U.S. Jones Act Compliant Offshore Wind Turbine Installation Vessel Study

A Report for the Roadmap Project for Multi-State Cooperation on Offshore Wind

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Final Report

Prepared for:

New York State Energy Research and Development Authority

Massachusetts Clean Energy Center

Massachusetts Department of Energy Resources

Rhode Island Office of Energy Resources

Clean Energy States Alliance

Prepared by:

GustoMSC

Houston, TX

Brian Cheater
Project Manager

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DOE Disclaimer

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NYSERDA Notice

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Abstract

This study created a framework for understanding what is required of a wind turbine installation vessel (WTIV) on the East Coast from technical and financial perspectives.

A pipeline of wind farm projects was based on offshore wind development areas identified in New York, Rhode Island, and Massachusetts. This pipeline provided a framework to define physical parameters such as number, size, and weight of turbines; water depth; and type, size and weight of the foundations.

These parameters fed into a study to define an installation methodology and a set of functional requirements for the installation vessels using both a feeder barge and a transit unit transportation option. Based on these functional requirements, designs were finalized and estimating packages were sent to U.S. shipyards. Indicative prices of $87 million (feeder barge) and $222 million (WTIV) were received for Jones Act compliant vessels. Operational expenses were estimated assuming the vessels were U.S. flagged.

This pipeline of work and cost data was used to create a basic cash flow model from the perspective of a vessel owner. Based on this model, at least 10 years of work, or a pipeline of approximately 3,500 to 4,000 megawatts of offshore wind capacity, would be required by a WTIV owner to provide a reasonable combination of day and internal rates of return.

This will require that a group of states and developers coordinate on an identified pipeline of projects. However, if the full potential of the offshore wind areas on the East Coast is realized, including areas not considered in this study, several vessels may be justified.

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Acronyms and Abbreviations

BOEM	Bureau of Ocean Energy Management
CAPEX	Capital Expenditure
Hs	Significant Wave Height
IRR	Internal Rate of Return
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
Tp	Peak Wave Period (sec)
te	metric tonne (1,000kg)
USCG	United States Coast Guard
VDL	Variable Deck Load
WOW	Waiting on Weather
WTIV	Wind Turbine Installation Vessel

Executive Summary

There is significant wind power potential off the East Coast of the United States, which is distributed over several states. Suitable vessels to construct offshore wind farms are key for the successful development of this resource. The Jones Act requires any vessel transporting cargo between U.S. ports be built and flagged in the U.S. For the purposes of the Jones Act, a bottom founded wind turbine foundation is considered a U.S. port. Consequently, a non-Jones Act wind turbine installation vessel (WTIV) is not able to transport components from an on-shore port to a turbine foundation. To use a foreign, non-Jones Act vessel, components from a U.S. port must be loaded onto a U.S. built feeder barge. The feeder barge is brought out to the project site where the foreign WTIV may lift the components off the feeder barge onto the foundation without moving. This strategy allows the use of foreign flagged vessels, but it requires additional Jones Act compliant feeder barges and costs.

This study examines the required functionality and financial considerations of both a Jones Act compliant WTIV and a feeder barge for input into a vessel owner's risk assessment. It is impossible to predict which individual projects will move forward or the associated timelines. Instead, this study looks at the maximum physical wind capacity (that could theoretically be developed) in the area and does not differentiate by state, developer, or project. It is an examination of the total capacity of the East Coast's offshore wind market to develop demand (in vessel-years) for a Jones Act WTIV. How and where this demand materializes is beyond the scope of this study. This study simply takes the developable capacity to provide perspective on the level of regional development required to justify capital investment of a WTIV or feeder barge. It will be up to the developers and WTIV owners to identify realistic potential pipelines and perform their own risk assessment before making any firm investment decisions.

This study took a sample of potential offshore wind development areas in the Northeast between New York and Massachusetts that have been leased to date by the U.S. Department of Interior's Bureau of Ocean Energy Management (BOEM) where existing, commercially available bottom-fixed technology may be used. Data on bathymetry, wind, wave, current, and soil conditions was identified. Eight-megawatt (MW) turbines were laid out in a 9 x 9 rotor diameters grid to tally the number of turbines that could theoretically be installed according to water depth range. This approach required a model of the potential number of turbines by water depth and does not differentiate by state or developer. From this, a design water depth of 55 m was identified for the vessel design and physical installation scenarios.

The installation work for an individual project was broken into three campaigns allowing year-round utilization of the vessel (where permitted) as shown:

- Installation of pin-piles
- Installation of jackets
- Installation of turbines

The installation work can be completed using two options for transporting materials from port to the project sites:

- A transiting WTIV that loads up directly in port
- A field bound WTIV supplied from port by feeder barges

Typical installation procedures using these two transportation options were developed in order to estimate the expected amount of time required to complete the installation. Based on a bottom-up estimate of the installation schedule, it will require at least 23 vessel years (a vessel occupied continuously for one year is one vessel year) to build out to the 55 m contour in the study area. This is based on a self-transiting WTIV; the feeder barge concept would remove approximately five years from the schedule, but this reduction in time would have to balance the cost of providing the feeder barge(s). Other factors may lead to using feeder barges, such as port restrictions.

Several factors influence the design and construction of a WTIV. Installation of hundreds of turbines will require an industrial like approach with simplified one-step operations; therefore, the WTIV should have the crane capacity and reach to enable installation of large components as a single completed unit (foundations for example). The vessel will have to work with available port facilities and the Jones Act requires vessels be built in the U.S.

To satisfy the requirements for the WTIV, the GustoMSC NG-9800C-US design was tailored from an existing proven design (the NG-9800C). It had an average U.S. shipyard estimated price of $222 million with a construction time of approximately 34 months. The GustoMSC NG-3750C was developed to satisfy the requirements of the feeder barge. It had an average U.S. shipyard estimated price of $87 million and a construction time of approximately 25 months. For maximum efficiency, two or more feeder barges could be employed depending on project requirements.

To achieve a reasonable combination of day rates ($220,000) and internal rate of return (10%), at least 10 years of work or a pipeline of approximately 3,500 to 4,000 MW of offshore wind capacity is required for the WTIV. For the feeder barge, approximately 16 years of work at a day rate of $85,000 is required for an internal rate of return of 10%. This requires a group of states and developers coordinate on an identified pipeline of projects. However, if the full potential of the offshore wind areas on the East Coast is realized, several vessels may be justified for areas not considered in this study.

1 Introduction

There is significant potential for offshore wind power available off the East Coast of the United States. Looking at the identified BOEM wind energy areas (WEA) in the study area, this potential is distributed over several states. Massachusetts has the largest individual capacity in terms of the size of their WEAs and adopted legislation calling for the procurement of 1,600 MW of offshore wind by 2027. New York State currently has a single WEA, but committed to develop up to 2,400 MW of offshore wind by 2030 and is developing a master plan that includes identifying additional areas suitable for development. Beyond these existing commitments, the study area can support significant additional capacity in excess of 8,000 MW out to 55 meters of water depth.

Economic development of offshore wind power requires a large-scale industrial approach with a combination of large turbines and ultra-efficient installation methods to drive down the Levelized Cost of Energy of the power produced. European developers for the Borssele III and IV sites (4C Offshore, 2016) recently signed agreements at 54.5 euro/MWh (excl. 14 € / MWh transmission costs) or $74/MWh including transmission costs. This reduction is made possible through economies of scale and supply chain efficiency.

This study examined what type of installation vessel would fit the requirements of this regional market. A suitable installation vessel is a key enabler for the successful development of any large-scale wind farm. The Jones act requires any vessel transporting cargo between U.S. ports be built and flagged in the U.S. Additionally, the Jones Act considers any facility connected to the sea bottom, such as a wind turbine foundation, a U.S. port.

However, a WTIV is a very large investment that can only be supported with a pipeline of work. This study will attempt to clarify what type of installation vessel would work with the local infrastructure and the pipeline of work that is required to support construction of such a vessel.

2 Study Approach and Methods

This study assumed a hypothetical, but realistic, set of wind farm developments in the region (based on current identified wind areas) along with construction and installation methodologies. A set of functional technical requirements were developed to satisfy the possible build-out scenarios. Concept designs for both a WTIV and feeder jack-up were developed to satisfy the technical requirements. Estimating packages were submitted to selected U.S. shipyards to obtain build prices for Jones Act compliant vessels and a crewing model for a U.S. flagged vessel was created to provide data on operational costs. The study then established a vessel-specific financial model tracking capital (CAPEX) and operational expenses to generate Net Present Value (NPV), and Internal Rate of Return (IRR). A limited number of sensitivity studies in the financial modeling were undertaken.

To be sufficiently general, the study assumed a hypothetical wind farm complete with metocean conditions (wave heights, wind speeds, current speed) and an offshore installation strategy. This reflected expectations about potential regional wind farms along with industry practice and trends, but was not intended to be specific to any particular project and should be taken as indicative only.

The hypothetical scenario defined an envelope of expected construction fundamentals and operations in which those activities are conducted. These were used to generate a set of functional requirements for the wind farm installation vessel.

Based on the functional requirements, commercially available designs were selected, or modified as necessary, for two construction strategies:

- Transit strategy: Installation vessel loading turbine components at the staging area, sailing to installation location, and installing components.
- Feeder strategy: Installation vessel remaining offshore and being fed with wind turbine components by feeder units that transport the components from the staging area to the installation location. The actual installation vessel may be the same as for the transit strategy or a more cost-efficient unit can be used, which does not include the features specifically required for the transit strategy.

These designs formed the basis for the indicative costs and business plan development.

Wind farm technology is quickly evolving as turbine sizes are expanding with 10-15 MW designs on the horizon. Jacket designs continue to be refined and weights optimized. Monopiles are being deployed in deeper water depths and are, therefore, growing in size and weight. The philosophy adopted in this study was to look at the leading edge of what was commercially deployed and proven at the time. Where they were understood and it was reasonable to accommodate them, margins for future growth in turbine size were allowed for in the design. This study does not address wind farm installation in waters deeper than 55 m where floating foundations (which do not require a WTIV) may prove attractive.

Data for the hypothetical wind farms (including the assumed turbine size and weights) was based on a composite picture built from several different publicly available sources. It does not, in any way, represent a particular development; rather, it is a set of conservative assumptions chosen to frame-up the requirements of the WTIV. Taken together, they represent a design envelope for the WTIV.

A construction and installation methodology was required to drive the functional requirements. For this reason, several installation methodology assumptions were made. However, there are many possibilities and individual developments may differ from the one presented here for project specific reasons.

3 Regional Wind Farm Developments

This study took a sample of potential offshore wind development areas in the Northeast between New York and Massachusetts (hereafter the Study Area) where existing commercially available bottom fixed technology may be used. Data on bathymetry, wind, wave, current, and soil conditions are presented.

Eight-megawatt turbines were laid out in a 9 x 9 rotor diameters grid to tally the number of turbines that could theoretically be installed in the sample area according to water depth range. Details of the wind turbine and foundation are presented including installation challenges surrounding the foundations and the strategy chosen to rectify the issue.

Alternative transportation strategies are also discussed. Installation methodologies are presented using these strategies and used to build an overall project timeline to estimate the likely demand (in vessel years) for installation vessels on the East Coast.

3.1 Water Depth Survey

NREL report 60942 (Musial, 2013) presents a detailed analysis of possible wind turbine layouts in the Massachusetts wind area south of Nantucket so, this, along with the New York and Rhode Island wind areas were chosen as the Study Area. The Musial study is comprised of the lease areas: OCS A-0500, OCS-A 501, OCS-A 502 and OCS-A 503. The New York area is comprised of the lease area: OCS-A 512. The Rhode Island area is comprised of the lease areas: OCS-A 486 and OCS-A 487.

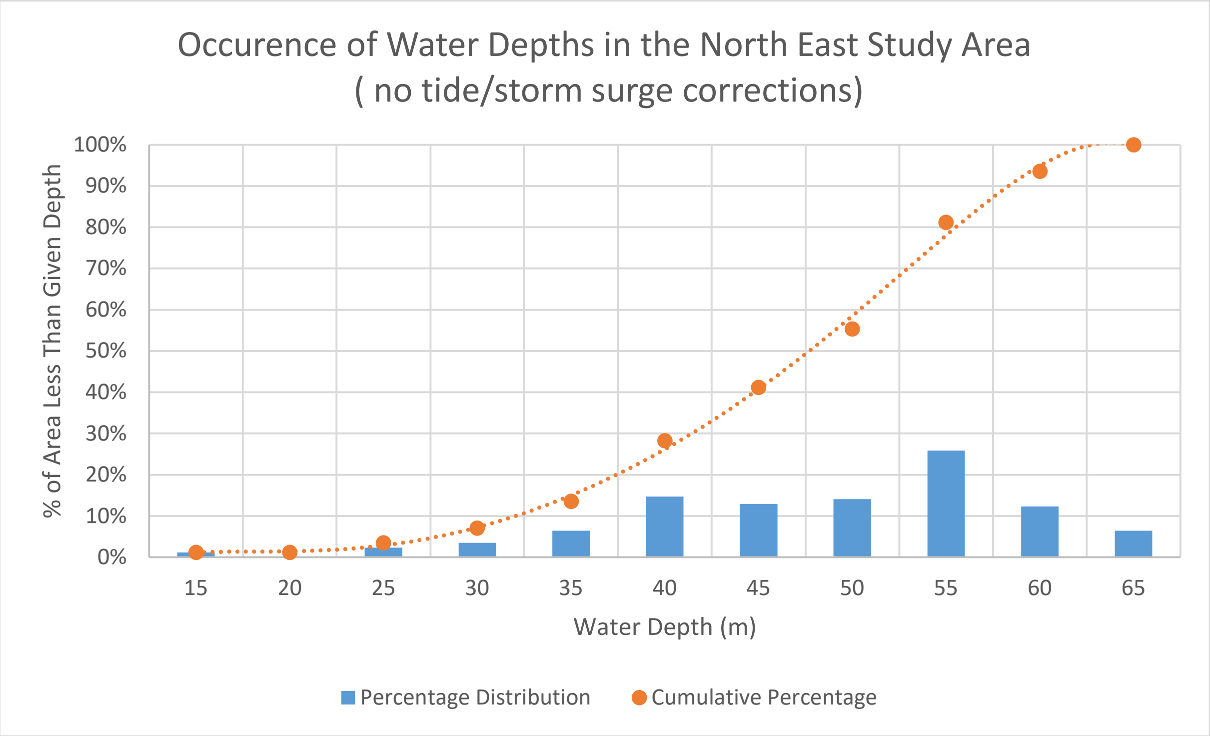
Based on the areas, the distribution of water depths was calculated based on bathymetry maps and summarized in Table 1. This table tallies the number of BOEM blocks (measuring approximately 3-mile x 3-mile) in each water depth range. From that, a distribution was derived and a cumulative percentage of water depth was calculated and plotted in Figure 1.

Table 1. Distribution of Water Depths over the Northeast Study Area

	NUMBER OF WIND LEASE BLOCKS versus MAXIMUM WATER DEPTH (m)											
STUDY AREA	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	Σ
1			3	4	8	12						27
2	2					7	22	24	44	21	11	131
3			1	2	3	6						12
Σ	2	0	4	6	11	25	22	24	44	21	11	**170**
	30	0	100	180	385	1000	990	1200	2420	1260	715	48.71

	PERCENTAGE DISTRIBUTION OF WATER DEPTH											
STUDY AREA	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	Σ
1	0.0%	0.0%	1.8%	2.4%	4.7%	7.1%	0.0%	0.0%	0.0%	0.0%	0.0%	16%
2	1.2%	0.0%	0.0%	0.0%	0.0%	4.1%	12.9%	14.1%	25.9%	12.4%	6.5%	77%
3	0.0%	0.0%	0.6%	1.2%	1.8%	3.5%	0.0%	0.0%	0.0%	0.0%	0.0%	7%
Σ	1%	0%	2%	4%	6%	15%	13%	14%	26%	12%	6%	
CUMUL	1%	1%	4%	7%	14%	28%	41%	55%	81%	94%	100%	

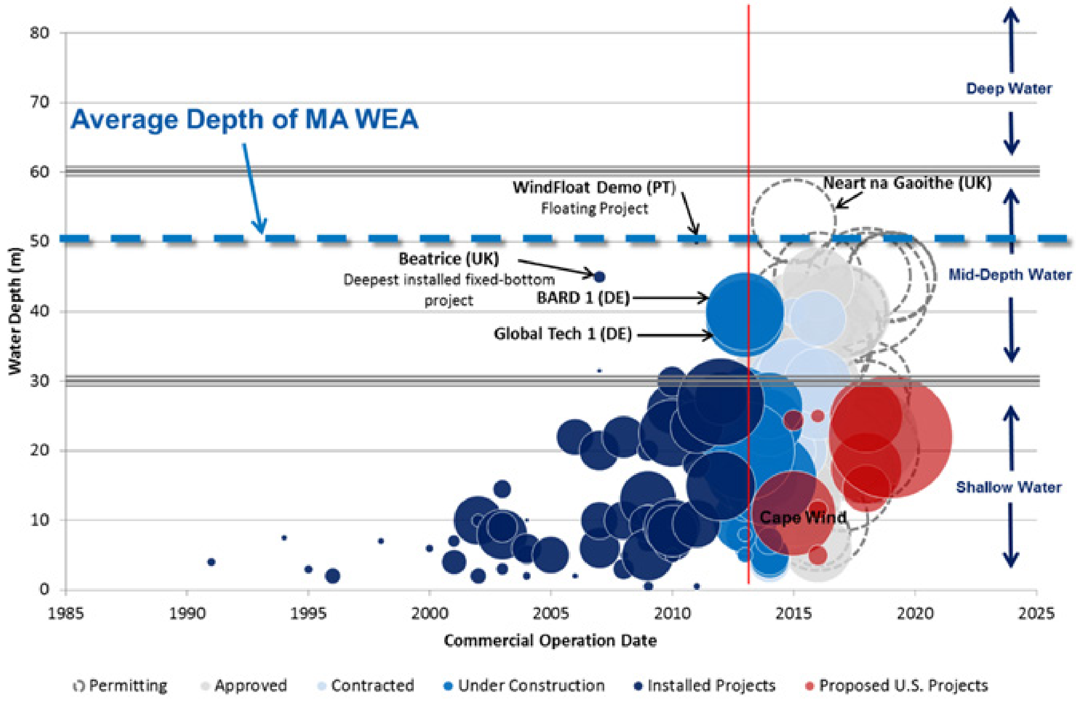
Figure 1. Occurrence of Water Depths over the Northeast Study Area



Water depths are observed to range from 15 m to 65 m with an average of 48.71 m. A design water depth limit of 45 m would cover only 41% of the Study Area, whereas a depth limit of 55 m would extend coverage up to 81%. Approximately 40% of the Study Area is between 45 m and 55 m. A final design water depth of 55 m was taken as a reasonable upper bound for the sample area region considered.

