the weather uptime value chosen (65 vs. 80%).

US Purpose-Built TIV

The construction cost of a purpose-built TIV for the Atlantic Coast market (similar in sophistication to the MPI Resolution in Europe), would be about 60-200% more expensive in the US than in an Asian shipyard, according to our interviews. For this analysis, we assume that an MPI Resolution class TIV can be built at a 100% cost markup in the US, resulting in a newbuild construction cost around $300 million. This would require dayrates of around $212,000 to service vessel financing, crew costs and a normal profit margin. We should note that there is considerable uncertainty about the ultimate cost of a US-built TIV; there is no track record in the US to provide guidance.

We assume that this vessel would ferry faster (6 hours one-way to the installation site) and install turbines faster (in 24 hours) than the RD MacDonald, and would be capable of carrying 4 complete turbine sets on board. Loading time in the staging port is assumed to take 4 hours per turbine, as in all other installation strategies. The installation period in this case would be shorter than in the previous two cases, namely 258 and 210 days, depending on whether the 65% or the 80% weather window is used. This would result in a total vessel-related cost of between $44 million and $55 million, only marginally higher than using the RD MacDonald in TIV mode.

European TIV

A low-end European TIV's dayrate would be similar to that of the RD MacDonald, but in euro terms, (€120,000-140,000), or $156,000-182,000, we used the midline number of $169,000 in our calculations. In addition, administrative costs associated with the Jones Act, redundant headcount and personnel deployment costs are anticipated to increase dayrates by another 3-4%. This is supplemented by the $65,000 dayrate for a feeder barge with jackup capabilities and the accompanying tug. These additional vessels are required in this strategy due to the Jones Act. Furthermore, the 2x30 days required for mobilization and demobilization of the European TIV will increase the total cost of the installation vessel by an additional 30-35% in case of the Cape Wind project.

The combination of a more expensive installation vessel and a long mobilization/demobilization period implies a $55 million to $65 million total vessel related cost range in the final scenario. Interestingly, even a considerably more expensive US-built TIV appears to be more economical to operate, as the 100% higher construction cost and the 25% higher dayrate would still be outweighed by the large cost disadvantage resulting from the long Trans-Atlantic crossing and the additional cost of the required feeder vessels in the case of the European TIV.

Case Study: Vessel Utilization in the Northeast US

Sea state is a key determinant of vessel economics, with significant wave height being the most important consideration, as wind and waves are generally closely correlated. TIV vessel operators in Europe report average, year-round uptime of approximately 65% in western Europe based on sea state, with conditions more benign to the east, and more harsh to the open sea in the west, for example, off the coast of Ireland. This uptime is based on average fleet conditions, but mostly those achieved by purpose-built TIVs.

Conditions in the Northeast United States, off the coasts of New York and New Jersey, appear more benign. The graph below shows the combined seasonal averages for National Data Buoy Center buoys stationed approximately 20-30 nautical miles into the Atlantic from Montauk and Islip, Long Island, New York; and Cape May, New Jersey. These buoys are located at the distance from shore and in the general location of a number of wind farms currently proposed or planned.

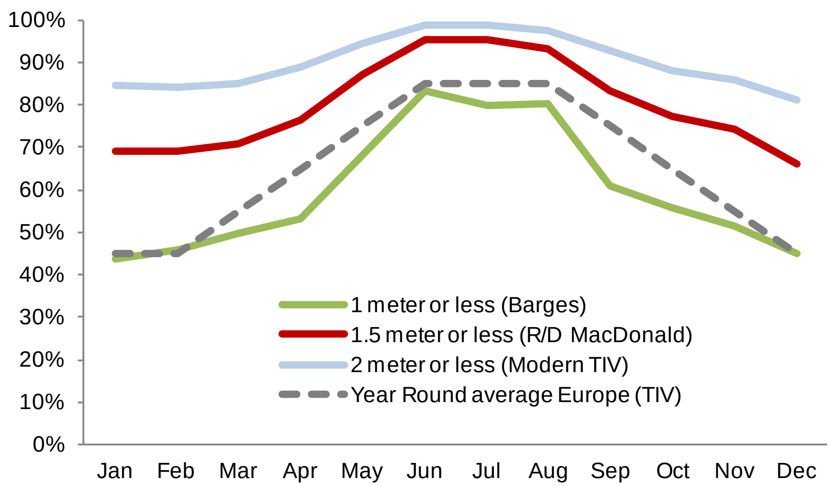


Figure 22: Percent of Days for Sea State Thresholds in Northeastern US

Source: National Data Buoy Center; Europe per Vessel Operators

Installation conditions appear favorable in the Northeast United States. Significant wave heights remain below 1 meter (3 ft) at least 80% of the time during the summer months, falling to 45% in the depths of winter, and averaging 60% for the year overall. Non-stabilized barges can operate under such conditions. Thus, conditions are such in the US that simple barges would enjoy a sea state determined utilization rate almost as high as the purpose-built TIV fleet in Europe, based on significant wave height alone.

The RD MacDonald, Weeks Marine's turbine installation vessel can jack-up in up to 1.5 meter (5 ft) waves. This provides a broad operating window in the Northeast, where the RD MacDonald is stationed. Sea states would be favorable more than 90% of the time during the summer, falling to about 65% in the depths of winter, and 80% for the year as a whole. Thus, the vessel would enjoy nearly 25% more operating days than a comparable TIV in Europe.

Finally, a large, state-of-the-art TIV can operate in sea states of up to 2 meters (7 ft). In the Northeast, such sea states are achieved 90% of the time, and nearly 100% during the summer months. Such a large vessel would improve utilization compared to the RD MacDonald, but in the Northeast, only by 12% or so. Certainly, more is better, but a vessel capable of jacking up in 1.5 meter (5 ft) waves would appear entirely suitable for operations from Rhode Island to Delaware, at a minimum.

It should be noted, however, that European and US operating windows are not entirely comparable. European numbers are based on actual operating experience, and thus are "net". Adjustments may include, for example, the choice to delay departure from port on a day with favorable sea states because high waves are expected on subsequent days. Simple buoy data does not accommodate such operating considerations. Indeed, Weeks Marine reports that uptime for the Atlantic City core sampling engagement—a project within a few miles of shore—achieved only 65% uptime in October, and this uptime ratio is expected to prevail more broadly for East Coast projects. Thus, wave data may not tell the whole story, and net uptime off the East Coast may ultimately prove no greater than in Western Europe. Our models are prepared under this more conservative assumption.

Chapter 9

Vessel Requirements & Gap Analysis

9 Vessel Requirements

9.1 Gap Analysis by Vessel Type

Gap analysis is ultimately driven by two factors. Rollout scenarios, as discussed in Chapter 7, determine the number, type, location and other characteristics of turbines and foundations to be installed. Vessel requirements are also determined by the installation strategies chosen. In the previous chapter, we have discussed using a jackup and barge approach, the use of US-built TIVs, and contracting of foreign-flagged TIVs to be secured from the European market. Each of these strategies results in different vessel requirements and differing opportunities for US vessel operators and the vessel supply chain.

Together, rollout scenarios and vessel strategies determine vessel needs. These are examined by vessel type below.

Survey Vessels

Survey vessels are assumed to be widely available across the US, as these vessels are used for a wide range of activities, including for scientific and naval research as well as for seismic studies for the offshore oil and gas industry.

Bathymetric analysis, the assessment of water depth and conditions, as well as seabed assessment to approximately 1 meter (3 ft) depth, can be completed by various vessel types equipped with sensors or by autonomous underwater vehicles (AUVs). Such sensors and AUVs are comparatively affordable and readily available on the market.

Geophysical surveys, that is, seismic surveys of the seabed to 100 meters (330 ft) depth or so can be conducted by the US geophysical vessel fleet. To the extent such a survey is necessary, the US fleet, primarily used in oil and gas applications, is more than capable of meeting offshore wind needs.

Finally, geotechnical surveys involving core samples can also be accomplished using nothing more than a fixed platform with drilling equipment welded to the deck. For example, the geotechnical borings and the cone penetration tests (CPTs) for the Atlantic City demonstration project were conducted by the Weeks 750 jackup rig with a drill attached to the deck. Core sampling is routinely conducted in coastal waters for projects like bridge or dock construction, and the existing fleet could theoretically be augmented by the jackup drilling fleet in the Gulf of Mexico, much of which is stacked and idle.

Consequently, we assume no gap of survey vessels. Rather, their availability will be primarily a function of scheduling and price, neither of which should pose a material obstacle to the offshore wind industry.

Installation Vessels

The critical shortage in US vessel capabilities is in the installation vessel category, particularly in turbine installation vessels (jackups and TIVs). Today, the US has only one dedicated turbine installation vessel, the RD MacDonald, which had not yet been fully kitted for offshore wind installation as of mid-2013. This vessel was specifically designed to be able to enter the Great Lakes region across the St. Lawrence Seaway. The resulting size restrictions dictate that it suffers certain limitations compared to a modern TIV. For example, the vessel may be restricted to operating in water depths less than 100 ft and, while it can install 3.6 MW turbines, it is not clear whether it can also install next generation 6 MW turbines as well.

We understand that foundation installation can be carried out by a wider variety of vessel types than only jackups and TIVs, even though we assume that foundations, transition pieces and turbines will be installed by the same vessel, a jackup or a TIV, in our vessel demand model. Foundations can be installed by using more generalized construction vessels, such as Donjon Marine's Chesapeake 1000 or Caldive's Pacific floating derrick. These and other existing US construction vessels have been proposed for the foundation installation work at the Cape Wind project.

Heavy Lift Vessels

We assume that heavy lift vessels are readily available in the Gulf Coast, currently servicing the offshore oil & gas industry. These vessels can in, all likelihood, be deployed to offshore wind installation projects as well, primarily for the installation of substations. We anticipate that all heavy lift vessels used in the Atlantic Coast and Gulf Coast regions will be chartered from the US Gulf of Mexico. The deployment of Gulf Coast heavy lift vessels to the Great Lakes region is problematic, given the size limitations along the St. Lawrence Seaway, which our catalogued heavy lift vessels exceed. However, smaller, mostly foreign-flagged heavy lift vessels with a crane rating of 300-700 tons regularly call in Great Lakes ports, and are suitable in size to navigate the St. Lawrence Seaway. As a consequence, the Great Lakes region will either have to use smaller substations, which can be lifted with "Seawaymax" sized heavy lift vessels, or build a large heavy lift vessel that will most likely be "locked in" to the Great Lakes system. Transferring heavy lift vessels to the Pacific Coast across the Panama Canal is also problematic, given the long distance and the long ferrying time. However, our understanding is that the Pacific Coast region has enough indigenous heavy lift capacity to support its emerging offshore wind industry.

9 Vessel Requirements

Cable-Lay Vessels

There are no US-flagged cable lay vessels in operation today. Foreign-flagged cable-lay vessels are generally considered exempt from Jones Act requirements, as federal regulators determined that the laying out of underwater cables or pipes does not constitute unloading of merchandise. Therefore, the Jones Act does not apply. Moreover, recent interpretations of the Dredging Act of 1906 suggest that the burial of underwater cables (typically carried out by the same cable-lay vessel) is not considered to be dredging activity that would implicate the Dredging Act, and thus it does not require coastwise-qualified vessels either. When the rock dumping method is chosen for cable burial, then rock transporting and dumping vessels are likely subject to Jones Act restrictions, and thus have to be coastwise-qualified.

However, both Congress and the CBP have introduced legal initiatives in recent years, which intended to modify these exceptions, and extend Jones Act-like restrictions to cable-laying activities and other areas. These efforts have been unsuccessful thus far, but similar attempts may constrain the activities of foreign-flagged cable-lay vessels in US waters in the future. In this case, foreign-flagged vessels can still install foreign-manufactured cable. In fact, three of the five leading export cable manufacturers (Prysmian, ABB, NKT) are European, while two of them are US-based (JDR, Nexans). If the Jones Act is to be enforced for cable laying operations in the future, then the cable will be manufactured in Europe and deployed using European vessels. If cable laying remains exempt from the Jones Act, then European cable-lay vessels will more likely install US-manufactured cable. Whichever solution is chosen by US policy-makers, we assume that cable-lay vessels are readily available in the global marketplace.

Fixed Leg Feeder Barges

To the extent the turbine installation vessel remains in the field, it must be supported by feeder barges which ferry turbine components from the staging port to the installation site. Turbine manufacturers require that these vessels be stabilized prior to the removal of turbine components. This may be accomplished by either using fixed leg vessels, for example, a jackup barge; or through heave compensation, for example, using a modern platform supply vessel.

Of these two, the feeder barge appears the more economical solution, with construction costs of $20-25 million per barge estimated by industry participants. These barges would, by definition, be US-built, as they would be involved in cabotage, that is, the transport of goods within US waters.

There are currently no fully-kitted jackup barges in the United States. Thus, one would likely be required prior to the inception of construction work, even for the Cape Wind project. However, such barges are not technically complex, a simple jackup platform can be modified at a relatively modest cost of about $5 to $10 million. Such vessels must have jackup legs, but otherwise would have minimal deck or other equipment. They would be towed to site by tugs.

We anticipate that such barges will be constructed or existing barges upgraded in timely fashion to support US wind projects.

Ordinary Barges (No Jackup Capability)

Foundations can be delivered to site using a number of techniques. Monopiles can be capped, floated and towed to site by tugs. Alternatively, foundations can be loaded on simple barges, with the barge similarly towed to site. Barges are readily available in the US, and the addition of cradles to support the turbine foundations—an investment of perhaps $5 million—would be sufficient to make them suitable for foundation transport. Importantly, foundations are much less delicate than turbine components, and thus fixed barges are not required for transfer of monopiles to either the installation vessel or directly to the turbine installation site.

For larger jacket foundations, alternative solutions may be required. In such a case, a sheer leg derrick barge like the Chesapeake 1000 may prove suitable. The vessel has large deck space and a 1,000 ton crane, sufficient for foundation installation. At the same time, the vessel is not stabilized and is thus limited to working in wave heights of 1 meter (3 ft) or less.

Tugs

Tugs feature prominently in a number of installation strategies. For example, a project employing an installation jackup, a foundation installation vessel, and two barges would require four tugs. Further, floating turbines are assumed to be installed using anchor handler tugs, with three tugs per turbine (per the Principle Power experience in Portugal). We assume tugs are readily available in the United States and that they are used in other applications when not employed in offshore wind work. As a result, there will be no exclusive offshore wind tug fleet in the US.

9 Vessel Requirements

Personnel Transfer Vessels

Personnel transfer vessels (PTVs) are required for both installation and maintenance. For installation, PTVs would supply crew changes and supplies to the installation vessels. Any number of vessels could act as PTVs, including some of the current fishing fleet and even certain pleasure craft. Of course, these would not be optimal solutions in many cases. More likely, specialized offshore wind PTVs will emerge which optimize speed, capacity, configuration and, most importantly, the ability to transfer personnel in elevated sea states. Vessel operators report that the key limiting factor on open water operations is the ability to transfer personnel from a transport vessel to the installation vessel. When waves exceed 1.5 meters (5 ft), even the most modern PTVs struggle to insure the safety of personnel attempting to transfer to an installation vessel.

The UK-based Carbon Trust has recently provided research grants for six innovative access system designs, which would enable the transfer of personnel and equipment to wind turbines in wave heights of up to 3 meters (10 ft). Carbon trust estimates that this would expand the operational weather window for personnel transfer from 210 days to 300 days a year in the case of Round 3 projects in the UK, which can be as far as 180 miles (300 km) offshore.

We assume that personnel and supply vessels of some sort will be available for US wind operations. Initially, these will most likely be general purpose or multiuse vessels enlisted to support offshore projects. Over time and as the offshore wind industry matures in the United States, purpose-built vessels optimized for wind installation are likely to emerge.

As these vessels will carry US goods and personnel within US waters, they will have to be constructed in the United States and be coastwise-qualified under the Jones Act.

Heavy Maintenance Vessels

Turbines require maintenance and repair subsequent to their installation. Thus, wind farms will require access to maintenance vessels with the ability to replace blades or gear box parts, for example. No such vessels exist today in the US. In all likelihood, during the first several years of project deployment, existing wind farms will turn to the installation fleet when major maintenance must be conducted on operating turbines. As a consequence, downtime for certain outages may be prolonged, as installation vessels may be in short supply at any given time.

Over time, and as economies of scale are attained, a dedicated maintenance fleet is likely to emerge. Very possibly, the early generation installation vessels may be retired to maintenance duty. For example, the RD MacDonald, a relatively modest installation vessel, may be superseded by larger and more capable vessels over time, and by the middle to late-2020s, such a vessel might be best employed in servicing existing projects.

We assume that maintenance vessels will be available as needed, with the caveat that in fact installation vessels may play this role for some time.

9.2 Overall US Vessel Requirements

Overall, the US will require nearly 20 construction vessels and almost 400 various survey, service and maintenance vessels by 2030 in the high case scenario. Please note that our modeling results represent vessel equivalent numbers, the actual number of vessels used in each region and scenario will likely be higher (see Box 1).

Within the construction vessel category, about half of the vessels are heavy lift and cable-lay vessels throughout the forecasting period, and irrespective of the installation strategy chosen. The relatively high heavy lift vessel requirement is due to the fact that some of these vessels would have to be ferried from the Gulf of Mexico to other offshore wind regions. We also use the higher end of substation requirements. Various experts estimate that one substation is needed for every 250 MW to every 400 MW of offshore wind power generation capacity, we used 250 MW in our calculations, meaning that more substations, and consequently more heavy lift vessel time is needed for a unit of generation capacity than the 400 MW figure would suggest.

The number of jackup vessels in the US ramps up to between 3.1 and 6.0 vessel equivalents by 2030 in the high case scenario, depending on the installation strategy. The number of TIVs required annually in 2030 in the high case varies between 3.1 and 6.1. Of the total 6.1 TIVs used in the EU TIV installation strategy, about 2.3 vessel equivalents are European TIVs deployed in the Atlantic Coast. Please note that our model calculations assume that foundation installation will be carried out by the same vessel as transition piece and turbine installation. However, in real life, foundations can be installed by more generalized construction vessels as well, such as floating derricks and various crane barges. About a third of the total vessel time attributed to jackups and TIVs in our forecast can potentially be attributed to other vessel types as well.

About 90% of the more than 300 O&M vessels forecast in the high case scenario by 2030 are small personnel transfer vessels deployed to carry out routine maintenance work, while the remaining ca. 10% is expected to be large repair vessels used for heavy maintenance operations.

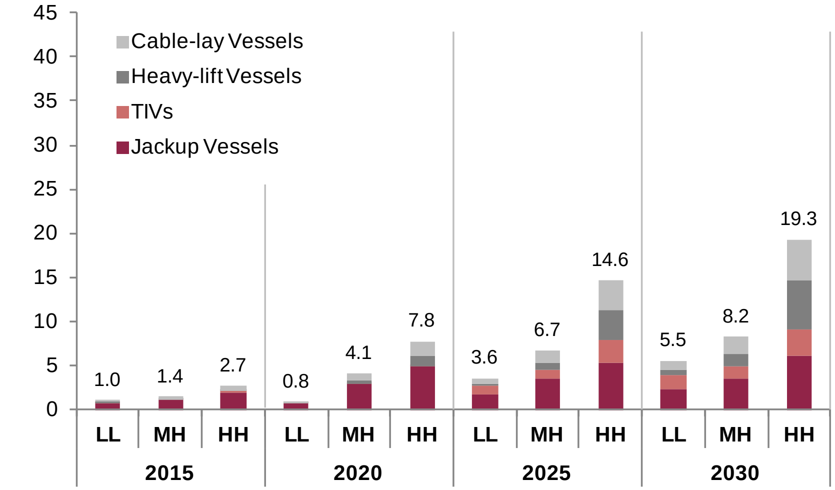


Figure 23: US Total – Annual Construction Vessel Requirements
US Jackup Strategy

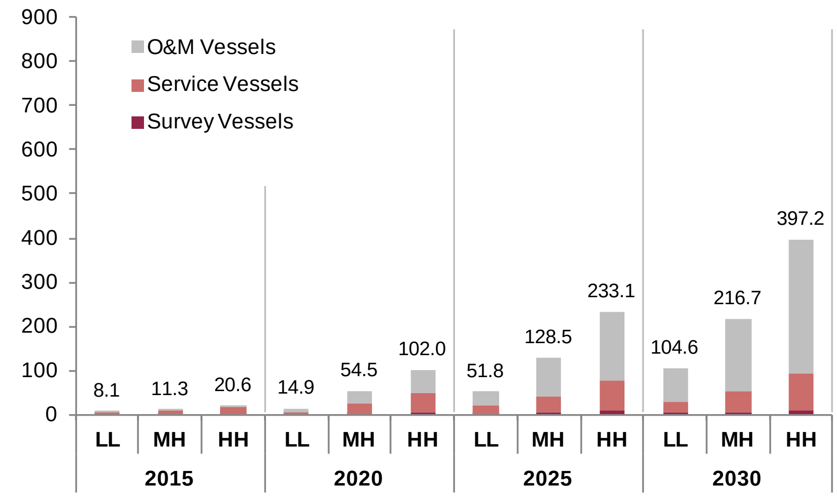


Figure 24: US Total – Annual Other Vessel Requirements
US Jackup Strategy

9 Vessel Requirements

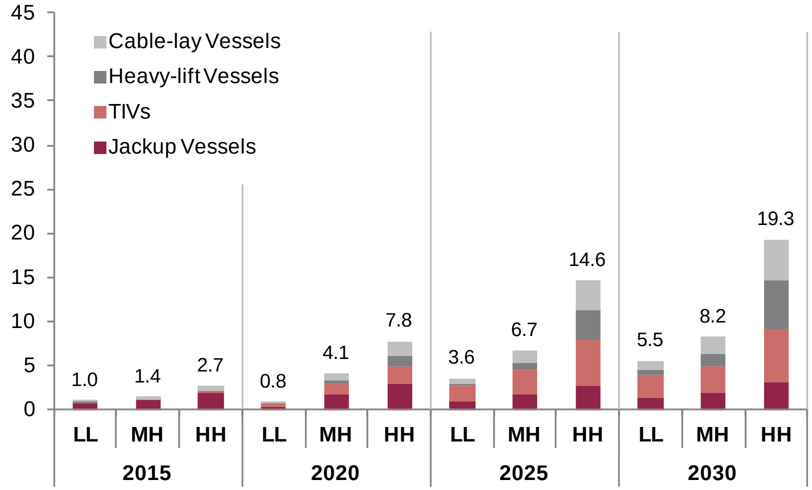


Figure 25: US Total – Annual Construction Vessel Requirements
US TIV Strategy

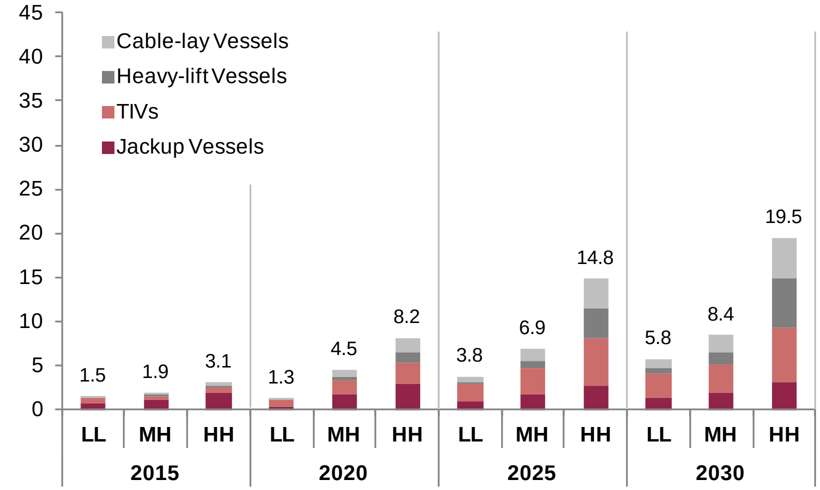


Figure 27: US Total – Annual Construction Vessel Requirements
EU TIV Strategy

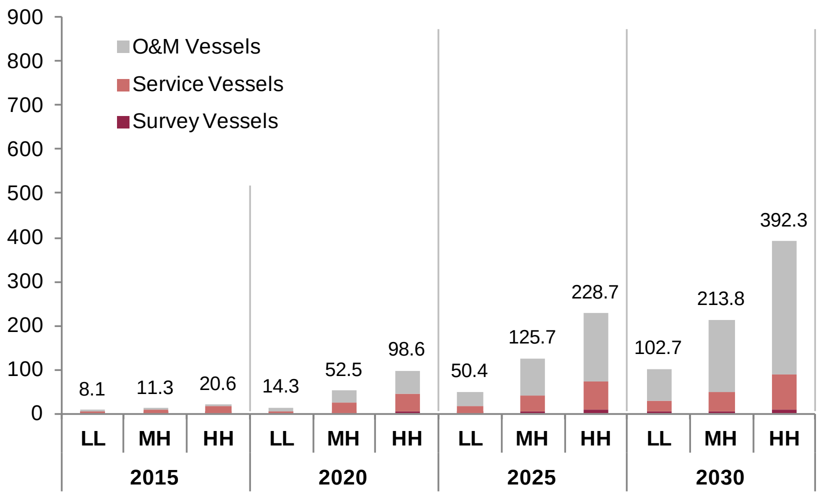


Figure 26: US Total – Annual Other Vessel Requirements
US TIV Strategy

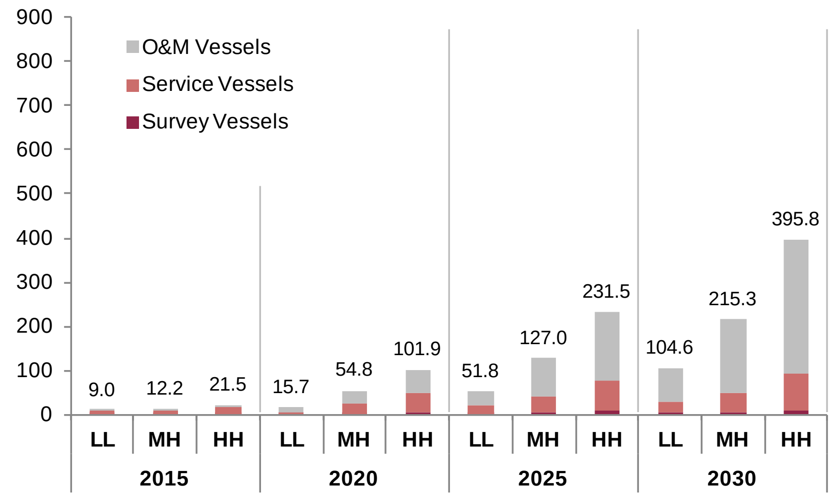


Figure 28: US Total – Annual Other Vessel Requirements
EU TIV Strategy

9.3 Atlantic Coast Vessel Requirements

The Atlantic Coast is the best-suited for offshore wind development among the US offshore wind regions, as it has a very good wind resource, a high population density (preventing large-scale onshore developments) and the proximity of several major load centers to potential offshore wind sites. The southeastern part of the Atlantic Coast (i.e. south of Virginia) is less prospective for offshore wind development, as state-level regulators are generally less supportive of subsidized power, while local populations have lower incomes and potential demand centers are less plentiful.

Wind power developers will face the choice between three installation strategies discussed in the 'Vessel Strategies' section of Chapter 8, namely

- The use of a US jackup vessel (such as the RD MacDonald) for offshore wind installation with feeder barge support.
- The use of a US-built TIV, which requires no feeder barge support
- The use of a European purpose-built TIV with feeder barge support.

Based on our cost estimates completed for the Cape Wind project in Chapter 8, we can conclude that the most cost-efficient solution would be to use a simple jackup vessel during the initial phases of offshore wind development. As capacity additions ramp up, it will probably be justified to construct a purpose-built US TIV at some point in the future, which is still a more cost-efficient solution than to charter a relatively advanced TIV from the European installation fleet.

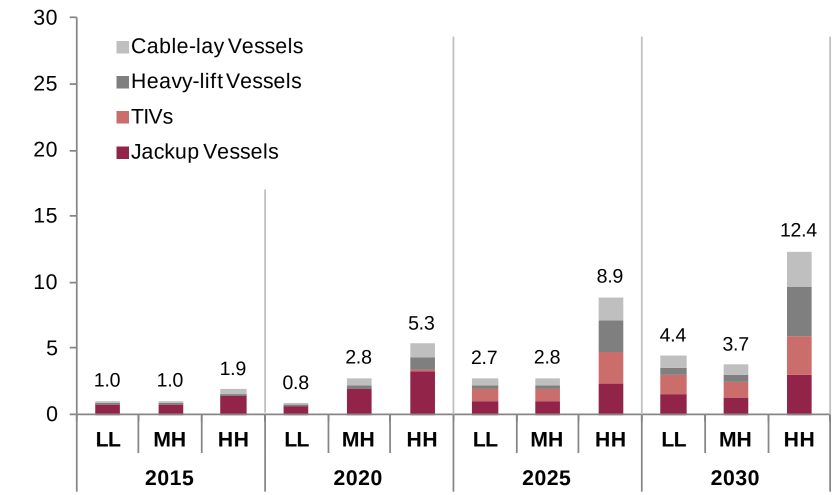


Figure 29: Atlantic Coast – Annual Construction Vessel Requirements
US Jackup Strategy

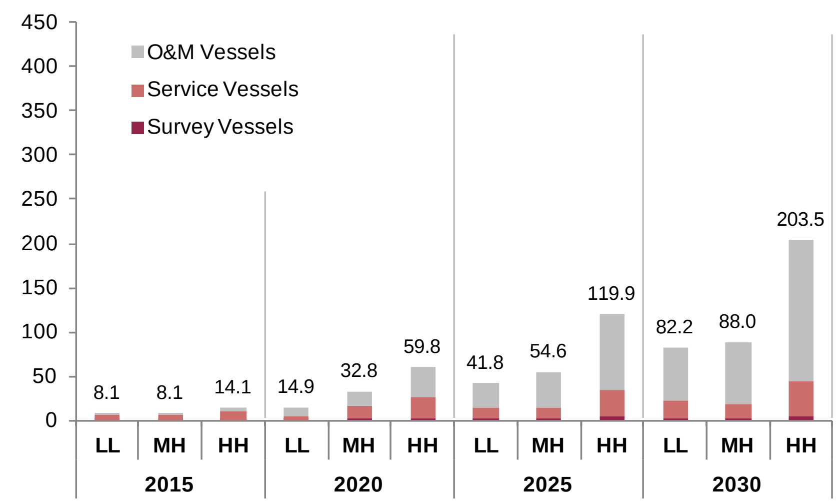


Figure 30: Atlantic Coast – Annual Other Vessel Requirements
US Jackup Strategy

9 Vessel Requirements

Assessment of Vessel Requirements

The Atlantic Coast will require more than 12 construction vessel year equivalents (YE) and over 200 other supporting vessel year equivalents in the high case scenario by 2030.

In the construction vessels category, roughly a fifth of the total vessel time will be attributed to heavy lift vessels. This relatively high number assumes that all heavy lift vessels will have to be mobilized from the Gulf Coast, where these vessels are readily available and currently are servicing the offshore oil and gas industry.

The ratio of TIVs and jackups used for foundation, transition piece and turbine installation varies considerably, depending on the installation strategy chosen. The Atlantic Coast is the only offshore wind region where a relatively widespread use of European installation vessels appears feasible. In our US jackup scenario, relying primarily on US-built jackups to carry out installation work with the support of feeder barges, the ratio of jackups to TIVs is 3 to 3 in the high case in 2030. If the US TIV installation strategy is used, then the region will only see 1.6 jackups, but 4.4 TIV equivalents deployed by 2030. If European TIVs are also used, then the number of jackups is estimated at 1.6 vessel equivalents, while the number of TIVs is about 4.6 vessel equivalents in 2030, of which 2.3 TIVs are European in the high case scenario.

In the service vessel category, barge and tug numbers also vary somewhat, depending on the installation strategy, as various strategies imply a differing degree of feeder barge and tug support. The barge and tug requirement is highest under the EU TIV strategy (with ca. 6.0 tugs and 3.9 feeder barges needed in 2030 in the high case scenario) and lowest in the US TIV strategy, as no feeder barges are needed to support TIVs in this case.

About 130 small PTV-type maintenance vessels and 28 heavy maintenance vessels are foreseen in the Atlantic Coast by 2030 under the high case scenario

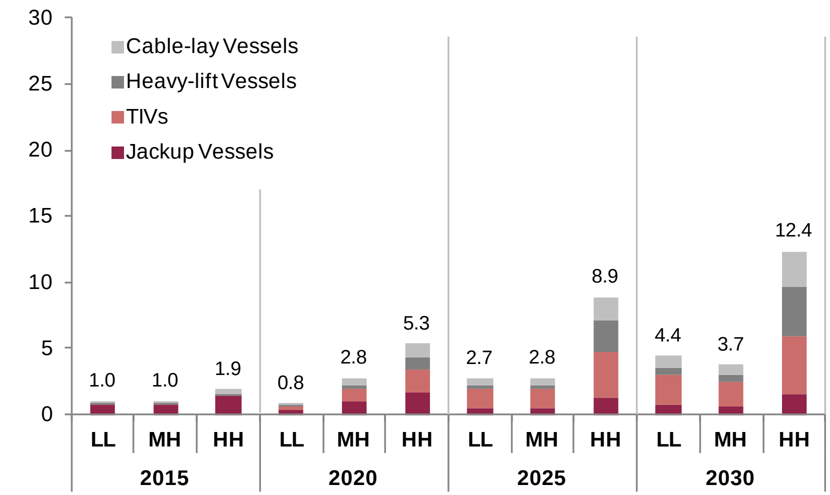


Figure 31: Atlantic Coast – Annual Construction Vessel Requirements
US TIV Strategy

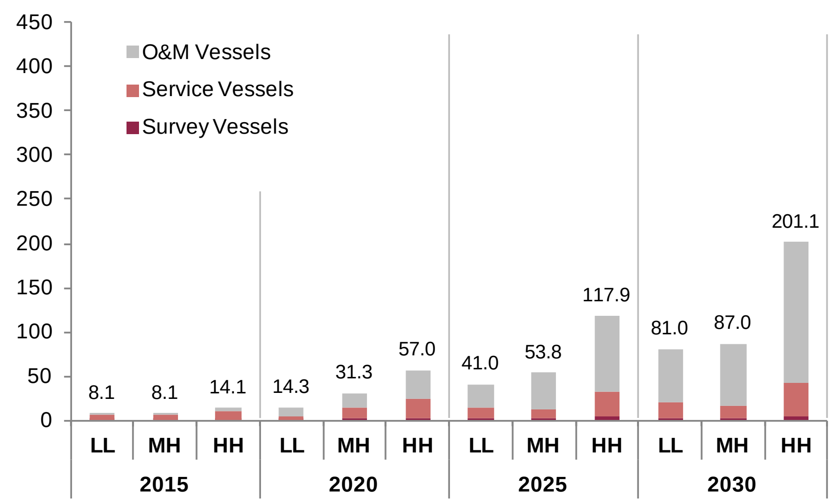


Figure 32: Atlantic Coast – Annual Other Vessel Requirements
US TIV Strategy

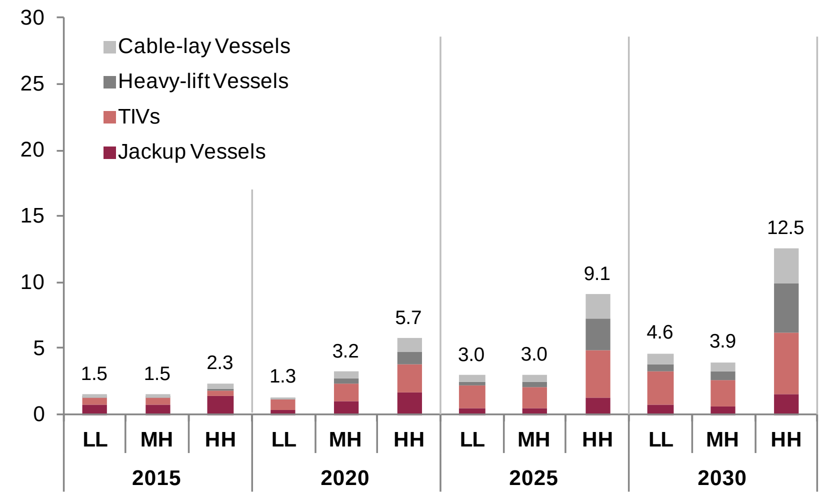


Figure 33: Atlantic Coast – Annual Construction Vessel Requirements
EU TIV Strategy

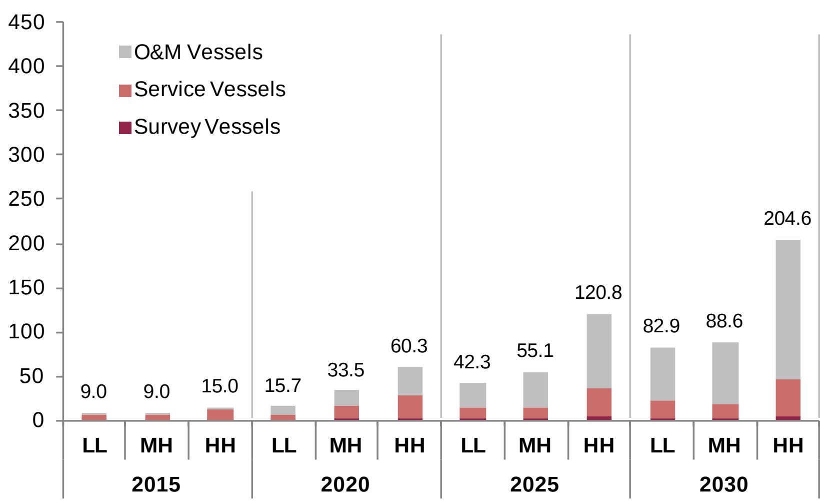


Figure 34: Atlantic Coast – Annual Other Vessel Requirements
EU TIV Strategy

9.4 Great Lakes Vessel Requirements

The Great Lakes region is somewhat unique among the surveyed US offshore wind regions in a sense that the navigation of larger vessels between the lakes and the Atlantic Ocean is limited by the size of a series of locks. In our view, this peculiarity merits a more detailed overview of navigational conditions (see in Appendix 3 entitled 'Offshore Wind Prospects in the Great Lakes Region').

The Great Lakes region has an excellent offshore wind resource, and some of its large load centers are located near potentially suitable offshore wind project sites. However, power demand there is not expected to increase considerably in the foreseeable future, as the region has been losing population since the decline of US manufacturing industries starting in the 1980's. The Great Recession starting in 2008-2009 also took a heavy toll on the region. Conditions for offshore wind installation are considered less favorable than in other US offshore wind regions, due primarily to icing conditions, significant wave heights and relatively high average water depths compared to some parts of the Atlantic Coast and the Gulf of Mexico. The region also has very good onshore wind potential, which will likely account for the vast majority of wind power capacity installation in any realistic scenario.

The Great Lakes region has three options for the installation of offshore wind capacities.

Option 1 – RD MacDonald

The RD MacDonald is the largest existing installation vessel in the US, which can still navigate the St. Lawrence Seaway. Thus it can be deployed for offshore wind installation projects in the Great Lakes region. Indeed, the vessel was specifically designed with a view of operating in the Great Lakes region. However, the RD MacDonald may be restricted to operating in water depths less than 100 ft (30.5 m) and it is only certified to install 3.6 MW turbines (with the possibility of also installing 4 or 5 MW turbines in the future). These are definite limitations, which may require other vessel solutions in the future, particularly if the offshore wind industry ramps up in the post-2020 period as we envision in our high case capacity deployment scenario. In this case, the operation of the RD MacDonald would be very similar to the one described in the US Jackup Strategy for the Atlantic Coast.

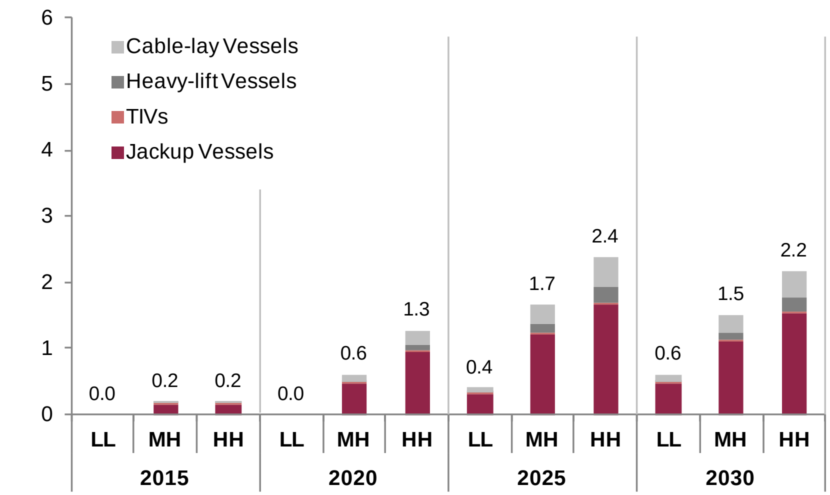


Figure 35: Great Lakes – Annual Construction Vessel Requirements
US Jackup Strategy

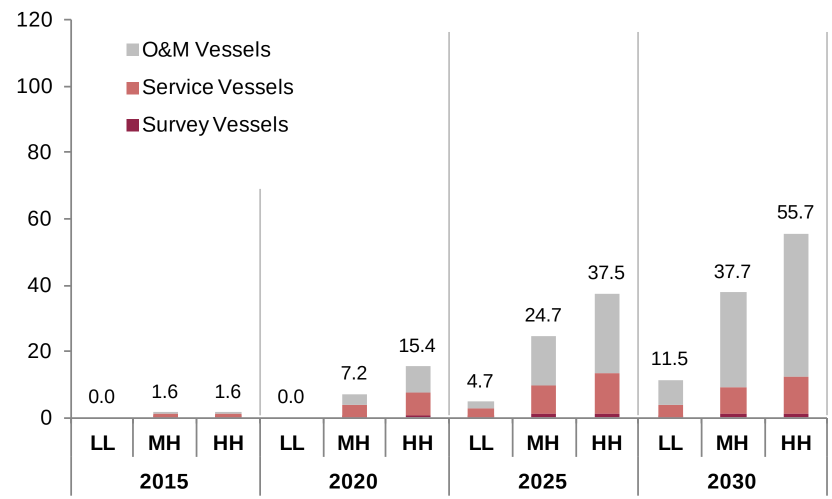


Figure 36: Great Lakes – Annual Other Vessel Requirements
US Jackup Strategy

9 Vessel Requirements

Option 2 – Purpose-built TIV serving the Great Lakes Region

If the pace of offshore wind development justifies the deployment of more advanced, higher capacity vessels than the RD MacDonald, then vessel operators may decide to construct a larger purpose-built TIV serving specifically the Great Lakes region. These vessels can install 6 MW or even possibly larger turbines with no difficulty. The local shipbuilding and manufacturing heavy industries in the Great Lakes region are considered capable of constructing such purpose-built installation vessels.

Given the 23.4 m maximum boat beam at multiple points of the Great Lakes – St. Lawrence Seaway System (due to the narrow locks), a purpose-built TIV exceeding these dimensions would have to reside permanently in one of three specific sectors of the Great Lakes – St. Lawrence System. There are specific chokepoints between the St. Lawrence River estuary and Lake Ontario, between Lake Ontario and Lake Erie, as well as between Lake Huron and Lake Superior. Lake Michigan, Lake Huron and Lake Erie constitute a continuous navigable waterway for larger vessels, including purpose-built TIVs as well. The permanent home of a Great Lakes TIV would most likely be Lake Michigan-Lake Huron-Lake Erie system, as the largest power load centers, such as Chicago, Detroit and Erie system, as the largest power load centers, such as Chicago, Detroit and Cleveland are alongside this continuous waterway. Constructing a dedicated vessel for Lake Ontario alone is much less likely, given the much more limited overall demand potential there, while a resident TIV on Lake Superior is not feasible in any deployment scenario. However, a resident Great Lakes TIV would face challenging economics even in the most densely populated section of the Great Lakes system, and would entirely depend on a continuous project flow along the shoreline between Chicago and Buffalo.

The cost of a moderately sophisticated purpose-built TIV, such as the MPI Resolution in Europe, would be at least $300 million in the Great Lakes region, but this figure can be considerably higher, as much as $450 million, at the front end of the learning curve. The operation of a purpose-built TIV would be similar to the one seen in the US TIV strategy illustrated in the Atlantic Coast region. This is a massive one-off investment, which would require such a high degree of certainty in future project flow that is hardly attainable anywhere in the US. The dayrates of a new TIV would be at least $212,000, similarly to the US TIV scenario, but the operational weather window would be lower in the Great Lakes region than in the Atlantic Coast due to higher waves, harsher weather and severe icing conditions lasting for several months on the lakes. This combination of steeper costs and lower installation efficiency would considerably challenge the economics of any potential offshore wind projects on the Great Lakes.

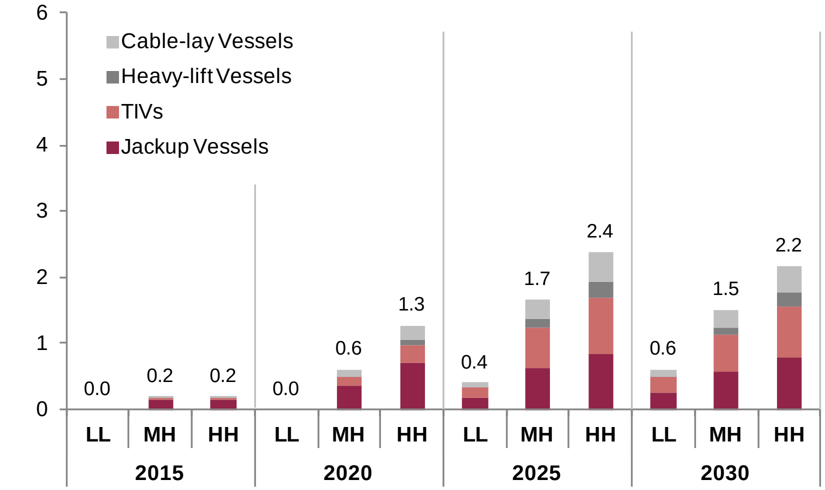


Figure 37: Great Lakes – Annual Construction Vessel Requirements
US TIV Strategy

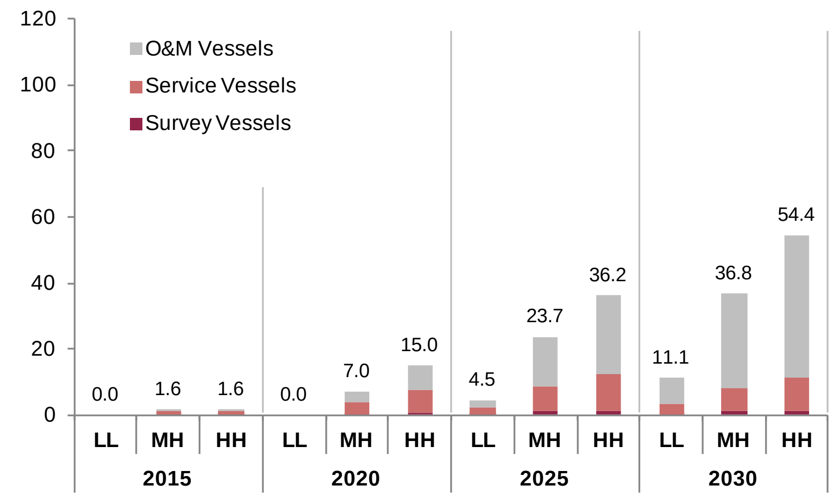


Figure 38: Great Lakes – Annual Other Vessel Requirements
US TIV Strategy

9 Vessel Requirements

Option 3 – Floating Turbine Platform Design

Should smaller installation vessels prove insufficient and the construction of new TIVs servicing exclusively the Great Lakes region too costly, a third option will be a move towards floating offshore wind turbines. Certain floating turbine types can be “installed” simply by towing pre-assembled turbines to their final installation site with a number of tugboats, which are readily available in the region. A similar installation method is anticipated on the Pacific Coast. The local shipbuilding industry is believed to be capable of delivering such floating platforms. However, they currently lack the experience in building large floating structures, unlike for example the shipyards serving the oil & gas industry in the Gulf Coast region. These floating structures would also be suitable for the relatively high water depths at some parts of the Great Lakes, but they would be somewhat more costly than simple monopile foundations based on current economics. Overhead clearance limits will also have to be taken to account when considering vertical tow options.

Overall, the Great Lakes region will likely resort to simpler installation vessels in the initial stages of offshore wind development, which can operate in no deeper than 70 ft waters, with the maximum turbine size limited at 4-5 MW. Later on, if and when the offshore wind industry takes off in the region, a shift will likely be towards floating turbines, which can be installed by using tugs, and turbine size will only be limited by the size of onshore assembly facilities. This option would also liberate the region from the costly option of building a dedicated TIV to service the most prospective sector of the Great Lakes system, which is the least feasible of the three available options.

Assessment of Vessel Requirements

Considering the choices detailed above, our forecast numbers suggest that a relatively simple jackup vessel, such as the RD MacDonald, could sufficiently serve the entire Great Lakes region until about 2020, and perhaps one more such vessel would have to be added before 2030 in the high case scenario, if Option 1 is preferred by developers. In the medium and low cases, one similar jackup vessel may be sufficient throughout the entire projection period.

At least one cable-lay vessel and one heavy lift vessel must be available in the region in the high case scenario, either by permanently stationing on the Great Lakes, or otherwise transferred to the region. However, justifying the construction of a dedicated heavy lift or cable-lay vessel unable to navigate the locks along the St. Lawrence Seaway may prove impractical, given that only 0.2 cable-lay vessel equivalents and 0.4 heavy lift vessel equivalents would be required in the high case scenario annually by 2030. This means that both a heavy lift vessel and a cable-lay vessel resident to the Great Lakes would likely be poorly utilized, even in the most bullish rollout scenario.

In the maintenance vessel category, about 37 PTV vessel equivalents and 6 large repair vessels would be needed under the high case scenario by 2030. Operating 6 heavy maintenance vessels on the Great Lakes may pose similar challenges as the securing of sufficient installation capacity does. These large repair vessels have to be capable of changing broken blades and lift heavy load, therefore, typically older generation jackup vessels are used for this purpose. However, in the context of the Great Lakes, these vessels would also have to take into consideration the difficult choices resulting from the limited size of locks along the St. Lawrence Seaway.

9.5 Gulf Coast Vessel Requirements

Regional Overview

The US Gulf Coast has great logistical and infrastructural advantages compared to all other US offshore wind regions, and most elements of the vessel-related supply chain required for the construction of offshore wind installation capacities is readily available in the region.

It has a vast existing offshore installation and supply vessel fleet servicing the oil and gas industry, as well as large-scale vessel construction capability. A large number of already existing, fixed offshore platforms could potentially be used for offshore wind turbine installation. A wide range of local vessel operators have considerable experience in the installation of large fixed and floating structures in the Gulf of Mexico.

Gulf Coast-based equipment manufacturers like NOV can provide cranes and other critical components for offshore wind installation vessels. Overall, the non-unionized shipyards in coastal states along the Gulf are well-positioned to capture a large portion of vessel and component orders from across the US associated with offshore wind installation.

The most notable disadvantages of the region include the relatively poor offshore wind resource, and a periodically recurring hurricane season, which can cause considerable disruptions and damage to offshore wind farms. The local population also has lower average income than in the Northeast, and is generally less supportive of subsidized forms of electricity generation.

The main installation strategies local offshore wind developers face are similar to those faced by Atlantic Coast developers, namely to use jackup vessels with feeder barge support and the use of US-built TIVs as a standalone installation vessel. At the same time, the use of European TIVs with US service vessel support is less feasible in the Gulf Coast, given the longer mobilization/ demobilization period across the Atlantic and the availability of other US-built installation vessels, which can be converted to offshore wind operations. Thus, the third possible installation strategy in the Gulf Coast region would be various hybrid solutions rather than relying on European TIVs. Given the ample logistical resources that are readily available in the region, this will likely mean the retooling of existing oil and gas platform installation vessels for offshore wind installation.

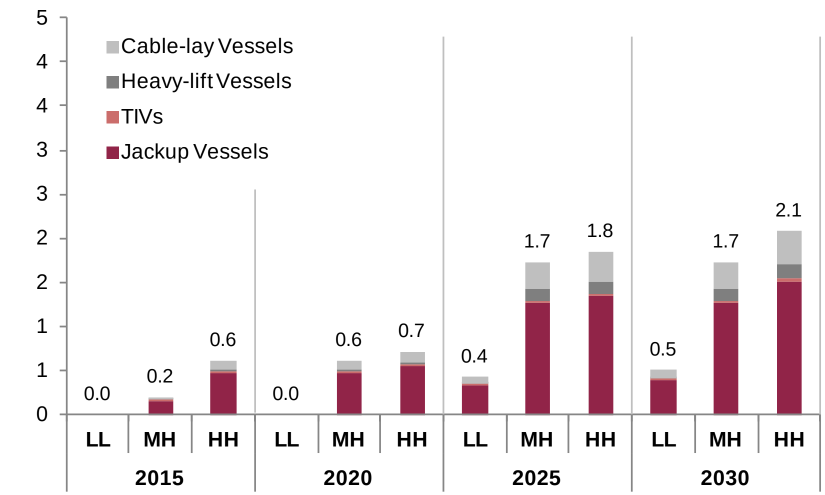


Figure 39: Gulf Coast – Annual Construction Vessel Requirements
US Jackup Strategy

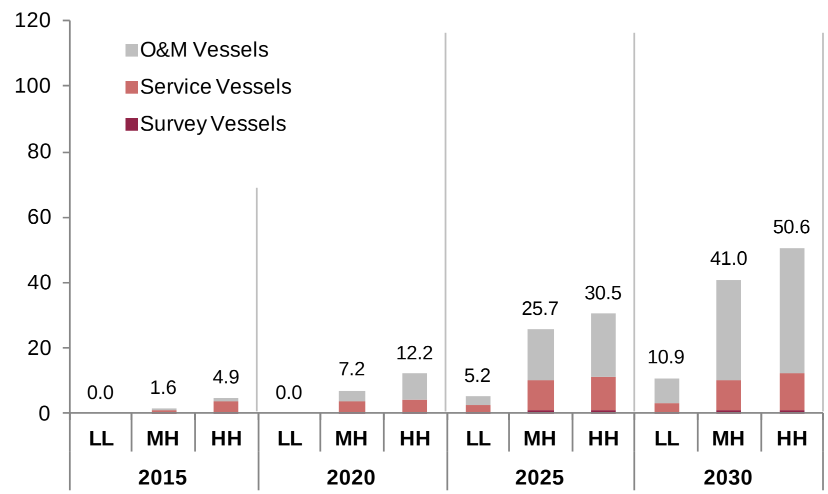


Figure 40: Gulf Coast – Annual Other Vessel Requirements
US Jackup Strategy

9 Vessel Requirements

Assessment of Vessel Requirements

Securing the relatively modest installation vessel requirements anticipated in the Gulf Coast region should not be a problem, considering the region's vast capabilities in offshore installation and its large available vessel capacities. Even in the high case scenario, one or two jackup vessels and/or purpose-built US TIVs can comfortably cover the region's installation capacity requirements through 2030, which is estimated at around 1.5 vessel equivalents in total by the end of the forecast period.

Other necessary vessel types required for a complete offshore wind supply chain (e.g. survey vessels, heavy lift vessels, cable-lay vessels, barges, tugs, PTVs and large jackup vessels for heavy maintenance) are readily available in the Gulf Coast region.

Moreover, there is a higher likelihood in the Gulf Coast region that uncommon vessel types will also play a role in foundation, transition piece and even turbine installation. These can be retooled jackup barges, readily available heavy lift vessels or other vessel types.

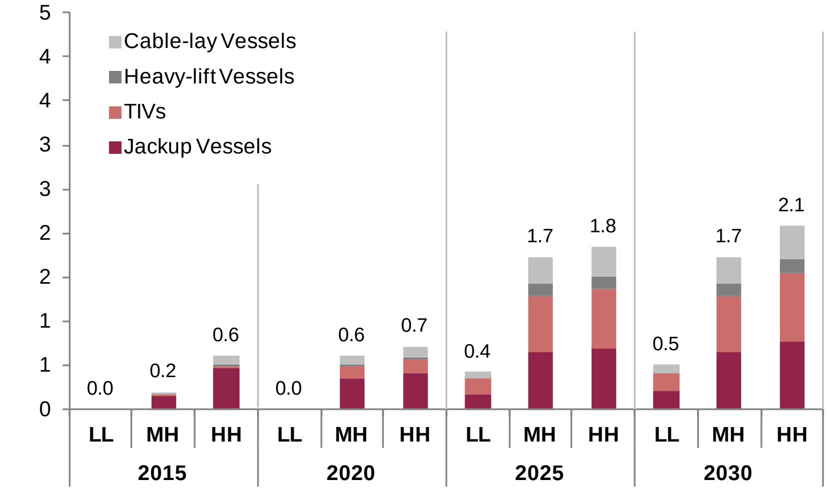


Figure 41: Gulf Coast – Annual Construction Vessel Requirements
US TIV Strategy

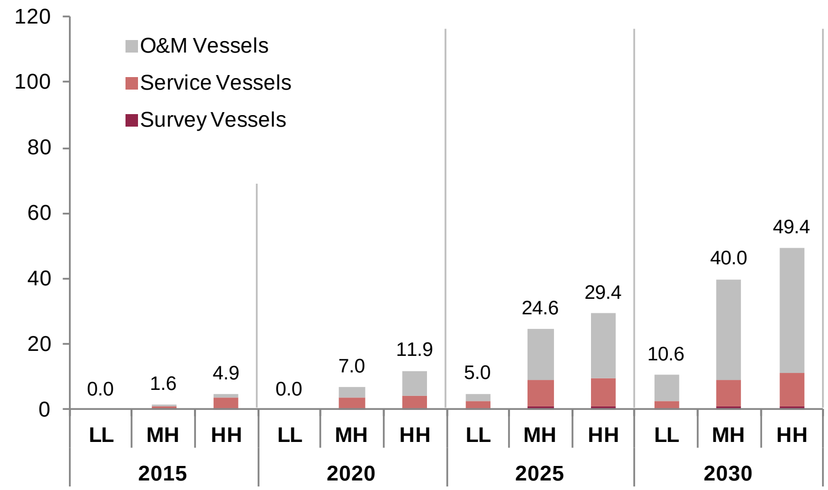


Figure 42: Gulf Coast – Annual Other Vessel Requirements
US TIV Strategy

9 Vessel Requirements

9.6 Pacific Coast Vessel Requirements

Regional Overview

The overall outlook for offshore wind development is favorable in the Pacific Coast. Economic and demographic growth justifies power sector investments, the local population has a high commitment to renewable energy, and electricity is already expensive, making offshore wind relatively more competitive with other power generation sources compared to other US offshore wind regions. However, the local population will likely resist building offshore structures within sight (i.e. within 20 miles) from the shore. Moreover, the Pacific Coast has essentially no continental shelf, and water depth starts to increase quite rapidly from the shoreline.

As a result of high water depths and the necessary distance from shore, fixed platform solutions are generally not deemed feasible for offshore wind installation in the Pacific Coast. Floating platform solutions, on the other hand, are well-suited for the Pacific Coast region, and installation vessel requirements are considerably easier to meet. Floating platform turbines are typically assembled in port, and towed to their final position offshore by a number of simple tugboats, which are readily available on a simple dayrate basis. However, certain floating platform designs may need additional specialized vessels during towing and installation operations. For example, the PelaStar tension leg platform (TLP), developed by Glosten Associates, requires the custom-built PelaStar support barge during the towing and the anchoring process. The PelaStar support barge also relies on a tugboat for propulsion.

Overall, the predominant “installation” method for the Pacific Coast region’s floating wind turbines will likely involve the extensive use of tugs. Some Californian shipyards, notably the Nassco shipyard in San Diego, are capable of constructing the floating platforms on which turbines would be mounted.

Installation of Principle Power’s Floating Prototype Wind Turbine ‘WindFloat’ with Three Tugboats
Source: Principle Power

9 Vessel Requirements

Assessment of Vessel Requirements

The only plausible offshore wind deployment strategy available in the Pacific Coast region relies on floating platforms. These floating turbines do not require dedicated turbine installation vessels, as the turbines can be assembled and mounted on the floating platform in a port. They can be towed to their intended installation site and installed using only tugboats.

As a result, our installation vessels only include heavy lift vessels and cable-lay vessels. The former is still required for substation installation, while the latter is necessary for any type of offshore wind installation. In our high case scenario, we anticipate that an annual 2.7 installation vessel equivalents will be required by 2030, roughly halfway split between heavy lift and cable-lay vessels. The corresponding figure in the medium case scenario is 1.3 installation vessel equivalents. In our model, we assume that 50% of the heavy lift vessels deployed in the Pacific Coast region will be chartered from the Gulf Coast. We do not anticipate any offshore wind capacity installations in the Low-Growth – Low Technology scenario.

The higher number of tugs used in turbine installation shows up in the service vessel category. On the other hand, no barges are required for offshore wind installations in the Pacific Coast, because tugs (and not jackups or TIVSs) are used to install the floating turbines. The relatively high number of operation & maintenance vessels is due to the large installed capacity envisioned in the high case scenario in the Pacific Coast.