By comparison to other projects in Europe or earlier proposed U.S. wind projects (see Figure 2), this Study Area is in deeper water. Consequently, foundation types such as monopiles that are successful in Europe must be requalified for the greater water depth or replaced with an alternate foundation such as a jacket. For waters beyond approximately 65 m, floating wind solutions may start to become attractive.

Figure 2. Distribution of Project Water Depths (including Europe) (Musial, 2013)



3.2 Wave, Wind and Current Conditions

A formal metocean data report for the region was not available, but a literature search provided some data points. An analysis of the expected metocean conditions at six sites was presented by (Damiani, 2016). Their results are summarized in Table 2. Cases 3 and 5 are assumed representative of the region of interest.

Table 2. Metocean Parameters for Six Sites (Damiani, 2016)

Case	Buoy	Name	Water Depth (m)	Hs 50yr (m)	Hmax 50yr (m)	Tp 50yr (sec)	HAT (m)	δ 1000yr (m)	Hmax 1000yr (m)	Deck Height (m)
1	41013	Frying Pan Shoals	23.5	10.82	18.33	13.34	1.26	1.25	18.33	13.2
2	42035	Galveston	12.8	7.24	9.98	10.91	0.47	6	9.98	13
3	**44025**	**Long Island**	**40.8**	**9.48**	**17.63**	**12.48**	**0.33**	**2.5**	**23.26**	**16**
4	41035	Onslow Bay	9.7	10.46	7.57	13.11	0.83	0.9	7.57	7
5	**44008**	**Nantucket**	**65.8**	**12.15**	**22.6**	**14.13**	**0.79**	**1.54**	**28.31**	**18**
6	42036	W. Tampa	50.6	7.63	14.19	11.2	0.84	1.5	17.81	12.7

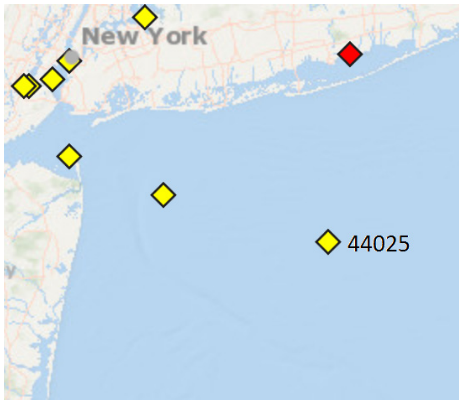
a. Hs is significant wave height in a winter storm as limited by breaking wave limit

b. Hmax is the maximum expected wave height as limited by breaking wave limit

c. δ is the expected 1, 000 year storm surge

Monthly distribution of expected wave heights was obtained from NOAA Buoy 44025 (Long Island) and presented in Table 3.

Table 3. Monthly Wave Statistics Buoy 44025 (NOAA, 2017)

	Buoy 44025			
MONTH	**Hs_mean (m)**	**Hs_max (m)**	**H_ext (m)**	**Location of Buoy 44025**
JAN	1.5	6.7	12.5	
FEB	1.5	6.1	11.3	
MAR	1.4	7.4	13.8	
APR	1.3	5.4	10.0	
MAY	1.1	5.0	9.3	
JUN	1.0	3.5	6.5	
JUL	1.0	5.1	9.5	
AUG	1.0	5.6	10.4	
SEP	1.3	6.7	12.5	
OCT	1.3	6.0	11.2	
NOV	1.4	6.5	12.1	
DEC	1.6	8.5	15.8	
ANNUAL	**1.6**	**8.5**	**15.8**	

This data is for regular storm conditions. Tropical hurricanes are outside the design envelopes of a WTIV and not considered here since a WTIV (as a mobile unit) is able to seek shelter in shallow water outside the main hurricane path.

As shown in Table 3, December is the worst month with a mean significant wave height of 1.6 m and a maximum of 8.5 m. The cumulative distribution of wind speed by month and total annual is presented in Table 4. The wind speeds reported are eight-minute averages per the National Data Buoy Center

(NOAA - NBDC, 2017). For an actual project, a site specific metocean report with one-, 10- and 50-year values for wind, wave, tide, storm surges, and current should be obtained.

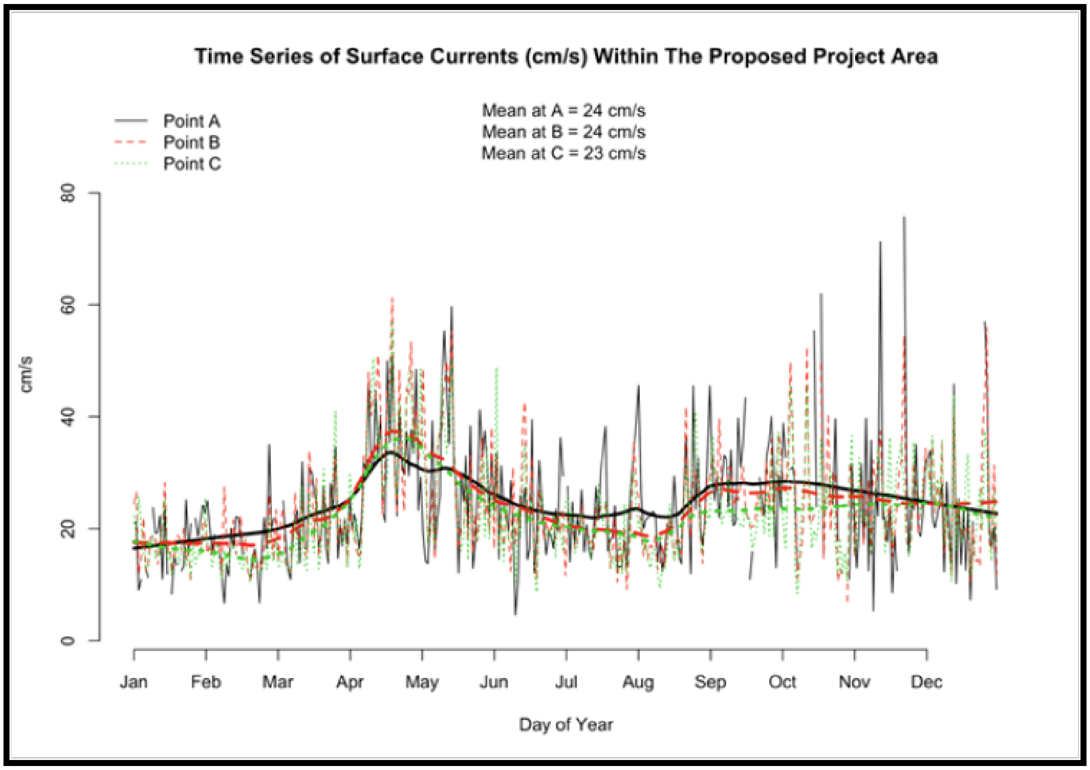
Table 4. NOAA Buoy 44025 Cumulative % Frequency of Occurrence

CUMULATIVE % FREQUENCY OF AVERAGE WIND SPEED AT BUOY 44025 BY MONTH													
Vwind (knots)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
45	-	-	-	-	-	-	-	-	-	-	-	-	999
44	-	-	-	-	-	-	-	999	-	-	-	999	999
43	-	999	-	-	-	-	-	-	-	-	-	999	999
42	999	-	999	-	-	-	-	-	-	-	-	-	999
41	999	-	999	-	-	-	-	-	-	999	-	-	999
40	999	999	999	-	999	-	-	-	-	999	999	999	999
39	999	999	999	-	999	-	-	999	-	999	-	999	999
38	999	999	999	-	-	-	-	-	-	999	999	999	999
37	999	999	999	999	999	-	-	999	-	999	999	999	999
36	999	998	999	999	999	-	-	-	-	999	999	999	999
35	998	997	998	999	999	-	-	-	999	999	999	997	999
34	996	997	997	999	998	-	-	999	999	998	998	996	998
33	993	996	996	999	998	-	999	-	999	997	997	993	997
32	989	994	994	999	997	999	999	-	999	995	994	988	996
31	983	992	992	999	997	999	999	999	998	992	991	982	994
30	977	988	988	998	996	999	999	999	998	990	987	974	991
29	969	984	982	997	995	999	999	999	996	987	982	965	988
28	958	978	975	994	994	999	999	999	995	983	975	952	984
27	943	966	967	991	992	998	999	999	992	978	968	938	978
26	924	954	955	986	990	998	998	998	989	970	955	919	970
25	896	929	939	980	987	996	997	997	984	958	937	893	959
24	867	905	919	973	983	993	996	996	978	944	920	865	946
23	832	880	900	964	978	990	994	993	972	927	896	835	932
22	793	849	876	953	973	987	992	988	963	904	873	801	915
21	750	814	849	938	964	982	988	982	949	878	843	759	894
20	706	779	820	919	952	975	983	974	934	848	807	718	871
19	661	736	786	896	939	965	975	962	916	813	765	675	844
18	600	680	742	862	920	948	961	947	890	765	712	623	808
17	555	628	703	831	897	930	943	931	862	725	662	572	775
16	505	574	661	791	872	908	917	909	822	681	608	524	736
15	457	523	620	744	840	877	888	877	775	634	554	474	694
14	407	474	567	699	802	836	849	839	723	584	497	427	648
13	358	426	510	649	757	783	802	795	666	531	444	375	597
12	310	378	456	593	706	720	742	742	605	479	390	325	543
11	252	326	393	519	634	639	665	664	531	414	327	270	475
10	207	280	340	453	567	559	587	595	465	356	276	223	414
9	169	234	292	385	491	474	505	514	396	298	229	180	352
8	137	197	243	321	408	391	421	432	329	246	183	144	291
7	104	156	197	254	329	310	334	349	266	199	143	113	232
6	79	122	152	194	256	234	254	269	209	152	111	86	179
5	58	90	112	139	185	162	182	198	151	110	81	63	129
4	35	60	70	85	116	95	108	125	94	68	51	40	80
3	21	37	44	52	66	54	66	80	56	43	31	24	48
2	12	21	24	27	33	27	35	44	30	23	17	14	26
1	6	10	10	11	15	12	15	20	12	11	8	5	11
0	2	2	4	3	5	3	5	4	3	2	2	1	3

There is little information available on current speed, but Figure 3 (AWS Truepower LLC, 2010) shows current data with a maximum observed peak current is 70 cm/sec. Seasonal averages are maximum in April, which corresponds to spring outflow from the Hudson River. This seasonal maximum may apply to the New York lease area, but would not be expected to affect the Massachusetts area.

Note, site-specific data processed to yield the 50-year maximum current speed would be required for an actual site assessment. For the purposes of this study, 0.7m/s is taken as an indicative value of the maximum current in the area for preliminary sizing.

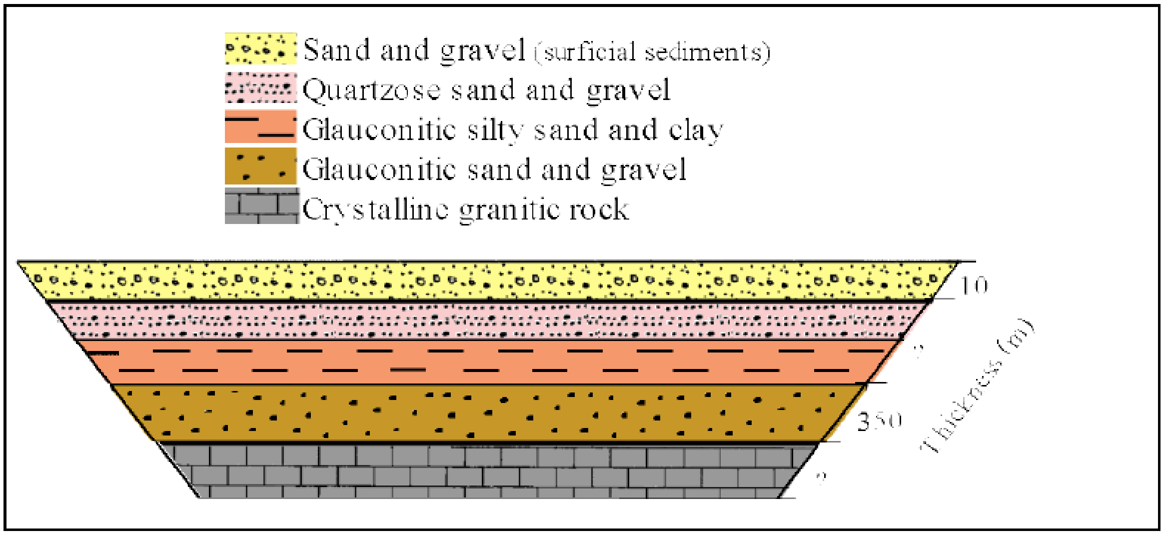
Figure 3. Time Series of Surface Currents New York (AWS Truepower LLC, 2010)



3.3 Soil Conditions

No site-specific geotechnical data is available, but indicative soil conditions from the region is included. As shown in Figure 4, the seabed consists of sand or gravel with an additional shallow layer of clay at the top in some areas (AWS Truepower LLC, 2010). “Below the benthic sediment layer are strata consisting of semi-consolidated quartzose sand and gravel overlying glauconitic silty sand and clay. It is not anticipated that the subsurface geology will impose a significant obstacle to the construction of a wind project.”

Figure 4. Indicative Stratification of Seabed (AWS Truepower LLC, 2010)



Soil conditions may range from high sand content (80% to 100%) in the northern two-thirds of the area to predominantly silt and clay content in the southern section. There is a risk of embedded rocks and boulders at some sites. Buried channels may also be present at some sites and should be carefully evaluated. As noted in AWS Truepower LLC, 2010, sandy sediments may present scouring issues.

All metocean, bathymetry, geophysical, and geotechnical data should be reconfirmed with site-specific data (refer to SNAME 5-5A (SNAME 5-5A, 2008), ISO 19905-1 Appendix D (ISO 19905-1, 2012), OGP Guidelines for the conduct of offshore drilling hazard site surveys of 2011, and ISO 19901-8:2004, Specific Requirements for Offshore Structures – Marine Soil Investigations).

The proposed concept of preloading diagonally on two out of four legs should greatly reduce the risk of punch-through during WTIV installation, but this should always be carefully verified (refer to SNAME T&R 5-5A, ISO 19905-1).

3.4 Wind Turbine

Turbine characteristics based on size are presented (Elkinton C, 2014) and summarized in Table 5. This study assumed that the wind farms use 8-MW turbines. Larger turbines are expected to become commercially available in the future, but at the time of writing, 8-MW represents a reasonable upper bound. Margins for future growth in turbine size were allowed for in the design of the WTIV.

Table 5. Summary of Wind Turbine Characteristics

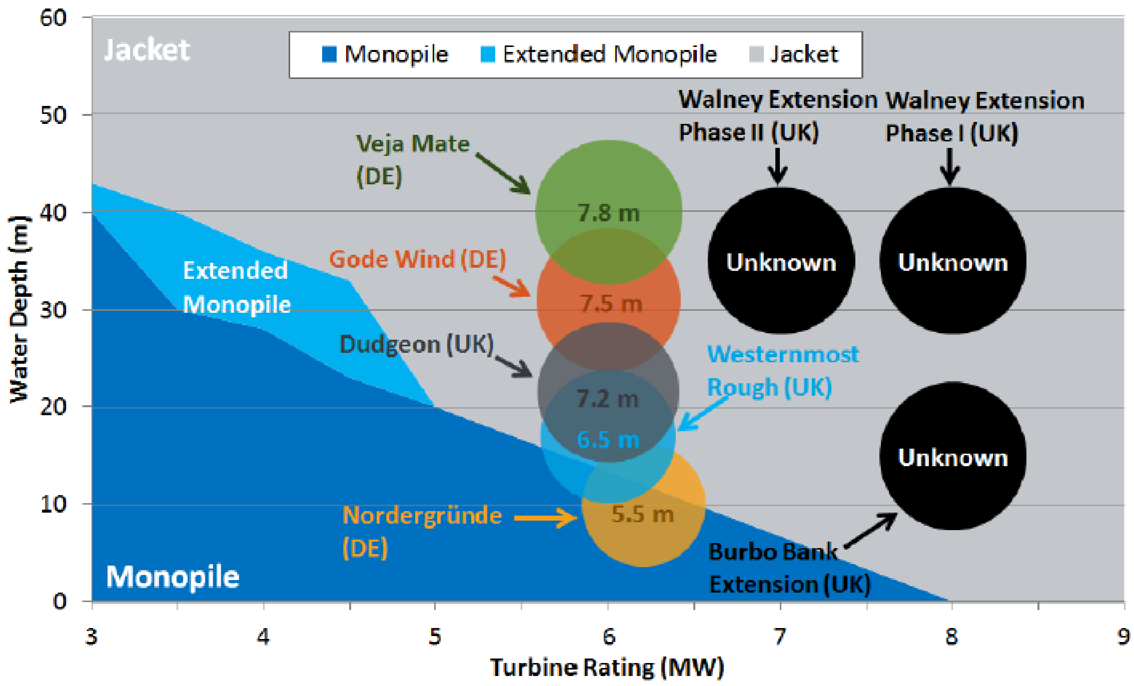
	TURBINE SIZE (MW)				
PARAMETER	4	5	6	7	**8**
ROTOR DIAM (m)	120	135	150	164	**175**
BLADE LENGTH (m)	59	66	73	80	**85**
BLADE WEIGHT (te)	19	23	28	34	**40**
BLADE CHORD(m)	4	5	5	6	**6**
NACELLE WEIGHT(te)	162	239	330	390	**450**
LIFTING FRAME (te)	16	24	33	39	**45**
TOTAL NACELLE(te)	178	263	363	429	**495**
NACELLE LENGTH(m)	13	16	18	20	**21**
NACELLE WIDTH(m)	5.2	6.3	7.4	8.5	**9.6**
TOWER LENGTH (m)	66	74	81	88	**94**
TOWER WEIGHT(te)	185	215	250	280	**500**
TOWER DIAM (m)	5	5.5	6	6.25	**6.75**
TOTAL LENGTH (m)	66	74	81	88	**94**
# SECTIONS	2	2	2	2	**2**
SECTION LENGTH(m)	33	37	41	44	**47**
SECTION WEIGHT(te)	93	108	125	140	**250**

3.5 Turbine Foundations

The water ranges from 15 m to 55 m over the Study Area. This is shallow for floating wind and deep for monopile foundations. Gravity Base Structure foundations were not considered as part of this study due to their significant weight and the amount of site preparation required to level and resurface the site offshore.

European developers are familiar and comfortable with monopiles as they have been successful with the smaller turbine sizes and lower water depths on earlier projects. A survey of monopile installations to date (See Figure 5) reveals this combination of turbine size and water depth exceeds that which is typically used currently for monopoles.

Figure 5. Foundation Type by Water Depth and Turbine Rating (Aaron Smith, 2015)



Monopiles are less efficient from a structural engineering perspective, but easy to manufacture. To provide sufficient strength against yield and buckling and adequate stiffness to keep the fundamental natural frequency above the range of excitations, pile diameter and wall thickness increase. This increase results in very rapid weight growth. Also, there are drivability challenges for large diameter piles and the risk of hitting embedded boulders.

Lattice jackets are more efficient from a structural engineering perspective, but more complex to manufacture. Lattice structures use widely spaced legs consisting of a tubular truss structure to provide stiffness and strength at optimum steel usage.

There is active research in the monopile and jacket communities to push the frontier for both foundations, optimizing weight and minimizing construction complexities, which makes it impossible to rule out one or the other for future developments.

However, for the purposes of this study, the turbines will assume to be supported by jackets because they are light enough for installation by the WTIV and are proven in the offshore oil and gas industry for these design loads and water depth. There is also significant U.S. experience building jackets. At the current time, monopiles are not yet considered to be commercially demonstrated for this combination of water depth (55 m) and turbine size (8 MW). Monopiles and gravity base structures may be used in certain circumstances in the U.S., such as in shallower water, but alternative methods may be required for installation depending on size and weight. The WTIV from this study could still install the turbines on top of the foundations.

No specific jacket design was available for this study, so a parametric study was completed based on publicly available data to obtain indicative dimensions and weights of the jackets suitable for the given wind turbine size and water depth range.

Using data from Elkinton (Elkinton C, 2014), a simple linear expression (y=mx+b) for jacket weight vs. turbine size (for a fixed water depth of 40m) was developed as shown in Table 6.

Table 6. Jacket Weight vs. Turbine Size

JACKET VARIATION BY SIZE		
WGHT in 40m WD	TURBINE SIZE (MW)	WGHT RATIO
609	5	1.000
684	6	1.123
759	7	1.246
834	8	1.369
	m =	0.123
	b =	0.384

Using data from Damiani (Damiani, 2016), a simple linear expression (y=mx+b) for jacket weight vs. water depth for a fixed turbine size of 5 MW was developed based on a conventional four-legged jacket as shown in Table 7 .

Table 7. Jacket Weight vs. Water Depth

VARIATION IN JACKET WEIGHT BY WATER DEPTH						
WATER DEPTH (m)	JACKET TTL	PILES 36%	TRUSS	DEDUCT	FINAL Truss	WGHT RATIO
9.7	794	286	508	0	508	0.8228
12.8	850	306	544	0	544	0.8808
23.5	906	326	580	0	580	0.9389
40.8	965	347	618	0	**618**	1.0000
50.6	1026	369	657	0	657	1.0632
65.8	1183	426	757	0	757	1.2259
					m	0.0063
					b	0.7745

These simple linear models were used to calculate the weight of a jacket required to support an 8 MW turbine in 55 m of water as shown in Table 8.

Table 8. Jacket Weight by Turbine Size and Water Depth

JACKET WEIGHT (te) - CONVENTIONAL 4 LEGS				
WATER	TURBINE SIZE (MW)			
DEPTH (m)	5	6	7	8
20	556	624	693	761
30	595	668	741	815
40	634	712	790	868
50	673	756	839	922
60	712	800	887	**975**

Per Table 8, an 8 MW turbine in 55 m of water is expected to require a jacket that weighs approximately 975 te, excluding piles and transition piece. To provide a conservative estimate on deck space and weight requirements, a square jacket with battered legs is assumed for this study; however, future developments may find other designs (such as tripods) advantageous.

The jackets are assumed to be four-leg pin piled lattice structures, which measures 30 m x 30 m x 70 m high with a weight of 1000te. In the worst case, they are located in waters 55 m deep with a 15-m air gap. A deck is fitted at the top with a transition piece for the wind turbine tower. Boat landings and access ladders are provided. Each pin pile is assumed to be 2.7 m in diameter x 80 m long with a weight of 150te.

Installation of the jacket foundations can be completed using either one of the following options:

1. Large WTIV jack up
2. Floating heavy lift crane vessel
3. Floating sheerleg crane

Option 1 would be limited to jackets and other foundations of 900–1,100te (such as pin pile supported jacket types). This would require a crane of 1,500te, which is the upper bound on current WTIV. Note that larger units could have cranes of 2,000–2,500te.

Option 2 could be used for larger jackets and other foundations (e.g., mat supported sleeve-piled jacket types), but the market for large floating heavy lift crane vessels is limited. Currently, there are very few cranes in the 1,500–2,000te range available worldwide and using one of the larger cranes over 2,000 te would prove cost prohibitive. In addition, to justify the mobilization cost, a volume of work would have to be guaranteed for the unit.

Option 3 could be for larger jackets and other foundations. While this would open access to the large sheerleg market and increase leasing options, it is limited to mild weather conditions. In addition, sheerleg cranes cannot slew and positioning of the load would be more difficult.

For the purposes of this study, option 1 was assumed so the jacket would be installed with the WTIV. This option was chosen for the following reasons:

- Technically feasible with pin-pile jackets
- Allows for more precise positioning of jackets in a wider range of weather windows
- Provides full utilization of the WTIV
- Removes the need for separate mobilization of a heavy lift vessel or sheerleg crane

To install the foundations, the WTIV will require a 1,500te crane with an outreach of 25 to 30 m. The 1,500te rating is required to safely lift the 1,000te jacket with allowances for dynamic amplification factors, splash zone effects such as wave loading and hydrodynamic added mass, lifting gear, and uncertainties in weight.

3.6 Regional Pipeline of Wind Farm Projects

This study followed the lead of NREL Report 60942 for the purposes of developing an assumed regional pipeline.

The Study Area from Section 3 was discretized and a pattern of turbines laid-out. The turbine spacing was taken as 1,600 m (9D), based on 8-MW turbines, and the layout follows a simple rectangular grid that is not optimized in any way for wake effects or directionality. This should represent an upper bound on the potential capacity of the existing lease areas in the Study Area and demand for a WTIV. Additional lease areas off other states outside of the Study Area and new areas leased by BOEM may further increase demand for a WTIV.

The total number of turbines that could be laid out were tallied by water depth range (summarized in Table 9).

Table 9. Theoretical Capacity of Study Area (Number and Power of Wind Turbines)

		TURBINE COUNT		INSTALLED POWER		
PHASE	WD (m)	Sub-Total [#]	CUMUL [#]	Sub-Total [MW]	CUMUL [MW]	CUMUL [%]
1	25-40m	189	189	1512	1512	15%
2	28-40m	100	289	800	2312	23%
3	35-50m	400	689	3200	5512	55%
4	50-55m	351	1040	2808	8320	84%
5	55-60m	130	1170	1040	9360	94%
6	60-65m	72	1242	576	9936	100%
	TOTAL:	1242	@ 8MW =	9936	MW	

For the purposes of this study, the maximum assumed water depth shall be taken as 55 m, as shown in Table 9, is deep enough to capture 84% of the available wind capacity. The hypothetical build-out scenario for this study assumes 8-MW wind turbines are used.

3.7 Staging Port

Due to the length of the legs (approximately 90 meters) for a WTIV capable of installing turbines in 55 m of water depth, access to ports without overhead obstructions or concerns with air draft is required.

The Port of New Bedford in Massachusetts has no air draft limitations and a terminal designed to accommodate offshore wind construction. For entry into port, the WTIV will require passage through an opening no more than 45.7 m wide with vertical sides. To accommodate the Port of New Bedford, the maximum allowable hull width is 42.0 m. The water depth in the channel has been dredged to 8.7 m with the maximum allowable draft at 8.7 m. The distance from the staging port to the furthest point of any wind farm in the Study Area is 120 nautical miles.

3.8 Installation Campaigns

Construction activities in the Northeast are strongly influenced by season. The WTIV is designed to operate year-round, but some construction activities are limited by season. For example, the optimal time to install turbines is during the summer when the winds and waves are lowest, trying to install turbines in winter would result in high downtime spent waiting on weather. Consequently, the construction activities are divided into campaigns based on their sensitivity to weather.

At a high level the installation can be considered as a series of campaigns as shown:

- Installation of piles (See Figure 6)
- Installation of jackets (See Figure 7)
- Installation of complete turbines (See Figure 8)

The vessel would be configured as appropriate for each campaign.

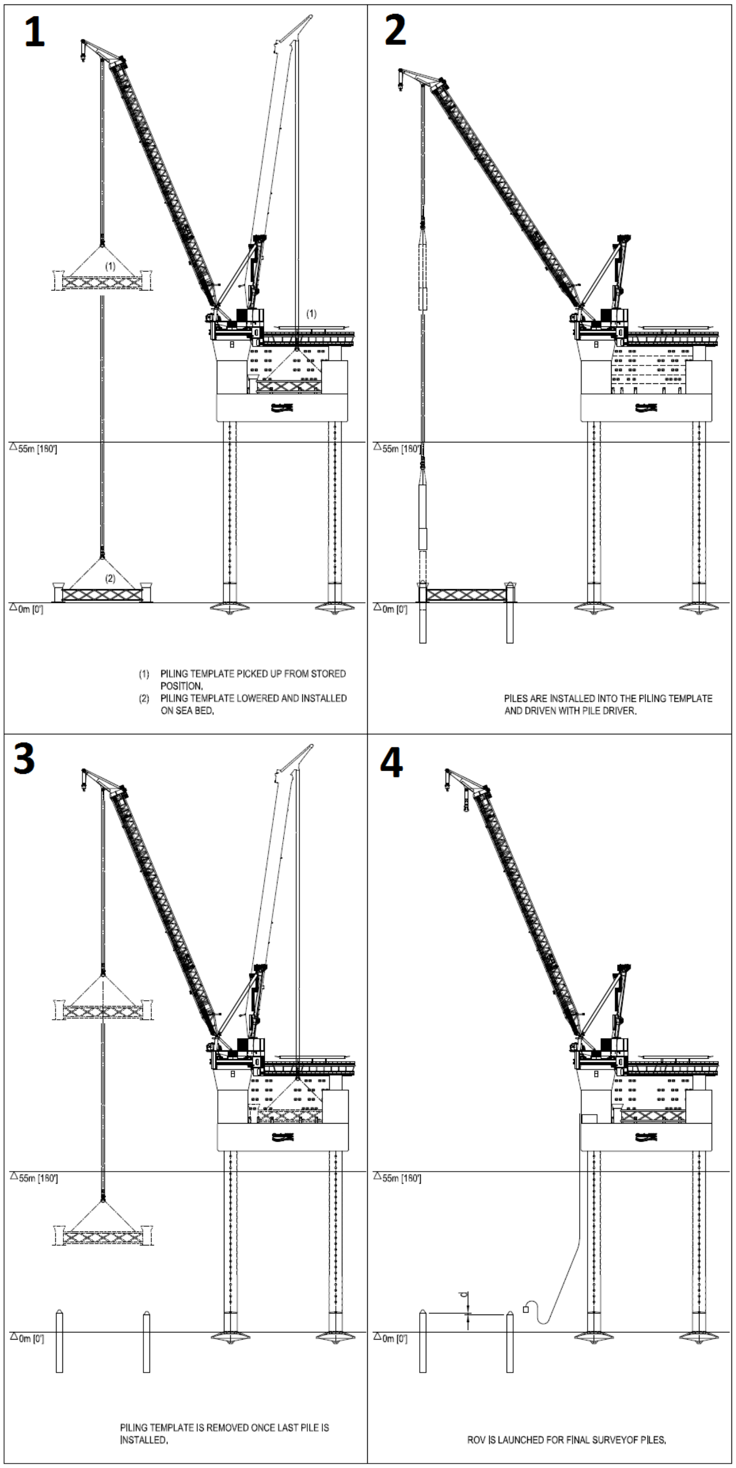
Campaign 1 requires a pile guide frame along with a survey team and possibly a ground penetrating sonar to probe the pile locations for embedded rocks. An ROV would be necessary for site survey. The pile installation is not as sensitive to weather and can be completed in more demanding circumstances including typical winter conditions. Restrictions on activity due to marine mammals would have to be considered. Mitigation techniques such as bubble curtains may allow for increased time for pile installation.

Campaign 2 requires a grouting spread on the deck of the WTIV with a grouting team onboard. As the lift and installation of the jacket is a weather sensitive operation, these campaigns would preferably be conducted in early spring or late fall to minimize weather delays.

Campaign 3 requires hook-up and commissioning personnel for the wind turbine. Access from the WTIV to the supporting foundation would be provided by gangway and could only be conducted in summer or early fall during optimal weather conditions.

Organization by campaigns allow construction activities on units designed for year-round operations. Also, by splitting into campaigns, the specialty crews will be more efficiently scheduled and through repetition, become more effective as the job progresses.

Figure 6. Campaign 1 Pile Installation Sequence



(1) PILING TEMPLATE PICKED UP FROM STORED POSITION.
(2) PILING TEMPLATE LOWERED AND INSTALLED ON SEA BED.

PILES ARE INSTALLED INTO THE PILING TEMPLATE AND DRIVEN WITH PILE DRIVER.

PILING TEMPLATE IS REMOVED ONCE LAST PILE IS INSTALLED.

ROV IS LAUNCHED FOR FINAL SURVEYOF PILES.