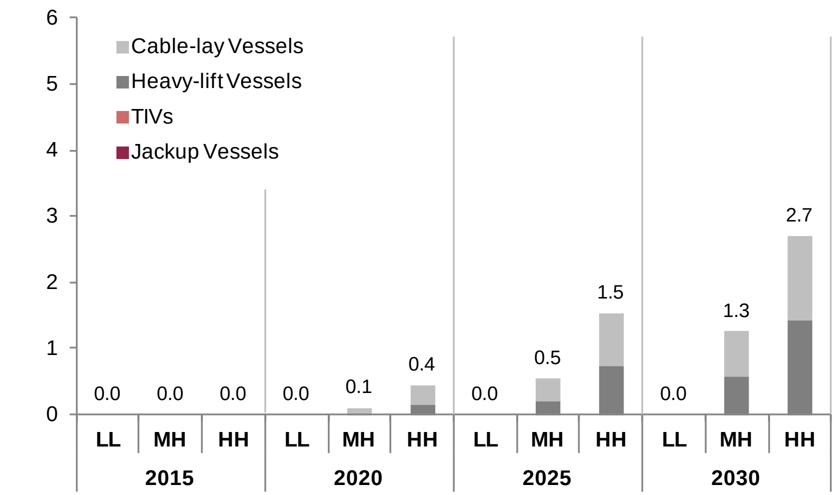


Figure 43: Pacific Coast – Annual Construction Vessel Requirements
Floating Turbine Strategy

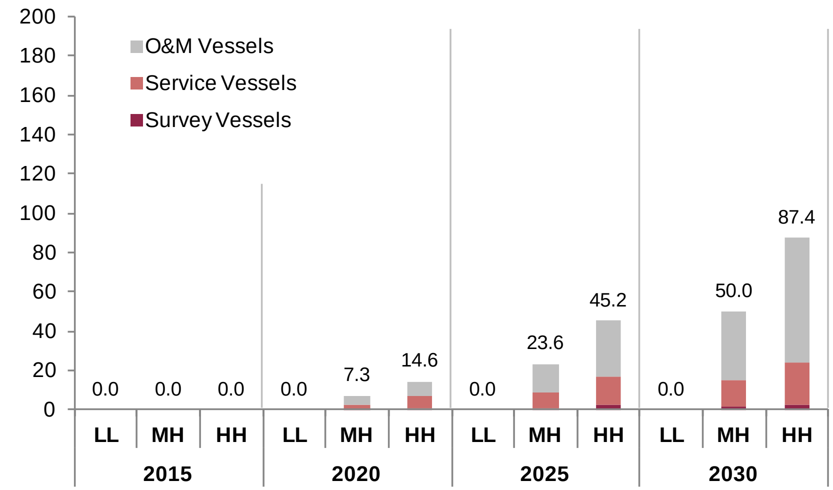


Figure 44: Pacific Coast – Annual Other Vessel Requirements
Floating Turbine Strategy

Appendix 1

Installation Vessel Profiles

Appendix 1 – Installation Vessel Profiles

Operating TIVs and Jackup Vessels

SEA POWER

Sea Power
Source: A2SEA

Sea Power
Source: Ship Spotting

Vessel Name	Sea Power
Vessel Type	Semi-Jackup
Status	Operational
Owner	A2SEA
Flag	Denmark
Yard	-
Year Built	1991/2002
Length [m]	92
Breadth [m]	22
Max. Draft [m]	4.3
Max. Water Depth [m]	24
Cargo Area [m2]	1,020
Payload [t]	2,386
Main Crane Load [t@m]	230 t @ 15 m
Crane Height [m]	-
Speed [knots]	7.8
Jackup Legs	4
Accommodation [persons]	16
Dynamic Positioning System	None
Known Offshore Wind Projects	Anholt (DK)

Appendix 1 – Installation Vessel Profiles

SEA ENERGY

Sea Energy
Source: Ship Spotting

Vessel Name	Sea Energy
Vessel Type	Semi-Jackup
Status	Operational
Owner	A2SEA
Flag	Denmark
Yard	-
Year Built	1990/2002
Length [m]	92
Breadth [m]	22
Max. Draft [m]	4.3
Max. Water Depth [m]	24
Cargo Area [m2]	1,020
Payload [t]	2,386
Main Crane Load [t@m]	110 t @ 20 m
Crane Height [m]	-
Speed [knots]	7.8
Jackup Legs	4
Accommodation [persons]	16
Dynamic Positioning System	None

Appendix 1 – Installation Vessel Profiles

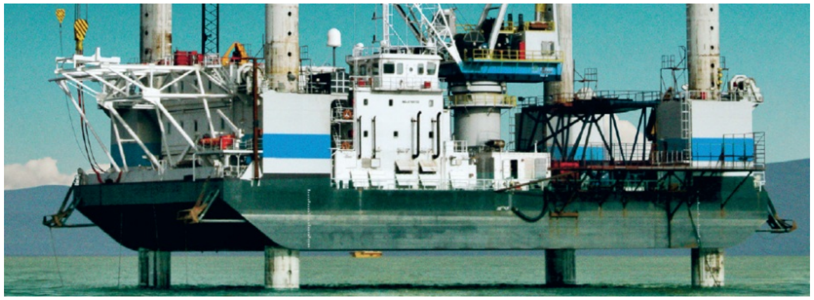
SEA JACK

Sea Jack
Source: Recharge

Vessel Name	Sea Jack
Vessel Type	Jackup Barge
Status	Operational
Owner	A2SEA
Flag	Denmark
Yard	-
Year Built	2003
Length [m]	91
Breadth [m]	33
Max. Draft [m]	5.5
Max. Water Depth [m]	30
Cargo Area [m2]	2,500
Payload [t]	2,500
Main Crane Load [t@m]	800 t
Crane Height [m]	-
Speed [knots]	-
Jackup Legs	4
Accommodation [persons]	23
Dynamic Positioning System	None
Known Offshore Wind Projects	Ormonde (UK) Sheringham Shoal (UK)

Appendix 1 – Installation Vessel Profiles

SEA WORKER



Sea Worker
Source: A2SEA

Sea Worker
Source: Offshore.no

Vessel Name	Sea Worker
Vessel Type	Jackup Barge
Status	Operational
Owner	A2SEA
Flag	Denmark
Yard	-
Year Built	2008
Length [m]	56
Breadth [m]	33
Max. Draft [m]	3.6
Max. Water Depth [m]	40
Cargo Area [m2]	750
Payload [t]	1,100
Main Crane Load [t@m]	400 t @ 17 m
Crane Height [m]	-
Speed [knots]	-
Jackup Legs	4
Accommodation [persons]	22
Dynamic Positioning System	None
Known Offshore Wind Projects	Gunfleet Sands (UK) London Array (UK) Anholt (DK)

Appendix 1 – Installation Vessel Profiles

SEA INSTALLER

Sea Installer
Source: Towingline.com

Sea Installer
Source: Offshorewind.biz

Vessel Name	Sea Installer
Vessel Type	TIV
Status	Operational
Owner	A2SEA
Flag	Denmark
Yard	Cosco (China)
Year Built	2012
Length [m]	132
Breadth [m]	39
Max. Draft [m]	5.3
Max. Water Depth [m]	45
Cargo Area [m2]	3,350
Payload [t]	5,000
Main Crane Load [t@m]	800 t @ 24 m
Crane Height [m]	102
Speed [knots]	12.0
Jackup Legs	4
Accommodation [persons]	35
Dynamic Positioning System	DP 2

Appendix 1 – Installation Vessel Profiles

WIND LIFT 1

Wind Lift I
Source: Bard

Vessel Name	Wind Lift 1
Vessel Type	TIV
Status	Operational
Owner	Bard
Flag	Germany
Yard	Western Shipyard (Lithuania)
Year Built	2010
Length [m]	102
Breadth [m]	36
Max. Draft [m]	3.5
Max. Water Depth [m]	45
Cargo Area [m2]	-
Payload [t]	2,600
Main Crane Load [t@m]	500 t @ 31 m
Crane Height [m]	121
Speed [knots]	-
Jackup Legs	4
Accommodation [persons]	50
Dynamic Positioning System	DP 1
Known Offshore Wind Projects	Bard Offshore (GER)

Appendix 1 – Installation Vessel Profiles

PAULINE

Pauline
Source: Gusto MSC

Vessel Name	Pauline
Vessel Type	Jackup Barge
Status	Operational
Owner	Besix
Flag	St. Vincent & G.
Yard	IHC Merwede (Netherlands)
Year Built	2002
Length [m]	48
Breadth [m]	24
Max. Draft [m]	2.5
Max. Water Depth [m]	30
Cargo Area [m2]	-
Payload [t]	1,500
Main Crane Load [t@m]	200 t
Crane Height [m]	-
Speed [knots]	-
Jackup Legs	4
Accommodation [persons]	-
Dynamic Positioning System	-

Appendix 1 – Installation Vessel Profiles

MV WIND

MV Wind
Source: Vacon PLC

Vessel Name	MV Wind
Vessel Type	Jackup Barge
Status	Operational
Owner	DBB Jack-Up Services
Flag	Denmark
Yard	Rupelmonde (Belgium)
Year Built	1995/2010
Length [m]	55
Breadth [m]	18
Max. Draft [m]	2.4
Max. Water Depth [m]	25
Cargo Area [m2]	-
Payload [t]	-
Main Crane Load [t@m]	1,200 t
Crane Height [m]	100
Speed [knots]	-
Jackup Legs	4
Accommodation [persons]	-
Dynamic Positioning System	DP 2
Known Offshore Wind Projects	North Hoyle (UK) Egmond aan Zee (NED)

Appendix 1 – Installation Vessel Profiles

GEOSEA NEPTUNE

Geosea Neptune
Source: Ship Spotting

Vessel Name	Neptune
Vessel Type	TIV
Status	Operational
Owner	Geosea
Flag	Luxembourg
Yard	IHC Merwede (Netherlands)
Year Built	2012
Length [m]	60
Breadth [m]	38
Max. Draft [m]	3.9
Max. Water Depth [m]	52
Cargo Area [m2]	1,600
Payload [t]	1,600
Main Crane Load [t@m]	600 t @ 26 m
Crane Height [m]	-
Speed [knots]	7.7
Jackup Legs	4
Accommodation [persons]	60
Dynamic Positioning System	DP 2
Known Offshore Wind Projects	Thornton Bank (BEL)

Appendix 1 – Installation Vessel Profiles

GEOSEA GOLIATH

Geosea Goliath
Source: Offshore Wind Biz

Vessel Name	Goliath
Vessel Type	Jackup Barge
Status	Operational
Owner	Geosea
Flag	Luxembourg
Yard	Lemants (Belgium)
Year Built	2008
Length [m]	56
Breadth [m]	32
Max. Draft [m]	3.6
Max. Water Depth [m]	40
Cargo Area [m2]	1,080
Payload [t]	1,600
Main Crane Load [t@m]	400 t @ 15 m
Crane Height [m]	-
Speed [knots]	-
Jackup Legs	4
Accommodation [persons]	12
Dynamic Positioning System	DP 2
Known Offshore Wind Projects	Borkum West II (GER)

Appendix 1 – Installation Vessel Profiles

GEOSEA VAGANT

Geosea Vagant
Source: Koerts International Towing

Vessel Name	Vagant
Vessel Type	Jackup Barge
Status	Operational
Owner	Geosea
Flag	Netherlands
Yard	IHC Merwede (Netherlands)
Year Built	2002
Length [m]	44
Breadth [m]	23
Max. Draft [m]	4.2
Max. Water Depth [m]	30
Cargo Area [m2]	-
Payload [t]	1,000
Main Crane Load [t@m]	-
Crane Height [m]	-
Speed [knots]	-
Jackup Legs	4
Accommodation [persons]	10
Dynamic Positioning System	None

Appendix 1 – Installation Vessel Profiles

GEOSEA BUZZARD

Geosea Buzzard
Source: Ship Spotting

Originally used in the offshore oil and gas sector, the Geosea Buzzard is now used for offshore wind farm projects.

Vessel Name	Buzzard
Vessel Type	Jackup Barge
Status	Operational
Owner	Geosea
Flag	St. Vincent & G.
Yard	De Biesbosch (Netherlands)
Year Built	1982
Length [m]	43
Breadth [m]	30
Max. Draft [m]	3.0
Max. Water Depth [m]	40
Cargo Area [m2]	-
Payload [t]	1,300
Main Crane Load [t@m]	-
Crane Height [m]	-
Speed [knots]	-
Jackup Legs	4
Accommodation [persons]	8
Dynamic Positioning System	None
Known Offshore Wind Projects	Thornton Bank (BEL)

Appendix 1 – Installation Vessel Profiles

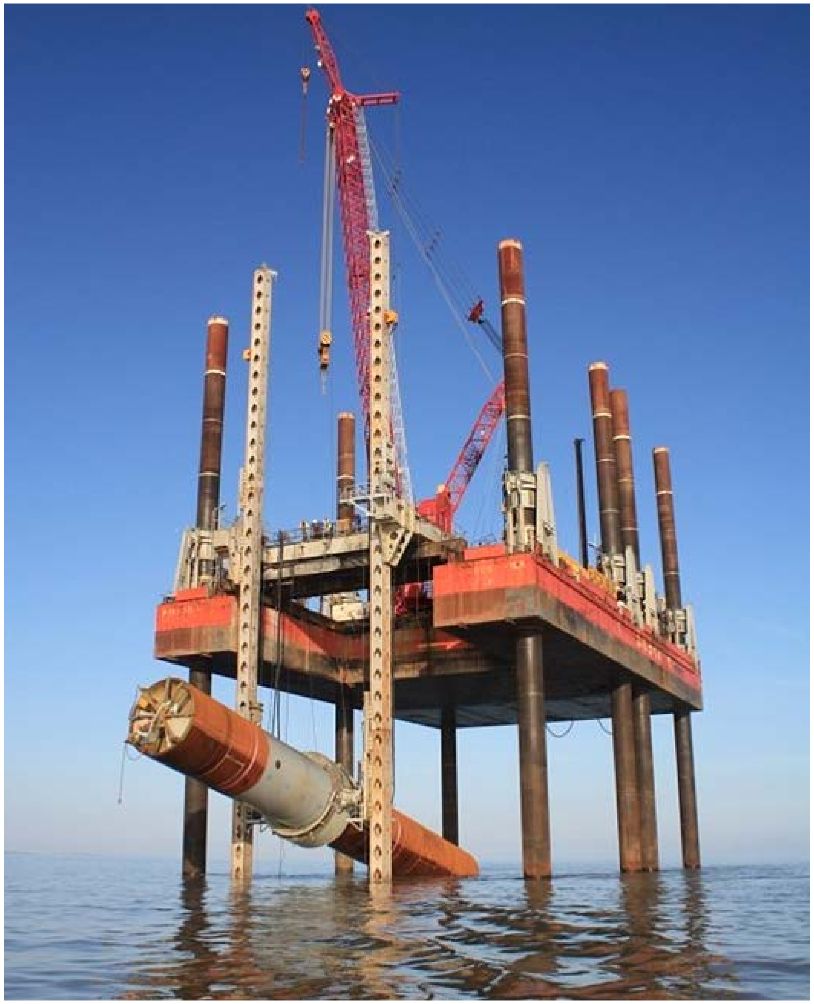
GMS ENDEAVOUR

GMS Endeavour
Source: Scira Offshore Energy

Vessel Name	GMS Endeavour
Vessel Type	Jackup Barge
Status	Operational
Owner	Gulf Marine Services
Flag	Panama
Yard	Gulf Marine Service WLL (UAE)
Year Built	2010
Length [m]	76
Breadth [m]	36
Max. Draft [m]	6.0
Max. Water Depth [m]	65
Cargo Area [m2]	1,035
Payload [t]	1,600
Main Crane Load [t@m]	300 t
Crane Height [m]	-
Speed [knots]	8.0
Jackup Legs	4
Accommodation [persons]	150
Dynamic Positioning System	DP 2
Known Offshore Wind Projects	Sheringham Shoal (UK)

Appendix 1 – Installation Vessel Profiles

EXCALIBUR



Excalibur
Source: Fugro Seacore

Vessel Name	Excalibur
Vessel Type	Jackup
Status	Operational
Owner	Fugro Seacore
Flag	Vanuatu
Yard	HDW Kiel (Germany)
Year Built	1978
Length [m]	60
Breadth [m]	32
Max. Draft [m]	2.8
Max. Water Depth [m]	40
Cargo Area [m2]	-
Payload [t]	1,352
Main Crane Load [t@m]	220 t @ 14 m
Crane Height [m]	64
Speed [knots]	-
Jackup Legs	8
Accommodation [persons]	50
Dynamic Positioning System	None
Known Offshore Wind Projects	Gunfleet Sands (UK)

Appendix 1 – Installation Vessel Profiles

INNOVATION

Innovation
Source: Offshore-mag.com

Innovation
Source: Heavyliftspecialist.com

Vessel Name	Innovation
Vessel Type	TIV
Status	Operational
Owner	HGO InfraSea Solutions (Hochtief – Geosea JV)
Flag	Germany
Yard	Crist Gdynia (Poland)
Year Built	2012
Length [m]	147
Breadth [m]	42
Max. Draft [m]	7.3
Max. Water Depth [m]	50
Cargo Area [m2]	-
Payload [t]	8,000
Main Crane Load [t@m]	1,500 t @ 31.5 m
Crane Height [m]	120
Speed [knots]	12.0
Jackup Legs	4
Accommodation [persons]	100
Dynamic Positioning System	DP 2

Appendix 1 – Installation Vessel Profiles

THOR

Thor
Source: Hochtief

Vessel Name	Thor
Vessel Type	Jackup Barge
Status	Operational
Owner	Hochtief
Flag	Germany
Yard	Gdansk (Poland)
Year Built	2010
Length [m]	70
Breadth [m]	40
Max. Draft [m]	8.3
Max. Water Depth [m]	50
Cargo Area [m2]	1,850
Payload [t]	3,300
Main Crane Load [t@m]	500 t @ 20 m
Crane Height [m]	-
Speed [knots]	-
Jackup Legs	4
Accommodation [persons]	48
Dynamic Positioning System	None

Appendix 1 – Installation Vessel Profiles

ODIN

Odin during the Installation of the Alpha Ventus Transformer Station
Source: Hochtief

Vessel Name	Odin
Vessel Type	Jackup Barge
Status	Operational
Owner	Hochtief
Flag	Germany
Yard	Crist Gdynia (Poland)
Year Built	2004
Length [m]	46
Breadth [m]	30
Max. Draft [m]	5.5
Max. Water Depth [m]	35
Cargo Area [m2]	-
Payload [t]	900
Main Crane Load [t@m]	300 t @ 15 m
Crane Height [m]	-
Speed [knots]	-
Jackup Legs	4
Accommodation [persons]	40
Dynamic Positioning System	None
Known Offshore Wind Projects	Alpha Ventus (GER)

Odin is one of the construction platforms used for the early wind farm installations. Originally used for port and bridge construction; and the offshore oil and gas sector. The barge was retrofitted in 2009 for the offshore wind sector.

Appendix 1 – Installation Vessel Profiles

JB-114

JB-114
Source: MarineTraffic.com

Vessel Name	**JB-114**
Vessel Type	Jackup/Heavy Lift
Status	Operational
Owner	Jack-Up Barge
Flag	Bahamas
Yard	Labroy Shipping (Singapore)
Year Built	2009
Length [m]	56
Breadth [m]	32
Max. Draft [m]	3.0
Max. Water Depth [m]	40
Cargo Area [m2]	-
Payload [t]	1,250
Main Crane Load [t@m]	300 t @ 16 m
Crane Height [m]	-
Speed [knots]	-
Jackup Legs	4
Accommodation [persons]	-
Dynamic Positioning System	None
Known Offshore Wind Projects	Lincs (UK) Belwind (BEL)

Appendix 1 – Installation Vessel Profiles

JB-115

JB-115
Source: Ship Spotting

Vessel Name	JB-115
Vessel Type	Jackup/Heavy Lift
Status	Operational
Owner	Jack-Up Barge
Flag	Bahamas
Yard	Labroy Shipping (Singapore)
Year Built	2009
Length [m]	56
Breadth [m]	32
Max. Draft [m]	3.0
Max. Water Depth [m]	40
Cargo Area [m2]	-
Payload [t]	1,250
Main Crane Load [t@m]	300 t @ 16 m
Crane Height [m]	-
Speed [knots]	-
Jackup Legs	4
Accommodation [persons]	-
Dynamic Positioning System	None

Appendix 1 – Installation Vessel Profiles

JB-117

JB-117 Installing Turbines at the Bard Offshore 1 Wind Farm
Source: Heavyliftspecialist.com

Vessel Name	JB-117
Vessel Type	Jackup/Heavy Lift
Status	Operational
Owner	Jack-Up Barge
Flag	Bahamas
Yard	Labroy Shipping (Singapore)
Year Built	2011
Length [m]	76
Breadth [m]	40
Max. Draft [m]	3.9
Max. Water Depth [m]	45
Cargo Area [m2]	
Payload [t]	2,250
Main Crane Load [t@m]	1,000 t @ 22 m
Crane Height [m]	-
Speed [knots]	-
Jackup Legs	4
Accommodation [persons]	-
Dynamic Positioning System	None

Appendix 1 – Installation Vessel Profiles

TITAN 2

KS Drilling Titan 2
Source: Semco

Vessel Name	Titan 2
Vessel Type	Liftboat
Status	Operational
Owner	KS Drilling
Flag	Panama
Yard	Semco Shipyard Lafitte Louisiana (US)
Year Built	2007
Length [m]	52
Breadth [m]	35
Max. Draft [m]	2.9
Max. Water Depth [m]	40
Cargo Area [m2]	-
Payload [t]	-
Main Crane Load [t@m]	176 t @ 12 m
Crane Height [m]	-
Speed [knots]	7.0
Jackup Legs	3
Accommodation [persons]	-
Dynamic Positioning System	-
Known Offshore Wind Projects	Gunfleet Sands (UK)

Appendix 1 – Installation Vessel Profiles

LISA A

Lisa A
Source: MCI

Vessel Name	LISA A
Vessel Type	Jackup
Status	Operational
Owner	MCI
Flag	Panama
Yard	Kaiser Swan, Portland (US)
Year Built	1977/2007
Length [m]	73
Breadth [m]	40
Max. Draft [m]	4.0
Max. Water Depth [m]	33
Cargo Area [m2]	1,000
Payload [t]	950
Main Crane Load [t@m]	425 t @ 18 m
Crane Height [m]	80
Speed [knots]	-
Jackup Legs	4
Accommodation [persons]	40
Dynamic Positioning System	None
Known Offshore Wind Projects	Rhyl Flats (UK)

Appendix 1 – Installation Vessel Profiles

NORA

Nora
Source: Master Marine

Vessel Name	NORA
Vessel Type	Jackup
Status	Operational
Owner	Master Marine
Flag	Cyprus
Yard	Drydocks World Graha (Indonesia)
Year Built	2012
Length [m]	118
Breadth [m]	50
Max. Draft [m]	7.4
Max. Water Depth [m]	50
Cargo Area [m2]	2,500
Payload [t]	7,200
Main Crane Load [t@m]	750 t @ 29 m
Crane Height [m]	-
Speed [knots]	8.0
Jackup Legs	4
Accommodation [persons]	260
Dynamic Positioning System	DP 2

Originally a heavy lift vessel, the Nora was converted to a jackup TIV in 2012. Unlike the new generation purpose built TIVs, the Nora has been fit with 4 jackup legs.

Appendix 1 – Installation Vessel Profiles

MEB JB1

MEB JB1
Source: Heavyliftspecialist.com

JB-117 Installing Turbines at the Bard Offshore 1 Wind Farm
Source: Heavyliftspecialist.com

Vessel Name	JB1
Vessel Type	Jackup Barge
Status	Operational
Owner	Muhibbah Marine
Flag	Germany
Yard	HDW Howaldswerke (Germany)
Year Built	1960/1995
Length [m]	49
Breadth [m]	31
Max. Draft [m]	3.0
Max. Water Depth [m]	ca. 30
Cargo Area [m2]	748
Payload [t]	-
Main Crane Load [t@m]	272 t @ 14 m
Crane Height [m]	-
Speed [knots]	-
Jackup Legs	8
Accommodation [persons]	20/60
Dynamic Positioning System	GPS

Appendix 1 – Installation Vessel Profiles

VICTORIA MATHIAS

Victoria Mathias
Source: Hafenradar.de

Vessel Name	Victoria Mathias
Vessel Type	TIV
Status	Operational
Owner	RWE Innogy
Flag	Germany
Yard	Daewoo (South Korea)
Year Built	2011
Length [m]	100
Breadth [m]	40
Max. Draft [m]	4.5
Max. Water Depth [m]	40
Cargo Area [m2]	-
Payload [t]	4,200
Main Crane Load [t@m]	1,000 t @ 21 m
Crane Height [m]	110
Speed [knots]	7.5
Jackup Legs	4
Accommodation [persons]	60
Dynamic Positioning System	DP 2
Known Offshore Wind Projects	Nordsee Ost (GER)

Appendix 1 – Installation Vessel Profiles

FRIEDRICH-ERNESTINE

Friedrich-Ernestine
Source: Shipspotting.com

Vessel Name	Friedrich-Ernestine
Vessel Type	TIV
Status	Operational
Owner	RWE Innogy
Flag	Germany
Yard	Daewoo (South Korea)
Year Built	2012
Length [m]	109
Breadth [m]	40
Max. Draft [m]	-
Max. Water Depth [m]	40
Cargo Area [m2]	-
Payload [t]	4,200
Main Crane Load [t@m]	1,000 t @ 21 m
Crane Height [m]	110
Speed [knots]	6.4
Jackup Legs	4
Accommodation [persons]	60
Dynamic Positioning System	DP 2
Known Offshore Wind Projects	Gwynt y Mor (UK)

Appendix 1 – Installation Vessel Profiles

SEAJACKS KRAKEN

Seajacks Kraken
Source: Geograph.ie

Vessel Name	Seajacks Kraken
Vessel Type	TIV
Status	Operational
Owner	Seajacks
Flag	Panama
Yard	Lamprell (UAE)
Year Built	2009
Length [m]	76
Breadth [m]	36
Max. Draft [m]	3.7
Max. Water Depth [m]	41
Cargo Area [m2]	900
Payload [t]	1,550
Main Crane Load [t@m]	300 t @ 16 m
Crane Height [m]	-
Speed [knots]	8.0
Jackup Legs	4
Accommodation [persons]	90
Dynamic Positioning System	DP 2
Known Offshore Wind Projects	Walney 2 (UK)

Appendix 1 – Installation Vessel Profiles

SEAJACKS LEVIATHAN

Seajacks Leviathan
Source: Seajacks

Vessel Name	Seajacks Leviathan
Vessel Type	TIV
Status	Operational
Owner	Seajacks
Flag	Panama
Yard	Lamprell (UAE)
Year Built	2009
Length [m]	76
Breadth [m]	36
Max. Draft [m]	3.7
Max. Water Depth [m]	41
Cargo Area [m2]	900
Payload [t]	1,550
Main Crane Load [t@m]	300 t @ 16 m
Crane Height [m]	-
Speed [knots]	8.0
Jackup Legs	4
Accommodation [persons]	90
Dynamic Positioning System	DP 2
Known Offshore Wind Projects	Greater Gabbard (UK) Sheringham Shoal (UK)

The Greater Gabbard project was the first project completed by both the operator and the vessel. The vessel installed two turbines every 5 days. The 5 days included the three hour sail time from port to location and one day for loading. The vessel can carry two turbines at a time.

Appendix 1 – Installation Vessel Profiles

SEAJACKS ZARATAN

Seajacks Zaratan
Source: Worldmaritimenews.com

Vessel Name	Seajacks Zaratan
Vessel Type	TIV
Status	Operational
Owner	Seajacks
Flag	Panama
Yard	Lamprell (UAE)
Year Built	2012
Length [m]	81
Breadth [m]	41
Max. Draft [m]	5.3
Max. Water Depth [m]	55
Cargo Area [m2]	2,000
Payload [t]	3,350
Main Crane Load [t@m]	800 t @ 24 m
Crane Height [m]	-
Speed [knots]	9.1
Jackup Legs	4
Accommodation [persons]	90
Dynamic Positioning System	DP 2

Appendix 1 – Installation Vessel Profiles

PACIFIC ORCA

Pacific Orca
Source: Knud E. Hansen

Vessel Name	Pacific Orca
Vessel Type	TIV
Status	Operational
Owner	Swire Blue Ocean
Flag	Cyprus
Yard	Samsung H. I. (South Korea)
Year Built	2012
Length [m]	161
Breadth [m]	49
Max. Draft [m]	6.0
Max. Water Depth [m]	70
Cargo Area [m2]	4,300
Payload [t]	6,600
Main Crane Load [t@m]	1,200 t @ 31 m
Crane Height [m]	118
Speed [knots]	13.0
Jackup Legs	6
Accommodation [persons]	111
Dynamic Positioning System	DP 2

Appendix 1 – Installation Vessel Profiles

PACIFIC OSPREY

Pacific Osprey – Artist Impression
Source: Renewablesinternational.net

Vessel Name	Pacific Osprey
Vessel Type	TIV
Status	Operational
Owner	Swire Blue Ocean
Flag	Cyprus
Yard	Samsung H. I. (South Korea)
Year Built	2012
Length [m]	161
Breadth [m]	49
Max. Draft [m]	5.5
Max. Water Depth [m]	70
Cargo Area [m2]	4,300
Payload [t]	6,600
Main Crane Load [t@m]	1,200 t @ 31 m
Crane Height [m]	118
Speed [knots]	13.0
Jackup Legs	6
Accommodation [persons]	111
Dynamic Positioning System	DP 2

Appendix 1 – Installation Vessel Profiles

SEAFOX 7

Seafox 7
Source: Offshore.no

Seafox 7
Source: Shipspotting.com

Vessel Name	Seafox 7
Vessel Type	TIV
Status	Operational
Owner	Workfox
Flag	Isle of Man
Yard	Labroy Shipping (Singapore)
Year Built	2008
Length [m]	75
Breadth [m]	32
Max. Draft [m]	3.4
Max. Water Depth [m]	40
Cargo Area [m2]	700
Payload [t]	1,120
Main Crane Load [t@m]	280 t @ 22 m
Crane Height [m]	-
Speed [knots]	-
Jackup Legs	4
Accommodation [persons]	113
Dynamic Positioning System	None

Appendix 1 – Installation Vessel Profiles

SEAFOX 5

Seafox 5
Source: Heavyliftspecialist.com

Vessel Name	Seafox 5
Vessel Type	TIV
Status	Operational
Owner	Workfox
Flag	Isle of Man
Yard	Keppel Fels (Singapore)
Year Built	2012
Length [m]	151
Breadth [m]	50
Max. Draft [m]	10.9
Max. Water Depth [m]	65
Cargo Area [m2]	3,750
Payload [t]	6,500
Main Crane Load [t@m]	1,200 t @ 25 m
Crane Height [m]	-
Speed [knots]	10.0
Jackup Legs	4
Accommodation [persons]	150
Dynamic Positioning System	DP 2
Known Offshore Wind Projects	Dan Tysk (GER)

MPI RESOLUTION

MPI Resolution
Source: Shipspotting.com

Vessel Name	MPI Resolution
Vessel Type	TIV
Status	Operational
Owner	MPI / Vroon
Flag	Netherlands
Yard	Shanhaiguan (China)
Year Built	2003
Length [m]	130
Breadth [m]	38
Max. Draft [m]	4.3
Max. Water Depth [m]	35
Cargo Area [m2]	3,200
Payload [t]	4,875
Main Crane Load [t@m]	600 t @ 25 m
Crane Height [m]	95
Speed [knots]	11.0
Jackup Legs	6
Accommodation [persons]	70
Dynamic Positioning System	SDP-11
Known Offshore Wind Projects	Thanet (UK)

Appendix 1 – Installation Vessel Profiles

MPI ADVENTURE

MPI Adventure
Source: MPI

Vessel Name	MPI Adventure
Vessel Type	TIV
Status	Operational
Owner	MPI / Vroon
Flag	Netherlands
Yard	Cosco (China)
Year Built	2011
Length [m]	139
Breadth [m]	41
Max. Draft [m]	5.5
Max. Water Depth [m]	40
Cargo Area [m2]	3,600
Payload [t]	6,000
Main Crane Load [t@m]	1,000 t @ 26 m
Crane Height [m]	105
Speed [knots]	12.5
Jackup Legs	6
Accommodation [persons]	112
Dynamic Positioning System	DP 2
Known Offshore Wind Projects	London Array (UK)

Appendix 1 – Installation Vessel Profiles

MPI DISCOVERY

MPI Discovery
Source: Bws.dk

Vessel Name	MPI Discovery
Vessel Type	TIV
Status	Operational
Owner	MPI / Vroon
Flag	Netherlands
Yard	Cosco (China)
Year Built	2011
Length [m]	139
Breadth [m]	41
Max. Draft [m]	5.5
Max. Water Depth [m]	40
Cargo Area [m2]	3,600
Payload [t]	6,000
Main Crane Load [t@m]	1,000 t @ 26 m
Crane Height [m]	105
Speed [knots]	12.5
Jackup Legs	6
Accommodation [persons]	112
Dynamic Positioning System	DP 2
Known Offshore Wind Projects	London Array (UK)