Figure 7. Campaign 2 Jacket Installation Sequence

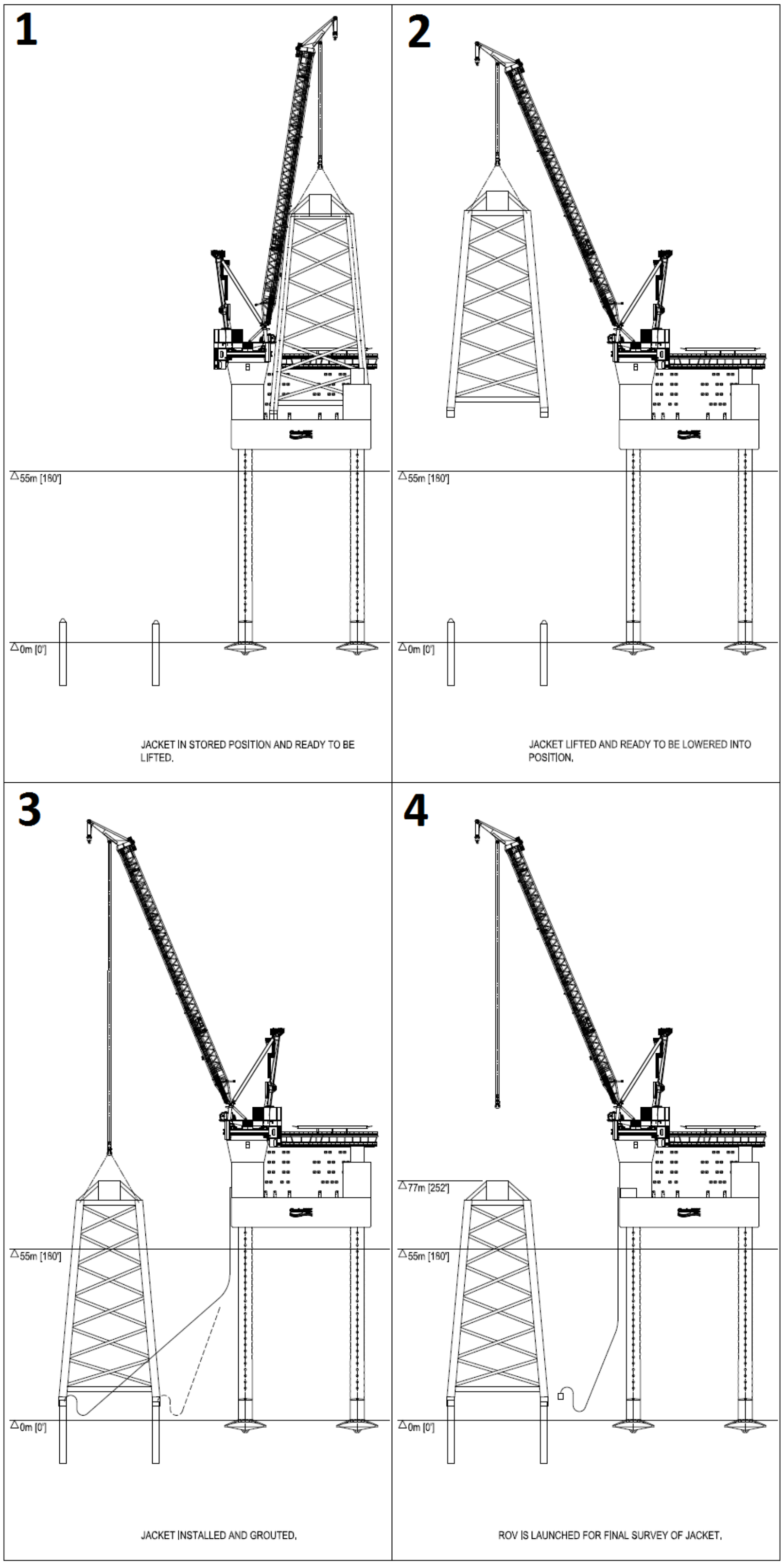
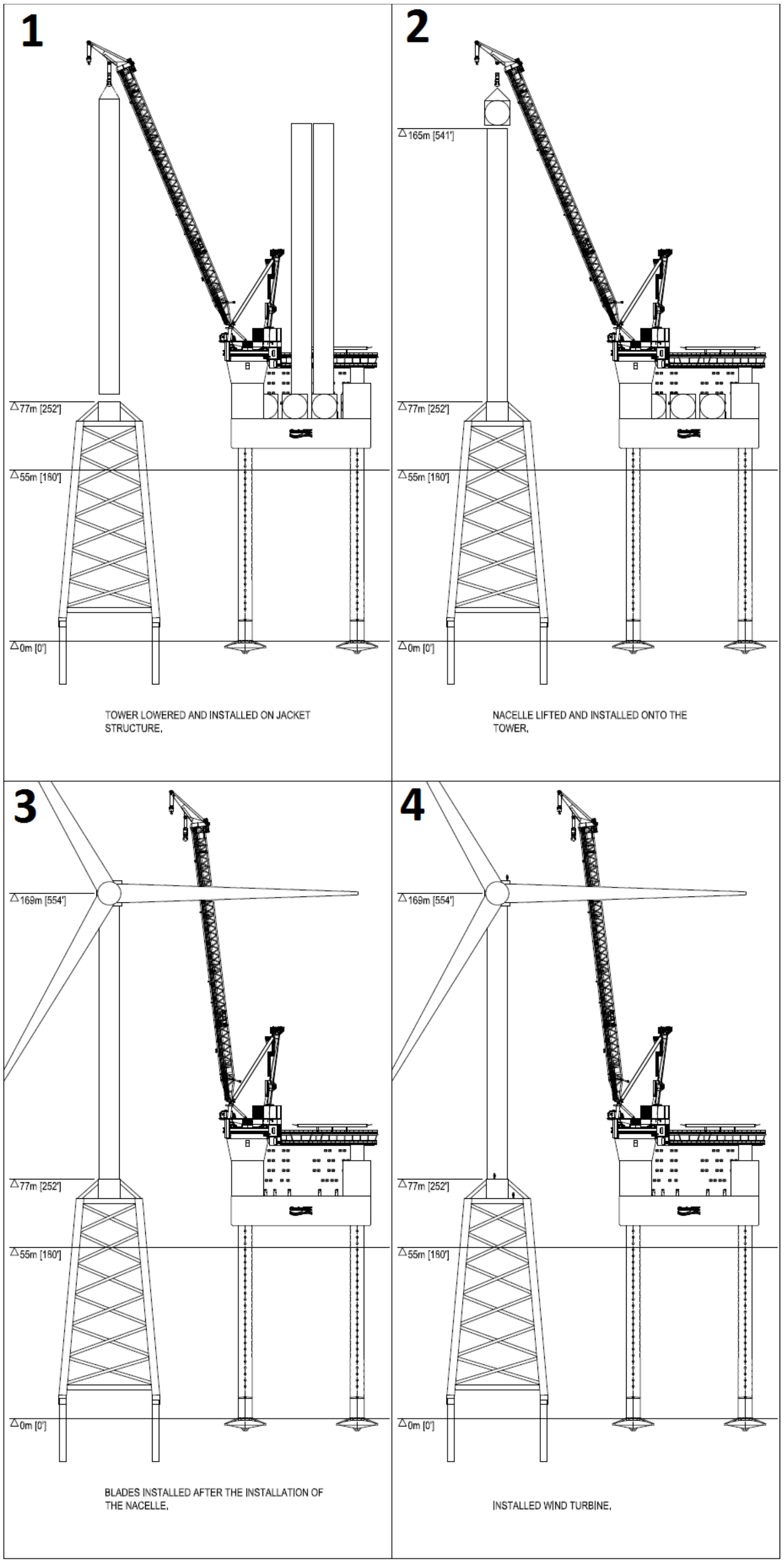


Figure 8. Campaign 3 Turbine Installation Sequence



3.9 Experience Factors

The campaigns must be completed multiple times and it is expected that as the crews gain experience, installation times will improve. For example, in Europe a turbine install can be completed in a single day, weather permitting. To account for this experience, the campaign times are multiplied by an experience factor.

Equation 1

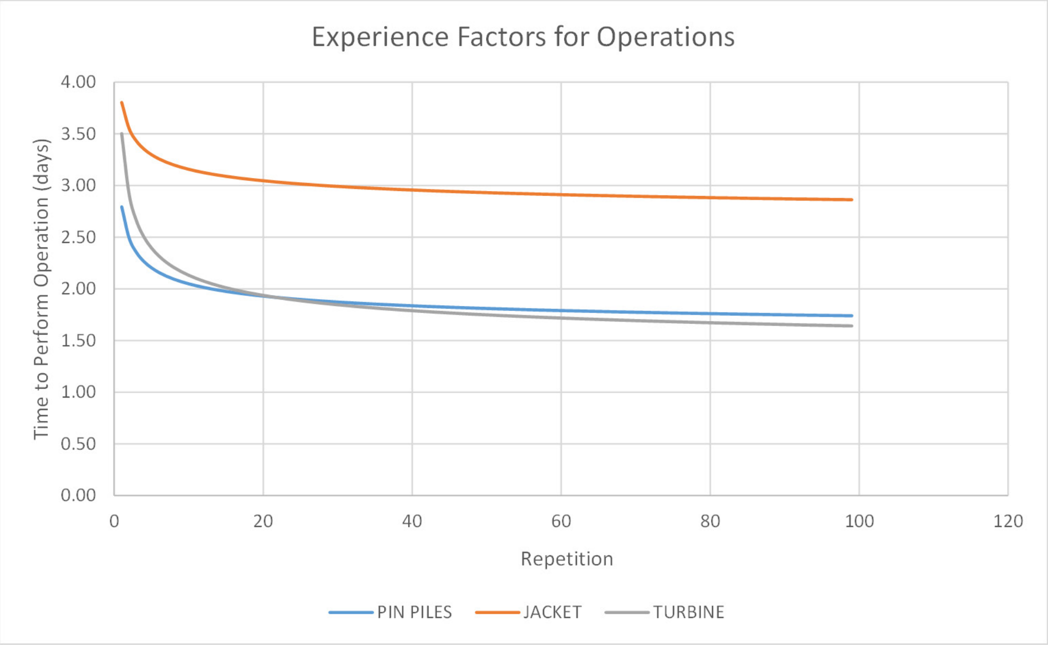
$$\boldsymbol{TIME_N = \frac{INITIAL}{(\ln(1+N))^{EF}}}$$

INITIAL times and experience factors coefficients are defined in Table 10. These figures should be updated per individual contractor practice and experience. Feeder options are expected to further benefit from remaining "rigged up" in field.

Table 10. Experience Factors for Repetitive Operations

		TRANSIT OPTION		FEEDER OPTION	
ACTIVITY	DESCRIPTION	INITIAL	EF	INITIAL	EF
1	PIN-PILES(4)	2.55	-0.25	2.1	-0.2
2	JACKET(1)	3.6	-0.15	2.3	-0.15
3	TURBINE(1)	3.025	-0.4	2.5	-0.4
4	IDLE	0	0	0	0

Figure 9. Plot of Experience Factors



3.10 Waiting on Weather (WoW) Factors

The campaigns would have to be completed in different weather conditions, which vary by the time of year. WoW = percent of time waiting on weather in any given month. For example, this may mean waiting for lower sea-states to go on location, weather induced delays in tug operations, or lower wind speeds for lifting operations. Vessel availability, planned and unplanned maintenance, must also be considered.

Table 11. Vessel Availability and Waiting on Weather Factors

	Hs_mean (m)	Vessel Availability (%)	Waiting on Weather (%)
JAN	1.5	95	40
FEB	1.5	95	40
MAR	1.4	95	35
APR	1.3	95	25
MAY	1.1	95	15
JUN	1.0	95	15
JUL	1.0	95	15
AUG	1.0	95	15
SEP	1.3	95	15
OCT	1.3	95	15
NOV	1.4	95	35
DEC	1.4	75	50

The WoW factor combined with the vessel availability percent is used to determine the number of campaigns that can be completed in any month. As conditions deteriorate going into winter, the WoW factors increase and operations become less efficient. Operations vary in weather condition sensitivity.

Pile installation would be the least sensitive and it is assumed they can be installed year-round subject to the installation vessel's ability to be on location and being rated for expected storm conditions in the given water depth. Operations will also be limited due to time-of-year restrictions by federal permitting agencies due to factors such as marine mammals.

Jacket installations would be limited from spring to late fall. Turbine installations are the most sensitive and restricted to summer and fall.

3.11 Transportation Strategies

Transportation of components and materials to site could be completed using two fundamentally different strategies: feeder option or transit option. Both feeder and non-feeder options will be examined to develop the design requirements, capital cost, and business case of each. This will be done from the vessel owner’s perspective.

In the transit option, a self-propelled WTIV transits into port, loads components and material, and then transits back to the work site where it will install the components. It will repeat this cycle until construction is complete. The WTIV in this option is normally fitted with a dynamic positioning system that can precisely hold the vessel on station (for jacking) or maneuver to a specific location.

In the feeder option, the WTIV remains in the field. A feeder unit is used to transport materials and components to the field where the WTIV is waiting to install them. Two or more feeder units are necessary to ensure the WTIV is constantly supplied. The feeder units would need to be jack-up units to minimize downtime due to weather or persistent swell conditions. Ideally, they would be self-propelled dynamic positioning units for maximum efficiency in transit and while maneuvering into position on-site or in harbor. The actual installation vessel may either be the same as the transit strategy or a more cost-efficient unit can be used that does not include the features specifically required for the transit strategy.

A minimum dynamic positioning class of DP2 will be required for positioning operations near another asset (Noble Denton 0035, 2013). A DP2 system is fitted with at least two independent computer control systems and will hold position and heading with the loss of any main single active or passive component, such as thruster, switchboard, generator, etc. (IMO MSC Circ 64)

3.11.1 Feeder Barge Option

A high-level breakdown of the operations required to complete the campaigns using the feeder barge strategy is given in Tables 12–15. It is assumed there are two feeder units delivering a constant supply of material to the installation vessel in the field. It is also assumed the vessels are fully utilized on the project with 5% downtime for maintenance.

Based on the feeder strategy, it is concluded that it takes 22 months to install a set of 100 turbines, ssuming year-round operations with two feeder barges feeding a WTIV.

Table 12 is for the first 100 turbines. If updated efficiency factors for later projects are applied, this can be reduced to 21 months.

Table 12. Feeder – Campaign 1 Operational Breakdown

1	OPERATION A - INSTALL one(1) PILE SET (4 total)	
	DESCRIPTION	TIME (hours)
TASK #	Total time in days: 1.8 TOTAL:	42
2000	POSITION, PRELOAD AND JACK-UP DP	4
2001	SITE SURVEY with ROV	1
2002	LIFT AND LOWER FRAME INTO POSITION ON SEABED	3
2003	LIFT FROM BARGE AND UPEND PILE 1	1
2004	DRIVE PILE 1	6
2005	LIFT FROM BARGE AND UPEND PILE 1	1
2006	DRIVE PILE 2	6
2007	LIFT FROM BARGE AND UPEND PILE 1	1
2008	DRIVE PILE 3	6
2009	LIFT FROM BARGE AND UPEND PILE 1	1
2010	DRIVE PILE 4	6
2011	AS-BUILT SURVEY AND METROLOGY	1
2012	LIFT AND SECURE FRAME	3
2013	JACK-DOWN AND REFLOAT READY FOR NEXT SET	2

Table 13. Feeder – Campaign 2 Operational Breakdown

2	OPERATION B- INSTALL one(1) JACKET	
	DESCRIPTION	TIME (hours)
TASK #	Total time in days: 1.9 TOTAL:	45
2000	POSITION, PRELOAD AND JACK-UP DP	4
2001	SITE SURVEY with ROV	1
2002	RIG and CUT SEAFASTENINGS	3
2003	LIFT, LOWER, STAB AND LEVEL JACKET ON PIN PILES	4
2004	GROUT AND CURE	24
2005	UNRIG JACKET	4
2006	AS-BUILT SURVEY	2
2007	JACK-DOWN AND REFLOAT READY FOR NEXT SET	3

Table 14. Feeder – Campaign 3 Operational Breakdown

3	OPERATION C - INSTALL one(1) TURBINE SET (each 8MW)	
	DESCRIPTION	TIME (hours)
TASK #	Total time in days: 2.1 TOTAL:	50
1000	POSITION, PRELOAD AND JACK-UP DP	4
1001	RIG AND CUT SEAFASTENINGS ON LOWER TOWER	2
1002	LIFT AND INSTALL LOWER TOWER	6
1003	RIG AND CUT SEAFASTENINGS ON UPPER TOWER	2
1004	LIFT AND INSTALL UPPER TOWER	4
1005	RIG AND CUT SEAFASTENINGS ON NACELLE/HUB ASSBLY	2
1006	LIFT AND INSTALL NACELLE/HUB ASSBLY	6
1007	RIG AND CUT SEAFASTENINGS ON BLADE 1	1
1008	LIFT AND INSTALL BLADE 1	4
1009	RIG AND CUT SEAFASTENINGS ON BLADE 2	1
1010	LIFT AND INSTALL BLADE 2	4
1011	RIG AND CUT SEAFASTENINGS ON BLADE 3	1
1012	LIFT AND INSTALL BLADE 3	4
1013	INTEGRATION ACTIVITIES	6
1014	JACK-DOWN AND REFLOAT	3

Table 15. Feeder Option Time to Install 100 Turbines

FEEDER OPTION											CUMULATIVE COUNT		
YEAR	MONTH	MONTH	WORKING (%)	WoW (%)	ACTIVITY	DESCRIPTION	EFFCTVE (%)	DURATION (days)	EXISTS (#)	ADD (#)	PILE SETS (#)	JACKETS (#)	TURBINES (#)
0	0										0	0	0
0	1	JAN	95%	40%	1	PIN-PILES(4)	100%	1.8	0	10	10	0	0
0	2	FEB	95%	40%	1	PIN-PILES(4)	100%	1.5	10	11	21	0	0
0	3	MAR	90%	35%	1	PIN-PILES(4)	100%	1.4	21	13	34	0	0
0	4	APR	90%	25%	1	PIN-PILES(4)	60%	1.4	34	9	43	0	0
0	5	MAY	95%	15%	2	JACKET(1)	100%	1.9	0	13	43	13	0
0	6	JUN	95%	15%	2	JACKET(1)	100%	1.6	13	15	43	28	0
0	7	JUL	95%	15%	2	JACKET(1)	100%	1.6	28	15	43	43	0
0	8	AUG	95%	15%	3	TURBINE(1)	100%	2.1	0	12	43	43	12
0	9	SEP	95%	15%	3	TURBINE(1)	100%	1.4	12	17	43	43	29
0	10	OCT	95%	15%	3	TURBINE(1)	75%	1.3	29	14	43	43	43
0	11	NOV	90%	35%	1	PIN-PILES(4)	80%	1.4	43	10	53	43	43
0	12	DEC	75%	50%	1	PIN-PILES(4)	100%	1.4	53	8	61	43	43
1	1	JAN	95%	40%	1	PIN-PILES(4)	100%	1.4	61	12	73	43	43
1	2	FEB	95%	40%	1	PIN-PILES(4)	100%	1.3	73	13	86	43	43
1	3	MAR	90%	35%	1	PIN-PILES(4)	100%	1.3	86	14	100	43	43
1	4	APR	90%	25%	2	JACKET(1)	70%	1.6	43	9	100	52	43
1	5	MAY	95%	15%	2	JACKET(1)	100%	1.5	52	16	100	68	43
1	6	JUN	95%	15%	2	JACKET(1)	100%	1.5	68	16	100	84	43
1	7	JUL	95%	15%	2	JACKET(1)	100%	1.5	84	16	100	100	43
1	8	AUG	95%	15%	3	TURBINE(1)	100%	1.2	43	20	100	100	63
1	9	SEP	95%	15%	3	TURBINE(1)	100%	1.2	63	20	100	100	83
1	**10**	**OCT**	**95%**	**15%**	**3**	**TURBINE(1)**	**85%**	**1.2**	**83**	**17**	**100**	**100**	**100**
1	11	NOV	90%	35%	4	IDLE	0%	0	0	0	100	100	100
1	12	DEC	75%	50%	4	IDLE	0%	0	0	0	100	100	100
2	1	JAN	95%	40%	4	IDLE	0%	0	0	0	100	100	100
2	2	FEB	95%	40%	4	IDLE	0%	0	0	0	100	100	100
2	3	MAR	90%	35%	4	IDLE	0%	0	0	0	100	100	100
2	4	APR	90%	25%	4	IDLE	0%	0	0	0	100	100	100
2	5	MAY	95%	15%	4	IDLE	0%	0	0	0	100	100	100
2	6	JUN	95%	15%	4	IDLE	0%	0	0	0	100	100	100
2	7	JUL	95%	15%	4	IDLE	0%	0	0	0	100	100	100
2	8	AUG	95%	15%	4	IDLE	0%	0	0	0	100	100	100
2	9	SEP	95%	15%	4	IDLE	0%	0	0	0	100	100	100
2	10	OCT	95%	15%	4	IDLE	0%	0	0	0	100	100	100
2	11	NOV	90%	35%	4	IDLE	0%	0	0	0	100	100	100
2	12	DEC	75%	50%	4	IDLE	0%	0	0	0	100	100	100
3	1	JAN	95%	40%	4	IDLE	0%	0	0	0	100	100	100
3	2	FEB	95%	40%	4	IDLE	0%	0	0	0	100	100	100
3	3	MAR	90%	35%	4	IDLE	0%	0	0	0	100	100	100
3	4	APR	90%	25%	4	IDLE	0%	0	0	0	100	100	100
3	5	MAY	95%	15%	4	IDLE	0%	0	0	0	100	100	100
3	6	JUN	95%	15%	4	IDLE	0%	0	0	0	100	100	100
3	7	JUL	95%	15%	4	IDLE	0%	0	0	0	100	100	100
3	8	AUG	95%	15%	4	IDLE	0%	0	0	0	100	100	100
3	9	SEP	95%	15%	4	IDLE	0%	0	0	0	100	100	100
3	10	OCT	95%	15%	4	IDLE	0%	0	0	0	100	100	100
3	11	NOV	90%	35%	4	IDLE	0%	0	0	0	100	100	100
3	12	DEC	75%	50%	4	IDLE	0%	0	0	0	100	100	100

Table 15 tracks the accumulation of piles, jackets, and turbines over time. The working column represents the amount of time the vessels are available and working on-site. The WoW is a seasonal correction for the number of days lost due to weather. The %Effective can be adjusted to account for discretionary time lost for refits, maintenance of because of idle time due to operational reasons. Each activity will trigger a duration to complete and tally the number of relevant items already installed. The number added is then calculated based on this duration, corrected for %WoW and %Effective, and added to the appropriate tally.

3.11.2 Transit Unit Option

A high-level breakdown of the operations required to complete the campaigns using the transit unit option is displayed in the following tables.

Table 16. Transit Option – Campaign 1 Operational Breakdown

1	TRANSIT OPTION	
	CAMPAIGN 1 - INSTALL four(4) PILE SETS (16 total) - Part 1	
	DESCRIPTION	TIME (hours)
TASK #	Total time in days = 9.1 / 4-sets = 2.3 days/1-set	217.2
1000	LOAD AND SECURE FRAME 4 hr	4
1001	LOAD 16 PILES @ 1 hr/pile	16
2000	TRANSIT TO SITE 120 nm @ **9** kts =	13.3
3000	POSITION, PRELOAD AND JACK-UP	4
3001	SITE SURVEY with ROV	1
3002	LIFT AND LOWER FRAME INTO POSITION ON SEABED	3
3003	LIFT AND UPEND PILE 1	1
3004	DRIVE PILE 1	6
3005	LIFT AND UPEND PILE 2	1
3006	DRIVE PILE 2	6
3007	LIFT AND UPEND PILE 3	1
3008	DRIVE PILE 3	6
3009	LIFT AND UPEND PILE 4	1
3010	DRIVE PILE 4	6
3011	AS-BUILT SURVEY AND METROLOGY	1
3012	LIFT AND SECURE FRAME	3
3013	JACK-DOWN AND REFLOAT	2
4000	TRANSIT TO SITE 2 3 nm @ **9** kts =	0.3
4001	POSITION, PRELOAD AND JACK-UP	4
4002	LIFT AND LOWER FRAME INTO POSITION ON SEABED	1
4003	SITE SURVEY with ROV	3
4004	LIFT AND UPEND PILE 1	1
4005	DRIVE PILE 1	6
4006	LIFT AND UPEND PILE 2	1
4007	DRIVE PILE 2	6
4008	LIFT AND UPEND PILE 3	1
4009	DRIVE PILE 3	6
4010	LIFT AND UPEND PILE 4	1
4011	DRIVE PILE 4	6
4012	AS-BUILT SURVEY AND METROLOGY	1
4013	LIFT AND SECURE FRAME	3
4014	JACK-DOWN AND REFLOAT	2

Table 16 continued

1	TRANSIT OPTION	
	CAMPAIGN 1 - INSTALL four(4) PILE SETS (16 total) - Part 2	
	DESCRIPTION	TIME (hours)
TASK #	Total time in days = 9.1 / 4-sets = 2.3 days/1-set	217.2
5000	TRANSIT TO SITE 3 3 nm @ **9** kts =	0.3
5001	POSITION, PRELOAD AND JACK-UP	4
5002	LIFT AND LOWER FRAME INTO POSITION ON SEABED	1
5003	SITE SURVEY with ROV	3
5004	LIFT AND UPEND PILE 1	1
5005	DRIVE PILE 1	6
5006	LIFT AND UPEND PILE 2	1
5007	DRIVE PILE 2	6
5008	LIFT AND UPEND PILE 3	1
5009	DRIVE PILE 3	6
5010	LIFT AND UPEND PILE 4	1
5011	DRIVE PILE 4	6
5012	AS-BUILT SURVEY AND METROLOGY	1
5013	LIFT AND SECURE FRAME	3
5014	JACK-DOWN AND REFLOAT	2
6000	TRANSIT TO SITE 4 3 nm @ **9** kts =	0.3
6001	POSITION, PRELOAD AND JACK-UP	4
6002	LIFT AND LOWER FRAME INTO POSITION ON SEABED	1
6003	SITE SURVEY with ROV	3
6004	LIFT AND UPEND PILE 1	1
6005	DRIVE PILE 1	6
6006	LIFT AND UPEND PILE 2	1
6007	DRIVE PILE 2	6
6008	LIFT AND UPEND PILE 3	1
6009	DRIVE PILE 3	6
6010	LIFT AND UPEND PILE 4	1
6011	DRIVE PILE 4	6
6012	AS-BUILT SURVEY AND METROLOGY	1
6013	LIFT AND SECURE FRAME	3
6014	AS-BUILT SURVEY AND METROLOGY	2
6015	JACK-DOWN AND REFLOAT	3
7000	RETURN TO PORT 120 nm @ **10** kts =	12

Table 17. Transit Option – Campaign 2 Operational Breakdown

2	TRANSIT OPTION					
	CAMPAIGN 2 - INSTALL one(1) JACKET					
	DESCRIPTION					TIME (hours)
TASK #	Total time in days:	3.5			TOTAL:	83.6
1000	LOAD AND SECURE JACKET ON CRIBBING			12	hr	12
1001						
2000	TRANSIT TO SITE	120	nm @	**9**	kts =	13.3
3000	POSITION, PRELOAD AND JACK-UP					4
3001	SITE SURVEY with ROV					1
3002	RIG and CUT SEAFASTENINGS					3
3003	LIFT, LOWER, STAB AND LEVEL JACKET ON PIN PILES					4
3004	GROUT AND CURE					24
3005	UNRIG JACKET					4
3006	AS-BUILT SURVEY					2
3007	JACK-DOWN AND REFLOAT					3
3008	RETURN TO PORT	120	nm @	**9**	kts =	13.3

Table 18. Transit Option – Campaign 3 Operational Breakdown

3	TRANSIT OPTION	
	CAMPAIGN 3 - INSTALL four(4) TURBINE SETS (each 8MW)	
	DESCRIPTION	TIME (hours)
TASK #	Total time in days = 10.4 / 4-sets = 2.6 days/1-set	249.5
1000	LOAD AND SECURE 8 TOWER SECTIONS 8 hr	8
1001	LOAD AND SECURE 4 NACELLES 8 hr	8
1002	LOAD AND SECURE 12 BLADES 6 hr	6
1003		
2000	TRANSIT TO SITE 1 120 nm @ **9** kts =	13.3
2001	POSITION, PRELOAD AND JACK-UP	4
2002	RIG AND CUT SEAFASTENINGS ON LOWER TOWER	2
2003	LIFT AND INSTALL LOWER TOWER	6
2004	RIG AND CUT SEAFASTENINGS ON UPPER TOWER	2
2005	LIFT AND INSTALL UPPER TOWER	4
2006	RIG AND CUT SEAFASTENINGS ON NACELLE/HUB ASSBLY	2
2007	LIFT AND INSTALL NACELLE/HUB ASSBLY	6
2008	RIG AND CUT SEAFASTENINGS ON BLADE 1	1
2009	LIFT AND INSTALL BLADE 1	4
2010	RIG AND CUT SEAFASTENINGS ON BLADE 2	1
2011	LIFT AND INSTALL BLADE 2	4
2012	RIG AND CUT SEAFASTENINGS ON BLADE 3	1
2013	LIFT AND INSTALL BLADE 3	4
2014	INTEGRATION ACTIVITIES	6
2015	JACK-DOWN AND REFLOAT	3
3000	TRANSIT TO SITE 2 3 nm @ **9** kts =	0.3
3001	POSITION, PRELOAD AND JACK-UP	4
3002	RIG AND CUT SEAFASTENINGS ON LOWER TOWER	2
3003	LIFT AND INSTALL LOWER TOWER	6
3004	RIG AND CUT SEAFASTENINGS ON UPPER TOWER	2
3005	LIFT AND INSTALL UPPER TOWER	4
3006	RIG AND CUT SEAFASTENINGS ON NACELLE/HUB ASSBLY	2
3007	LIFT AND INSTALL NACELLE/HUB ASSBLY	6
3008	RIG AND CUT SEAFASTENINGS ON BLADE 1	1
3009	LIFT AND INSTALL BLADE 1	4
3010	RIG AND CUT SEAFASTENINGS ON BLADE 2	1
3011	LIFT AND INSTALL BLADE 2	4
3012	RIG AND CUT SEAFASTENINGS ON BLADE 3	1
3013	LIFT AND INSTALL BLADE 3	4
3014	INTEGRATION ACTIVITIES	6
3015	JACK-DOWN AND REFLOAT	3

Table 18 continued

3	TRANSIT OPTION	
	CAMPAIGN 3 - INSTALL four(4) TURBINE SETS (each 8MW)	
	DESCRIPTION	TIME (hours)
TASK #	Total time in days = 10.4 / 4-sets = 2.6 days/1-set	249.5
4000	TRANSIT TO SITE 3 3 nm @ **9** kts =	0.3
4001	POSITION, PRELOAD AND JACK-UP	4
4002	RIG AND CUT SEAFASTENINGS ON LOWER TOWER	2
4003	LIFT AND INSTALL LOWER TOWER	6
4004	RIG AND CUT SEAFASTENINGS ON UPPER TOWER	2
4005	LIFT AND INSTALL UPPER TOWER	4
4006	RIG AND CUT SEAFASTENINGS ON NACELLE/HUB ASSBLY	2
4007	LIFT AND INSTALL NACELLE/HUB ASSBLY	6
4008	RIG AND CUT SEAFASTENINGS ON BLADE 1	1
4009	LIFT AND INSTALL BLADE 1	4
4010	RIG AND CUT SEAFASTENINGS ON BLADE 2	1
4011	LIFT AND INSTALL BLADE 2	4
4012	RIG AND CUT SEAFASTENINGS ON BLADE 3	1
4013	LIFT AND INSTALL BLADE 3	4
4014	INTEGRATION ACTIVITIES	6
4015	JACK-DOWN AND REFLOAT	3
5000	TRANSIT TO SITE 4 3 nm @ **9** kts =	0.3
5001	POSITION, PRELOAD AND JACK-UP	4
5002	RIG AND CUT SEAFASTENINGS ON LOWER TOWER	2
5003	LIFT AND INSTALL LOWER TOWER	6
5004	RIG AND CUT SEAFASTENINGS ON UPPER TOWER	2
5005	LIFT AND INSTALL UPPER TOWER	4
5006	RIG AND CUT SEAFASTENINGS ON NACELLE/HUB ASSBLY	2
5007	LIFT AND INSTALL NACELLE/HUB ASSBLY	6
5008	RIG AND CUT SEAFASTENINGS ON BLADE 1	1
5009	LIFT AND INSTALL BLADE 1	4
5010	RIG AND CUT SEAFASTENINGS ON BLADE 2	1
5011	LIFT AND INSTALL BLADE 2	4
5012	RIG AND CUT SEAFASTENINGS ON BLADE 3	1
5013	LIFT AND INSTALL BLADE 3	4
5014	INTEGRATION ACTIVITIES	6
5015	JACK-DOWN AND REFLOAT	3
6000	RETURN TO PORT 120 nm @ **9** kts =	13.3

Table 19. Transit Option Time to Install 100 turbines

TRANSIT OPTION											CUMULATIVE COUNT		
YEAR	MONTH	MONTH	WORKING (%)	WoW (%)	ACTIVITY	DESCRIPTION	EFFCTVE (%)	DURATION (days)	EXISTS (#)	ADD (#)	PILE SETS (#)	JACKETS (#)	TURBINES (#)
0	0										0	0	0
0	1	JAN	95%	40%	1	PIN-PILES(4)	100%	2.3	0	**7**	7	0	0
0	2	FEB	95%	40%	1	PIN-PILES(4)	100%	1.9	7	**9**	16	0	0
0	3	MAR	90%	35%	1	PIN-PILES(4)	100%	1.8	16	**10**	26	0	0
0	4	APR	90%	25%	2	JACKET(1)	100%	3.5	0	**6**	26	6	0
0	5	MAY	95%	15%	2	JACKET(1)	100%	3.2	6	**8**	26	14	0
0	6	JUN	95%	15%	2	JACKET(1)	100%	3	14	**8**	26	22	0
0	7	JUL	95%	15%	2	JACKET(1)	100%	2.9	22	**8**	26	30	0
0	8	AUG	95%	15%	3	TURBINE(1)	100%	2.6	0	**9**	26	30	9
0	9	SEP	95%	15%	3	TURBINE(1)	100%	1.9	9	**13**	26	30	22
0	10	OCT	95%	15%	3	TURBINE(1)	40%	1.6	22	**6**	26	30	28
0	11	NOV	90%	35%	1	PIN-PILES(4)	70%	1.7	26	**7**	33	30	28
0	12	DEC	75%	50%	1	PIN-PILES(4)	90%	1.7	33	**6**	39	30	28
1	1	JAN	95%	40%	1	PIN-PILES(4)	100%	1.6	39	**11**	50	30	28
1	2	FEB	95%	40%	1	PIN-PILES(4)	100%	1.6	50	**11**	61	30	28
1	3	MAR	90%	35%	1	PIN-PILES(4)	100%	1.6	61	**11**	72	30	28
1	4	APR	90%	25%	2	JACKET(1)	100%	2.9	30	**7**	72	37	28
1	5	MAY	95%	15%	2	JACKET(1)	100%	2.9	37	**8**	72	45	28
1	6	JUN	95%	15%	2	JACKET(1)	100%	2.9	45	**8**	72	53	28
1	7	JUL	95%	15%	2	JACKET(1)	100%	2.8	53	**9**	72	62	28
1	8	AUG	95%	15%	2	JACKET(1)	100%	2.8	62	**9**	72	71	28
1	9	SEP	95%	15%	3	TURBINE(1)	100%	1.6	28	**15**	72	71	43
1	10	OCT	95%	15%	3	TURBINE(1)	100%	1.5	43	**16**	72	71	59
1	11	NOV	90%	35%	1	PIN-PILES(4)	100%	1.6	72	**11**	83	71	59
1	12	DEC	75%	50%	4	IDLE	100%	0	0	**0**	83	71	59
2	1	JAN	95%	40%	1	PIN-PILES(4)	60%	1.6	83	**6**	89	71	59
2	2	FEB	95%	40%	1	PIN-PILES(4)	100%	1.6	89	**11**	100	71	59
2	3	MAR	90%	35%	2	JACKET(1)	100%	2.8	71	**6**	100	77	59
2	4	APR	90%	25%	2	JACKET(1)	100%	2.8	77	**7**	100	84	59
2	5	MAY	95%	15%	2	JACKET(1)	100%	2.8	84	**9**	100	93	59
2	6	JUN	95%	15%	2	JACKET(1)	80%	2.8	93	**7**	100	100	59
2	7	JUL	95%	15%	3	TURBINE(1)	100%	1.5	59	**16**	100	100	75
2	8	AUG	95%	15%	3	TURBINE(1)	100%	1.4	75	**17**	100	100	92
2	**9**	**SEP**	**95%**	**15%**	**3**	**TURBINE(1)**	**45%**	**1.4**	**92**	**8**	**100**	**100**	**100**
2	10	OCT	95%	15%	4	IDLE	100%	0	0	**0**	100	100	100
2	11	NOV	90%	35%	4	IDLE	100%	0	0	**0**	100	100	100
2	12	DEC	75%	50%	4	IDLE	100%	0	0	**0**	100	100	100
3	1	JAN	95%	40%	4	IDLE	100%	0	0	**0**	100	100	100
3	2	FEB	95%	40%	4	IDLE	100%	0	0	**0**	100	100	100
3	3	MAR	90%	35%	2	JACKET(1)	60%	2.8	100	**4**	100	104	100
3	4	APR	90%	25%	2	JACKET(1)	60%	2.8	104	**4**	100	108	100
3	5	MAY	95%	15%	3	TURBINE(1)	100%	1.4	100	**17**	100	108	117
3	6	JUN	95%	15%	3	TURBINE(1)	60%	1.4	117	**10**	100	108	127
3	7	JUL	95%	15%	3	TURBINE(1)	80%	1.4	127	**14**	100	108	141
3	8	AUG	95%	15%	4	IDLE	100%	0	0	**0**	100	108	141
3	9	SEP	95%	15%	4	IDLE	100%	0	0	**0**	100	108	141
3	10	OCT	95%	15%	4	IDLE	100%	0	0	**0**	100	108	141
3	11	NOV	90%	35%	4	IDLE	100%	0	0	**0**	100	108	141
3	12	DEC	75%	50%	4	IDLE	100%	0	0	**0**	100	108	141

3.11.3 Build-out Schedules for Transit and Feeder Options

The build out rates were estimated based on the time required to install a group of 100 turbines. Using a feeder barge option, a group of 100 turbines can be installed in approximately 22 months for the first project and 21 months for later ones. Using a self-propelled transit WTIV option, a group of 100 turbines can be installed in approximately 33 months for the first project and 28 months for later ones.