Appendix 1 – Installation Vessel Profiles

RD MACDONALD

RD MacDonald
Source: Weeks Marine

RD MacDonald
Source: Weeks Marine

Vessel Name	RD MacDonald
Vessel Type	Jackup Barge
Status	Operational
Owner	Weeks Marine
Flag	US
Yard	BAE Systems Jacksonville, FL (US)
Year Built	2012
Length [m]	79
Breadth [m]	24
Max. Draft [m]	4.4
Max. Water Depth [m]	22
Cargo Area [m2]	955
Payload [t]	2,300
Main Crane Load [t@m]	680 t @ 43 m
Crane Height [m]	46
Speed [knots]	-
Jackup Legs	8
Accommodation [persons]	-
Dynamic Positioning System	-

Appendix 1 – Installation Vessel Profiles

BRAVE TERN

Brave Tern
Source: Shipspotting.com

Vessel Name	Brave Tern
Vessel Type	TIV
Status	Operational
Owner	Fred. Olsen Windcarrier
Flag	Malta
Yard	Lamprell (UAE)
Year Built	2012
Length [m]	132
Breadth [m]	39
Max. Draft [m]	6.0
Max. Water Depth [m]	45
Cargo Area [m2]	3,200
Payload [t]	5,300
Main Crane Load [t@m]	800 t @ 24 m
Crane Height [m]	102
Speed [knots]	12.0
Jackup Legs	4
Accommodation [persons]	80
Dynamic Positioning System	DP 2
Known Offshore Wind Projects	Borkum Riffgat (GER)

Appendix 1 – Installation Vessel Profiles

Under Construction TIVs and Jackup Vessels:

BOLD TERN

Bold Tern
Source: Offshorewind.biz

Bold Tern
Source: 4coffshore.com

Vessel Name	Bold Tern
Vessel Type	TIV
Status	Under construction
Owner	Fred. Olsen Windcarrier
Flag	Malta
Yard	Lamprell (UAE)
Year Built	2013
Length [m]	132
Breadth [m]	39
Max. Draft [m]	6.0
Max. Water Depth [m]	45
Cargo Area [m2]	3,200
Payload [t]	5,300
Main Crane Load [t@m]	800 t @ 24 m
Crane Height [m]	102
Speed [knots]	12.0
Jackup Legs	4
Accommodation [persons]	80
Dynamic Positioning System	DP 2

Appendix 1 – Installation Vessel Profiles

VIDAR

Vidar – Artist Impression
Source: Eworldship.com

Vidar – Artist Impression
Source: Worldmaritimenews.com

Vessel Name	Vidar
Vessel Type	TIV
Status	Under construction
Owner	Hochtief
Flag	Germany
Yard	Crist Gdynia (Poland)
Year Built	2013
Length [m]	137
Breadth [m]	41
Max. Draft [m]	6.3
Max. Water Depth [m]	50
Cargo Area [m2]	3,400
Payload [t]	6,500
Main Crane Load [t@m]	1,200 t @ 28 m
Crane Height [m]	-
Speed [knots]	10.0
Jackup Legs	4
Accommodation [persons]	90
Dynamic Positioning System	DP 2

Appendix 1 – Installation Vessel Profiles

AEOLUS

Aeolus – Artist Impression
Source: Maritime Journal

Vessel Name	Aeolus
Vessel Type	TIV
Status	Under construction
Owner	Van Oord
Flag	Netherlands
Yard	Sietas (Germany)
Year Built	2013
Length [m]	139
Breadth [m]	38
Max. Draft [m]	5.7
Max. Water Depth [m]	45
Cargo Area [m2]	-
Payload [t]	6,500
Main Crane Load [t@m]	900 t @ 30 m
Crane Height [m]	120
Speed [knots]	12.0
Jackup Legs	4
Accommodation [persons]	74
Dynamic Positioning System	DP 2

Appendix 1 – Installation Vessel Profiles

SEAJACKS HYDRA

Steel Cutting Ceremony at Lamprell's Hamriyah Facility in Dubai
Source: Offshorewind.biz

Vessel Name	Seajacks Hydra
Vessel Type	TIV
Status	Under construction
Owner	Seajacks
Flag	-
Yard	Lamprell (UAE)
Year Built	2014
Length [m]	-
Breadth [m]	-
Max. Draft [m]	-
Max. Water Depth [m]	48
Cargo Area [m2]	900
Payload [t]	3,350
Main Crane Load [t@m]	400 t
Crane Height [m]	-
Speed [knots]	-
Jackup Legs	4
Accommodation [persons]	90
Dynamic Positioning System	DP 2

Appendix 1 – Installation Vessel Profiles

WIND II

Wind II
Source: Offshorewind.biz

Vessel Name	Wind II
Vessel Type	TIV
Status	Under Construction
Owner	DBB Jack-Up Services
Flag	-
Yard	Nordic Yards (Germany)
Year Built	2014
Length [m]	80
Breadth [m]	32
Max. Draft [m]	-
Max. Water Depth [m]	45
Cargo Area [m2]	-
Payload [t]	-
Main Crane Load [t@m]	-
Crane Height [m]	-
Speed [knots]	-
Jackup Legs	4
Accommodation [persons]	-
Dynamic Positioning System	DP 2

Appendix 1 – Installation Vessel Profiles

INWIND INSTALLER

Inwind Installer – Artist Impression
Source: INWIND

Vessel Name	INWIND Installer
Vessel Type	TIV
Status	Concept
Owner	Inwind
Flag	-
Yard	-
Year Built	-
Length [m]	101
Breadth [m]	68
Max. Draft [m]	4.5
Max. Water Depth [m]	65
Cargo Area [m2]	3,500
Payload [t]	4,500
Main Crane Load [t@m]	1,200 t @ 25 m
Crane Height [m]	105
Speed [knots]	-
Jackup Legs	3
Accommodation [persons]	90
Dynamic Positioning System	DP 2

Appendix 1 – Installation Vessel Profiles

DEEPWATER INSTALLER

Deepwater Installer – Artist Impression
Source: Renewableenergyworld.com

Deepwater Installer – Artist Impression
Source: Gaoh Offshore

Vessel Name	Deepwater Installer
Vessel Type	TIV
Status	Concept
Owner	Gaoh Offshore
Flag	-
Yard	STX (South Korea)
Year Built	-
Length [m]	140
Breadth [m]	40
Max. Draft [m]	6.5
Max. Water Depth [m]	50
Cargo Area [m2]	6,000
Payload [t]	10,450
Main Crane Load [t@m]	1,600 t @ 20 m
Crane Height [m]	105
Speed [knots]	10.0
Jackup Legs	4
Accommodation [persons]	120
Dynamic Positioning System	DP 2

Appendix 1 – Installation Vessel Profiles

Heavy Lift Vessels Involved in Offshore Wind Operations

SVANEN

Ballast Nedam's *Svanen* Heavy Lift Vessel at the London Array Wind Farm Construction

Source: Londonarray.com

Vessel Name	Svanen
Vessel Type	Heavy Lift
Status	Operational
Owner	Ballast Nedam
Flag	Bahamas
Yard	Grootint (Netherlands)
Year Built	1990/1995
Length [m]	103
Breadth [m]	72
Max. Draft [m]	4.5
Max. Water Depth [m]	-
Cargo Area [m2]	-
Payload [t]	-
Main Crane Load [t@m]	8,200 t
Crane Height [m]	76
Speed [knots]	7.0
Jackup Legs	-
Accommodation [persons]	-
Dynamic Positioning System	None

Appendix 1 – Installation Vessel Profiles

STANISLAV YUDIN

Seaway Heavy Lifting's *Stanislav Yudin* Vessel
Source: Shipspotting.com

Vessel Name	Stanislav Yudin
Vessel Type	Heavy Lift
Status	Operational
Owner	Seaway Heavy Lifting
Flag	Cyprus
Yard	Wartsila (Finland)
Year Built	1985
Length [m]	183
Breadth [m]	36
Max. Draft [m]	8.9
Max. Water Depth [m]	-
Cargo Area [m2]	2,560
Payload [t]	5,000
Main Crane Load [t@m]	2,500 t
Crane Height [m]	78.3
Speed [knots]	12
Jackup Legs	-
Accommodation [persons]	143
Dynamic Positioning System	-

Appendix 1 – Installation Vessel Profiles

OLEG STRASHNOV

The *Oleg Strashnov* Heavy Lift Vessel
Source: Worldmaritimenews.com

Vessel Name	Oleg Strashnov
Vessel Type	Heavy Lift
Status	Operational
Owner	Seaway Heavy Lifting
Flag	Cyprus
Yard	IHC Merwede (Netherlands)
Year Built	2011
Length [m]	183
Breadth [m]	47
Max. Draft [m]	14
Max. Water Depth [m]	-
Cargo Area [m2]	4,000
Payload [t]	-
Main Crane Load [t@m]	5,000 t @ 32 m
Crane Height [m]	102
Speed [knots]	14
Jackup Legs	-
Accommodation [persons]	220
Dynamic Positioning System	DP 3

Appendix 1 – Installation Vessel Profiles

RAMBIZ

The Rambiz Heavy Lift Vessel at the Karehamn Wind Farm Construction
Source: Scaldis Salvage and Marine Contractors

Vessel Name	Rambiz
Vessel Type	Heavy Lift
Status	Operational
Owner	Scaldis SMC
Flag	Belgium
Yard	Huisman-Itrec Schiedam (Netherlands)
Year Built	1995/2000
Length [m]	85
Breadth [m]	44
Max. Draft [m]	3.6
Max. Water Depth [m]	-
Cargo Area [m2]	1,500
Payload [t]	-
Main Crane Load [t@m]	1,700 t
Crane Height [m]	79
Speed [knots]	6.1
Jackup Legs	-
Accommodation [persons]	70
Dynamic Positioning System	None

Appendix 1 – Installation Vessel Profiles

Operating Crane Barges in the US

CHESAPEAKE 1000

Chesapeake 1000
Source: Donjon Marine

Vessel Name	Chesapeake 1000
Vessel Type	Crane Barge
Status	Operational
Owner	Donjon Marine
Flag	US
Yard	
Year Built	1972
Length [m]	58
Breadth [m]	31
Max. Draft [m]	2.7
Max. Water Depth [m]	-
Cargo Area [m2]	1,860
Payload [t]	2,415
Main Crane Load [t@m]	907 t @ 19 m
Crane Height [m]	70 m boom length + 7.6 m jib boom
Speed [knots]	-
Jackup Legs	-
Accommodation [persons]	60
Dynamic Positioning System	-

Chesapeake 1000 is the largest capacity crane barge on the US East Coast; its home base is Port of NY/NJ. The vessel is equipped with a sheer leg derrick crane, which moves up and down, but cannot rotate. The vessel is ordinarily used for salvage operations and ship-to-dock or dock-to-ship transfers. The crane barge can be fitted with a hammer for monopile installation, although its owner company does not have one. Chesapeake 1000 appears to be a leading contender for the Block Island jacket installation.

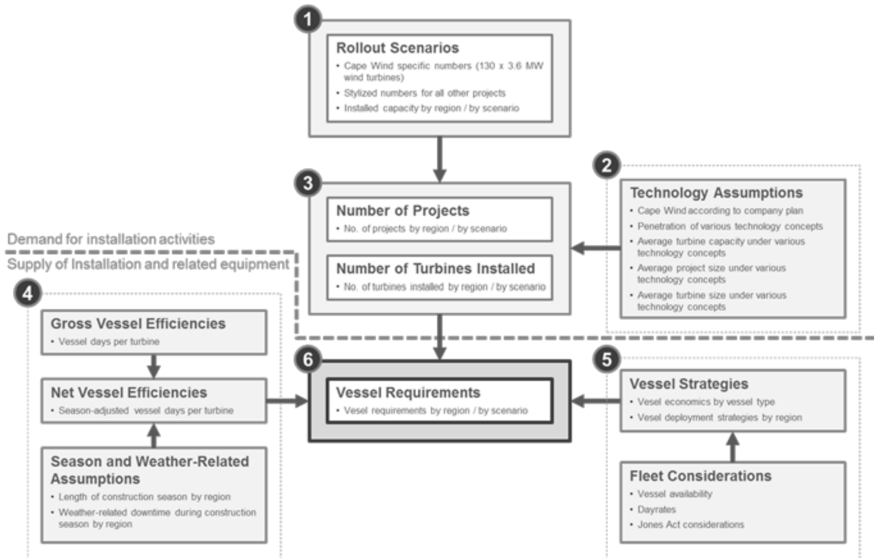
Appendix 1 – Installation Vessel Profiles

E.P. PAUP

E.P. Paup
Source: Manson Construction Co.

Vessel Name	E.P. Paup
Vessel Type	Crane Barge
Status	Operational
Owner	Manson Construction
Flag	US
Yard	Gunderson Marine Portland, OR (US)
Year Built	2009
Length [m]	116
Breadth [m]	32
Max. Draft [m]	3
Max. Water Depth [m]	-
Cargo Area [m2]	-
Payload [t]	-
Main Crane Load [t@m]	1,000 t
Crane Height [m]	64
Speed [knots]	-
Jackup Legs	-
Accommodation [persons]	156
Dynamic Positioning System	-

The E.P. Paup is a 1,000-ton derrick barge that was built to serve the oil & gas industry in the Gulf of Mexico. The vessel's primary purpose is the installation and removal of oil and gas platforms, but it may also participate in the construction of US offshore wind projects in the future. The barge was built by Gunderson Marine in Portland, Oregon in 2009. The E.P. Paup is not self-propelled; the vessel is towed from location to location by a tug, and uses a crew boat for personnel transfer.



Appendix 2

Modeling Assumptions

Appendix 2 – Modeling Assumptions

Modeling Logic

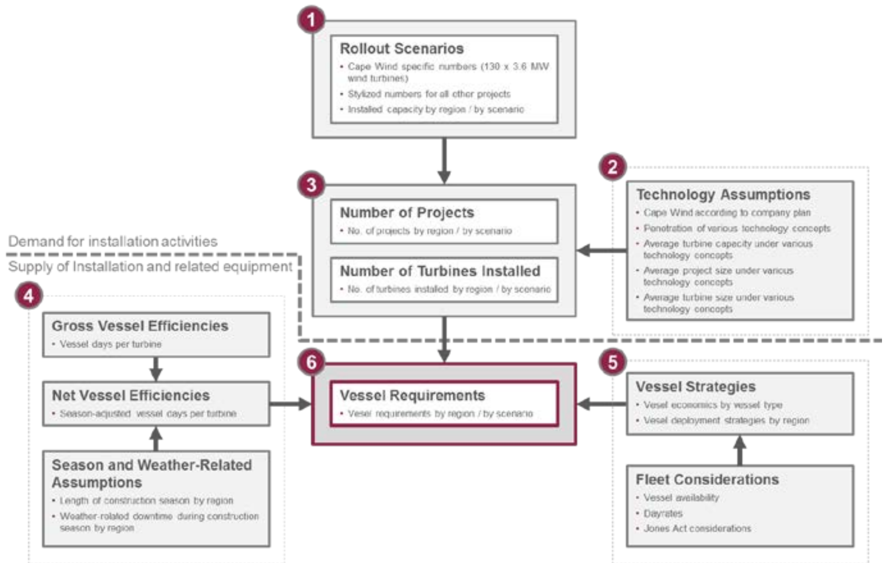


Figure 45: Overview of Vessel Demand Model
Source: Douglas-Westwood

Rollout scenarios

Deployment Scenarios		54GW by 2030 (HH) High Growth- High Tech Scenario		28GW by 2030 Moderate Growth with High Technology Adoption (MH)		10GW by 2030 - Low Growth - Low Tech Scenario (LL)	
		2020	2030	2020	2030	2020	2030
Total Capacity Deployed by Milestone Date (in GW)		7.0	54.0	3.5	28.0	1.0	10.0
Regional Distribution							
	Atlantic Coast	4.0	28.0	2.0	12.0	1.0	8.0
	Great Lakes	1.0	6.0	0.5	4.0	0.0	1.0
	Gulf Coast	1.0	5.0	0.5	4.0	0.0	1.0
	Pacific Coast	1.0	15.0	0.5	8.0	0.0	0.0

Table 21: Overview of Rollout Scenarios
Source: Douglas-Westwood, Department of Energy, NREL, Navigant

To develop our forecast, Douglas-Westwood, in conjunction with Navigant Consulting and the National Renewable Energy Laboratory (NREL) and in cooperation with the Department of Energy (DOE), established detailed rollout scenarios for four US offshore regions on the basis of DOE's headline offshore wind capacity targets in three distinct deployment scenarios.

Our scenarios are based on the rate of offshore wind technology deployment and on the advancement of offshore wind technology. The High Growth – High Technology (HH) scenario projects a 54 GW total installed capacity in the US by 2030, more than 50% of it in the Atlantic Coast. The Medium Growth – High Technology (MH) scenario foresees 28 GW of total installed offshore wind capacity by 2030, while the Low Growth – Low Technology (LL) scenario anticipates only 10 GW of cumulative capacity by 2030.

Based on these total capacities and average project/turbine sizes determined in conjunction with NREL, and by relying on our estimates on the penetration rate of various technology concepts (see 'Key Characteristics and Penetration Rate of Various Technology Concepts' section below), we calculated the total number of projects and turbines installed in all scenarios and regions.

Appendix 2 – Modeling Assumptions

Scenario Development

Rollout and development scenarios were stylized, informed by known projects, but smoothed over time. However, Cape Wind was modeled as a discreet project, as its parameters are largely known and fixed.

Cape Wind-Related Assumptions

As of the writing of this Report, Cape Wind foresaw a 2-year construction period beginning in 2014. In our model, the deployment of offshore wind capacities in the US begins in 2015. Therefore, our assumed start date of 2015 for the Cape Wind project differs from the start date indicated by the project's developer; however, this discrepancy is necessary to be consistent with our deployment scenarios. A stylized version of the Cape Wind project was employed in the model by adjusting its installation schedule to our rollout scenarios.

Our scenarios assume that the Cape Wind proceeds with the proposed 468 MW nameplate capacity in its planned location about 6 miles offshore in the Nantucket Sound. Cape Wind has indicated that it intends to proceed with the project even if power purchase agreements are limited to those already secured, notably for a capacity of 364 MW (101 turbines). It is important to note that our model does not take into account this lower case scenario for Cape Wind. Instead, we assume that the entire planned capacity will eventually be built in each scenario, albeit at different time horizons.

In our model, construction start for the Cape Wind project is expected in 2015 in all scenarios. In the High Growth – High Technology (HH) scenario, we assume that the project will be finished in just 2 years, with 50% of total capacity constructed in 2015, and 50% in 2016. There are also parallel projects running in both years in the Atlantic Coast in this scenario. In the Medium Growth – High Technology (MH) scenario, we assume that the Cape Wind Project will constitute all installed capacity in the Atlantic Coast in 2015 and 2016, and about 43% of total Atlantic Coast installed capacity in 2017. In the Low Growth – Low Technology (LL) scenario, we expect the Cape Wind project to constitute all installed capacity between 2015 and 2017 and 10.3% of total installed capacity in the Atlantic Coast in 2018.

We assume that all other offshore wind projects constructed in parallel with the Cape Wind project in the Atlantic Coast region in the 2015-2018 period will consist of 6 MW turbines. The amount of installed capacity in addition to Cape Wind is different in each scenario.

Cape Wind - Installed Capacity by Turbine Size									
		3.6 MW				6 MW			
		2015	2016	2017	2018	2015	2016	2017	2018
US	HH	234	234	0	0	266	391	950	1,225
	MH	150	200	118	0	100	100	357	600
	LL	150	150	150	18	0	0	0	157
AC	HH	234	234	0	0	66	166	600	750
	MH	150	200	118	0	0	0	157	350
	LL	150	150	150	18	0	0	0	157
GL	HH	0	0	0	0	50	75	125	200
	MH	0	0	0	0	50	50	75	75
	LL	0	0	0	0	0	0	0	0
GC	HH	0	0	0	0	150	150	175	175
	MH	0	0	0	0	50	50	75	75
	LL	0	0	0	0	0	0	0	0
PC	HH	0	0	0	0	0	0	50	100
	MH	0	0	0	0	0	0	50	100
	LL	0	0	0	0	0	0	0	0

Table 22: Cape Wind-Related Assumptions
Source: Douglas-Westwood

Key Characteristics and Penetration Rate of Various Technology Concepts

We assigned specific values for average turbine capacity and average project size within the ranges specified for Key Technology Concepts (developed in collaboration with NREL) under each scenario. The average project size will be 250 MW for Today's Standard Technology, 500 MW for the Next Generation Technology, 1,000 MW for Future Advanced Technology, 10 MW for 1st Generation (Pilot Scale) Floating Technology and 1,000 MW for 2nd Generation (Commercial Scale) Floating Technology in all scenarios and throughout all regions during the entire forecast period.

We assume some variation in the average turbine capacity under the different scenarios. We estimate that turbine capacity will average 3.6 MW in Today's Standard Technology and 6 MW in the Next Generation Technology in all scenarios and across all regions. Future Advanced Technology will see average turbine capacities of 10 MW in the HH and MH scenarios, but only 7 MW (the lower end of the NREL-specified range) in the LL scenario due to the lower level of technological progress in this scenario.

Appendix 2 – Modeling Assumptions

For 1st Generation Floating Technology, we expect turbine capacities to average 2 MW in the first two years of application (2017 and 2018) in the HH and MH scenarios, and 5 MW from 2019 onwards. In the LL scenario, we expect 1st Generation Floating Technology to be deployed only from 2021 and turbine capacities to remain at 2 MW through the period leading up to 2030. Turbine size for 2nd Generation Floating Technology is expected at 7 MW in the first year of deployment (2019) in both the HH and MH scenarios and at 10 MW from 2020 onwards. In the LL scenario, we do not expect 2nd Generation Floating Technology to develop at all.

Finally, we assume various penetration rates for each technology concept under each scenario varying by region. We assume that no offshore wind capacities will be installed in 2013 and 2014 under any scenarios in any of the surveyed regions.

In the Atlantic Coast, we assume that the Cape Wind project will be the only one using Today's Standard Technology (3.6 MW turbines), while other projects will be using Next Generation Technology (6 MW turbines) exclusively until 2020 in all scenarios. The HH and MH scenarios will see a gradual shift from Next Generation Technology to Future Advanced Technology between 2021 and 2025, and all offshore wind turbines will be using Future Advanced Technology from 2026 onwards. In the LL scenario, a gradual transition to Future Advanced Technology also begins in 2021, but the penetration of Future Advanced Technologies peaks at 50% in 2025, and Next Generation and Future Technologies will have 50-50% penetration rates in each year from 2026. We assumed that no floating technology will be deployed in the Atlantic Coast over the forecast period due to the higher costs of the technology and the widespread availability of locations with suitable water depths for fixed platform installation.

In the Great Lakes region, we expect all offshore wind capacities to represent Next Generation Technology (6 MW turbines) between 2015 and 2020. From 2021, we assume that the penetration rate of Next Generation Technologies will decrease to 80% in the HH and MH scenarios, with the remaining 20% equally split between Future Advanced Technologies and 1st Generation Floating Technologies between 2021 and 2025, and between Future Advanced Technologies and 2nd Generation Floating Technologies from 2026 onwards. In the LL scenario, we assume that Next Generation technologies will have 100% share from 2015 through the end of the forecast period.

In the Gulf Coast, we assume that Next Generation Technology will be the only deployed technology paradigm from 2015 through 2030 characterized by a 6MW average turbine capacity and 500 MW average turbine size.

In the Pacific Coast, we regard floating technologies as the only feasible technology concept for offshore wind development. In the HH and MH scenarios, we estimate 1st Generation Floating Technologies to have a 100% penetration rate in 2017 and 2018, a 50% share in 2019 and no application at all after 2020. In both high technology scenarios, we expect 2nd Generation Floating Technologies to appear in 2019 with a 50% penetration rate and maintain a 100% share in all installed capacity from 2020 through the end of our forecast period. In the LL scenario, we do not anticipate any offshore wind development in the Pacific Coast region.

Vessel efficiency assumptions

We assessed 12 generic vessel types in four categories (3 survey vessel types - environmental, geophysical and geotechnical survey vessels; 4 construction vessel types – jackups, TIVs, heavy lift vessels and cable-lay vessels; 3 types of service vessels – tugs, barges, supply vessels, and 2 generic O&M vessel types – smaller personnel transfer vessels and heavy maintenance vessels). We estimated turbine installation efficiencies for each phases of an offshore wind farm's lifecycle. Of these, the pre-construction phase consists of carrying out various necessary surveys, the construction phase is divided up to 4 sub-stages, namely foundation installation, transition piece installation, substation installation and cable laying operations. Construction vessels are assumed to operate one or more specific phases of construction, while service vessels are generally operating throughout the entire construction phase. The operation and maintenance (O&M) phase begins after the production start at the facility, and O&M vessels are expected to operate throughout the lifetime of a project.

We assumed various efficiency rates for turbine installation (measured in vessel days per annum per turbine or, in certain cases, as vessel days per annum per project) in each phases for various vessel types.

Survey Vessels

In the case of survey vessels used in the pre-construction phase, we assume that both environmental survey vessels and geophysical survey vessels can complete surveys that cover 200 turbines each year (after adjusting for seasonal and weather-related factors), while the net turbine efficiency rate for geotechnical survey vessels comes down to 180 turbines per year (given the more demanding nature of geotechnical surveys, including drilling into the seabed). This translates to a (net) per turbine vessel efficiency of 1.8 vessel days per turbine for environmental and geophysical survey vessels, and a 2.0 net vessel days per turbine for geotechnical survey vessels.

Appendix 2 – Modeling Assumptions

We assumed that separate vessels are required for all three types of surveys, (i.e. various surveys cannot be completed in parallel by using the same vessel for carrying out two or more types of surveys at once). This assumption is supported by the differing nature of the various types of surveys (e.g. a geotechnical survey requires extensive drilling into the seabed) and the various survey vessels' differing level of sophistication as well as their differing dayrates.

Construction Vessels

For the construction phase, we assumed that foundation installation, transition piece installation and turbine installation will be carried out by the same vessel type (either jackups or TIVs), which is typically the case in Northwest Europe. We assumed that heavy lift vessels are required to install the substations in all cases (although some smaller developments in Europe saw jackups performing the same task in the past), and specialized cable-lay vessels are used to install all associated cable work (including both array and export cables) at all offshore wind projects.

Foundation Installation

Based on our conversations with European installation companies, we assumed that foundation installation takes a net 2.5 vessel days per turbine in the case of the simpler monopile-type foundations (i.e. an installation vessel can install a net 12 monopiles each month after adjusting for season & weather-related factors), and net 2.8 vessel days per turbine for more sophisticated non-monopile type foundations (i.e. 10-11 non-monopile foundations per vessel per month). The share of monopile vs. non-monopile foundations is an exogenous input to our model, see the 'Installation-related Assumptions' section for further details.

Transition Piece Installation

For transition piece installation, we used a net 1.5 vessel days per turbine installation efficiency rate for both jackups and TIVs. This number is derived from empirical data from actual projects, even though a higher efficiency rate of 1 vessel day per transition piece is theoretically possible at current technological standards.

Turbine Installation

Turbine installation is assumed to be carried out either by jackup vessels or by TIVs. We developed three scenarios with differing assumptions on the share of Jackups vs. TIVs and on the origin of TIVs used in turbine installation. The relative share of jackups vs. TIVs in each scenario is manually inputted to our model (see 'Installation-related Assumptions' section for further details). Based on our consultations with installation companies, we used the same vessel efficiency rates for both jackups and TIVs for turbine installations, which were as follows:

Turbine size lower than 5 MW: 2.5 net vessel days per turbine (12 turbines per vessel per month) throughout the projection period.

Turbine size between 5-6 MW: 2.65 net vessel days per turbine (11 turbines per vessel per month) throughout the projection period.

Turbine size higher than 6 MW: 2.8 net vessel days per turbine (10.5 turbines per vessel per month) throughout the projection period.

There are different installation methods for turbines. We have made no specific assumptions as to whether turbines are installed in a so-called "bunny-ear" configuration, component-by-component or as a complete turbine.

The flat net turbine installation efficiency rates conceal an implicit efficiency improvement, as the average turbine size is constantly increasing throughout the projection period, thus installation vessels will be capable of installing an increasing amount of offshore wind capacity, but a constant number of increasingly larger turbines. This implicit efficiency improvement is consistent with our expectation for increasing vessel efficiency over time due to learning curve effects.

All efficiency rates for foundation, transition piece and turbine installation are annualized net numbers, meaning that no further weather and season-related adjustments were necessary.

Appendix 2 – Modeling Assumptions

The efficiency numbers for foundation, transition piece and turbine installation were derived from the experience gained by European operators in the North Sea. Our interviews with major installation companies suggest that the overall weather uptime coefficient is around 65% in the North Sea offshore wind region, and our efficiency numbers implicitly assume the same weather uptime for US offshore wind regions as well. US buoy data indicates that wave heights are generally more benign in the surveyed US regions than in the North Sea. If we consider only significant wave height as limiting factor (assuming that strong winds and high waves always coincide), then the weather uptime can be as high as 80% in the Atlantic Coast for a jackup vessel or a TIV. However, recent experience of US operators involved in geotechnical surveys in the Atlantic Coast suggests that a 65% operational weather window is in fact more realistic, if we consider other limiting factors, such as fog, as well.

Substation Installation

The installation of a substation is assumed to last 5 weeks, or 35 days net (we used the lower end of the range given by industry experts) for each project. A large 100 turbine project was used a basis for this estimation, but we used this efficiency number for all offshore wind projects uniformly. We also assumed that one substation is required for each 250 MW of installed offshore wind capacity, and that exclusively heavy lift vessels are used to perform this particular task. For the final heavy lift vessel requirement estimate, we also assumed that a certain proportion of these heavy lift vessels have to be chartered from the main offshore oil producing region in the US Gulf Coast (see the "Installation-related assumptions" section for more details).

Cable Laying Operations

For cable laying operations, we assumed that one array cable is needed for one turbine (even though different arrangements are also possible), and that one vessel day is required for the installation of each array cables. This efficiency rate is a somewhat conservative estimate (assuming simultaneous trenching of the cables); higher efficiency rates (i.e. fewer vessel days per turbine) are possible with simpler cable laying methods.

For export cable-laying, we assumed that an average wind farm will require 50 miles (80 km) of cable (i.e. the wind farm's distance from the interconnector is 50 miles) and that a cable-lay vessel can lay 5 miles (8 km) of export cable per day, thus 10 vessel days are required for each wind farm project. Furthermore, we assumed that one export cable is used for each 250 MW of installed offshore wind capacity (e.g. we expect a 1,000 MW project to require 4 export cables), and that a cable-lay vessel can carry the 50 miles of cable needed for an average project on a single run.

We calculated with a 25% weather related downtime in case of all cable-lay operations, but we made no further season-related adjustments, as we understand that cable-laying operations can be carried out in a relatively wide range of weather conditions (e.g. also during the winter months for limited periods) – see 'Season and weather-related assumptions' section for more details.

Service Vessels

In the service vessel category, we assumed that both jackup vessels and European-built TIVs (see 'Installation-related Assumptions' section for details on various installation scenarios) will operate by using one barge to supply the installation vessel with all necessary components for foundation, transition piece and turbine installation (i.e. both jackups and non-US built TIVs are operating in a one feeder barge system).

We assumed that 1 tug is required for each non-self-propelled jackup, TIV, heavy lift vessel and feeder barge. The share of non-self-propelled vessels in these categories are detailed in the 'Installation-related Assumptions' section. In addition, we assume that, on the Pacific Coast, tugs are used exclusively to "install" floating wind turbines by towing them from the port (where they are assembled) to their intended installation location. We calculate that 3 tugs are required for the installation of each floating turbine on the Pacific Coast, and that 1 turbine can be installed per day in this way. No additional weather-related factors were taken to consideration, as tugs are assumed to be readily available on a simple dayrate basis.

Appendix 2 – Modeling Assumptions

We assumed that one Supply Vessel is needed to service 10 turbines during the construction phase. This efficiency number is based on the specific efficiency given to personnel transfer vessels, and used uniformly to all supply vessels in the model.