Assuming a full build out of the Study Area, there is at least 23 vessel years of work out to the 55 m contour and an additional three vessel years of work out to the 65 m contour based on the transit vessel strategy (Table 20).

There is at least 18 vessel years of work out to the 55 m contour and an additional three vessel years of work out to the 65 m contour based on the feeder strategy (Table 21).

Table 20. Available Vessel Years of Work vs. Max Water Depth with Transit Option

TRANSIT VESSEL OPTION - MAX BUILD OUT IN STUDY AREA						
		MAX	INSTALLED			
PHASE	GROUP	WATER [m]	ANNUAL [#]	CUMUL [#]	CUMUL [MW]	YEAR
1	1	40	100	100	800	3
1	2	40	89	189	1512	5
2	1	40	100	289	2312	7
3	1	50	100	389	3112	9
3	2	50	100	489	3912	11
3	3	50	100	589	4712	13
3	4	50	100	689	5512	15
4	1	55	100	789	6312	17
4	2	55	81	870	6960	19
4	3	55	100	970	7760	21
4	4	55	70	1040	8320	23
5	1	60	53	1093	8744	24
5	2	60	8	1101	8808	24
5	3	60	59	1160	9280	25
5	4	60	10	1170	9360	25
6	1	65	3	1173	9384	25
6	2	65	4	1177	9416	25
6	3	65	44	1221	9768	26
6	4	65	21	1242	9936	26

Table 21. Available Vessel Years of Work vs. Max Water Depth with Feeder Option

FEEDER VESSEL OPTION - MAX BUILD OUT IN STUDY AREA						
		MAX	INSTALLED			
PHASE	GROUP	WATER [m]	ANNUAL [#]	CUMUL [#]	CUMUL [MW]	YEAR
1	1	40	100	100	800	2
1	2	40	89	189	1512	4
2	1	40	100	289	2312	4
3	1	50	100	389	3112	6
3	2	50	100	489	3912	8
3	3	50	100	589	4712	10
3	4	50	100	689	5512	12
4	1	55	100	789	6312	14
4	2	55	81	870	6960	15
4	3	55	100	970	7760	17
4	4	55	70	1040	8320	18
5	1	60	53	1093	8744	19
5	2	60	8	1101	8808	19
5	3	60	59	1160	9280	20
5	4	60	10	1170	9360	20
6	1	65	3	1173	9384	20
6	2	65	4	1177	9416	20
6	3	65	44	1221	9768	21
6	4	65	21	1242	9936	21

The schedules in tables 20 and 21 were developed to feed the financial model in this study.

The actual schedules will depend on individual development decisions. There are many factors beyond scheduling to consider when deciding on the transportation strategy, such as project economics and how the Jones Act could be interpreted for a specific project (i.e., if exemptions/waivers are granted).

Individual developers will need project specific financing details to determine if the five years of time saved justifies the additional cost of two feeder units. Such matters are project specific and are outside the scope of the current study, which simply presents both options as data points for future consideration and assessment.

4 Functional Requirements for Installation Vessel

4.1 Philosophy

The philosophy is to use a self-contained WTIV that can perform as many functions as possible required for turbine installation. The unit should be capable of safely and securely handling the required weights at the heights/reaches demanded from a platform designed for the on-site water depths and metocean conditions. It should do so in a way that does not place any of the personnel or the components at unnecessary risk.

Wind farm installation should be a repetitive assembly-line process and designed for the lowest complexity possible with installation equipment supporting simplicity. The installation method and equipment should:

- Reduce the risk of schedule delays through improved operability and simplicity of operation
- Reduce the number of operations required offshore
- Reduce personnel exposure from working in small boats, over the side, or at height
- Reduce incidence of overhead loads and equipment damage risk
- Maintain positive control of all loads using intelligent tugger systems, installation aids and upending equipment/tools
- Increase efficiency of operations to reduce completion time
- Provide flexibility for multiple functions
- Provide deck space, handling gear, transportation and accommodation to support the different work-crews such as ROV crew, turbine installation crew, commissioning personnel, etc.
- Have sufficient margin/flexibility to adapt to changing requirements
- Increase weather windows
- Ease loading operations in port
- Support lifting operations from the back of floating barges or supply vessels
- Support lowering operations through the splash zone
- Allow high-accuracy positioning of components such as blades and hold them steady throughout the connection process

4.2 Core Functional Requirements for both Options

4.2.1 Rules

The unit is required to satisfy all applicable rules and regulations for U.S. flag and the U.S. Coast Guard. The unit will be built and classed with a recognized classification society such as American Bureau of Shipping or Det Norske Veritas–Germanischer Lloyd.

Means of evacuation shall accommodate the full range of possible air gaps. Essential services such as firewater or cooling water will be consistently provided, even while in jacked-up mode.

4.2.2 Elevated Conditions

For an actual project, a site-specific, metocean report with one-, 10-, and 50-year extreme values for wind, wave, tide, storm surges, and current should be obtained. In addition to that, site-specific geo-technical data should be obtained per the requirements of ISO 19901-8 “Marine Soil Investigations” or OGPs’ “Guidelines for the conduct of offshore drilling hazard site.” The unit should then pass a site-specific assessment using these conditions per SNAME 5-5A or ISO 19905.

For design purposes, to ensure a reasonable degree of year-round operability, the vessels will have the ability to withstand the 50-year winter storm in the elevated condition for New York. Maximum water depth is 50 m in winter and 55 m in summer. Any conditions exceeding these limits will require the unit to move off-station to sheltered waters. Winter operations off Nantucket will be limited to shallower water in accordance with the nomograms in the approved operating manual. Fifty-year metocean values for offshore New York (see Table 2) are rounded up as shown in Table 22.

Table 22. Summary of Elevated Condition Design Values for NYS Winter Storm (see Table 2)

50 yr Design Values		NY	Design
Hs_50yr	(m)	9.48	10
Hmax_50yr	(m)	17.63	18
Tp_50yr	(sec)	12.48	14
HAT	(m)	0.33	0.5
Storm Surge	(m)	2.5	2.5

.

Additionally, the associated one-minute (non-hurricane) wind at 10 m is to be taken as 38 m/s (74 knots). This value is a typical limiting wind speed for the elevated condition of large WTIV units and will ensure a reasonable degree of year-round operability. For comparison, the 50-year site-specific wind speed was not available; however, from Table 4, the wind speed is expected to be less than 45 knots with an annual non-exceedance of 0.999. The maximum current is to be taken as 1.2 m/s (2.3 knots), which is a typical limiting current speed for the elevated condition of large WTIV units. For comparison, Figure 3 shows a peak observation of 0.7m/s.

4.2.3 Afloat

While afloat, the vessel is required to comply with all applicable stability regulations from the U.S. Flag administration as well as IMO MODU Code. Stability will be verified for all applicable loading conditions. The vessel must transit at a speed of at least nine knots under its own power and have a dynamic positioning system to facilitate port entry and positioning at the turbine locations.

4.2.4 Jacking and Preloading

While afloat, the vessels must be capable of going on location and jacking-up in sea states of at least 1.5m (Hs), surface currents of 1.5 knots and wind of 20 knots all acting collinearly. The vessel will be supplied with a high-speed continuous jacking system suitably designed for the total elevated weight with maximum variable deck load (VDL) and 100–150 jacking moves per year for a minimum of 20 years.

4.2.5 GeoTechnical Data

No site-specific geotechnical data is available, but indicative soil conditions from the region are given in Section 3.3. Based on the limited information available, the design should assume limited penetration and low spudcan fixity.

4.2.6 Design Temperatures

Design temperatures shall be suitable for year-round operation in the Northeast and the Gulf of Mexico.

Steel Design temperature:	-10°C (except for leg footings)
	0°C (for leg footings)
For HVAC:	
Maximum ambient temperature:	+35°C, 100%RH
	+50°C, 15%RH
Minimum ambient temperature:	-10°C
Maximum seawater temperature:	+35°C
Minimum seawater temperature:	0°C

4.2.7 Principal Dimensions, Capacities, and Deck Loads

For design purposes, the beam of the vessels are not to exceed 42 m and the transit draft of unit should not exceed 7.9m (including the tip of the spudcans). The staging ports are assumed to have no overhead limits, navigational channels of 9-10m water depth, and open widths of 45.72 m, which will allow port entry (under DPS2) for vessels up to 42m in beam subject to approval by the harbor pilots. The main deck will be designed for uniform deck load of 5te/m^2 or higher.

For campaign 1, the unit will need to carry the guide frame (estimated at 30m x 30m x 6m high/300te), four sets (four each) of piles, piling hammer, leveling and ROV equipment, and construction containers. Total area = 3000m^2 and VDL at least 3500te.

For campaign 2, the unit will need to carry at least one jacket (30m x 30m x 70m high/1000te) complete with lifting gear and load spreaders, as well as the ROV spread and grouting plant. It will also need to carry miscellaneous construction containers. Allow at least 2600m^2.

For campaign 3, the unit will need to carry minimum four 8-MW turbine sets at a time. Deck area required is approximately 2900m^2 and the VDL required is estimated at 4000te. These will need to be stored off the bow or the stern for any vessel entering or departing port; however, for a WTIV that remains in the field, these may be over the side.

4.3 Specific Requirements for Wind Turbine Installation Vessel (WTIV)

Suitable living accommodations, designed for a minimum of 90 people, will be provided on the WTIV for the vessel crew required to safely operate the jack-up and for turbine contractors installing the turbine components. The WTIV should be self-sufficient for a 21-day period and have the means to load/discharge provisions offshore, ability to transfer crew by boat or helicopter, and a helideck suitable for a Super Puma or Sikorski S61N/S92A. However, helicopter operations during transit are not permitted.

The main crane should have the following installation capabilities:

- Pile installation will need to lift and upend piles that may weigh up to 150te and 80m length and then lower them down into position in the guide frame. An upending bucket may be required. The design outreach from the side of the unit for the pile installation is 48m.
- Jacket installation will need to lift jackets, which for 55m of water may weigh 1000te, stand 70m tall, and measure 30 m x 30 m at the base. It will need to have a minimum hook height of 100m above the water surface at an outreach of 21 m (= 30m/2 base + 1m margin + 5 m hull clearance) from the side of the unit. A clearance of 5 m shall be maintained between the jacket and crane boom.
- Turbine installation will need to lift 500te to an elevation of 120 m above the water surface at an outreach of 21 m from the side of the unit.

An intelligent tugger-line system will help control the load in all circumstances as recommended by the turbine manufacturer.

4.4 Specific Requirements for Feeder Barge

Over-hanging cargo such as blades stored on the WTIV or feeder units should account for any obstacles on the hurricane barrier (gate control room, posts, antennas, etc.). Blades for example, may protrude over the bow or stern, but they must not extend over the side.

Onshore cranes will load the feeder barge in port to allow for at least 14 days of self-sufficiency. While it is offshore, the installation vessel will perform the offloads and it does not require a main cargo crane. However, it should be suitable for future retrofitting of a crane for wind turbine maintenance and repair purposes.

5 Design Details of Wind Turbine Installation Vessel

The NG-9800C-US was developed by GustoMSC to satisfy the functional requirements of the Northeast regional market, as previously outlined in section 4. This unit is derived from the GustoMSC NG-9000C design (e.g., Fred Olsen Windcarrier's Brave Tern) that was successfully used on the Block Island wind project with certain key modifications:

- The crane capacity increased from 800te to 1500te to suit the next generation of wind turbines in deeper water up to 55 m.
- The beam of the unit is set to 42 m to suit the limitations of available ports.
- The upgraded jacking system capacity allows for a higher variable load and total elevated weight.

Principal dimensions of the unit are shown in Table 23.

Table 23. Principal Particulars of NG9800C

NG 9800C-US - PRINCIPAL PARTICULARS	
Hull Length (main deck)	127.8 m (419 ft)
Hull Width	42 m (138 ft)
Hull Depth	10 m (33 ft)
Hull Draft	5.8 m (19 ft)
Leg Length (incl spudcan)	92 m (302 ft)
Leg Length under hull (max)	69 m (226 ft)
Transit Speed	11 knots
Variable Load	6400 te (7041 ST)
Main Crane	1500 te (1650 ST)
PoB	90 persons

The brochure of the GustoMSC type NG-9800C-US is presented in APPENDIX A – PRODUCT BROCHURE – NG-9800C-US. Figures 10 through 13 give an impression of the unit.

Figure 10. Rendering #1 of two NG-9800C-US installing foundations (left) and turbines (right)

Figure 11. Rendering #2 of two NG-9800C-US installing foundations (left) and turbines (right)

Figure 12. Rendering #3 of two NG-9800C-US installing turbines (left) and foundations (right)

Figure 13. Rendering #4 of two NG-9800C-US installing turbines (left) and foundations (right)

6 Design Details of Feeder Unit

The NG-3750C Feeder was developed by GustoMSC to satisfy the functional requirements of the Northeast regional market, as outlined in section 4. It is derived from the established GustoMSC NG-3750C design. The main crane was removed to reduce costs and increase deck space, but can be installed at a future date for wind farm maintenance purposes. Principal dimensions of the unit are shown in Table 24.

Table 24. Principal Particulars of NG-3750C

NG 3750C - PRINCIPAL PARTICULARS	
Hull Length (main deck)	70.5 m (231 ft)
Hull Width	38 m (125 ft)
Hull Depth	6.5 m (21 ft)
Hull Draft	m (0 ft)
Leg Length (incl spudcan)	86 m (282 ft)
Leg Length under hull (max)	68 m (223 ft)
Transit Speed	6-7 knots
Variable Load	3400 te (3740 ST)
Main Crane	N/A
PoB	12 persons

The brochure of the GustoMSC type NG-3750C is presented in APPENDIX B – PRODUCT BROCHURE – NG-3750C.

7 CAPEX and Schedule Estimates

The following three shipyards agreed to submit bids as part of the study:

- World Marine – Pascagoula MI
- Edison Chouest/Bollinger – Cut-Off LA
- Conrad Industries – Morgan City LA

GustoMSC supplied the yards with the standard estimating packages consisting of:

- Basic construction drawings
- General Arrangements
- Outline Specification including list of major equipment
- Design Weight
- Steel Quantities
- Specification of the Legs
- Specification and Estimate for the Jacking System
- Specification and Estimate for the Main Crane

Two bids were received back from the yards for the NG-9800C-US with an average CAPEX of $222 million. An indicative construction schedule is in Figure 14.

Figure 14. Indicative Construction Schedule for the NG 9800C

INDICATIVE CONSTRUCTION SCHEDULE FOR NG 9800C-US WTIV																																					
	Duration	Month																																			
Activity	Months	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
START NG-9800C		X																																			
ENGINEERING	10	■	■	■	■	■	■	■	■	■	■																										
PROCUREMENT	24		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■											
CONSTRUCTION	27						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
LAUNCH																									X												
COMMISSIONING	3																															■	■	■			
SEA-TRIALS	1																																	■			
END NG-9800C	0																																		X		

Three bids were received back from the yards for the NG-3750C with an average CAPEX of $87 million. An indicative construction schedule is in Figure 15.

Figure 15. Indicative Construction Schedule for the NG-3750

INDICATIVE CONSTRUCTION SCHEDULE FOR NG 3750 FEEDER BARGE																																					
	Duration	Month																																			
Activity	Months	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
START NG-3750		X																																			
ENGINEERING	9	■	■	■	■	■	■	■	■	■																											
PROCUREMENT	12		■	■	■	■	■	■	■	■	■	■	■	■																							
CONSTRUCTION	18							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■												
LAUNCH																						X															
COMMISSIONING	3																						■	■	■												
SEA-TRIALS	1																									■											
END NG-3750	0																									X											

Funding assistance is available from the MARAD administered “Federal Ship Financing Program” commonly known as Title XI. This offers financing at reduced rates with as little as 12.5% equity investment by the owner.

MARAD Title XI offers guarantees for up to 87.5% of the actual cost. But to be eligible, obligors must:

1. Be an individual, corporation or other business that is U.S. organized, based in the U.S. and recognized as a U.S. citizen. However, there may be remedies to this requirement for foreign owners through a lease financing arrangement. (Kearn, 2014)
2. Demonstrate sufficient skill and experience to operate the vessel.
3. Maintain creditworthiness and limit debt to no more than twice the net worth of the unit.

Furthermore, the design must be approved by MARAD and a recognized classification society such as American Bureau of Shipping.

8 Crewing Cost Estimates

In all cases, a jack-up unit must be manned in accordance with the minimum requirements contained in its Safe Manning Certificate. The safe manning requirements are contained in the U.S. Code of Federal Regulations (US CFR 46-Pt 15), the International Maritime Organization (IMO A.890, 2000) and for guidance purposes only, renewable UK (renewableUK, 2013).

The NG-9800C-US has a total personnel-on-board of 90 people, but only 28 full-time permanent positions are required to safely man and operate the vessels as summarized in the Table 25.