Operation & Maintenance

For the O&M phase, we assumed that one personnel transfer vessel (PTV) is required for the maintenance of each 25 turbines throughout the entire year. We estimate that one larger repair vessel (capable of lifting large wind turbine components, e.g. an older generation jackup vessel) is required for each 1,000 MW of cumulative offshore wind capacity in the Atlantic Coast, in the Great Lakes and in the Gulf Coast regions. In the Pacific Coast, we assumed that no repair vessels will be needed, as offshore wind turbines installed on a floating platform can be towed into port for repair work. No season and weather-related factors were taken to account in this category. We did not factor in any decommissioning of offshore wind installations within the forecast period, assuming that the actual lifetime of large offshore wind turbines will be at least 25 years; therefore no decommissioning will be necessary in the 2015 to 2030 period, when actual installation takes place. As a result of this assumption, we applied O&M vessel requirements to the entire (cumulative) stock of offshore wind turbines throughout the projection period.

Season and weather-related assumptions

In the case of cable lay vessels, we applied a weather-related downtime coefficient, as our calculated turbine efficiency number is not a clean net number (i.e. it does not take into account season and weather-related factors). However, we made no season-related adjustments, as we understand that cable-laying operations can, to a varying degree, be carried out in all seasons (e.g. also during the winter months for limited periods). These are exogenous factors (i.e. manual inputs or independent variables) to our model.

Our turbine efficiency numbers for all other vessel categories are understood to be net numbers already taking to account season and weather-related factors.

Installation-related assumptions

We used a number of independent variables related to the installation of offshore wind projects. We set the share of non-monopile foundations as an exogenous input to our model, and used a 25% share for all regions, except for the Pacific Coast, where we only used floating turbines (and hence no fixed foundations) in our calculations, given the high water depths and the general lack of viability of monopile type foundations in this region. Based on our conversations with major installation companies, we conclude that monopile foundations will not likely disappear with the gradual increase of turbine size over time. The higher costs and technical challenges associated with other foundation types, particularly jackets, continue to put pressure on developers to seek new ways to use monopile foundations for bigger 6-7 MW turbines as well. Therefore, in our view, it is justified to expect monopile foundations to remain the predominant foundation type in the foreseeable future in all US offshore wind regions except for the Pacific Coast, where monopile foundations are not feasible.

We assumed that foundation installation, transition piece installation and turbine installation will be carried out by the same vessel type (either jackups or TIVs) in all scenarios throughout the entire projection period.

We developed three installation scenarios and determined the share of jackups vs. TIVs in each of these installation scenarios. In our first installation scenario, we assumed that US-built jackup vessels will install the majority of offshore wind turbines with the help of feeder barges that shuttle between the port and the installation site, supplying wind turbine components for the jackup vessel carrying out the installation work. In this scenario, we only foresee the application of some (US-built) TIVs after 2020 in the Atlantic Coast, where the US offshore wind industry will likely develop fastest.

In our second installation scenario, we assumed that purpose-built TIVs will spread faster in all regions, and that these vessels will be entirely built in the US. The penetration rate of (US-built) TIVs will be faster in the US Atlantic Coast in this scenario as well. TIVs will be carrying all foundation and transition pieces as well as the turbines on board, and thus will require no feeder barges in this scenario.

Appendix 2 – Modeling Assumptions

In the third scenario, we assumed the same, relatively high penetration rate of purpose-built TIVs vs. jackups, but we assumed that a portion of the TIVs used in the Atlantic Coast will be European-built (initially 100% will be European, gradually decreasing to 50% by 2023). We believe that the operation of European TIVs is not feasible in other regions. The Jones Act requires European TIVs to operate with the support of feeder barges, which transport all turbine components from US ports to the installation site. For other installation vessels (e.g. US-built TIVs and US-built jackups), we used the same assumptions as in the other two scenarios (i.e. US TIVs will carry turbine components themselves, while jackups will also require feeder barge support). We assumed that a one-way repositioning across the Atlantic takes 30 days (due to the relatively slow speed of large purpose-built TIVs), but we also assumed that European TIVs will only take the round trip once every year, and stay in the Atlantic coast during the entire construction season, if they are repositioned (i.e. they will not shuttle between Europe and the US for each project).

Some of the heavy lift vessels used for substation installation will have to be chartered from the Gulf of Mexico, where most of these vessels normally operate, servicing the offshore oil & gas industry. We assumed that 100% of heavy lift vessels in the Atlantic Coast and 50% if heavy lift vessel in the Pacific Coast will have to be dispatched from the Gulf Coast for each construction season. We anticipate, that the Great Lakes region will not be able to use heavy lift vessels operating in the Gulf of Mexico, as the width of an average heavy lift vessel exceeds the limit that the St. Lawrence Seaway can accommodate. We assume that all heavy lift vessels used for offshore wind installations in the US Gulf Coast will be contracted from those normally operating in the Gulf of Mexico, but we assumed that these will be readily available and calculated with zero distance/transit time when assessing their availability in the US Gulf Coast. For transferring heavy lift vessels from the Gulf Coast to the other regions, we calculated with rounded average shipping distances from Port Arthur, TX (i.e. 2,000 miles to the Atlantic Coast and 5,000 miles to the Pacific Coast), and we assumed a 14 miles per hour (16 knots) average speed for heavy lift vessels over these distances.

These approximate distances from the US Gulf Coast can be manually adjusted in our model, depending on where the focus of offshore wind operations is expected to be within a given region.

We also calculated with a minimum repositioning time that each construction and survey vessels require between two projects (i.e. return to its home port, fill up with fuel and load the necessary installation equipment). This is also an exogenous input to our model. We assumed that both construction and survey vessels require an additional 5 days between finishing one and starting another offshore wind project.

We also used exogenous inputs to our model to determine the number of tugs required under each region. We assumed that 50% of jackup vessels, 30% of TIVs, 50% of heavy lift vessels and 50% of feeder barges will be non-self-propelled, and thus require tugs for repositioning. These assumptions are based on our assessment of the existing installation vehicle fleet and on our conversations with installation vessel operators. We understand that at least half of the jackup vessels and feeder barges are self-propelled. The majority of purpose-built TIVs and heavy lift vessels are also self-propelled, but these vessels require, to varying degrees, tugs on the construction site to facilitate their positioning.

Douglas Westwood

Appendix 2 – Modeling Assumptions

Annual Installed Capacity (MW)																			
		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
US	HH	0	0	500	625	950	1,225	1,575	2,125	2,575	3,125	3,675	4,225	4,775	5,175	5,525	5,875	6,025	6,025
	MH	0	0	250	300	475	600	775	1,100	1,375	1,650	1,925	2,200	2,475	2,650	2,825	3,000	3,150	3,250
	LL	0	0	150	150	150	175	175	200	400	500	625	775	880	980	1,075	1,165	1,300	1,300
AC	HH	0	0	300	400	600	750	900	1,050	1,250	1,550	1,850	2,150	2,450	2,650	2,850	3,050	3,100	3,100
	MH	0	0	150	200	275	350	425	600	675	750	825	900	975	1,050	1,125	1,200	1,250	1,250
	LL	0	0	150	150	150	175	175	200	300	400	500	600	675	750	825	900	1,025	1,025
GL	HH	0	0	50	75	125	200	250	300	350	400	450	500	550	550	550	550	550	550
	MH	0	0	50	50	75	75	100	150	200	250	300	350	400	400	400	400	400	400
	LL	0	0	0	0	0	0	0	0	50	50	50	75	100	110	125	140	150	150
GC	HH	0	0	150	150	175	175	175	175	225	275	325	375	425	475	475	475	475	475
	MH	0	0	50	50	75	75	100	150	200	250	300	350	400	400	400	400	400	400
	LL	0	0	0	0	0	0	0	0	50	50	75	100	105	120	125	125	125	125
PC	HH	0	0	0	0	50	100	250	600	750	900	1,050	1,200	1,350	1,500	1,650	1,800	1,900	1,900
	MH	0	0	0	0	50	100	150	200	300	400	500	600	700	800	900	1,000	1,100	1,200
	LL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Average Turbine Size (MW)																			
		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
US	HH	0.0	0.0	4.9	5.1	5.8	5.7	6.0	7.1	7.6	8.0	8.4	8.8	9.2	9.3	9.3	9.4	9.4	9.4
	MH	0.0	0.0	4.6	4.4	5.0	5.3	6.0	6.7	7.3	7.7	8.1	8.4	8.8	8.9	9.0	9.0	9.1	9.1
	LL	0.0	0.0	3.6	3.6	3.6	5.8	6.0	6.0	6.1	6.2	6.2	6.3	6.4	6.4	6.4	6.4	6.4	6.4
AC	HH	0.0	0.0	4.1	4.6	6.0	6.0	6.0	6.0	6.8	7.6	8.4	9.2	10.0	10.0	10.0	10.0	10.0	10.0
	MH	0.0	0.0	3.6	3.6	5.0	6.0	6.0	6.0	6.8	7.6	8.4	9.2	10.0	10.0	10.0	10.0	10.0	10.0
	LL	0.0	0.0	3.6	3.6	3.6	5.8	6.0	6.0	6.1	6.2	6.3	6.4	6.5	6.5	6.5	6.5	6.5	6.5
GL	HH	0.0	0.0	6.0	6.0	6.0	6.0	6.0	6.0	6.3	6.3	6.3	6.3	6.3	6.8	6.8	6.8	6.8	6.8
	MH	0.0	0.0	6.0	6.0	6.0	6.0	6.0	6.0	6.3	6.3	6.3	6.3	6.3	6.8	6.8	6.8	6.8	6.8
	LL	0.0	0.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
GC	HH	0.0	0.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
	MH	0.0	0.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
	LL	0.0	0.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
PC	HH	0.0	0.0	0.0	0.0	2.0	2.0	6.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	MH	0.0	0.0	0.0	0.0	2.0	2.0	6.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	LL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Average Project Size (MW)																			
		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
US	HH	0	0	383	406	474	460	501	641	694	743	794	846	898	912	917	922	924	924
	MH	0	0	350	333	386	418	501	591	658	712	759	800	839	864	873	880	886	889
	LL	0	0	250	250	250	474	500	500	538	580	620	655	692	691	692	693	697	697
AC	HH	0	0	305	354	500	500	500	500	600	700	800	900	1,000	1,000	1,000	1,000	1,000	1,000
	MH	0	0	250	250	393	500	500	500	600	700	800	900	1,000	1,000	1,000	1,000	1,000	1,000
	LL	0	0	250	250	250	474	500	500	550	600	650	700	750	750	750	750	750	750
GL	HH	0	0	500	500	500	500	500	500	501	501	501	501	501	600	600	600	600	600
	MH	0	0	500	500	500	500	500	500	501	501	501	501	501	600	600	600	600	600
	LL	0	0	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
GC	HH	0	0	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
	MH	0	0	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
	LL	0	0	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
PC	HH	0	0	0	0	10	10	505	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
	MH	0	0	0	0	10	10	505	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
	LL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 23: Overview of Modeling Assumptions

Source: Douglas-Westwood

Appendix 2 – Modeling Assumptions

Number of Turbines Installed																			
		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
US	HH	0	0	103	123	164	216	263	298	339	391	438	480	518	557	592	627	641	641
	MH	0	0	55	68	95	113	129	164	188	213	237	260	283	297	315	332	347	357
	LL	0	0	42	42	42	30	29	33	66	81	100	123	138	154	168	182	203	203
AC	HH	0	0	73	87	100	125	150	175	184	204	220	234	245	265	285	305	310	310
	MH	0	0	42	56	55	58	71	100	99	99	98	98	98	105	113	120	125	125
	LL	0	0	42	42	42	30	29	33	49	65	79	94	104	115	127	138	158	158
GL	HH	0	0	8	13	21	33	42	50	56	63	71	79	87	81	81	81	81	81
	MH	0	0	8	8	13	13	17	25	32	40	48	56	63	59	59	59	59	59
	LL	0	0	0	0	0	0	0	0	8	8	8	13	17	18	21	23	25	25
GC	HH	0	0	25	25	29	29	29	29	38	46	54	63	71	79	79	79	79	79
	MH	0	0	8	8	13	13	17	25	33	42	50	58	67	67	67	67	67	67
	LL	0	0	0	0	0	0	0	0	8	8	13	17	18	20	21	21	21	21
PC	HH	0	0	0	0	25	50	42	60	75	90	105	120	135	150	165	180	190	190
	MH	0	0	0	0	25	50	25	20	30	40	50	60	70	80	90	100	110	120
	LL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Number of Projects																			
		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
US	HH	0.0	0.0	1.4	1.6	6.8	12.3	3.1	3.7	4.0	4.5	4.9	5.3	5.7	6.0	6.4	6.7	6.9	6.9
	MH	0.0	0.0	0.8	1.0	6.0	11.0	1.5	2.0	2.2	2.5	2.7	3.0	3.3	3.3	3.5	3.7	3.8	3.9
	LL	0.0	0.0	0.6	0.6	0.6	0.4	0.4	0.4	0.7	0.9	1.0	1.2	1.3	1.5	1.6	1.7	1.9	1.9
AC	HH	0.0	0.0	1.0	1.1	1.2	1.5	1.8	2.1	2.1	2.2	2.3	2.4	2.5	2.7	2.9	3.1	3.1	3.1
	MH	0.0	0.0	0.6	0.8	0.7	0.7	0.9	1.2	1.1	1.1	1.0	1.0	1.0	1.1	1.1	1.2	1.3	1.3
	LL	0.0	0.0	0.6	0.6	0.6	0.4	0.4	0.4	0.5	0.7	0.8	0.9	0.9	1.0	1.1	1.2	1.4	1.4
GL	HH	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	0.9	0.9	0.9	0.9	0.9
	MH	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.7	0.7	0.7	0.7	0.7
	LL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.3
GC	HH	0.0	0.0	0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.0	1.0	1.0	1.0
	MH	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.8	0.8	0.8	0.8	0.8
	LL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3
PC	HH	0.0	0.0	0.0	0.0	5.0	10.0	0.5	0.6	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8	1.9	1.9
	MH	0.0	0.0	0.0	0.0	5.0	10.0	0.3	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2
	LL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 23: Overview of Modeling Assumptions (continued)
Source: Douglas-Westwood

Appendix 2 – Modeling Assumptions

General Characteristics of Various Technology Concepts by Scenario																			
Average Turbine Capacity (MW)		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Today's Standard Technology	HH	0.0	0.0	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Next Generation Technology	HH	0.0	0.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Future Advanced Technology	HH	0.0	0.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
1st Generation Floating Technology*	HH	0.0	0.0	0.0	0.0	2.0	2.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
2nd Generation Floating Technology	HH	0.0	0.0	0.0	0.0	0.0	0.0	7.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Today's Standard Technology	MH	0.0	0.0	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Next Generation Technology	MH	0.0	0.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Future Advanced Technology	MH	0.0	0.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
1st Generation Floating Technology*	MH	0.0	0.0	0.0	0.0	2.0	2.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
2nd Generation Floating Technology	MH	0.0	0.0	0.0	0.0	0.0	0.0	7.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Today's Standard Technology	LL	0.0	0.0	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Next Generation Technology	LL	0.0	0.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Future Advanced Technology	LL	0.0	0.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
1st Generation Floating Technology*	LL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2nd Generation Floating Technology	LL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avg. Project Size (MW)		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Today's Standard Technology	HH	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250
Next Generation Technology	HH	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
Future Advanced Technology	HH	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
1st Generation Floating Technology*	HH	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
2nd Generation Floating Technology	HH	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Today's Standard Technology	MH	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250
Next Generation Technology	MH	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
Future Advanced Technology	MH	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
1st Generation Floating Technology*	MH	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
2nd Generation Floating Technology	MH	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Today's Standard Technology	LL	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250
Next Generation Technology	LL	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
Future Advanced Technology	LL	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
1st Generation Floating Technology*	LL	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
2nd Generation Floating Technology	LL	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000

Table 23: Overview of Modeling Assumptions (continued)
Source: Douglas-Westwood

Appendix 2 – Modeling Assumptions

Penetration Rate of Various Technology Concepts by Region and by Scenario																			
AC		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Today's Standard Technology	HH	0%	0%	78%	59%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Next Generation Technology	HH	0%	0%	22%	42%	100%	100%	100%	100%	80%	60%	40%	20%	0%	0%	0%	0%	0%	0%
Future Advanced Technology	HH	0%	0%	0%	0%	0%	0%	0%	0%	20%	40%	60%	80%	100%	100%	100%	100%	100%	100%
1st Generation Floating Technology*	HH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2nd Generation Floating Technology	HH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Today's Standard Technology	MH	0%	0%	100%	100%	43%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Next Generation Technology	MH	0%	0%	0%	0%	57%	100%	100%	100%	80%	60%	40%	20%	0%	0%	0%	0%	0%	0%
Future Advanced Technology	MH	0%	0%	0%	0%	0%	0%	0%	0%	20%	40%	60%	80%	100%	100%	100%	100%	100%	100%
1st Generation Floating Technology*	MH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2nd Generation Floating Technology	MH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Today's Standard Technology	LL	0%	0%	100%	100%	100%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Next Generation Technology	LL	0%	0%	0%	0%	0%	90%	100%	100%	90%	80%	70%	60%	50%	50%	50%	50%	50%	50%
Future Advanced Technology	LL	0%	0%	0%	0%	0%	0%	0%	0%	10%	20%	30%	40%	50%	50%	50%	50%	50%	50%
1st Generation Floating Technology*	LL	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2nd Generation Floating Technology	LL	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
GL		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Today's Standard Technology	HH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Next Generation Technology	HH	0%	0%	100%	100%	100%	100%	100%	100%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%
Future Advanced Technology	HH	0%	0%	0%	0%	0%	0%	0%	0%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
1st Generation Floating Technology*	HH	0%	0%	0%	0%	0%	0%	0%	0%	10%	10%	10%	10%	10%	0%	0%	0%	0%	0%
2nd Generation Floating Technology	HH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%	10%	10%	10%	10%
Today's Standard Technology	MH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Next Generation Technology	MH	0%	0%	100%	100%	100%	100%	100%	100%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%
Future Advanced Technology	MH	0%	0%	0%	0%	0%	0%	0%	0%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
1st Generation Floating Technology*	MH	0%	0%	0%	0%	0%	0%	0%	0%	10%	10%	10%	10%	10%	0%	0%	0%	0%	0%
2nd Generation Floating Technology	MH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%	10%	10%	10%	10%
Today's Standard Technology	LL	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Next Generation Technology	LL	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Future Advanced Technology	LL	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1st Generation Floating Technology*	LL	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2nd Generation Floating Technology	LL	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 23: Overview of Modeling Assumptions (continued)
Source: Douglas-Westwood

Appendix 2 – Modeling Assumptions

Penetration Rate of Various Technology Concepts by Region and by Scenario (continued)																			
GC		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Today's Standard Technology	HH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Next Generation Technology	HH	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Future Advanced Technology	HH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1st Generation Floating Technology*	HH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2nd Generation Floating Technology	HH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Today's Standard Technology	MH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Next Generation Technology	MH	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Future Advanced Technology	MH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1st Generation Floating Technology*	MH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2nd Generation Floating Technology	MH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Today's Standard Technology	LL	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Next Generation Technology	LL	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Future Advanced Technology	LL	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1st Generation Floating Technology*	LL	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2nd Generation Floating Technology	LL	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PC		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Today's Standard Technology	HH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Next Generation Technology	HH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Future Advanced Technology	HH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1st Generation Floating Technology*	HH	0%	0%	0%	0%	100%	100%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2nd Generation Floating Technology	HH	0%	0%	0%	0%	0%	0%	50%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Today's Standard Technology	MH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Next Generation Technology	MH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Future Advanced Technology	MH	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1st Generation Floating Technology*	MH	0%	0%	0%	0%	100%	100%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2nd Generation Floating Technology	MH	0%	0%	0%	0%	0%	0%	50%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Today's Standard Technology	LL	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Next Generation Technology	LL	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Future Advanced Technology	LL	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1st Generation Floating Technology*	LL	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2nd Generation Floating Technology	LL	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 23: Overview of Modeling Assumptions (continued)
Source: Douglas-Westwood

Appendix 2 – Modeling Assumptions

Vessel Efficiency Assumptions																			
Vessel days per turbine		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Pre-Construction Phase																			
Survey Vessels																			
Environmental Survey	net	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Geophysical Survey	net	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Geothechnical Survey	net	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Construction Phase																			
Construction Vessels																			
1. Foundation Installation																			
Jackup Vessels																			
Monopile	net	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Non-Monopile	net	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
TIVs																			
Monopile	net	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Non-Monopile	net	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
2. Transition Piece Installation																			
Jackup Vessels	net	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
TIVs	net	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
3. Turbine Installation (Annualized numbers)																			
Jackup Vessels																			
<5MW	net	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
5-6MW	net	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
>6MW	net	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
TIVs																			
<5MW	net	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
5-6MW	net	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
>6MW	net	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
4. Substation Installation																			
Heavy-lift Vessels (per project numbers!)	net	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
5. Cable laying																			
Cable-lay Vessels																			
Array	gross	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Export (per project numbers!)	gross	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Service Vessels																			
Tugs	net	One tug for each non-self propelled Jackup, TIV, Heavy-lift vessel and Barge - see Installation Assumptions for the share of non-self propelled vessels																	
Barges	net	One feeder barge for each jackup and for each European-built TIV																	
Supply Vessels	net	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5
O&M Phase																			
Operation & Mainenance Vessels																			
Personnel Transer Vessels	net	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
Heavy Maintenance Vessels	net	One repair vessel per each 1,000 MW installed																	

Table 23: Overview of Modeling Assumptions (continued)
Source: Douglas-Westwood

Appendix 2 – Modeling Assumptions

Construction Season-Related Assumptions		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Construction Season Length (days)		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
	AC	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270
	GL	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270
	GC	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270
	PC	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270
Construction Season Length (years)		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
	AC	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
	GL	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
	GC	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
	PC	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
Weather Downtime in Construction Season		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
	AC	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%
	GL	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%
	GC	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%
	PC	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%

Foundation Types		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
% of Non-Monopiles		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
	AC	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%
	GL	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%
	GC	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%
	PC	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Foundation/Transition Piece/Turbine Installation Method (% of Jackups vs. TIVs)		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
US Jackup (+ Feeder Barge) Scenario		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
	AC	100%	100%	100%	100%	100%	100%	100%	100%	75%	50%	50%	50%	50%	50%	50%	50%	50%	50%
	GL	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	GC	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	PC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
US TIV Scenario		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
	AC	100%	100%	100%	75%	75%	50%	50%	50%	50%	25%	25%	25%	25%	25%	25%	25%	25%	25%
	GL	100%	100%	100%	75%	75%	75%	75%	75%	75%	50%	50%	50%	50%	50%	50%	50%	50%	50%
	GC	100%	100%	100%	75%	75%	75%	75%	75%	75%	50%	50%	50%	50%	50%	50%	50%	50%	50%
	PC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
EU TIV (+Feeder Barge) Scenario		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
	AC	100%	100%	100%	75%	75%	50%	50%	50%	50%	25%	25%	25%	25%	25%	25%	25%	25%	25%
	GL	100%	100%	100%	75%	75%	75%	75%	75%	75%	50%	50%	50%	50%	50%	50%	50%	50%	50%
	GC	100%	100%	100%	75%	75%	75%	75%	75%	75%	50%	50%	50%	50%	50%	50%	50%	50%	50%
	PC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
% of European TIVs in total TIVs used		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
	AC	100%	100%	100%	100%	100%	100%	100%	100%	75%	75%	50%	50%	50%	50%	50%	50%	50%	50%
	GL	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	GC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	PC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Repositioning Time Required From Europe (days, one way)		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
	AC	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
	GL	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0
	GC	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
	PC	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0

Heavy-Lift Vessel Requirements		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
% of Heavy-Lift Vessels Chartered from USGC		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
	AC	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	GL	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	GC	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	PC	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
Distance from USGC (miles)		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
	AC	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
	GL	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
	GC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PC	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000

Table 23: Overview of Modeling Assumptions (continued)

Source: Douglas-Westwood

Appendix 2 – Modeling Assumptions

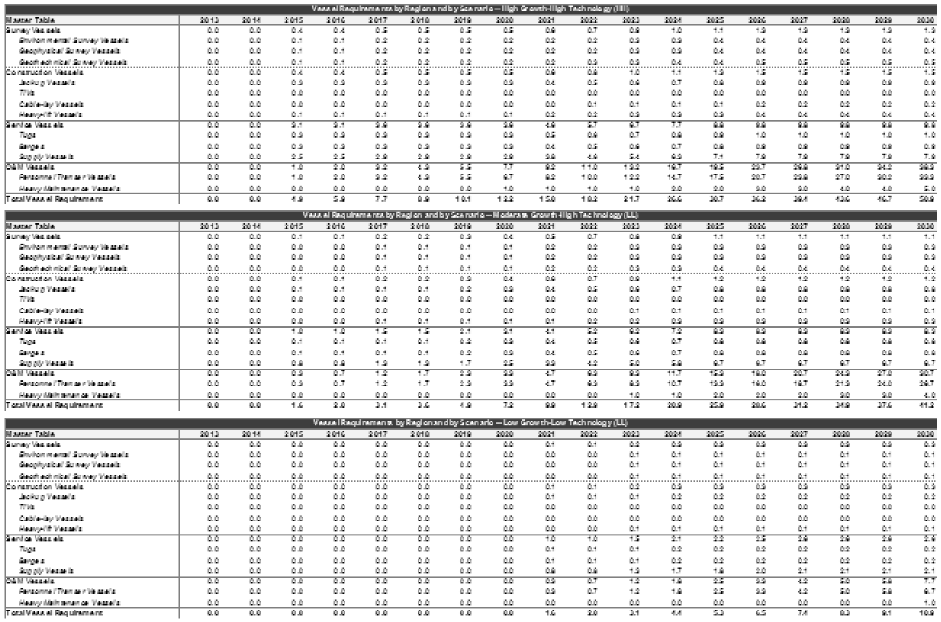
Downtime Between Projects

Min. Delay Btw. Projects (days)	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
AC	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
GL	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
GC	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
PC	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0

Tug Requirement Assumptions

% of Non-Self-Propelled Jackups	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
AC	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
GL	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
GC	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
PC	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
% of Non-Self-Propelled TIVs	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
AC	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%
GL	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%
GC	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%
PC	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%
% of Non-Self-Propelled Heavy-Lift Vessels	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
AC	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
GL	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
GC	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
PC	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
% of Non-Self-Propelled Feeder Barges	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
AC	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
GL	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
GC	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
PC	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%

Table 23: Overview of Modeling Assumptions (continued)
Source: Douglas-Westwood



Appendix 3

Detailed Modeling Results

Appendix 3 – Detailed Modeling Results

Vessel Requirements by Region and by Scenario -- High Growth-High Technology (HH)

Master Table	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Survey Vessels	0.0	0.0	1.7	2.0	3.0	4.2	4.2	5.0	5.6	6.5	7.2	7.9	8.6	9.2	9.8	10.3	10.5	10.5
Environmental Survey Vessels	0.0	0.0	0.5	0.6	1.0	1.4	1.4	1.6	1.8	2.1	2.3	2.6	2.8	3.0	3.1	3.3	3.4	3.4
Geophysical Survey Vessels	0.0	0.0	0.5	0.6	1.0	1.4	1.4	1.6	1.8	2.1	2.3	2.6	2.8	3.0	3.1	3.3	3.4	3.4
Geotechnical Survey Vessels	0.0	0.0	0.6	0.7	1.1	1.5	1.5	1.8	2.0	2.3	2.6	2.8	3.1	3.3	3.5	3.7	3.8	3.8
Construction Vessels	0.0	0.0	2.7	3.2	4.5	6.4	6.4	7.8	8.6	10.3	11.7	13.2	14.6	15.9	17.4	18.8	19.3	19.3
Jackup Vessels	0.0	0.0	2.0	2.3	2.8	3.5	4.2	4.8	4.4	4.0	4.5	4.9	5.4	5.6	5.8	6.0	6.0	6.0
TIVs	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	1.0	2.0	2.2	2.3	2.4	2.6	2.8	3.0	3.1	3.1
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.1	0.2	0.5	1.1	0.8	1.1	1.4	1.9	2.4	2.9	3.4	4.0	4.6	5.3	5.5	5.5
Heavy-lift Vessels	0.0	0.0	0.5	0.6	1.1	1.6	1.3	1.7	1.9	2.3	2.7	3.0	3.4	3.7	4.2	4.6	4.7	4.7
Service Vessels	0.0	0.0	14.7	17.2	23.7	31.8	35.4	42.1	45.6	50.7	56.8	62.6	68.1	72.7	77.0	81.4	83.3	83.3
Tugs	0.0	0.0	2.1	2.5	3.3	4.5	4.9	5.9	6.0	6.3	7.2	8.1	8.9	9.6	10.3	11.0	11.3	11.3
Barges	0.0	0.0	2.0	2.3	2.8	3.5	4.2	4.8	4.4	4.0	4.5	4.9	5.4	5.6	5.8	6.0	6.0	6.0
Supply Vessels	0.0	0.0	10.6	12.5	17.5	23.8	26.3	31.4	35.2	40.3	45.1	49.6	53.8	57.5	61.0	64.5	66.0	66.0
O&M Vessels	0.0	0.0	4.2	9.2	17.2	27.7	38.2	54.8	69.9	87.0	108.0	130.9	156.4	182.4	210.8	240.6	271.0	303.4
Personnel Transer Vessels	0.0	0.0	4.2	9.2	16.2	25.7	36.2	48.8	62.9	79.0	97.0	116.9	138.4	161.4	185.8	211.6	238.0	264.4
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	1.0	2.0	2.0	6.0	7.0	8.0	11.0	14.0	18.0	21.0	25.0	29.0	33.0	39.0
Total Vessel Requirement	**0.0**	**0.0**	**23.3**	**31.6**	**48.4**	**70.2**	**84.2**	**109.7**	**129.7**	**154.4**	**183.8**	**214.5**	**247.7**	**280.2**	**314.9**	**351.2**	**384.1**	**416.5**

Vessel Requirements by Region and by Scenario -- Moderate Growth-High Technology (LL)

Master Table	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Survey Vessels	0.0	0.0	0.9	1.2	1.9	2.5	2.1	2.7	3.1	3.5	3.9	4.3	4.8	5.0	5.2	5.5	5.8	5.9
Environmental Survey Vessels	0.0	0.0	0.3	0.4	0.6	0.8	0.7	0.9	1.0	1.1	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.9
Geophysical Survey Vessels	0.0	0.0	0.3	0.4	0.6	0.8	0.7	0.9	1.0	1.1	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.9
Geotechnical Survey Vessels	0.0	0.0	0.3	0.4	0.7	0.9	0.7	1.0	1.1	1.3	1.4	1.6	1.7	1.8	1.9	2.0	2.1	2.1
Construction Vessels	0.0	0.0	1.4	1.8	2.6	3.4	2.8	4.1	4.5	5.0	5.6	6.1	6.7	7.0	7.3	7.7	8.1	8.2
Jackup Vessels	0.0	0.0	1.1	1.3	1.5	1.6	2.0	2.8	2.6	2.5	2.8	3.1	3.4	3.4	3.5	3.5	3.6	3.6
TIVs	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.5	1.0	1.0	1.0	1.0	1.1	1.1	1.2	1.3	1.3
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.1	0.3	0.7	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.1	1.2	1.3	1.4
Heavy-lift Vessels	0.0	0.0	0.3	0.3	0.7	1.1	0.6	0.8	0.9	1.0	1.2	1.3	1.5	1.6	1.7	1.8	1.9	2.0
Service Vessels	0.0	0.0	8.0	10.0	13.9	17.3	17.2	23.0	25.3	27.9	31.2	34.5	37.9	39.3	41.3	43.4	45.1	46.3
Tugs	0.0	0.0	1.1	1.4	1.9	2.4	2.3	3.2	3.3	3.4	3.8	4.2	4.7	4.8	5.1	5.3	5.5	5.7
Barges	0.0	0.0	1.1	1.3	1.5	1.6	2.0	2.8	2.6	2.5	2.8	3.1	3.4	3.4	3.5	3.5	3.6	3.6
Supply Vessels	0.0	0.0	5.8	7.2	10.5	13.3	12.9	17.0	19.4	22.0	24.6	27.2	29.8	31.0	32.8	34.5	36.0	37.0
O&M Vessels	0.0	0.0	2.3	5.2	9.4	14.8	20.9	28.7	36.5	46.3	59.1	71.0	85.9	99.3	113.5	130.3	145.7	164.5
Personnel Transer Vessels	0.0	0.0	2.3	5.2	9.4	14.8	19.9	26.7	34.5	43.3	53.1	64.0	75.9	88.3	101.5	115.3	129.7	144.5
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	2.0	3.0	6.0	7.0	10.0	11.0	12.0	15.0	16.0	20.0
Total Vessel Requirement	**0.0**	**0.0**	**12.7**	**18.1**	**27.8**	**38.0**	**43.0**	**58.6**	**69.5**	**82.7**	**99.8**	**116.0**	**135.2**	**150.5**	**167.4**	**186.9**	**204.7**	**224.9**

Vessel Requirements by Region and by Scenario -- Low Growth-Low Technology (LL)

Master Table	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Survey Vessels	0.0	0.0	0.7	0.7	0.7	0.5	0.5	0.5	1.1	1.3	1.6	2.0	2.2	2.5	2.7	2.9	3.2	3.2
Environmental Survey Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.9	1.0	1.0
Geophysical Survey Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.9	1.0	1.0
Geotechnical Survey Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.0	1.2	1.2
Construction Vessels	0.0	0.0	1.0	1.0	1.0	0.8	0.7	0.8	1.6	2.0	2.5	3.2	3.6	4.0	4.4	4.9	5.5	5.5
Jackup Vessels	0.0	0.0	0.8	0.8	0.8	0.6	0.6	0.6	1.0	0.9	1.2	1.5	1.6	1.8	2.0	2.2	2.4	2.4
TIVs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.5
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.6	0.6
Heavy-lift Vessels	0.0	0.0	0.2	0.2	0.2	0.1	0.1	0.1	0.3	0.4	0.4	0.6	0.6	0.7	0.8	0.9	1.0	1.0
Service Vessels	0.0	0.0	5.7	5.7	5.7	4.2	4.0	4.6	8.7	10.2	12.6	15.6	17.5	19.5	21.4	23.2	25.9	25.9
Tugs	0.0	0.0	0.8	0.8	0.8	0.6	0.6	0.7	1.1	1.2	1.5	1.8	2.1	2.3	2.6	2.8	3.1	3.1
Barges	0.0	0.0	0.8	0.8	0.8	0.6	0.6	0.6	1.0	0.9	1.2	1.5	1.6	1.8	2.0	2.2	2.4	2.4
Supply Vessels	0.0	0.0	4.2	4.2	4.2	3.0	2.9	3.3	6.6	8.1	10.0	12.3	13.8	15.4	16.9	18.3	20.4	20.4
O&M Vessels	0.0	0.0	1.7	3.3	5.0	6.2	7.4	9.7	12.4	15.6	20.6	25.5	32.0	39.2	46.9	54.2	63.4	75.5
Personnel Transer Vessels	0.0	0.0	1.7	3.3	5.0	6.2	7.4	8.7	11.4	14.6	18.6	23.5	29.0	35.2	41.9	49.2	57.4	65.5
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	2.0	2.0	3.0	4.0	5.0	5.0	6.0	10.0
Total Vessel Requirement	**0.0**	**0.0**	**9.1**	**10.8**	**12.4**	**11.7**	**12.6**	**15.7**	**23.8**	**29.2**	**37.4**	**46.2**	**55.3**	**65.2**	**75.5**	**85.2**	**98.0**	**110.2**

Table 24: Modeling Results – US Total – US Jackup Strategy

Annualized vessel equivalent numbers

Appendix 3 – Detailed Modeling Results

Vessel Requirements by Region and by Scenario -- High Growth-High Technology (HH)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	1.7	2.0	3.0	4.2	4.2	5.0	5.6	6.5	7.2	7.9	8.6	9.2	9.8	10.3	10.5	10.5
Environmental Survey Vessels	0.0	0.0	0.5	0.6	1.0	1.4	1.4	1.6	1.8	2.1	2.3	2.6	2.8	3.0	3.1	3.3	3.4	3.4
Geophysical Survey Vessels	0.0	0.0	0.5	0.6	1.0	1.4	1.4	1.6	1.8	2.1	2.3	2.6	2.8	3.0	3.1	3.3	3.4	3.4
Geotechnical Survey Vessels	0.0	0.0	0.6	0.7	1.1	1.5	1.5	1.8	2.0	2.3	2.6	2.8	3.1	3.3	3.5	3.7	3.8	3.8
Construction Vessels	0.0	0.0	2.7	3.2	4.5	6.4	6.4	7.8	8.6	10.3	11.7	13.2	14.6	15.9	17.4	18.8	19.3	19.3
Jackup Vessels	0.0	0.0	2.0	1.8	2.1	2.1	2.5	2.8	3.1	2.1	2.3	2.6	2.8	2.9	3.0	3.1	3.1	3.1
TIVs	0.0	0.0	0.1	0.6	0.8	1.5	1.8	2.1	2.3	4.0	4.4	4.7	5.0	5.3	5.6	5.9	6.0	6.0
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.1	0.2	0.5	1.1	0.8	1.1	1.4	1.9	2.4	2.9	3.4	4.0	4.6	5.3	5.5	5.5
Heavy-lift Vessels	0.0	0.0	0.5	0.6	1.1	1.6	1.3	1.7	1.9	2.3	2.7	3.0	3.4	3.7	4.2	4.6	4.7	4.7
Service Vessels	0.0	0.0	14.7	16.3	22.5	29.4	32.5	38.8	43.4	47.4	53.1	58.5	63.7	68.1	72.3	76.5	78.3	78.3
Tugs	0.0	0.0	2.1	2.1	2.9	3.5	3.7	4.5	5.1	5.0	5.7	6.4	7.1	7.7	8.3	9.0	9.2	9.2
Barges	0.0	0.0	2.0	1.8	2.1	2.1	2.5	2.8	3.1	2.1	2.3	2.6	2.8	2.9	3.0	3.1	3.1	3.1
Supply Vessels	0.0	0.0	10.6	12.5	17.5	23.8	26.3	31.4	35.2	40.3	45.1	49.6	53.8	57.5	61.0	64.5	66.0	66.0
O&M Vessels	0.0	0.0	4.2	9.2	17.2	27.7	38.2	54.8	69.9	87.0	108.0	130.9	156.4	182.4	210.8	240.6	271.0	303.4
Personnel Transer Vessels	0.0	0.0	4.2	9.2	16.2	25.7	36.2	48.8	62.9	79.0	97.0	116.9	138.4	161.4	185.8	211.6	238.0	264.4
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	1.0	2.0	2.0	6.0	7.0	8.0	11.0	14.0	18.0	21.0	25.0	29.0	33.0	39.0
Total Vessel Requirement	**0.0**	**0.0**	**23.3**	**30.7**	**47.3**	**67.7**	**81.3**	**106.4**	**127.5**	**151.1**	**180.1**	**210.4**	**243.3**	**275.6**	**310.2**	**346.3**	**379.2**	**411.6**

Vessel Requirements by Region and by Scenario -- Moderate Growth-High Technology (LL)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.9	1.2	1.9	2.5	2.1	2.7	3.1	3.5	3.9	4.3	4.8	5.0	5.2	5.5	5.8	5.9
Environmental Survey Vessels	0.0	0.0	0.3	0.4	0.6	0.8	0.7	0.9	1.0	1.1	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.9
Geophysical Survey Vessels	0.0	0.0	0.3	0.4	0.6	0.8	0.7	0.9	1.0	1.1	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.9
Geotechnical Survey Vessels	0.0	0.0	0.3	0.4	0.7	0.9	0.7	1.0	1.1	1.3	1.4	1.6	1.7	1.8	1.9	2.0	2.1	2.1
Construction Vessels	0.0	0.0	1.4	1.8	2.6	3.4	2.8	4.1	4.5	5.0	5.6	6.1	6.7	7.0	7.3	7.7	8.1	8.2
Jackup Vessels	0.0	0.0	1.1	1.0	1.1	0.9	1.2	1.7	1.9	1.3	1.4	1.6	1.8	1.7	1.8	1.8	1.8	1.8
TIVs	0.0	0.0	0.0	0.4	0.4	0.7	0.9	1.2	1.3	2.2	2.3	2.5	2.7	2.7	2.8	2.9	3.0	3.0
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.1	0.3	0.7	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.1	1.2	1.3	1.4
Heavy-lift Vessels	0.0	0.0	0.3	0.3	0.7	1.1	0.6	0.8	0.9	1.0	1.2	1.3	1.5	1.6	1.7	1.8	1.9	2.0
Service Vessels	0.0	0.0	8.0	9.4	13.3	16.2	15.8	21.1	24.1	25.8	28.9	32.0	35.1	36.5	38.5	40.5	42.2	43.3
Tugs	0.0	0.0	1.1	1.2	1.6	1.9	1.7	2.4	2.7	2.5	2.9	3.2	3.5	3.7	3.9	4.1	4.3	4.4
Barges	0.0	0.0	1.1	1.0	1.1	0.9	1.2	1.7	1.9	1.3	1.4	1.6	1.8	1.7	1.8	1.8	1.8	1.8
Supply Vessels	0.0	0.0	5.8	7.2	10.5	13.3	12.9	17.0	19.4	22.0	24.6	27.2	29.8	31.0	32.8	34.5	36.0	37.0
O&M Vessels	0.0	0.0	2.3	5.2	9.4	14.8	20.9	28.7	36.5	46.3	59.1	71.0	85.9	99.3	113.5	130.3	145.7	164.5
Personnel Transer Vessels	0.0	0.0	2.3	5.2	9.4	14.8	19.9	26.7	34.5	43.3	53.1	64.0	75.9	88.3	101.5	115.3	129.7	144.5
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	2.0	3.0	6.0	7.0	10.0	11.0	12.0	15.0	16.0	20.0
Total Vessel Requirement	**0.0**	**0.0**	**12.7**	**17.6**	**27.2**	**36.9**	**41.6**	**56.6**	**68.2**	**80.6**	**97.5**	**113.5**	**132.4**	**147.8**	**164.5**	**184.0**	**201.7**	**222.0**

Vessel Requirements by Region and by Scenario -- Low Growth-Low Technology (LL)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.7	0.7	0.7	0.5	0.5	0.5	1.1	1.3	1.6	2.0	2.2	2.5	2.7	2.9	3.2	3.2
Environmental Survey Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.9	1.0	1.0
Geophysical Survey Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.9	1.0	1.0
Geotechnical Survey Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.0	1.2	1.2
Construction Vessels	0.0	0.0	1.0	1.0	1.0	0.8	0.7	0.8	1.6	2.0	2.5	3.2	3.6	4.0	4.4	4.9	5.5	5.5
Jackup Vessels	0.0	0.0	0.8	0.6	0.6	0.3	0.3	0.3	0.7	0.5	0.6	0.8	0.8	0.9	1.0	1.1	1.2	1.2
TIVs	0.0	0.0	0.0	0.2	0.2	0.3	0.3	0.3	0.6	1.1	1.3	1.6	1.8	2.0	2.2	2.4	2.7	2.7
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.6	0.6
Heavy-lift Vessels	0.0	0.0	0.2	0.2	0.2	0.1	0.1	0.1	0.3	0.4	0.4	0.6	0.6	0.7	0.8	0.9	1.0	1.0
Service Vessels	0.0	0.0	5.7	5.4	5.4	3.7	3.6	4.1	8.2	9.5	11.7	14.4	16.2	18.0	19.8	21.4	23.9	23.9
Tugs	0.0	0.0	0.8	0.7	0.7	0.4	0.4	0.4	0.9	0.9	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.3
Barges	0.0	0.0	0.8	0.6	0.6	0.3	0.3	0.3	0.7	0.5	0.6	0.8	0.8	0.9	1.0	1.1	1.2	1.2
Supply Vessels	0.0	0.0	4.2	4.2	4.2	3.0	2.9	3.3	6.6	8.1	10.0	12.3	13.8	15.4	16.9	18.3	20.4	20.4
O&M Vessels	0.0	0.0	1.7	3.3	5.0	6.2	7.4	9.7	12.4	15.6	20.6	25.5	32.0	39.2	46.9	54.2	63.4	75.5
Personnel Transer Vessels	0.0	0.0	1.7	3.3	5.0	6.2	7.4	8.7	11.4	14.6	18.6	23.5	29.0	35.2	41.9	49.2	57.4	65.5
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	2.0	2.0	3.0	4.0	5.0	5.0	6.0	10.0
Total Vessel Requirement	**0.0**	**0.0**	**9.1**	**10.5**	**12.1**	**11.2**	**12.2**	**15.2**	**23.3**	**28.4**	**36.4**	**45.0**	**54.0**	**63.7**	**73.9**	**83.4**	**96.1**	**108.2**

Table 25: Modeling Results – US Total – US TIV Strategy

Annualized vessel equivalent numbers

Appendix 3 – Detailed Modeling Results

Vessel Requirements by Region and by Scenario -- High Growth-High Technology (HH)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	1.7	2.0	3.0	4.2	4.2	5.0	5.6	6.5	7.2	7.9	8.6	9.2	9.8	10.3	10.5	10.5
Environmental Survey Vessels	0.0	0.0	0.5	0.6	1.0	1.4	1.4	1.6	1.8	2.1	2.3	2.6	2.8	3.0	3.1	3.3	3.4	3.4
Geophysical Survey Vessels	0.0	0.0	0.5	0.6	1.0	1.4	1.4	1.6	1.8	2.1	2.3	2.6	2.8	3.0	3.1	3.3	3.4	3.4
Geotechnical Survey Vessels	0.0	0.0	0.6	0.7	1.1	1.5	1.5	1.8	2.0	2.3	2.6	2.8	3.1	3.3	3.5	3.7	3.8	3.8
Construction Vessels	0.0	0.0	3.1	3.6	5.0	6.8	6.8	8.2	8.9	10.6	11.9	13.4	14.8	16.1	17.5	19.0	19.5	19.5
Jackup Vessels	0.0	0.0	2.0	1.8	2.1	2.1	2.5	2.8	3.1	2.1	2.3	2.6	2.8	2.9	3.0	3.1	3.1	3.1
TIVs	0.0	0.0	0.5	1.1	1.2	2.0	2.2	2.5	2.6	4.3	4.6	4.9	5.2	5.5	5.8	6.1	6.1	6.1
of which European	0.0	0.0	0.5	0.9	1.0	1.6	1.9	2.1	1.6	2.4	1.7	1.8	1.8	2.0	2.1	2.3	2.3	2.3
Cable-lay Vessels	0.0	0.0	0.1	0.2	0.5	1.1	0.8	1.1	1.4	1.9	2.4	2.9	3.4	4.0	4.6	5.3	5.5	5.5
Heavy-lift Vessels	0.0	0.0	0.5	0.6	1.1	1.6	1.3	1.7	1.9	2.3	2.7	3.0	3.4	3.7	4.2	4.6	4.7	4.7
Service Vessels	0.0	0.0	15.5	17.7	24.1	32.0	35.4	42.0	45.8	51.1	55.7	61.2	66.5	71.1	75.5	80.0	81.8	81.8
Tugs	0.0	0.0	2.5	2.6	3.5	4.5	4.8	5.7	6.0	6.3	6.6	7.3	8.1	8.8	9.4	10.1	10.4	10.4
Barges	0.0	0.0	2.5	2.6	3.1	3.8	4.3	4.9	4.7	4.5	4.0	4.3	4.6	4.9	5.1	5.3	5.4	5.4
Supply Vessels	0.0	0.0	10.6	12.5	17.5	23.8	26.3	31.4	35.2	40.3	45.1	49.6	53.8	57.5	61.0	64.5	66.0	66.0
O&M Vessels	0.0	0.0	4.2	9.2	17.2	27.7	38.2	54.8	69.9	87.0	108.0	130.9	156.4	182.4	210.8	240.6	271.0	303.4
Personnel Transer Vessels	0.0	0.0	4.2	9.2	16.2	25.7	36.2	48.8	62.9	79.0	97.0	116.9	138.4	161.4	185.8	211.6	238.0	264.4
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	1.0	2.0	2.0	6.0	7.0	8.0	11.0	14.0	18.0	21.0	25.0	29.0	33.0	39.0
Total Vessel Requirement	**0.0**	**0.0**	**24.6**	**32.6**	**49.3**	**70.7**	**84.6**	**110.0**	**130.3**	**155.1**	**182.8**	**213.3**	**246.3**	**278.8**	**313.6**	**349.9**	**382.8**	**415.2**
Vessel Requirements by Region and by Scenario -- Moderate Growth-High Technology (LL)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.9	1.2	1.9	2.5	2.1	2.7	3.1	3.5	3.9	4.3	4.8	5.0	5.2	5.5	5.8	5.9
Environmental Survey Vessels	0.0	0.0	0.3	0.4	0.6	0.8	0.7	0.9	1.0	1.1	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.9
Geophysical Survey Vessels	0.0	0.0	0.3	0.4	0.6	0.8	0.7	0.9	1.0	1.1	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.9
Geotechnical Survey Vessels	0.0	0.0	0.3	0.4	0.7	0.9	0.7	1.0	1.1	1.3	1.4	1.6	1.7	1.8	1.9	2.0	2.1	2.1
Construction Vessels	0.0	0.0	1.9	2.2	3.0	3.9	3.3	4.5	4.8	5.3	5.8	6.4	6.9	7.2	7.6	8.0	8.3	8.4
Jackup Vessels	0.0	0.0	1.1	1.0	1.1	0.9	1.2	1.7	1.9	1.3	1.4	1.6	1.8	1.7	1.8	1.8	1.8	1.8
TIVs	0.0	0.0	0.5	0.8	0.9	1.2	1.3	1.7	1.6	2.5	2.6	2.7	2.9	2.9	3.0	3.1	3.2	3.2
of which European	0.0	0.0	0.5	0.7	0.7	1.0	1.1	1.4	1.0	1.3	0.8	0.8	0.8	0.9	0.9	1.0	1.0	1.0
Cable-lay Vessels	0.0	0.0	0.0	0.1	0.3	0.7	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.1	1.2	1.3	1.4
Heavy-lift Vessels	0.0	0.0	0.3	0.3	0.7	1.1	0.6	0.8	0.9	1.0	1.2	1.3	1.5	1.6	1.7	1.8	1.9	2.0
Service Vessels	0.0	0.0	8.9	10.7	14.5	17.8	17.7	23.3	25.6	27.9	30.2	33.2	36.3	37.8	39.9	42.0	43.8	44.9
Tugs	0.0	0.0	1.5	1.7	2.1	2.6	2.4	3.2	3.3	3.3	3.3	3.7	4.0	4.2	4.4	4.7	4.9	5.0
Barges	0.0	0.0	1.6	1.8	1.9	2.0	2.3	3.1	2.9	2.6	2.3	2.4	2.6	2.6	2.7	2.8	2.8	2.8
Supply Vessels	0.0	0.0	5.8	7.2	10.5	13.3	12.9	17.0	19.4	22.0	24.6	27.2	29.8	31.0	32.8	34.5	36.0	37.0
O&M Vessels	0.0	0.0	2.3	5.2	9.4	14.8	20.9	28.7	36.5	46.3	59.1	71.0	85.9	99.3	113.5	130.3	145.7	164.5
Personnel Transer Vessels	0.0	0.0	2.3	5.2	9.4	14.8	19.9	26.7	34.5	43.3	53.1	64.0	75.9	88.3	101.5	115.3	129.7	144.5
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	2.0	3.0	6.0	7.0	10.0	11.0	12.0	15.0	16.0	20.0
Total Vessel Requirement	**0.0**	**0.0**	**14.1**	**19.3**	**28.9**	**39.0**	**43.9**	**59.3**	**70.1**	**83.1**	**99.1**	**115.0**	**134.0**	**149.3**	**166.2**	**185.8**	**203.5**	**223.8**
Vessel Requirements by Region and by Scenario -- Low Growth-Low Technology (LL)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.7	0.7	0.7	0.5	0.5	0.5	1.1	1.3	1.6	2.0	2.2	2.5	2.7	2.9	3.2	3.2
Environmental Survey Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.9	1.0	1.0
Geophysical Survey Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.9	1.0	1.0
Geotechnical Survey Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.0	1.2	1.2
Construction Vessels	0.0	0.0	1.5	1.5	1.5	1.2	1.2	1.3	2.0	2.4	2.8	3.4	3.8	4.2	4.7	5.1	5.8	5.8
Jackup Vessels	0.0	0.0	0.8	0.6	0.6	0.3	0.3	0.3	0.7	0.5	0.6	0.8	0.8	0.9	1.0	1.1	1.2	1.2
TIVs	0.0	0.0	0.5	0.7	0.7	0.8	0.8	0.8	0.9	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.9	2.9
of which European	0.0	0.0	0.5	0.7	0.7	0.8	0.8	0.8	0.6	1.0	0.7	0.8	0.9	0.9	1.0	1.1	1.2	1.2
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.6	0.6
Heavy-lift Vessels	0.0	0.0	0.2	0.2	0.2	0.1	0.1	0.1	0.3	0.4	0.4	0.6	0.6	0.7	0.8	0.9	1.0	1.0
Service Vessels	0.0	0.0	6.6	6.6	6.6	5.0	4.9	5.4	9.3	11.0	12.8	15.6	17.5	19.5	21.4	23.1	25.8	25.8
Tugs	0.0	0.0	1.2	1.2	1.2	0.9	0.9	1.0	1.3	1.4	1.5	1.8	2.0	2.2	2.5	2.7	3.0	3.0
Barges	0.0	0.0	1.3	1.3	1.3	1.1	1.0	1.1	1.3	1.4	1.3	1.5	1.7	1.9	2.0	2.2	2.5	2.5
Supply Vessels	0.0	0.0	4.2	4.2	4.2	3.0	2.9	3.3	6.6	8.1	10.0	12.3	13.8	15.4	16.9	18.3	20.4	20.4
O&M Vessels	0.0	0.0	1.7	3.3	5.0	6.2	7.4	9.7	12.4	15.6	20.6	25.5	32.0	39.2	46.9	54.2	63.4	75.5
Personnel Transer Vessels	0.0	0.0	1.7	3.3	5.0	6.2	7.4	8.7	11.4	14.6	18.6	23.5	29.0	35.2	41.9	49.2	57.4	65.5
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	2.0	2.0	3.0	4.0	5.0	5.0	6.0	10.0
Total Vessel Requirement	**0.0**	**0.0**	**10.5**	**12.1**	**13.8**	**13.0**	**13.9**	**17.0**	**24.7**	**30.3**	**37.8**	**46.5**	**55.5**	**65.3**	**75.7**	**85.4**	**98.2**	**110.3**

Table 26: Modeling Results – US Total – EU TIV Strategy

Annualized vessel equivalent numbers

Appendix 3 – Detailed Modeling Results

Vessel Requirements by Region and by Scenario -- High Growth-High Technology (HH)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	1.2	1.4	1.6	2.0	2.4	2.8	2.9	3.3	3.5	3.7	3.9	4.2	4.6	4.9	4.9	4.9
Environmental Survey Vessels	0.0	0.0	0.4	0.5	0.5	0.6	0.8	0.9	0.9	1.1	1.1	1.2	1.3	1.4	1.5	1.6	1.6	1.6
Geophysical Survey Vessels	0.0	0.0	0.4	0.5	0.5	0.6	0.8	0.9	0.9	1.1	1.1	1.2	1.3	1.4	1.5	1.6	1.6	1.6
Geotechnical Survey Vessels	0.0	0.0	0.4	0.5	0.6	0.7	0.9	1.0	1.0	1.2	1.3	1.3	1.4	1.5	1.6	1.7	1.8	1.8
Construction Vessels	0.0	0.0	1.9	2.3	2.8	3.5	4.4	5.3	5.7	6.6	7.4	8.2	8.9	9.9	11.0	12.1	12.4	12.4
Jackup Vessels	0.0	0.0	1.3	1.6	1.9	2.4	2.8	3.3	2.6	2.0	2.1	2.3	2.4	2.6	2.7	2.9	3.0	3.0
TIVs	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.9	2.0	2.1	2.3	2.4	2.6	2.7	2.9	3.0	3.0
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.1	0.2	0.3	0.5	0.7	0.9	1.0	1.4	1.7	2.0	2.3	2.7	3.2	3.6	3.7	3.7
Heavy-lift Vessels	0.0	0.0	0.4	0.4	0.5	0.6	0.8	1.1	1.1	1.3	1.5	1.7	1.8	2.1	2.3	2.6	2.6	2.6
Service Vessels	0.0	0.0	10.0	12.0	13.9	17.5	21.0	24.6	24.4	25.6	27.7	29.6	31.1	33.7	36.4	39.1	39.7	39.7
Tugs	0.0	0.0	1.4	1.7	2.1	2.6	3.2	3.8	3.4	3.2	3.6	3.9	4.2	4.7	5.1	5.6	5.7	5.7
Barges	0.0	0.0	1.3	1.6	1.9	2.4	2.8	3.3	2.6	2.0	2.1	2.3	2.4	2.6	2.7	2.9	3.0	3.0
Supply Vessels	0.0	0.0	7.3	8.7	10.0	12.5	15.0	17.5	18.4	20.4	22.0	23.4	24.5	26.5	28.5	30.5	31.0	31.0
O&M Vessels	0.0	0.0	2.9	6.4	11.4	17.4	23.4	32.4	40.7	49.9	60.7	72.1	84.9	97.5	111.9	127.1	142.5	158.9
Personnel Transer Vessels	0.0	0.0	2.9	6.4	10.4	15.4	21.4	28.4	35.7	43.9	52.7	62.1	71.9	82.5	93.9	106.1	118.5	130.9
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	1.0	2.0	2.0	4.0	5.0	6.0	8.0	10.0	13.0	15.0	18.0	21.0	24.0	28.0
Total Vessel Requirement	**0.0**	**0.0**	**16.0**	**22.1**	**29.7**	**40.4**	**51.2**	**65.1**	**73.8**	**85.4**	**99.4**	**113.5**	**128.7**	**145.3**	**163.8**	**183.1**	**199.5**	**215.9**

Vessel Requirements by Region and by Scenario -- Moderate Growth-High Technology (LL)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.7	0.9	0.9	0.9	1.1	1.6	1.6	1.6	1.6	1.6	1.6	1.7	1.8	1.9	2.0	2.0
Environmental Survey Vessels	0.0	0.0	0.2	0.3	0.3	0.3	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
Geophysical Survey Vessels	0.0	0.0	0.2	0.3	0.3	0.3	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
Geotechnical Survey Vessels	0.0	0.0	0.2	0.3	0.3	0.3	0.4	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7
Construction Vessels	0.0	0.0	1.0	1.4	1.4	1.5	1.9	2.8	2.7	2.7	2.8	2.8	2.8	3.1	3.3	3.6	3.7	3.7
Jackup Vessels	0.0	0.0	0.8	1.0	1.0	1.1	1.3	1.9	1.4	1.0	0.9	0.9	0.9	1.0	1.1	1.2	1.2	1.2
TIVs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.0	0.9	0.9	0.9	1.0	1.1	1.2	1.2	1.2
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.6	0.6	0.6
Heavy-lift Vessels	0.0	0.0	0.2	0.2	0.3	0.3	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.7	0.7	0.7
Service Vessels	0.0	0.0	5.7	7.7	7.6	8.1	9.9	13.9	13.1	12.2	12.2	12.1	12.1	13.0	14.0	14.9	15.6	15.6
Tugs	0.0	0.0	0.8	1.1	1.1	1.2	1.4	2.1	1.7	1.4	1.4	1.4	1.4	1.5	1.7	1.8	1.9	1.9
Barges	0.0	0.0	0.8	1.0	1.0	1.1	1.3	1.9	1.4	1.0	0.9	0.9	0.9	1.0	1.1	1.2	1.2	1.2
Supply Vessels	0.0	0.0	4.2	5.6	5.5	5.8	7.1	10.0	9.9	9.9	9.8	9.8	9.8	10.5	11.3	12.0	12.5	12.5
O&M Vessels	0.0	0.0	1.7	3.9	6.1	8.4	12.3	17.3	21.2	26.2	31.1	36.0	40.9	46.1	51.6	57.4	63.4	70.4
Personnel Transer Vessels	0.0	0.0	1.7	3.9	6.1	8.4	11.3	15.3	19.2	23.2	27.1	31.0	34.9	39.1	43.6	48.4	53.4	58.4
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	12.0
Total Vessel Requirement	**0.0**	**0.0**	**9.1**	**13.8**	**16.0**	**19.0**	**25.1**	**35.6**	**38.6**	**42.7**	**47.6**	**52.5**	**57.4**	**63.9**	**70.7**	**77.8**	**84.7**	**91.7**

Vessel Requirements by Region and by Scenario -- Low Growth-Low Technology (LL)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.7	0.7	0.7	0.5	0.5	0.5	0.8	1.0	1.3	1.5	1.7	1.8	2.0	2.2	2.5	2.5
Environmental Survey Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8
Geophysical Survey Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8
Geotechnical Survey Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9	0.9
Construction Vessels	0.0	0.0	1.0	1.0	1.0	0.8	0.7	0.8	1.2	1.7	2.0	2.5	2.7	3.1	3.4	3.8	4.4	4.4
Jackup Vessels	0.0	0.0	0.8	0.8	0.8	0.6	0.6	0.6	0.7	0.6	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.5
TIVs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.5
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.4	0.6	0.6
Heavy-lift Vessels	0.0	0.0	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.8	0.8
Service Vessels	0.0	0.0	5.7	5.7	5.7	4.2	4.0	4.6	6.4	7.9	9.8	11.5	12.8	14.2	15.7	17.1	19.5	19.5
Tugs	0.0	0.0	0.8	0.8	0.8	0.6	0.6	0.7	0.8	0.9	1.1	1.3	1.4	1.6	1.8	1.9	2.2	2.2
Barges	0.0	0.0	0.8	0.8	0.8	0.6	0.6	0.6	0.7	0.6	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.5
Supply Vessels	0.0	0.0	4.2	4.2	4.2	3.0	2.9	3.3	4.9	6.5	7.9	9.4	10.4	11.5	12.7	13.8	15.8	15.8
O&M Vessels	0.0	0.0	1.7	3.3	5.0	6.2	7.4	9.7	11.7	14.3	18.4	22.2	27.3	33.0	39.0	44.6	51.9	60.2
Personnel Transer Vessels	0.0	0.0	1.7	3.3	5.0	6.2	7.4	8.7	10.7	13.3	16.4	20.2	24.3	29.0	34.0	39.6	45.9	52.2
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	2.0	2.0	3.0	4.0	5.0	5.0	6.0	8.0
Total Vessel Requirement	**0.0**	**0.0**	**9.1**	**10.8**	**12.4**	**11.7**	**12.6**	**15.7**	**20.2**	**24.9**	**31.5**	**37.7**	**44.5**	**52.1**	**60.2**	**67.7**	**78.3**	**86.6**