Table 25. Indicative Crewing Costs for NG9800C US

FULL TIME PERMANENT ON-BOARD AT ANY ONE TIME								
NUMBER		DESCRIPTION			SHIFT	REGULATORY REFERENCE		BASE RATE (USD)
1		MASTER/DPO		MIN MANNING	on call			280,000
2	DAY	1st MATE/DPO		MIN MANNING	8	US CFR46 - Part 15	IMO A.890	196,000
3	EVEN	2nd MATE/DPO		MIN MANNING	8	US CFR46 - Part 15	IMO A.890	140,000
4	NIGHT	3rd MATE/DPO		MIN MANNING	8	US CFR46 - Part 15	IMO A.890	154,000
5	DAY	SEAMAN	1-1	MIN MANNING	12	US CFR46 - Part 15	IMO A.890	70,000
6	DAY	SEAMAN	1-2	MIN MANNING	12	US CFR46 - Part 15	IMO A.890	70,000
7	NIGHT	SEAMAN	2-1	MIN MANNING	12	US CFR46 - Part 15	IMO A.890	60,000
8	NIGHT	SEAMAN	2-2	MIN MANNING	12	US CFR46 - Part 15	IMO A.890	60,000
9		CHIEF ENGINEER		MIN MANNING	on call	US CFR46 - Part 15	IMO A.890	234,000
10	DAY	1st ENGINEER		MIN MANNING	8	US CFR46 - Part 15	IMO A.890	182,000
11	EVEN	2nd ENGINEER		MIN MANNING	8	US CFR46 - Part 15	IMO A.890	143,000
12	NIGHT	3rd ENGINEER		MIN MANNING	8	US CFR46 - Part 15	IMO A.890	143,000
13	DAY	OILER	1-1	MIN MANNING	12	US CFR46 - Part 15	IMO A.890	120,000
14	DAY	OILER	1-2	MIN MANNING	12	US CFR46 - Part 15	IMO A.890	120,000
15	NIGHT	OILER	2-1	MIN MANNING	12	US CFR46 - Part 15	IMO A.890	105,000
16	NIGHT	OILER	2-2	MIN MANNING	12	US CFR46 - Part 15	IMO A.890	105,000
17		CHIEF STEWARD		FULL CREW	on call		IMO A.890	80,000
18	DAY	STEWARD		FULL CREW	12		IMO A.890	60,000
19	NIGHT	STEWARD		FULL CREW	12		IMO A.890	40,000
20		CHIEF COOK		FULL CREW	on call		IMO A.890	70,000
21	DAY	COOK ASST		FULL CREW	12		IMO A.890	50,000
22	NIGHT	COOK ASST		FULL CREW	12		IMO A.890	45,000
23		JACKING MASTER		FULL CREW	on call		IMO A.890	120,000
24	DAY	CRANE OPERATOR	1	FULL CREW	12		IMO A.890	90,000
25	NIGHT	CRANE OPERATOR	2	FULL CREW	12		IMO A.890	80,000
26	DAY	RIGGER	1-1	FULL CREW	12		IMO A.890	50,000
27	NIGHT	RIGGER	1-2	FULL CREW	12		IMO A.890	50,000
28		MEDIC		FULL CREW	on call		IMO A.890	70,000
							TTL	2,987,000

The average annual cost per crew member is $106,678, which is rounded up to $125,000 per person for study purposes. The remaining 62 berths can be filled with temporary support crew such as assistant stewards and cooks or charter personnel such as construction and commissioning personnel.

9 Business Model for the WTIV

A simple cash flow financial model was developed to assess the business case of the WTIV itself. This model tracks cash flow in and out of a vessel owner's account over the life of the unit. These are models of individual vessels and do not consider overall project economics such as field development costs or overall installation scenarios of which the individual vessel is only one component. This report is intended to provide data for input into a larger overall analysis that a developer might undertake with project specific data—for example, examining the benefit of jackets vs. monopiles or using feeder barges vs. using an alternative.

The individual vessel cash flow model is assumed to begin when financing is in place. Construction of the WTIV is expected to last three years during which a vessel construction project team (on the owner's account) will be required to oversee construction and provide due diligence checks and oversight. A total of 12 people is estimated at an average total rate of $125k/year.

The unit is projected to begin work on wind farm installation immediately after leaving the shipyard and take 23 years of dedicated work completing turbine installations out to the 55-m contour line. The utilization rate is anticipated to be 95% normal, but reduced on years where there is a switch from one area to another or scheduled maintenance such as a special survey or dry-docking.

Insurance costs were fixed at 0.1% of CAPEX per year. All costs and revenue are corrected for inflation using a 2% rate of inflation. There are many other unknown details of the financial model such as future interest rates or possible tax credits.

These will be subjected to a sensitivity analysis where possible or conservative assumptions were made.

- Tax rate was left at 35% flat and no allowance made for tax credits or other forms of tax reduction in order to be conservative.
- No allowance was made for financing assistance from organizations such as the MARAD. administered "Federal Ship Financing Programming" commonly known as Title XI.
- Net losses are not carried forward to offset future taxes.
- The unit is expected to be fully depreciated over the life of the project and has a residual value of zero.

The loan is amortized over 10 years with interest rates ranging from 4% to 8% and discount rates range from 8% to 12% in the sensitivity study. Additionally, debt leverage ratios ranged from 50% to 65%.

A target day rate for the unit is $220,000 per day based on comparable target day rates for similar units. This was subject to a sensitivity analysis of +/- $20k/day with the results shown in Figures 16 through 22 and summarized in Table 26. The values reported are for a discount rate of 9%.

Table 26. Summary of IRR for WTIV

MINIMUM IRR (%)		
day rate $k	10yr life	20yr life
200	8.1	9.8
220	10	11.6
240	11.8	13.2

With the target day rate, the WTIV can return an IRR of 10% if sold after 10 years or 11.6% if held for 20 years. Looking at Table 20, 10 years of work requires a pipeline of approximately 439 turbines. Assuming 8-MW turbines, this equates to 3,512 MW of offshore wind capacity.

Table 27. Summary of NPV for WTIV

MINIMUM NPV ($million)		
day rate $k	10yr life	20yr life
200	35	56
220	60	91
240	85	126

Combining the target day rate with a discount rate of 9%, the unit can return an NPV of $60 million if sold after 10 years or a NPV of $91 million if held for 20 years. For day rates less than $142,000 per day, NPV is never positive. For day rates greater than $224,000 per day, NPV is never negative for any discount rate in this model.

This study did not cover alternative uses of the WTIV such as decommissioning of oil and gas platforms in the Gulf of Mexico, construction work on marine infrastructure projects nationwide, or use of the WTIV in markets overseas.

Figure 16. Sample Cash Flow Time Series for Day Rate of $220,000 per day

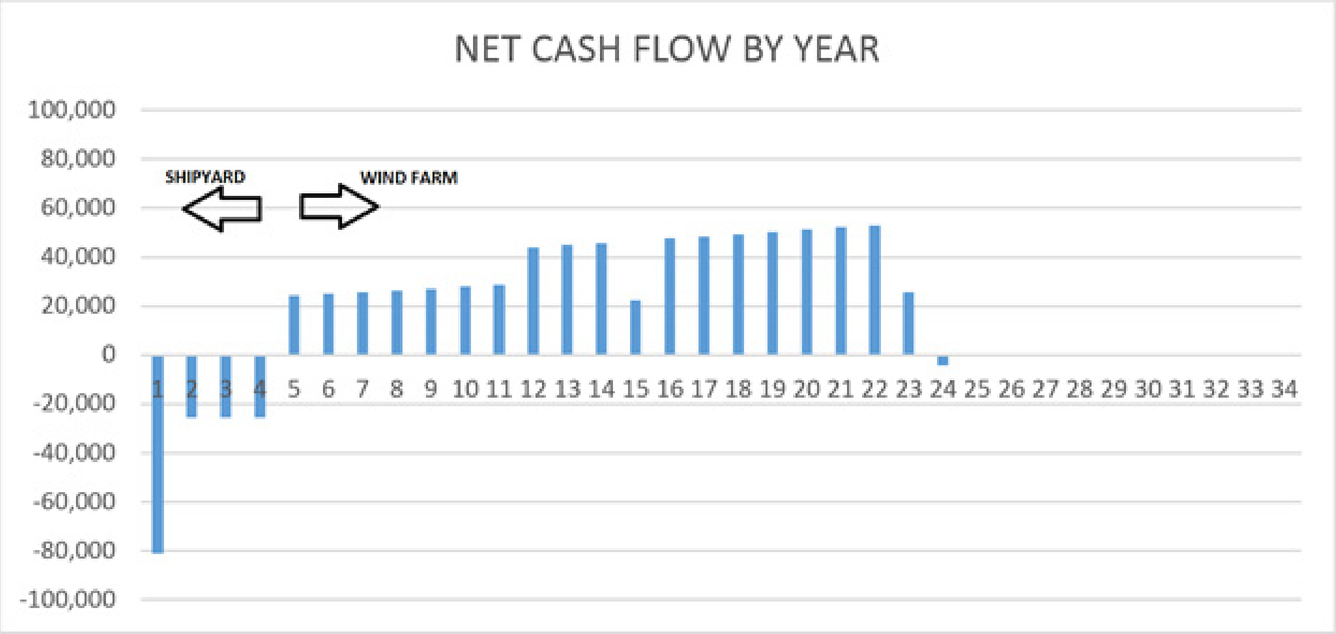
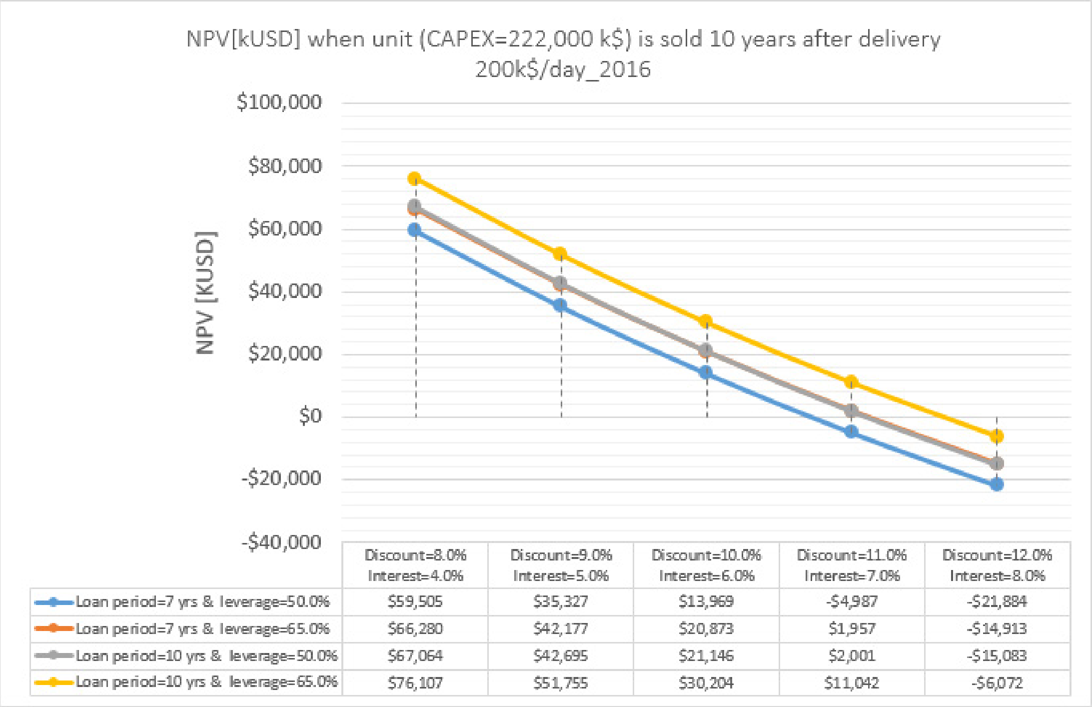
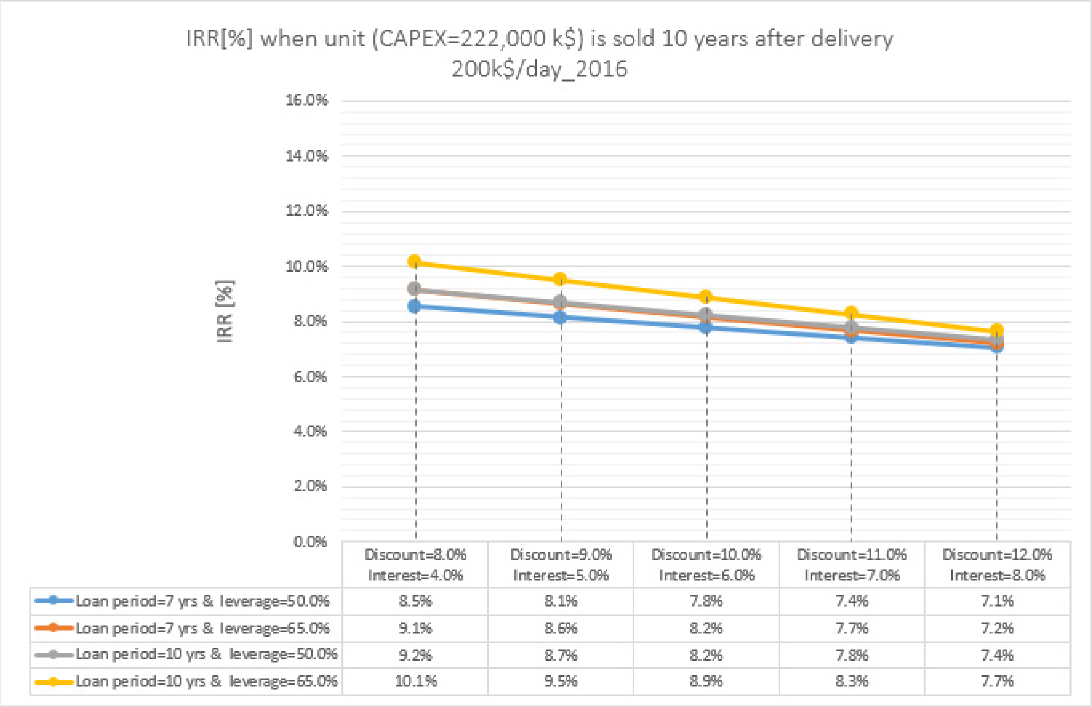


Figure 17. WTIV Variation in NPV and IRR with day rate of $200k and Unit Sold after 10 years

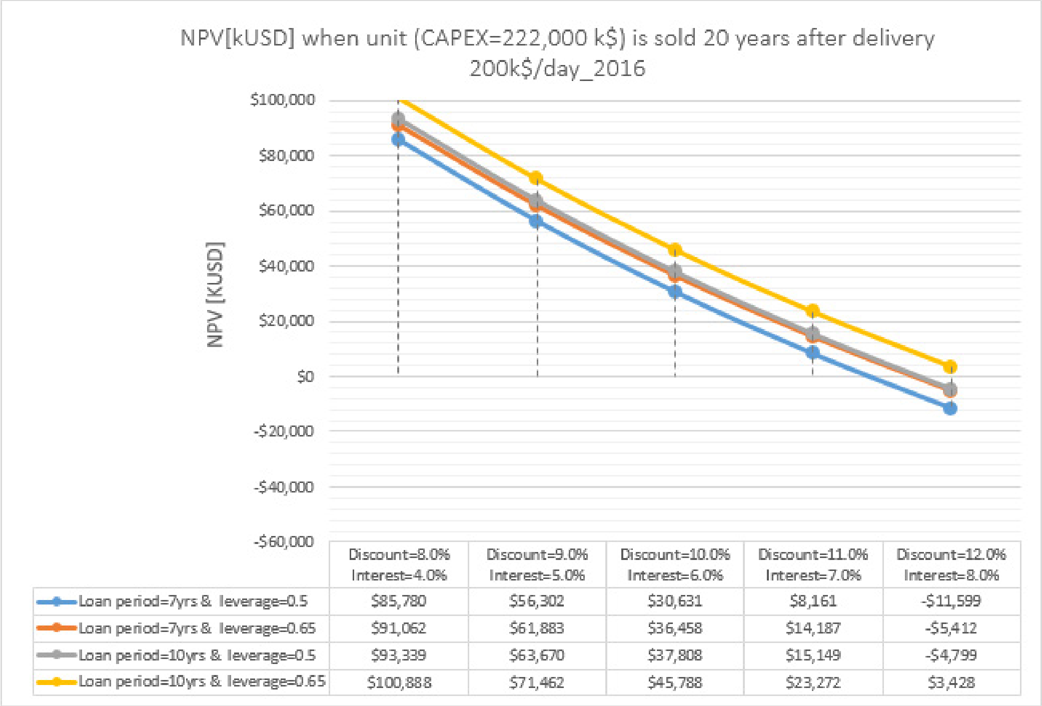

NPV[kUSD] when unit (CAPEX=222,000 k$) is sold 10 years after delivery
200k$/day_2016

	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7 yrs & leverage=50.0%	$59,505	$35,327	$13,969	-$4,987	-$21,884
Loan period=7 yrs & leverage=65.0%	$66,280	$42,177	$20,873	$1,957	-$14,913
Loan period=10 yrs & leverage=50.0%	$67,064	$42,695	$21,146	$2,001	-$15,083
Loan period=10 yrs & leverage=65.0%	$76,107	$51,755	$30,204	$11,042	-$6,072


IRR[%] when unit (CAPEX=222,000 k$) is sold 10 years after delivery
200k$/day_2016

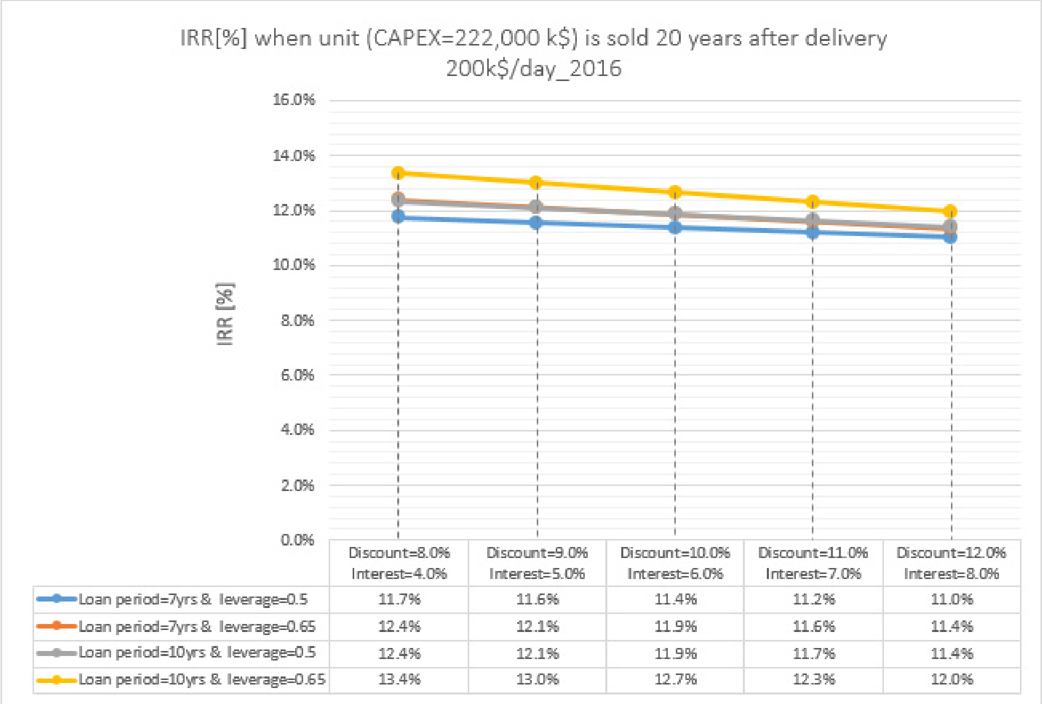
	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7 yrs & leverage=50.0%	8.5%	8.1%	7.8%	7.4%	7.1%
Loan period=7 yrs & leverage=65.0%	9.1%	8.6%	8.2%	7.7%	7.2%
Loan period=10 yrs & leverage=50.0%	9.2%	8.7%	8.2%	7.8%	7.4%
Loan period=10 yrs & leverage=65.0%	10.1%	9.5%	8.9%	8.3%	7.7%