Table 27: Modeling Results – Atlantic Coast – US Jackup Strategy

Annualized vessel equivalent numbers

Appendix 3 – Detailed Modeling Results

Vessel Requirements by Region and by Scenario -- High Growth-High Technology (HH)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	1.2	1.4	1.6	2.0	2.4	2.8	2.9	3.3	3.5	3.7	3.9	4.2	4.6	4.9	4.9	4.9
Environmental Survey Vessels	0.0	0.0	0.4	0.5	0.5	0.6	0.8	0.9	0.9	1.1	1.1	1.2	1.3	1.4	1.5	1.6	1.6	1.6
Geophysical Survey Vessels	0.0	0.0	0.4	0.5	0.5	0.6	0.8	0.9	0.9	1.1	1.1	1.2	1.3	1.4	1.5	1.6	1.6	1.6
Geothechnical Survey Vessels	0.0	0.0	0.4	0.5	0.6	0.7	0.9	1.0	1.0	1.2	1.3	1.3	1.4	1.5	1.6	1.7	1.8	1.8
Construction Vessels	0.0	0.0	1.9	2.3	2.8	3.5	4.4	5.3	5.7	6.6	7.4	8.2	8.9	9.9	11.0	12.1	12.4	12.4
Jackup Vessels	0.0	0.0	1.3	1.2	1.4	1.2	1.5	1.7	1.8	1.0	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.6
TIVs	0.0	0.0	0.0	0.4	0.5	1.2	1.5	1.7	1.8	2.9	3.1	3.3	3.5	3.8	4.1	4.3	4.4	4.4
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.1	0.2	0.3	0.5	0.7	0.9	1.0	1.4	1.7	2.0	2.3	2.7	3.2	3.6	3.7	3.7
Heavy-lift Vessels	0.0	0.0	0.4	0.4	0.5	0.6	0.8	1.1	1.1	1.3	1.5	1.7	1.8	2.1	2.3	2.6	2.6	2.6
Service Vessels	0.0	0.0	10.0	11.4	13.2	15.5	18.7	21.8	23.0	24.0	26.0	27.7	29.2	31.7	34.2	36.7	37.3	37.3
Tugs	0.0	0.0	1.4	1.4	1.7	1.8	2.2	2.6	2.8	2.6	2.9	3.2	3.4	3.8	4.2	4.6	4.7	4.7
Barges	0.0	0.0	1.3	1.2	1.4	1.2	1.5	1.7	1.8	1.0	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.6
Supply Vessels	0.0	0.0	7.3	8.7	10.0	12.5	15.0	17.5	18.4	20.4	22.0	23.4	24.5	26.5	28.5	30.5	31.0	31.0
O&M Vessels	0.0	0.0	2.9	6.4	11.4	17.4	23.4	32.4	40.7	49.9	60.7	72.1	84.9	97.5	111.9	127.1	142.5	158.9
Personnel Transer Vessels	0.0	0.0	2.9	6.4	10.4	15.4	21.4	28.4	35.7	43.9	52.7	62.1	71.9	82.5	93.9	106.1	118.5	130.9
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	1.0	2.0	2.0	4.0	5.0	6.0	8.0	10.0	13.0	15.0	18.0	21.0	24.0	28.0
Total Vessel Requirement	**0.0**	**0.0**	**16.0**	**21.4**	**28.9**	**38.4**	**48.9**	**62.4**	**72.3**	**83.8**	**97.7**	**111.7**	**126.8**	**143.3**	**161.5**	**180.7**	**197.1**	**213.5**
Vessel Requirements by Region and by Scenario -- Moderate Growth-High Technology (LL)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.7	0.9	0.9	0.9	1.1	1.6	1.6	1.6	1.6	1.6	1.6	1.7	1.8	1.9	2.0	2.0
Environmental Survey Vessels	0.0	0.0	0.2	0.3	0.3	0.3	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
Geophysical Survey Vessels	0.0	0.0	0.2	0.3	0.3	0.3	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
Geothechnical Survey Vessels	0.0	0.0	0.2	0.3	0.3	0.3	0.4	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7
Construction Vessels	0.0	0.0	1.0	1.4	1.4	1.5	1.9	2.8	2.7	2.7	2.8	2.8	2.8	3.1	3.3	3.6	3.7	3.7
Jackup Vessels	0.0	0.0	0.8	0.8	0.8	0.6	0.7	1.0	1.0	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
TIVs	0.0	0.0	0.0	0.3	0.3	0.6	0.7	1.0	1.0	1.4	1.4	1.4	1.4	1.5	1.6	1.7	1.8	1.8
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.6	0.6	0.6
Heavy-lift Vessels	0.0	0.0	0.2	0.2	0.3	0.3	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.7	0.7	0.7
Service Vessels	0.0	0.0	5.7	7.2	7.2	7.2	8.7	12.4	12.3	11.5	11.4	11.4	11.3	12.2	13.1	14.0	14.6	14.6
Tugs	0.0	0.0	0.8	0.9	0.9	0.8	1.0	1.4	1.4	1.1	1.1	1.1	1.1	1.2	1.3	1.4	1.5	1.5
Barges	0.0	0.0	0.8	0.8	0.8	0.6	0.7	1.0	1.0	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
Supply Vessels	0.0	0.0	4.2	5.6	5.5	5.8	7.1	10.0	9.9	9.9	9.8	9.8	9.8	10.5	11.3	12.0	12.5	12.5
O&M Vessels	0.0	0.0	1.7	3.9	6.1	8.4	12.3	17.3	21.2	26.2	31.1	36.0	40.9	46.1	51.6	57.4	63.4	70.4
Personnel Transer Vessels	0.0	0.0	1.7	3.9	6.1	8.4	11.3	15.3	19.2	23.2	27.1	31.0	34.9	39.1	43.6	48.4	53.4	58.4
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	12.0
Total Vessel Requirement	**0.0**	**0.0**	**9.1**	**13.4**	**15.6**	**18.1**	**24.0**	**34.0**	**37.9**	**41.9**	**46.8**	**51.7**	**56.6**	**63.1**	**69.8**	**76.9**	**83.7**	**90.7**
Vessel Requirements by Region and by Scenario -- Low Growth-Low Technology (LL)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.7	0.7	0.7	0.5	0.5	0.5	0.8	1.0	1.3	1.5	1.7	1.8	2.0	2.2	2.5	2.5
Environmental Survey Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8
Geophysical Survey Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8
Geothechnical Survey Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9	0.9
Construction Vessels	0.0	0.0	1.0	1.0	1.0	0.8	0.7	0.8	1.2	1.7	2.0	2.5	2.7	3.1	3.4	3.8	4.4	4.4
Jackup Vessels	0.0	0.0	0.8	0.6	0.6	0.3	0.3	0.3	0.5	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8
TIVs	0.0	0.0	0.0	0.2	0.2	0.3	0.3	0.3	0.5	0.9	1.1	1.3	1.5	1.6	1.8	2.0	2.2	2.2
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.4	0.6	0.6
Heavy-lift Vessels	0.0	0.0	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.8	0.8
Service Vessels	0.0	0.0	5.7	5.4	5.4	3.7	3.6	4.1	6.0	7.4	9.1	10.8	12.0	13.3	14.7	16.0	18.3	18.3
Tugs	0.0	0.0	0.8	0.7	0.7	0.4	0.4	0.4	0.7	0.7	0.8	1.0	1.1	1.2	1.4	1.5	1.7	1.7
Barges	0.0	0.0	0.8	0.6	0.6	0.3	0.3	0.3	0.5	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8
Supply Vessels	0.0	0.0	4.2	4.2	4.2	3.0	2.9	3.3	4.9	6.5	7.9	9.4	10.4	11.5	12.7	13.8	15.8	15.8
O&M Vessels	0.0	0.0	1.7	3.3	5.0	6.2	7.4	9.7	11.7	14.3	18.4	22.2	27.3	33.0	39.0	44.6	51.9	60.2
Personnel Transer Vessels	0.0	0.0	1.7	3.3	5.0	6.2	7.4	8.7	10.7	13.3	16.4	20.2	24.3	29.0	34.0	39.6	45.9	52.2
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	2.0	2.0	3.0	4.0	5.0	5.0	6.0	8.0
Total Vessel Requirement	**0.0**	**0.0**	**9.1**	**10.5**	**12.1**	**11.2**	**12.2**	**15.2**	**19.8**	**24.4**	**30.9**	**37.0**	**43.7**	**51.2**	**59.2**	**66.6**	**77.1**	**85.4**

Table 28: Modeling Results – Atlantic Coast – US TIV Strategy

Annualized vessel equivalent numbers

Appendix 3 – Detailed Modeling Results

Vessel Requirements by Region and by Scenario -- High Growth-High Technology (HH)

Master Table	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Survey Vessels	0.0	0.0	1.2	1.4	1.6	2.0	2.4	2.8	2.9	3.3	3.5	3.7	3.9	4.2	4.6	4.9	4.9	4.9
Environmental Survey Vessels	0.0	0.0	0.4	0.5	0.5	0.6	0.8	0.9	0.9	1.1	1.1	1.2	1.3	1.4	1.5	1.6	1.6	1.6
Geophysical Survey Vessels	0.0	0.0	0.4	0.5	0.5	0.6	0.8	0.9	0.9	1.1	1.1	1.2	1.3	1.4	1.5	1.6	1.6	1.6
Geotechnical Survey Vessels	0.0	0.0	0.4	0.5	0.6	0.7	0.9	1.0	1.0	1.2	1.3	1.3	1.4	1.5	1.6	1.7	1.8	1.8
Construction Vessels	0.0	0.0	2.3	2.7	3.2	4.0	4.8	5.7	6.0	6.9	7.6	8.4	9.1	10.1	11.2	12.3	12.5	12.5
Jackup Vessels	0.0	0.0	1.3	1.2	1.4	1.2	1.5	1.7	1.8	1.0	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.6
TIVs	0.0	0.0	0.5	0.9	1.0	1.6	1.9	2.1	2.1	3.2	3.3	3.5	3.7	4.0	4.2	4.5	4.6	4.6
of which European	0.0	0.0	0.5	0.9	1.0	1.6	1.9	2.1	1.6	2.4	1.7	1.8	1.8	2.0	2.1	2.3	2.3	2.3
Cable-lay Vessels	0.0	0.0	0.1	0.2	0.3	0.5	0.7	0.9	1.0	1.4	1.7	2.0	2.3	2.7	3.2	3.6	3.7	3.7
Heavy-lift Vessels	0.0	0.0	0.4	0.4	0.5	0.6	0.8	1.1	1.1	1.3	1.5	1.7	1.8	2.1	2.3	2.6	2.6	2.6
Service Vessels	0.0	0.0	10.9	12.8	14.7	18.1	21.6	25.1	25.4	27.7	28.6	30.4	32.0	34.7	37.4	40.1	40.8	40.8
Tugs	0.0	0.0	1.8	2.0	2.3	2.8	3.3	3.8	3.7	3.9	3.8	4.1	4.4	4.9	5.3	5.8	6.0	6.0
Barges	0.0	0.0	1.8	2.1	2.4	2.9	3.3	3.8	3.3	3.4	2.8	2.9	3.1	3.3	3.6	3.8	3.9	3.9
Supply Vessels	0.0	0.0	7.3	8.7	10.0	12.5	15.0	17.5	18.4	20.4	22.0	23.4	24.5	26.5	28.5	30.5	31.0	31.0
O&M Vessels	0.0	0.0	2.9	6.4	11.4	17.4	23.4	32.4	40.7	49.9	60.7	72.1	84.9	97.5	111.9	127.1	142.5	158.9
Personnel Transer Vessels	0.0	0.0	2.9	6.4	10.4	15.4	21.4	28.4	35.7	43.9	52.7	62.1	71.9	82.5	93.9	106.1	118.5	130.9
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	1.0	2.0	2.0	4.0	5.0	6.0	8.0	10.0	13.0	15.0	18.0	21.0	24.0	28.0
Total Vessel Requirement	**0.0**	**0.0**	**17.3**	**23.3**	**30.9**	**41.5**	**52.2**	**66.1**	**75.1**	**87.8**	**100.5**	**114.6**	**129.8**	**146.5**	**165.0**	**184.3**	**200.7**	**217.1**

Vessel Requirements by Region and by Scenario -- Moderate Growth-High Technology (LL)

Master Table	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Survey Vessels	0.0	0.0	0.7	0.9	0.9	0.9	1.1	1.6	1.6	1.6	1.6	1.6	1.6	1.7	1.8	1.9	2.0	2.0
Environmental Survey Vessels	0.0	0.0	0.2	0.3	0.3	0.3	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
Geophysical Survey Vessels	0.0	0.0	0.2	0.3	0.3	0.3	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
Geotechnical Survey Vessels	0.0	0.0	0.2	0.3	0.3	0.3	0.4	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7
Construction Vessels	0.0	0.0	1.5	1.8	1.9	2.0	2.3	3.2	3.1	3.1	3.0	3.0	3.0	3.3	3.5	3.8	3.9	3.9
Jackup Vessels	0.0	0.0	0.8	0.8	0.8	0.6	0.7	1.0	1.0	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
TIVs	0.0	0.0	0.5	0.7	0.7	1.0	1.1	1.4	1.3	1.7	1.6	1.6	1.6	1.7	1.8	1.9	2.0	2.0
of which European	0.0	0.0	0.5	0.7	0.7	1.0	1.1	1.4	1.0	1.3	0.8	0.8	0.8	0.9	0.9	1.0	1.0	1.0
Cable-lay Vessels	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.6	0.6	0.6
Heavy-lift Vessels	0.0	0.0	0.2	0.2	0.3	0.3	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.7	0.7	0.7
Service Vessels	0.0	0.0	6.6	8.5	8.5	8.9	10.6	14.6	13.8	13.5	12.7	12.6	12.6	13.6	14.5	15.5	16.2	16.2
Tugs	0.0	0.0	1.2	1.4	1.4	1.4	1.7	2.3	2.0	1.8	1.6	1.6	1.6	1.7	1.8	1.9	2.0	2.0
Barges	0.0	0.0	1.3	1.5	1.5	1.6	1.8	2.4	1.9	1.8	1.3	1.3	1.3	1.4	1.5	1.6	1.6	1.6
Supply Vessels	0.0	0.0	4.2	5.6	5.5	5.8	7.1	10.0	9.9	9.9	9.8	9.8	9.8	10.5	11.3	12.0	12.5	12.5
O&M Vessels	0.0	0.0	1.7	3.9	6.1	8.4	12.3	17.3	21.2	26.2	31.1	36.0	40.9	46.1	51.6	57.4	63.4	70.4
Personnel Transer Vessels	0.0	0.0	1.7	3.9	6.1	8.4	11.3	15.3	19.2	23.2	27.1	31.0	34.9	39.1	43.6	48.4	53.4	58.4
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	12.0
Total Vessel Requirement	**0.0**	**0.0**	**10.5**	**15.1**	**17.3**	**20.2**	**26.3**	**36.7**	**39.7**	**44.3**	**48.4**	**53.2**	**58.1**	**64.7**	**71.5**	**78.6**	**85.5**	**92.5**

Vessel Requirements by Region and by Scenario -- Low Growth-Low Technology (LL)

Master Table	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Survey Vessels	0.0	0.0	0.7	0.7	0.7	0.5	0.5	0.5	0.8	1.0	1.3	1.5	1.7	1.8	2.0	2.2	2.5	2.5
Environmental Survey Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8
Geophysical Survey Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8
Geotechnical Survey Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9	0.9
Construction Vessels	0.0	0.0	1.5	1.5	1.5	1.2	1.2	1.3	1.6	2.0	2.3	2.7	3.0	3.3	3.7	4.0	4.6	4.6
Jackup Vessels	0.0	0.0	0.8	0.6	0.6	0.3	0.3	0.3	0.5	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8
TIVs	0.0	0.0	0.5	0.7	0.7	0.8	0.8	0.8	0.8	1.3	1.4	1.6	1.7	1.9	2.0	2.2	2.5	2.5
of which European	0.0	0.0	0.5	0.7	0.7	0.8	0.8	0.8	0.6	1.0	0.7	0.8	0.9	0.9	1.0	1.1	1.2	1.2
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.4	0.6	0.6
Heavy-lift Vessels	0.0	0.0	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.8	0.8
Service Vessels	0.0	0.0	6.6	6.6	6.6	5.0	4.9	5.4	7.1	9.0	10.2	12.1	13.3	14.8	16.3	17.7	20.2	20.2
Tugs	0.0	0.0	1.2	1.2	1.2	0.9	0.9	1.0	1.1	1.2	1.2	1.4	1.6	1.7	1.9	2.1	2.4	2.4
Barges	0.0	0.0	1.3	1.3	1.3	1.1	1.0	1.1	1.1	1.3	1.1	1.2	1.4	1.5	1.6	1.8	2.0	2.0
Supply Vessels	0.0	0.0	4.2	4.2	4.2	3.0	2.9	3.3	4.9	6.5	7.9	9.4	10.4	11.5	12.7	13.8	15.8	15.8
O&M Vessels	0.0	0.0	1.7	3.3	5.0	6.2	7.4	9.7	11.7	14.3	18.4	22.2	27.3	33.0	39.0	44.6	51.9	60.2
Personnel Transer Vessels	0.0	0.0	1.7	3.3	5.0	6.2	7.4	8.7	10.7	13.3	16.4	20.2	24.3	29.0	34.0	39.6	45.9	52.2
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	2.0	2.0	3.0	4.0	5.0	5.0	6.0	8.0
Total Vessel Requirement	**0.0**	**0.0**	**10.5**	**12.1**	**13.8**	**13.0**	**13.9**	**17.0**	**21.2**	**26.3**	**32.2**	**38.4**	**45.3**	**52.9**	**61.0**	**68.5**	**79.2**	**87.5**

Table 29: Modeling Results – Atlantic Coast – EU TIV Strategy

Annualized vessel equivalent numbers

Appendix 3 – Detailed Modeling Results

Vessel Requirements by Region and by Scenario -- High Growth-High Technology (HH)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.1	0.2	0.3	0.5	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.3	1.3	1.3	1.3	1.3
Environmental Survey Vessels	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4
Geophysical Survey Vessels	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4
Geotechnical Survey Vessels	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Construction Vessels	0.0	0.0	0.2	0.3	0.5	0.8	1.0	1.3	1.4	1.7	1.9	2.1	2.4	2.2	2.2	2.2	2.2	2.2
Jackup Vessels	0.0	0.0	0.2	0.2	0.4	0.6	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.5	1.5	1.5	1.5	1.5
TIVs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Heavy-lift Vessels	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.5	0.4	0.4	0.4	0.4	0.4
Service Vessels	0.0	0.0	1.2	1.7	2.9	4.6	5.8	6.9	7.7	8.8	9.9	11.1	12.2	11.3	11.3	11.3	11.3	11.3
Tugs	0.0	0.0	0.2	0.2	0.4	0.7	0.8	1.0	1.1	1.3	1.4	1.6	1.8	1.6	1.6	1.6	1.6	1.6
Barges	0.0	0.0	0.2	0.2	0.4	0.6	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.5	1.5	1.5	1.5	1.5
Supply Vessels	0.0	0.0	0.8	1.3	2.1	3.3	4.2	5.0	5.6	6.3	7.1	7.9	8.7	8.1	8.1	8.1	8.1	8.1
O&M Vessels	0.0	0.0	0.3	0.8	1.7	3.0	4.7	7.7	9.9	12.4	16.3	19.5	24.0	27.2	31.4	34.7	38.9	43.1
Personnel Transer Vessels	0.0	0.0	0.3	0.8	1.7	3.0	4.7	6.7	8.9	11.4	14.3	17.5	21.0	24.2	27.4	30.7	33.9	37.1
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	2.0	2.0	3.0	3.0	4.0	4.0	5.0	6.0
Total Vessel Requirement	**0.0**	**0.0**	**1.8**	**3.1**	**5.4**	**9.0**	**12.1**	**16.7**	**19.9**	**23.9**	**29.3**	**33.9**	**39.9**	**41.9**	**46.1**	**49.4**	**53.6**	**57.8**

Vessel Requirements by Region and by Scenario -- Moderate Growth-High Technology (LL)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	0.9	1.0	0.9	0.9	0.9	0.9	0.9
Environmental Survey Vessels	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Geophysical Survey Vessels	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Geotechnical Survey Vessels	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.3
Construction Vessels	0.0	0.0	0.2	0.2	0.3	0.3	0.4	0.6	0.8	1.0	1.2	1.4	1.7	1.5	1.5	1.5	1.5	1.5
Jackup Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.3	0.5	0.6	0.8	0.9	1.1	1.2	1.1	1.1	1.1	1.1	1.1
TIVs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Heavy-lift Vessels	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Service Vessels	0.0	0.0	1.2	1.2	1.7	1.7	2.3	3.5	4.4	5.5	6.6	7.7	8.8	8.2	8.2	8.2	8.2	8.2
Tugs	0.0	0.0	0.2	0.2	0.2	0.2	0.3	0.5	0.6	0.8	0.9	1.1	1.3	1.2	1.2	1.2	1.2	1.2
Barges	0.0	0.0	0.2	0.2	0.2	0.2	0.3	0.5	0.6	0.8	0.9	1.1	1.2	1.1	1.1	1.1	1.1	1.1
Supply Vessels	0.0	0.0	0.8	0.8	1.3	1.3	1.7	2.5	3.2	4.0	4.8	5.6	6.3	5.9	5.9	5.9	5.9	5.9
O&M Vessels	0.0	0.0	0.3	0.7	1.2	1.7	2.3	3.3	4.6	6.2	9.1	11.3	14.9	17.2	19.6	22.9	25.3	28.6
Personnel Transer Vessels	0.0	0.0	0.3	0.7	1.2	1.7	2.3	3.3	4.6	6.2	8.1	10.3	12.9	15.2	17.6	19.9	22.3	24.6
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	2.0	2.0	2.0	3.0	3.0	4.0
Total Vessel Requirement	**0.0**	**0.0**	**1.8**	**2.2**	**3.4**	**3.9**	**5.3**	**7.8**	**10.3**	**13.3**	**17.7**	**21.4**	**26.4**	**27.8**	**30.2**	**33.5**	**35.9**	**39.2**

Vessel Requirements by Region and by Scenario -- Low Growth-Low Technology (LL)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.3	0.3	0.3	0.4	0.4	0.4
Environmental Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Geophysical Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Geotechnical Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Construction Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.6
Jackup Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5
TIVs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heavy-lift Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Service Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.2	1.2	1.7	2.3	2.5	2.9	3.2	3.5	3.5
Tugs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.2	0.3	0.4	0.4	0.5	0.5	0.5
Barges	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5
Supply Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8	0.8	1.3	1.7	1.8	2.1	2.3	2.5	2.5
O&M Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.0	1.5	2.2	2.9	3.7	4.7	5.7	7.7
Personnel Transer Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.0	1.5	2.2	2.9	3.7	4.7	5.7	6.7
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
Total Vessel Requirement	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1.8**	**2.2**	**2.5**	**3.7**	**5.1**	**6.2**	**7.5**	**8.8**	**10.1**	**12.1**

Table 30: Modeling Results – Great Lakes – US Jackup Strategy

Annualized vessel equivalent numbers

Appendix 3 – Detailed Modeling Results

Vessel Requirements by Region and by Scenario -- High Growth-High Technology (HH)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.1	0.2	0.3	0.5	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.3	1.3	1.3	1.3	1.3
Environmental Survey Vessels	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4
Geophysical Survey Vessels	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4
Geothechnical Survey Vessels	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Construction Vessels	0.0	0.0	0.2	0.3	0.5	0.8	1.0	1.3	1.4	1.7	1.9	2.1	2.4	2.2	2.2	2.2	2.2	2.2
Jackup Vessels	0.0	0.0	0.2	0.2	0.3	0.5	0.6	0.7	0.8	0.6	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8
TIVs	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.6	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Heavy-lift Vessels	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.5	0.4	0.4	0.4	0.4	0.4
Service Vessels	0.0	0.0	1.2	1.6	2.7	4.4	5.4	6.5	7.3	7.8	8.8	9.8	10.8	10.0	10.0	10.0	10.0	10.0
Tugs	0.0	0.0	0.2	0.2	0.3	0.5	0.7	0.8	0.9	0.9	1.0	1.1	1.2	1.1	1.1	1.1	1.1	1.1
Barges	0.0	0.0	0.2	0.2	0.3	0.5	0.6	0.7	0.8	0.6	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Supply Vessels	0.0	0.0	0.8	1.3	2.1	3.3	4.2	5.0	5.6	6.3	7.1	7.9	8.7	8.1	8.1	8.1	8.1	8.1
O&M Vessels	0.0	0.0	0.3	0.8	1.7	3.0	4.7	7.7	9.9	12.4	16.3	19.5	24.0	27.2	31.4	34.7	38.9	43.1
Personnel Transer Vessels	0.0	0.0	0.3	0.8	1.7	3.0	4.7	6.7	8.9	11.4	14.3	17.5	21.0	24.2	27.4	30.7	33.9	37.1
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	2.0	2.0	3.0	3.0	4.0	4.0	5.0	6.0
Total Vessel Requirement	**0.0**	**0.0**	**1.8**	**3.0**	**5.2**	**8.7**	**11.8**	**16.3**	**19.5**	**22.9**	**28.1**	**32.7**	**38.5**	**40.6**	**44.9**	**48.1**	**52.3**	**56.6**

Vessel Requirements by Region and by Scenario -- Moderate Growth-High Technology (LL)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	0.9	1.0	0.9	0.9	0.9	0.9	0.9
Environmental Survey Vessels	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Geophysical Survey Vessels	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Geothechnical Survey Vessels	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.3
Construction Vessels	0.0	0.0	0.2	0.2	0.3	0.3	0.4	0.6	0.8	1.0	1.2	1.4	1.7	1.5	1.5	1.5	1.5	1.5
Jackup Vessels	0.0	0.0	0.2	0.1	0.2	0.2	0.2	0.4	0.5	0.4	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6
TIVs	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.4	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Heavy-lift Vessels	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Service Vessels	0.0	0.0	1.2	1.1	1.6	1.6	2.2	3.3	4.1	4.9	5.9	6.8	7.8	7.2	7.2	7.2	7.2	7.2
Tugs	0.0	0.0	0.2	0.1	0.2	0.2	0.3	0.4	0.5	0.5	0.6	0.7	0.9	0.8	0.8	0.8	0.8	0.8
Barges	0.0	0.0	0.2	0.1	0.2	0.2	0.2	0.4	0.5	0.4	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6
Supply Vessels	0.0	0.0	0.8	0.8	1.3	1.3	1.7	2.5	3.2	4.0	4.8	5.6	6.3	5.9	5.9	5.9	5.9	5.9
O&M Vessels	0.0	0.0	0.3	0.7	1.2	1.7	2.3	3.3	4.6	6.2	9.1	11.3	14.9	17.2	19.6	22.9	25.3	28.6
Personnel Transer Vessels	0.0	0.0	0.3	0.7	1.2	1.7	2.3	3.3	4.6	6.2	8.1	10.3	12.9	15.2	17.6	19.9	22.3	24.6
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	2.0	2.0	2.0	3.0	3.0	4.0
Total Vessel Requirement	**0.0**	**0.0**	**1.8**	**2.1**	**3.3**	**3.8**	**5.2**	**7.6**	**10.0**	**12.7**	**16.9**	**20.5**	**25.4**	**26.9**	**29.3**	**32.6**	**35.0**	**38.3**

Vessel Requirements by Region and by Scenario -- Low Growth-Low Technology (LL)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.3	0.3	0.3	0.4	0.4	0.4
Environmental Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Geophysical Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Geothechnical Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Construction Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.6
Jackup Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
TIVs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heavy-lift Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Service Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	1.0	1.0	1.5	2.0	2.2	2.6	2.9	3.1	3.1
Tugs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.3
Barges	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Supply Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8	0.8	1.3	1.7	1.8	2.1	2.3	2.5	2.5
O&M Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.0	1.5	2.2	2.9	3.7	4.7	5.7	7.7
Personnel Transer Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.0	1.5	2.2	2.9	3.7	4.7	5.7	6.7
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
Total Vessel Requirement	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1.8**	**2.0**	**2.4**	**3.5**	**4.9**	**5.9**	**7.1**	**8.5**	**9.7**	**11.7**

Table 31: Modeling Results – Great Lakes – US TIV Strategy

Annualized vessel equivalent numbers

Appendix 3 – Detailed Modeling Results

Vessel Requirements by Region and by Scenario -- High Growth-High Technology (HH)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.7	0.9	1.0	1.1	1.3	1.3	1.3	1.3	1.3
Environmental Survey Vessels	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Geophysical Survey Vessels	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Geotechnical Survey Vessels	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.5
Construction Vessels	0.0	0.0	0.6	0.6	0.7	0.7	0.7	0.7	0.9	1.2	1.4	1.6	1.8	2.1	2.1	2.1	2.1	2.1
Jackup Vessels	0.0	0.0	0.5	0.5	0.6	0.6	0.6	0.6	0.7	0.9	1.0	1.2	1.3	1.5	1.5	1.5	1.5	1.5
TIVs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Heavy-lift Vessels	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4
Service Vessels	0.0	0.0	3.5	3.5	4.0	4.0	4.0	4.0	5.2	6.4	7.5	8.7	9.8	11.0	11.0	11.0	11.0	11.0
Tugs	0.0	0.0	0.5	0.5	0.6	0.6	0.6	0.6	0.7	0.9	1.1	1.2	1.4	1.6	1.6	1.6	1.6	1.6
Barges	0.0	0.0	0.5	0.5	0.6	0.6	0.6	0.6	0.7	0.9	1.0	1.2	1.3	1.5	1.5	1.5	1.5	1.5
Supply Vessels	0.0	0.0	2.5	2.5	2.9	2.9	2.9	2.9	3.8	4.6	5.4	6.3	7.1	7.9	7.9	7.9	7.9	7.9
O&M Vessels	0.0	0.0	1.0	2.0	3.2	4.3	5.5	7.7	9.2	11.0	13.2	16.7	19.5	23.7	26.8	31.0	34.2	38.3
Personnel Transer Vessels	0.0	0.0	1.0	2.0	3.2	4.3	5.5	6.7	8.2	10.0	12.2	14.7	17.5	20.7	23.8	27.0	30.2	33.3
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	2.0	2.0	3.0	3.0	4.0	4.0	5.0
Total Vessel Requirement	**0.0**	**0.0**	**5.5**	**6.5**	**8.4**	**9.6**	**10.7**	**12.9**	**15.9**	**19.3**	**22.9**	**28.0**	**32.3**	**38.0**	**41.2**	**45.4**	**48.5**	**52.7**

Vessel Requirements by Region and by Scenario -- Moderate Growth-High Technology (LL)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.7	0.8	0.9	1.1	1.1	1.1	1.1	1.1	1.1
Environmental Survey Vessels	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Geophysical Survey Vessels	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Geotechnical Survey Vessels	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Construction Vessels	0.0	0.0	0.2	0.2	0.3	0.3	0.4	0.6	0.8	1.0	1.3	1.5	1.7	1.7	1.7	1.7	1.7	1.7
Jackup Vessels	0.0	0.0	0.2	0.2	0.2	0.2	0.3	0.5	0.6	0.8	0.9	1.1	1.3	1.3	1.3	1.3	1.3	1.3
TIVs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Heavy-lift Vessels	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Service Vessels	0.0	0.0	1.2	1.2	1.7	1.7	2.3	3.5	4.6	5.8	6.9	8.1	9.3	9.3	9.3	9.3	9.3	9.3
Tugs	0.0	0.0	0.2	0.2	0.2	0.2	0.3	0.5	0.7	0.8	1.0	1.2	1.3	1.3	1.3	1.3	1.3	1.3
Barges	0.0	0.0	0.2	0.2	0.2	0.2	0.3	0.5	0.6	0.8	0.9	1.1	1.3	1.3	1.3	1.3	1.3	1.3
Supply Vessels	0.0	0.0	0.8	0.8	1.3	1.3	1.7	2.5	3.3	4.2	5.0	5.8	6.7	6.7	6.7	6.7	6.7	6.7
O&M Vessels	0.0	0.0	0.3	0.7	1.2	1.7	2.3	3.3	4.7	6.3	9.3	11.7	15.3	18.0	20.7	24.3	27.0	30.7
Personnel Transer Vessels	0.0	0.0	0.3	0.7	1.2	1.7	2.3	3.3	4.7	6.3	8.3	10.7	13.3	16.0	18.7	21.3	24.0	26.7
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	2.0	2.0	2.0	3.0	3.0	4.0
Total Vessel Requirement	**0.0**	**0.0**	**1.8**	**2.2**	**3.4**	**3.9**	**5.3**	**7.8**	**10.6**	**13.8**	**18.3**	**22.2**	**27.4**	**30.1**	**32.7**	**36.4**	**39.1**	**42.7**

Vessel Requirements by Region and by Scenario -- Low Growth-Low Technology (LL)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Environmental Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Geophysical Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Geotechnical Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Construction Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.5
Jackup Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4
TIVs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heavy-lift Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Service Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.2	1.7	2.3	2.4	2.8	2.9	2.9	2.9	2.9
Tugs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4
Barges	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4
Supply Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8	1.3	1.7	1.8	2.0	2.1	2.1	2.1	2.1
O&M Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.2	1.8	2.5	3.3	4.2	5.0	5.8	7.7
Personnel Transer Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.2	1.8	2.5	3.3	4.2	5.0	5.8	6.7
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
Total Vessel Requirement	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1.8**	**2.2**	**3.4**	**4.8**	**5.7**	**6.9**	**7.9**	**8.7**	**9.6**	**11.4**

Table 32: Modeling Results – Gulf Coast – US Jackup Strategy

Annualized vessel equivalent numbers

Douglas Westwood

Appendix 3 – Detailed Modeling Results

Vessel Requirements by Region and by Scenario -- High Growth-High Technology (HH)

Master Table	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Survey Vessels	0.0	0.0	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.7	0.9	1.0	1.1	1.3	1.3	1.3	1.3	1.3
Environmental Survey Vessels	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Geophysical Survey Vessels	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Geotechnical Survey Vessels	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.5
Construction Vessels	0.0	0.0	0.6	0.6	0.7	0.7	0.7	0.7	0.9	1.2	1.4	1.6	1.8	2.1	2.1	2.1	2.1	2.1
Jackup Vessels	0.0	0.0	0.5	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.5	0.6	0.7	0.8	0.8	0.8	0.8	0.8
TIVs	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.4	0.5	0.6	0.7	0.8	0.8	0.8	0.8	0.8
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Heavy-lift Vessels	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4
Service Vessels	0.0	0.0	3.5	3.3	3.8	3.8	3.8	3.8	4.9	5.6	6.7	7.7	8.7	9.8	9.8	9.8	9.8	9.8
Tugs	0.0	0.0	0.5	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.7	0.8	1.0	1.1	1.1	1.1	1.1	1.1
Barges	0.0	0.0	0.5	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.5	0.6	0.7	0.8	0.8	0.8	0.8	0.8
Supply Vessels	0.0	0.0	2.5	2.5	2.9	2.9	2.9	2.9	3.8	4.6	5.4	6.3	7.1	7.9	7.9	7.9	7.9	7.9
O&M Vessels	0.0	0.0	1.0	2.0	3.2	4.3	5.5	7.7	9.2	11.0	13.2	16.7	19.5	23.7	26.8	31.0	34.2	38.3
Personnel Transer Vessels	0.0	0.0	1.0	2.0	3.2	4.3	5.5	6.7	8.2	10.0	12.2	14.7	17.5	20.7	23.8	27.0	30.2	33.3
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	2.0	2.0	3.0	3.0	4.0	4.0	5.0
Total Vessel Requirement	**0.0**	**0.0**	**5.5**	**6.3**	**8.2**	**9.3**	**10.5**	**12.7**	**15.6**	**18.5**	**22.1**	**27.0**	**31.2**	**36.8**	**40.0**	**44.1**	**47.3**	**51.5**

Vessel Requirements by Region and by Scenario -- Moderate Growth-High Technology (LL)

Master Table	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Survey Vessels	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.7	0.8	0.9	1.1	1.1	1.1	1.1	1.1	1.1
Environmental Survey Vessels	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Geophysical Survey Vessels	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Geotechnical Survey Vessels	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Construction Vessels	0.0	0.0	0.2	0.2	0.3	0.3	0.4	0.6	0.8	1.0	1.3	1.5	1.7	1.7	1.7	1.7	1.7	1.7
Jackup Vessels	0.0	0.0	0.2	0.1	0.2	0.2	0.2	0.4	0.5	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6
TIVs	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Heavy-lift Vessels	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Service Vessels	0.0	0.0	1.2	1.1	1.6	1.6	2.2	3.3	4.4	5.1	6.2	7.2	8.2	8.2	8.2	8.2	8.2	8.2
Tugs	0.0	0.0	0.2	0.1	0.2	0.2	0.3	0.4	0.5	0.5	0.7	0.8	0.9	0.9	0.9	0.9	0.9	0.9
Barges	0.0	0.0	0.2	0.1	0.2	0.2	0.2	0.4	0.5	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Supply Vessels	0.0	0.0	0.8	0.8	1.3	1.3	1.7	2.5	3.3	4.2	5.0	5.8	6.7	6.7	6.7	6.7	6.7	6.7
O&M Vessels	0.0	0.0	0.3	0.7	1.2	1.7	2.3	3.3	4.7	6.3	9.3	11.7	15.3	18.0	20.7	24.3	27.0	30.7
Personnel Transer Vessels	0.0	0.0	0.3	0.7	1.2	1.7	2.3	3.3	4.7	6.3	8.3	10.7	13.3	16.0	18.7	21.3	24.0	26.7
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	2.0	2.0	2.0	3.0	3.0	4.0
Total Vessel Requirement	**0.0**	**0.0**	**1.8**	**2.1**	**3.3**	**3.8**	**5.2**	**7.6**	**10.4**	**13.2**	**17.6**	**21.3**	**26.3**	**29.0**	**31.7**	**35.3**	**38.0**	**41.7**

Vessel Requirements by Region and by Scenario -- Low Growth-Low Technology (LL)

Master Table	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Environmental Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Geophysical Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Geotechnical Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Construction Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.5
Jackup Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
TIVs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heavy-lift Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Service Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	1.0	1.5	2.0	2.1	2.5	2.6	2.6	2.6	2.6
Tugs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3
Barges	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Supply Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8	1.3	1.7	1.8	2.0	2.1	2.1	2.1	2.1
O&M Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.2	1.8	2.5	3.3	4.2	5.0	5.8	7.7
Personnel Transer Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.2	1.8	2.5	3.3	4.2	5.0	5.8	6.7
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
Total Vessel Requirement	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1.8**	**2.0**	**3.2**	**4.5**	**5.4**	**6.6**	**7.6**	**8.4**	**9.2**	**11.1**

Table 33: Modeling Results – Gulf Coast – US TIV Strategy

Annualized vessel equivalent numbers

Appendix 3 – Detailed Modeling Results

Vessel Requirements by Region and by Scenario -- High Growth-High Technology (HH)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.0	0.0	0.6	1.2	0.7	1.0	1.2	1.4	1.7	1.9	2.2	2.4	2.6	2.9	3.0	3.0
Environmental Survey Vessels	0.0	0.0	0.0	0.0	0.2	0.4	0.2	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9	1.0	1.0
Geophysical Survey Vessels	0.0	0.0	0.0	0.0	0.2	0.4	0.2	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9	1.0	1.0
Geotechnical Survey Vessels	0.0	0.0	0.0	0.0	0.2	0.4	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.9	1.0	1.1	1.1
Construction Vessels	0.0	0.0	0.0	0.0	0.6	1.3	0.2	0.4	0.6	0.8	1.0	1.3	1.5	1.8	2.1	2.5	2.7	2.7
Jackup Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TIVs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.2	0.6	0.1	0.2	0.2	0.3	0.4	0.6	0.7	0.9	1.1	1.3	1.4	1.4
Heavy-lift Vessels	0.0	0.0	0.0	0.0	0.4	0.7	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.3	1.3
Service Vessels	0.0	0.0	0.0	0.0	2.8	5.7	4.5	6.6	8.2	9.9	11.6	13.3	15.0	16.7	18.4	20.1	21.3	21.3
Tugs	0.0	0.0	0.0	0.0	0.3	0.7	0.4	0.6	0.7	0.9	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.3
Barges	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Supply Vessels	0.0	0.0	0.0	0.0	2.5	5.0	4.2	6.0	7.5	9.0	10.5	12.0	13.5	15.0	16.5	18.0	19.0	19.0
O&M Vessels	0.0	0.0	0.0	0.0	1.0	3.0	4.7	7.1	10.1	13.7	17.9	22.7	28.1	34.1	40.7	47.9	55.5	63.1
Personnel Transer Vessels	0.0	0.0	0.0	0.0	1.0	3.0	4.7	7.1	10.1	13.7	17.9	22.7	28.1	34.1	40.7	47.9	55.5	63.1
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Vessel Requirement	**0.0**	**0.0**	**0.0**	**0.0**	**5.0**	**11.2**	**10.1**	**15.0**	**20.1**	**25.8**	**32.2**	**39.1**	**46.7**	**54.9**	**63.8**	**73.3**	**82.5**	**90.1**

Vessel Requirements by Region and by Scenario -- Moderate Growth-High Technology (LL)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.0	0.0	0.6	1.2	0.4	0.3	0.5	0.6	0.8	1.0	1.1	1.3	1.4	1.6	1.8	1.9
Environmental Survey Vessels	0.0	0.0	0.0	0.0	0.2	0.4	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6
Geophysical Survey Vessels	0.0	0.0	0.0	0.0	0.2	0.4	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6
Geotechnical Survey Vessels	0.0	0.0	0.0	0.0	0.2	0.4	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7
Construction Vessels	0.0	0.0	0.0	0.0	0.6	1.3	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.7	0.8	0.9	1.1	1.3
Jackup Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TIVs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.2	0.6	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.6
Heavy-lift Vessels	0.0	0.0	0.0	0.0	0.4	0.7	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7
Service Vessels	0.0	0.0	0.0	0.0	2.8	5.7	2.7	2.2	3.3	4.4	5.5	6.6	7.7	8.8	9.9	11.0	12.1	13.3
Tugs	0.0	0.0	0.0	0.0	0.3	0.7	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.3
Barges	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Supply Vessels	0.0	0.0	0.0	0.0	2.5	5.0	2.5	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
O&M Vessels	0.0	0.0	0.0	0.0	1.0	3.0	4.0	4.8	6.0	7.6	9.6	12.0	14.8	18.0	21.6	25.6	30.0	34.8
Personnel Transer Vessels	0.0	0.0	0.0	0.0	1.0	3.0	4.0	4.8	6.0	7.6	9.6	12.0	14.8	18.0	21.6	25.6	30.0	34.8
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Vessel Requirement	**0.0**	**0.0**	**0.0**	**0.0**	**5.0**	**11.2**	**7.2**	**7.4**	**9.9**	**12.9**	**16.2**	**20.0**	**24.1**	**28.7**	**33.7**	**39.1**	**45.0**	**51.2**

Vessel Requirements by Region and by Scenario -- Low Growth-Low Technology (LL)																		
Master Table	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Environmental Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Geophysical Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Geotechnical Survey Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Construction Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jackup Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TIVs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
of which European	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cable-lay Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heavy-lift Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Service Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tugs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Barges	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Supply Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O&M Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Personnel Transer Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heavy Maintenance Vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Vessel Requirement	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Table 34: Modeling Results – Pacific Coast – Floating Turbine Strategy

Annualized vessel equivalent numbers

Appendix 4

Offshore Wind Prospects in the Great Lakes Region

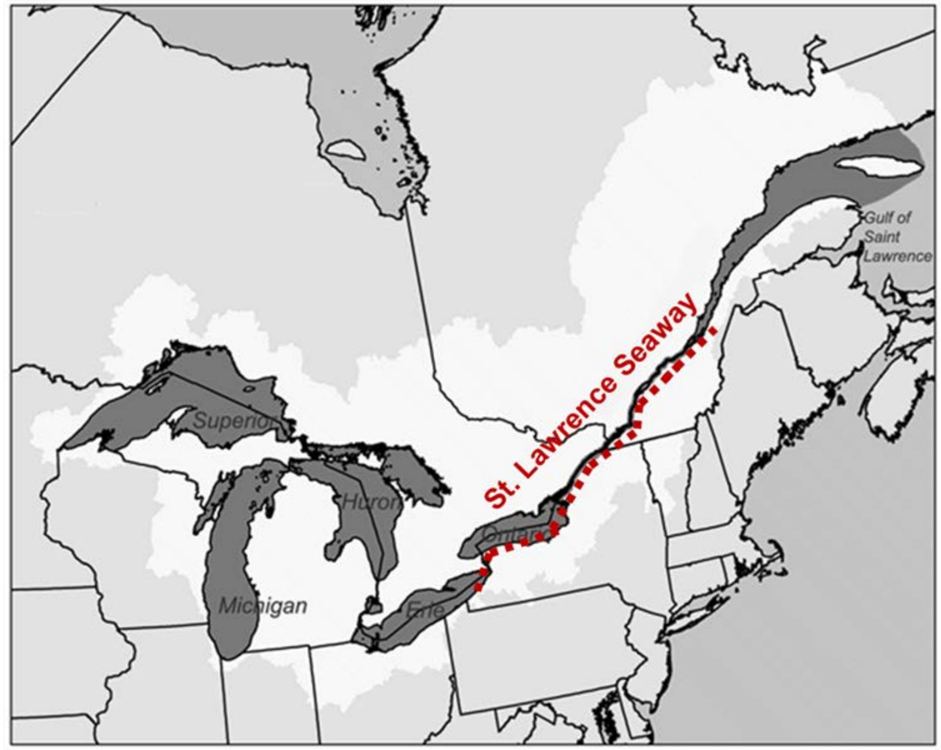
The Significance of the St. Lawrence Seaway

The Great Lakes – St. Lawrence Seaway System, which was opened in 1959, is a deep draft waterway extending 2,340 miles (3,700 km) from the Atlantic Ocean to Lake Superior. The St. Lawrence Seaway itself is a portion of the System and only encompasses the waterway section between Montreal and Lake Erie. The main purpose of the Seaway is to allow deep-draft oceangoing vessels to travel between the Atlantic Ocean and the Great Lakes by using a series of locks and canals.

The size of vessels that can navigate the Seaway is limited by the size of its 14 locks. The St. Lawrence Seaway can accommodate ships up to 225.5 meters (740 ft) long and 23.7 meters (78 ft) wide with a maximum deadweight ton of 25,000. The maximum draft allowed in the Seaway was upgraded in 2006 to 8.08 meters (26 ft 6 in) and there are plans to expand the draft to 8.15 meters (26 ft 9in), just above the 8.2 meters (27 ft) depth level maintained in the channels. The vessels which were built to the maximum size permissible by the locks on the Seaway are informally called “Seawaymax” size vessels.

It takes between 8.5 to 10 days to navigate the entire 2,340-mile (3,700 km) length of the Great Lakes – St. Lawrence Seaway System from Duluth (in the westernmost section of Lake Superior) to the Atlantic Ocean. On the Welland Canal, the slowest section of the seaway, the average transit time is about 11-12 hours. The average transit time on the Montreal-Lake Ontario section is 24 hours up-bound and 22 hours down-bound.

The Seaway is only open for navigation during the official navigation season, which generally spans from late-March or early-April to December, or about 275 days in an average year (the exact season length varies year by year).



The St. Lawrence Seaway
Source: Douglas-Westwood

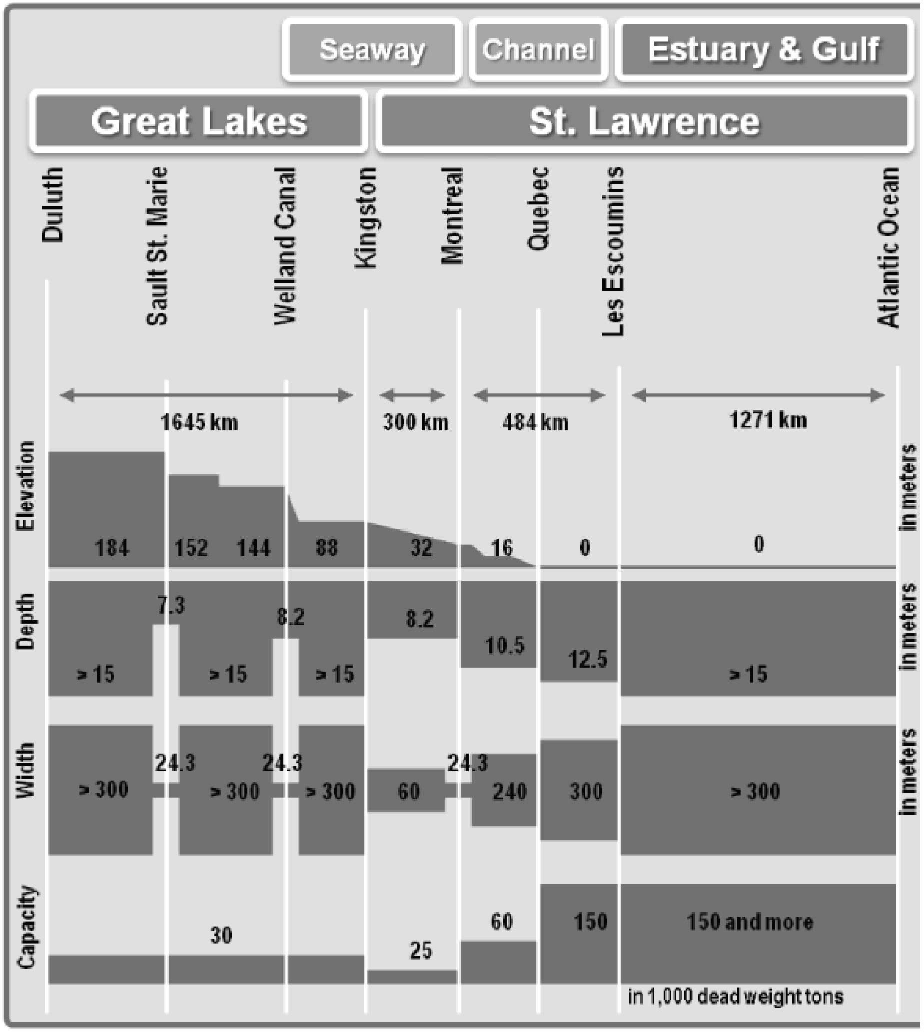


Figure 46: Key Characteristics of Various Sections of the St. Lawrence Seaway

Source: Hofstra University

Vessel-Related Aspects of the St. Lawrence Seaway System

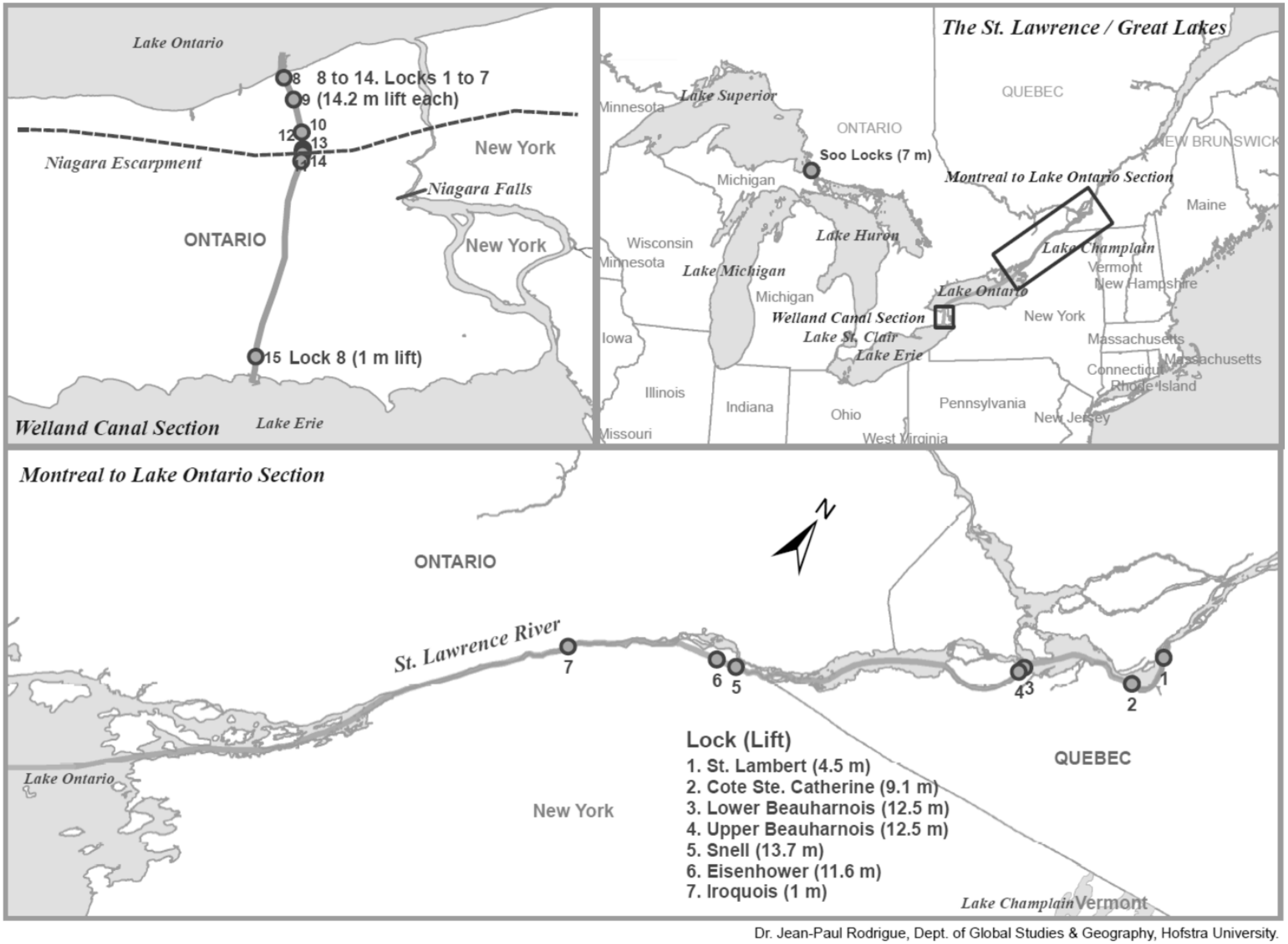
The R/D MacDonald was specifically designed to be able to navigate the St. Lawrence Seaway; its maximum breadth is 23.7 meters, just below the allowable maximum boat beam limit of 23.8 meters in the Seaway. The vessel's draft of 4.4 meters is also comfortably below the 8.2 meter water depth level in the Seaway's shallowest sections.

Most survey vessels as well as most service vessel types, including feeder barges, will likely be able to navigate the Seaway during the official navigation season (late-March through December). However, the relatively limited dimensions of the waterway, particularly its narrow breadth (23.8 meters) and low water depth (8.2 meters) at its narrowest and shallowest point upstream of Montreal, will likely prevent most large construction vessel types from entering the Great Lakes region from the Atlantic Coast via the St. Lawrence Seaway.

The typical breadth of a heavy lift vessel that will likely be needed for substation installations ranges between 25 and 30 meters, more than the 23.8 meter maximum allowable limit across the Seaway. The draft of these heavy lift vessels, in many cases, is also higher than the 8.2 meter limit near Montreal. The breadth of the catalogued European jackup vessels and TIVs range between 20 and 50 meters, meaning that some of them may be able to navigate the Seaway, but the majority of them will be excluded from the Great Lakes region. The 8.2 meter water depth in the seaway is less problematic for these vessels. Cable-lay vessels appear to fall generally within the "Seawaymax" range in terms of width, draft and deadweight tonnage.

The Chesapeake 1000, the largest capacity crane barge on the US East Coast, and the most suitable vessel for heavier jacket-type foundation installation work, has a 31 meters boat beam, thus it is similarly excluded from participation in Great Lakes offshore wind projects. This means that the Great Lakes region will have to build its own fleet of heavy lift vessels (or crane barges) that will be needed for foundation and substation installations, as well as a fleet of larger, more sophisticated turbine installation vessels once the offshore wind industry's development enters a phase of rapid growth.

Appendix 4 – Offshore Wind Prospects in the Great Lakes Region



Location of Locks along the St. Lawrence Seaway
Source: Hofstra University

Appendix 4 – Offshore Wind Prospects in the Great Lakes Region

Historical Perspective of the Offshore Wind Industry

The topic of offshore wind power in the Great Lakes region is relatively new, with initial discussions in some states beginning in the early 2000s. Since then, each of the Great Lakes states (Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Wisconsin) have established a renewable portfolio standard (RPS) to drive up the amount of energy that must come from renewable sources. These RPS policies have raised interest in both onshore and offshore wind power.

Major Load Centers

In the Great Lakes region many of the population centers are located near or on the lakeshore. Since the second half of the 20th century, many Great Lakes cities have experienced population declines, although the region is still home to 17 of the top 100 metropolitan areas in the United States.

Load Centers Adjacent to Lake Area
Source: Great Lakes Commission

Manufacturing Capabilities in the Great Lakes Region

The shipbuilding and ship repair facilities on the Great Lakes represent a broad range of versatility and experience, including expertise in modular, sub-assembly and assembly line projects.

Great Lakes yards have an experienced workforce and a long established record of completing newbuild projects. They also have competed successfully in the wider North American market, building everything from New York City ferries, to internationally used dredges, US Coast Guard buoy tenders, to littoral combat ships for the US Navy.

Given the freshwater environment on the Great Lakes, vessel hulls have much longer life spans than oceangoing vessels, thus the majority of shipyard work in the Lakes is comprised of off-season maintenance, repair work, and refits.

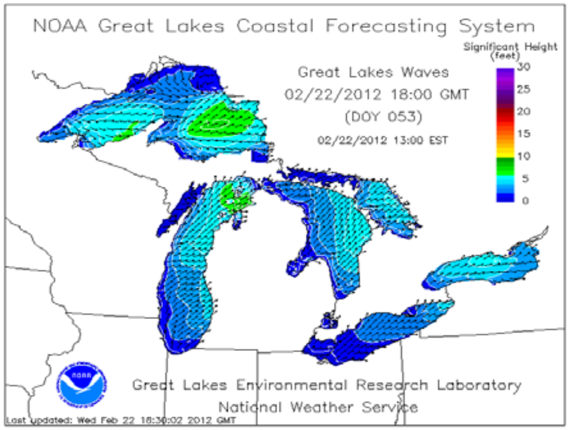
Several Great Lakes yards have experience in design and construction of aluminum hulls, which are particularly well-suited for the Great Lakes freshwater environment.

Given the long life spans of domestic Great Lakes cargo carriers, newbuilds for this market are sparse; thus many Great Lakes shipyards have targeted and developed expertise to serve such niche markets as work boats and specialty craft.

Operating cost advantages have resulted in a growing tendency to favor integrated tug barges (ITBs), both newbuilds and conversions, over self-propelled vessels for Great Lakes bulk cargo trades; thus Great Lakes yards have much experience in this type of vessel design and construction.

Great Lakes Technical Site Assessment

The Great Lakes differ across a range of basic physical features including water depth, surface area, and volume. Although Lake Michigan is nearly the deepest in terms of maximum depth, it contains several unique bathymetric attributes, including notable increases in lake-bed elevation at considerable distances offshore. Lake Huron remains relatively shallow (less than 60 meters or 195 ft) throughout a considerable amount of the south-central portion, and the same trend follows for Lake Erie's Western Basin (less than 15 meters or 50 ft). Lakes Superior and Ontario each exhibit a typical, radial depth pattern.



Significant Wave Height in February 2012
Source: NOAA GLERL

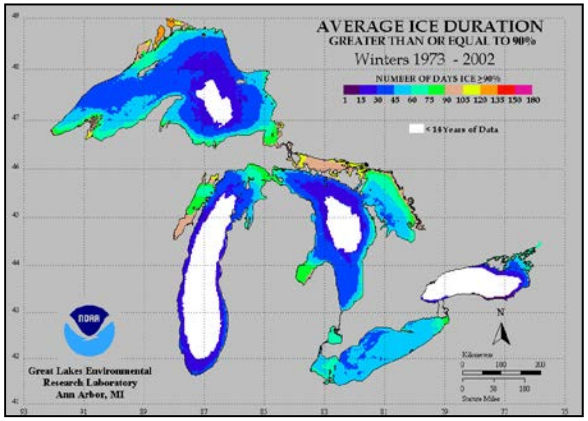
The lakes also differ in their wave patterns. Severe storms can produce waves in the range of 20-30 ft in some areas (particularly Lakes Superior and Michigan), although average annual wave height falls below this level (5-15 ft). Typically, for each of the lakes, the highest waves occur in conjunction with the highest frequency of storms during the autumn months. Both spring and autumn months produce higher waves relative to winter and summer months. Common 'hotspots' for the greatest wave height observations are located in areas such as southeastern Lake Superior, northeastern Lake Huron, and northern Lake Michigan, some of which overlap with areas that exhibit strong, consistent winds in the region.

In winter, temperatures drop and many areas of the lakes ice over (to the fullest extent on Lake Erie, the shallowest of the lakes; Michigan, Superior, Huron, and Ontario rarely exhibit full ice coverage). Ice cover extent and duration vary by lake according to several factors including water temperature, water depth, turbulent motion, and general climate patterns.

	Michigan	Superior	Huron	Ontario	Erie
Avg. Depth (m)	85	147	59	86	19
Max. Depth (m)	282	406	229	244	64
Total Surface Area (mi²)	22,300	31,700	23,000	7,340	9,910
Shoreline Length (mi.)	1,638	2,726	3,827	712	871

Table 35: Selected Physical Parameters of the Great Lakes
Source: Great Lakes Commission

Among the lakes, ice coverage has shown a decreasing trend, ranging from about a 10 to 18% decrease from the 1970s to the 1990s. Through 2009, total ice cover has decreased by 15% across the entire basin. In addition to ice coverage and storm frequency, seasonal fluctuations result in water level changes in the basin. Spring months bring increased snow and ice melt, the runoff of which re-establishes the thermal structure of the relatively calm, warm summer period. The highest water levels occur in spring due to increased runoff, and the lowest levels occurring in early winter, a time of higher levels of evaporation.



Average Ice Duration Greater Than 90% Ice Concentration
Source: NOAA GLERL

Appendix 4 – Offshore Wind Prospects in the Great Lakes Region

Case Study: New York Power Authority Offshore Wind Project

In September 2011, the New York Power Authority (NYPA) terminated a competitive solicitation process for a proposed Great Lakes offshore wind project, without awarding a project development contract. The project targeted between 120-500 MW of offshore wind capacity on Lake Ontario and Lake Erie.

Five wind developers submitted proposals to develop an offshore wind farm in the proposed area, namely Apex Offshore Wind LLC, Great Winds LLC, NRG Bluewater Wind Great Lakes LLC, Pattern Renewables Development Co. LLC, and RES Americas Developments Inc.

A feasibility study concluded that the project was technically feasible, but generation cost would have been two to four times higher than that of an onshore wind project. The NYPA estimated that a 150 MW project would have required an annual subsidy of between $60-150 million, resulting in a significant cost premium to the power authority.

Cost of construction would have been recovered in 20 years through a power purchase agreement with the NYPA.

Report ID: P-000740		
Role	**Name**	**Date**
Author(s)	Akos Losz	9/10/2013
	Steven Kopits	9/10/2013
Approved by	Steven Kopits (Project Director)	9/10/2013

About Douglas-Westwood

Established in 1990, Douglas-Westwood is an independent employee-owned company and the leading provider of market research and consulting services within the engineering, OEM and oilfield services sectors of the energy industry. We have offices in New York, Houston, Faversham (UK), London (UK), Aberdeen (UK) and Singapore. To date we have completed more than 900 projects for clients in over 70 countries around the world and have received 19 industry awards for our work.

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