Figure 18. WTIV Variation in NPV and IRR with day rate of $200k and Unit Sold after 20 years



NPV[kUSD] when unit (CAPEX=222,000 k$) is sold 20 years after delivery
200k$/day_2016

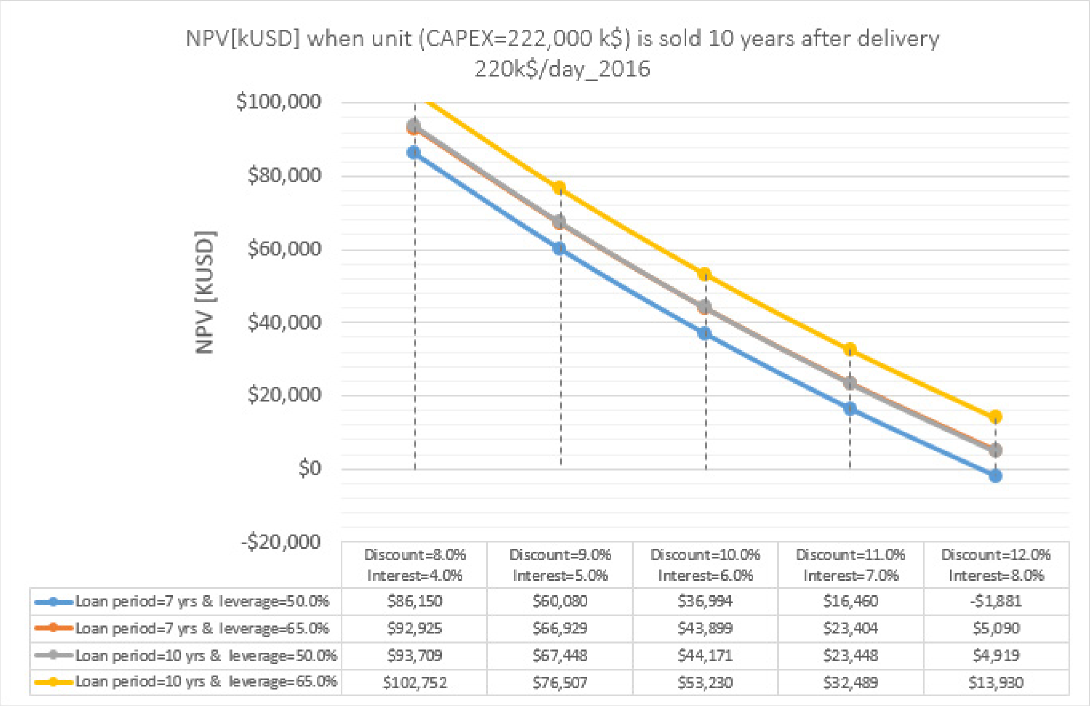
	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7yrs & leverage=0.5	$85,780	$56,302	$30,631	$8,161	-$11,599
Loan period=7yrs & leverage=0.65	$91,062	$61,883	$36,458	$14,187	-$5,412
Loan period=10yrs & leverage=0.5	$93,339	$63,670	$37,808	$15,149	-$4,799
Loan period=10yrs & leverage=0.65	$100,888	$71,462	$45,788	$23,272	$3,428



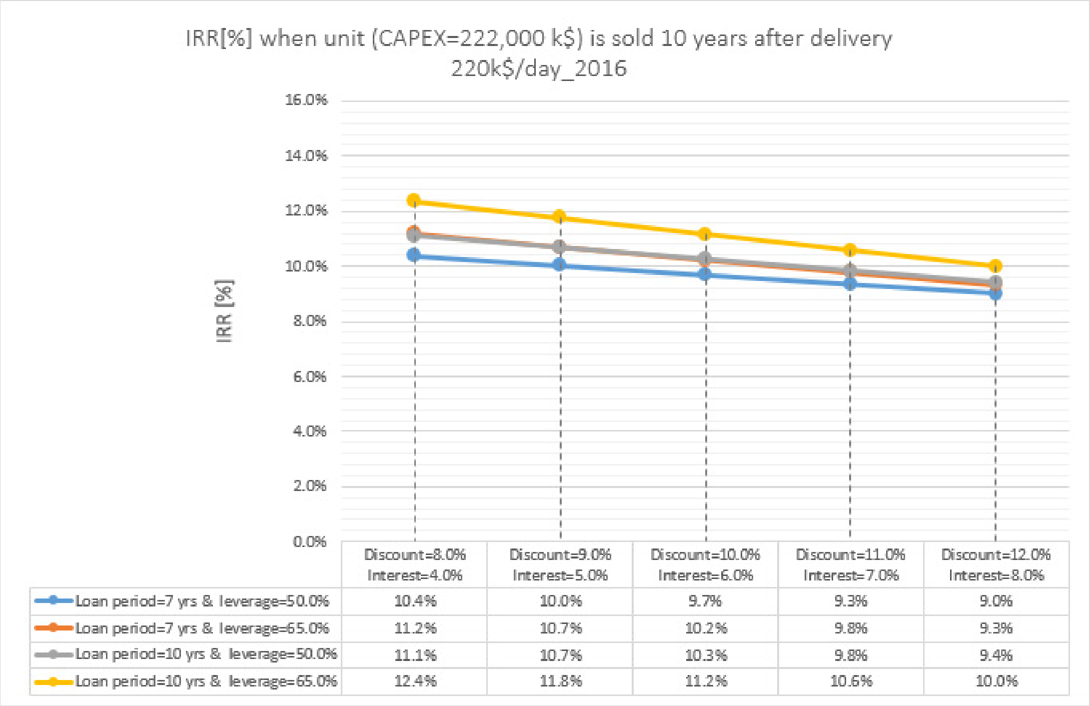
IRR[%] when unit (CAPEX=222,000 k$) is sold 20 years after delivery
200k$/day_2016

	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7yrs & leverage=0.5	11.7%	11.6%	11.4%	11.2%	11.0%
Loan period=7yrs & leverage=0.65	12.4%	12.1%	11.9%	11.6%	11.4%
Loan period=10yrs & leverage=0.5	12.4%	12.1%	11.9%	11.7%	11.4%
Loan period=10yrs & leverage=0.65	13.4%	13.0%	12.7%	12.3%	12.0%

Figure 19. WTIV Variation in NPV and IRR with day rate of $220k and Unit Sold after 10 years

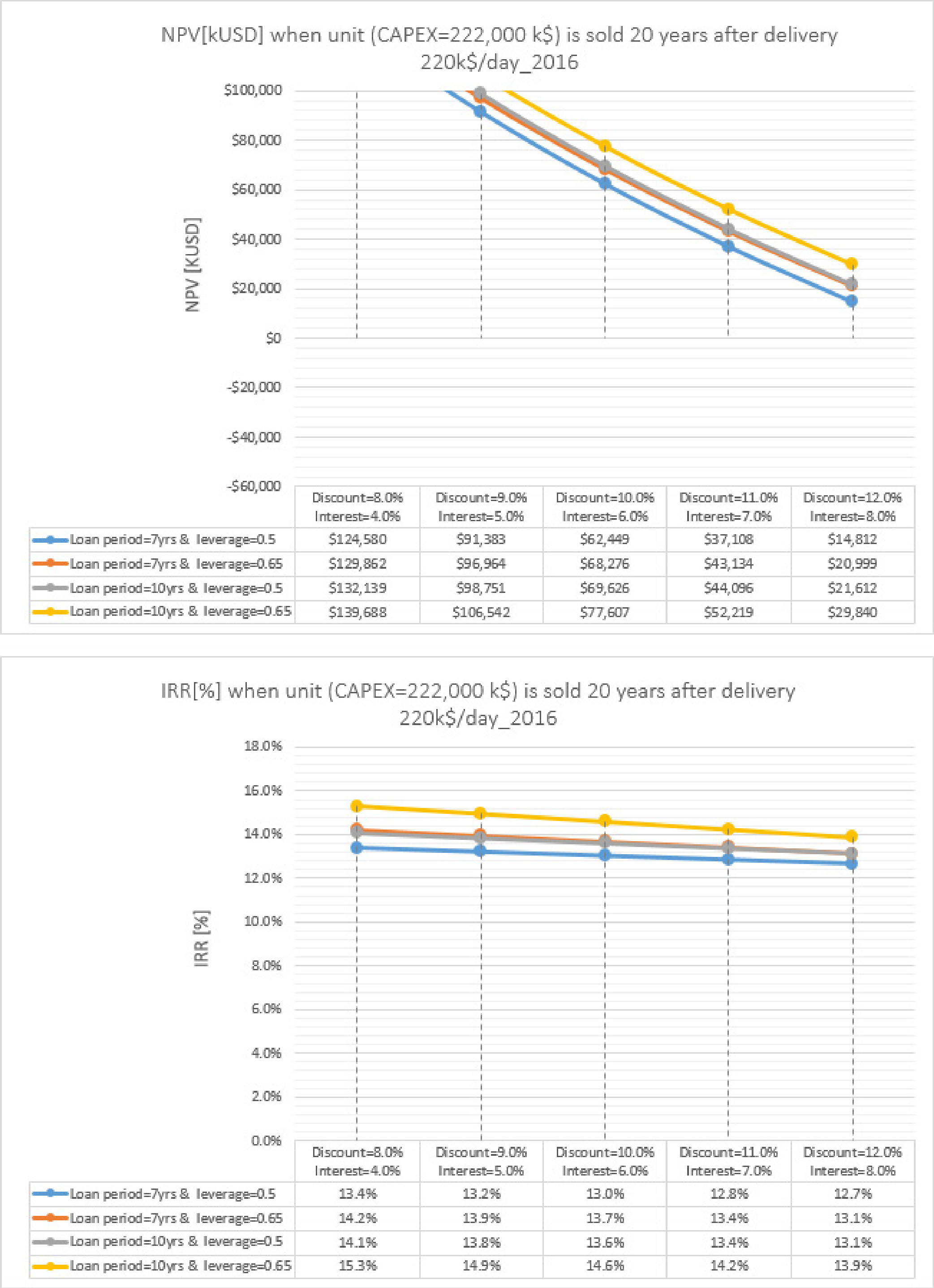


	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7 yrs & leverage=50.0%	$86,150	$60,080	$36,994	$16,460	-$1,881
Loan period=7 yrs & leverage=65.0%	$92,925	$66,929	$43,899	$23,404	$5,090
Loan period=10 yrs & leverage=50.0%	$93,709	$67,448	$44,171	$23,448	$4,919
Loan period=10 yrs & leverage=65.0%	$102,752	$76,507	$53,230	$32,489	$13,930



	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7 yrs & leverage=50.0%	10.4%	10.0%	9.7%	9.3%	9.0%
Loan period=7 yrs & leverage=65.0%	11.2%	10.7%	10.2%	9.8%	9.3%
Loan period=10 yrs & leverage=50.0%	11.1%	10.7%	10.3%	9.8%	9.4%
Loan period=10 yrs & leverage=65.0%	12.4%	11.8%	11.2%	10.6%	10.0%

Figure 20. WTIV Variation in NPV and IRR with day rate of $220k and Unit Sold after 20 years



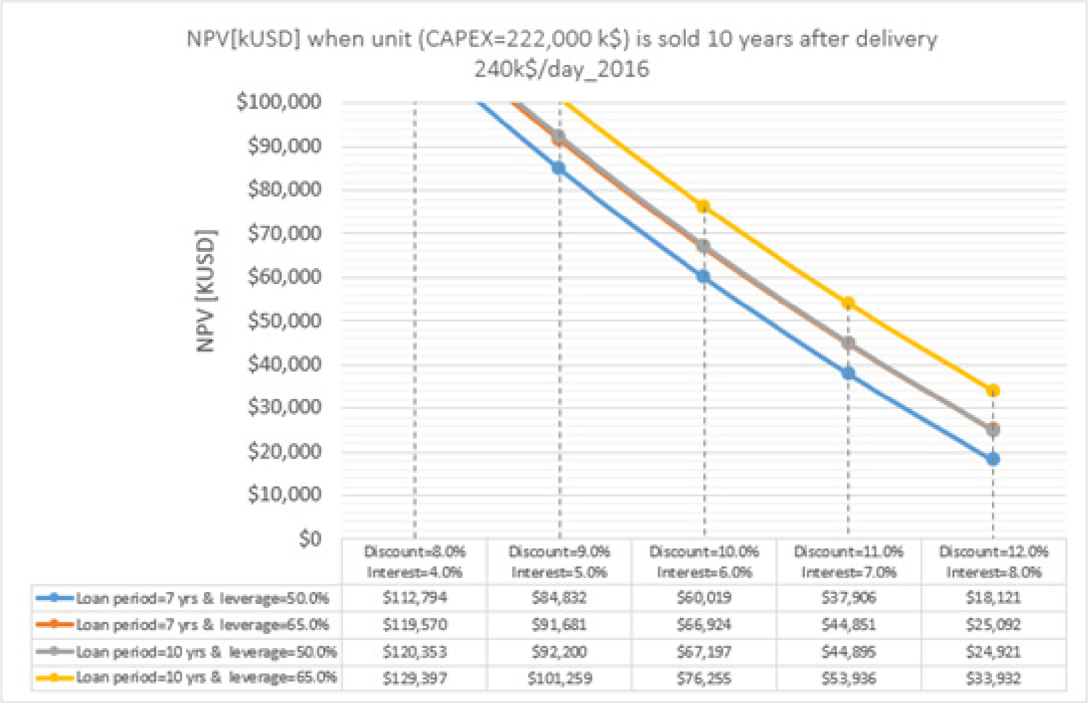
NPV[kUSD] when unit (CAPEX=222,000 k$) is sold 20 years after delivery 220k$/day_2016

	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7yrs & leverage=0.5	$124,580	$91,383	$62,449	$37,108	$14,812
Loan period=7yrs & leverage=0.65	$129,862	$96,964	$68,276	$43,134	$20,999
Loan period=10yrs & leverage=0.5	$132,139	$98,751	$69,626	$44,096	$21,612
Loan period=10yrs & leverage=0.65	$139,688	$106,542	$77,607	$52,219	$29,840

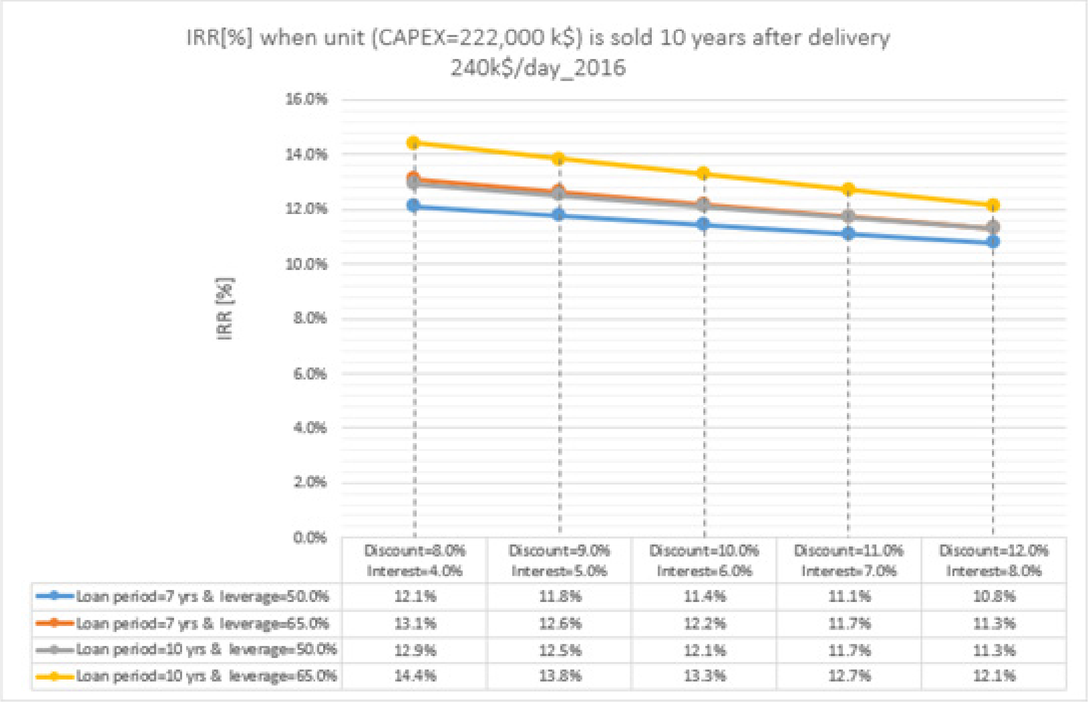
IRR[%] when unit (CAPEX=222,000 k$) is sold 20 years after delivery 220k$/day_2016

	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7yrs & leverage=0.5	13.4%	13.2%	13.0%	12.8%	12.7%
Loan period=7yrs & leverage=0.65	14.2%	13.9%	13.7%	13.4%	13.1%
Loan period=10yrs & leverage=0.5	14.1%	13.8%	13.6%	13.4%	13.1%
Loan period=10yrs & leverage=0.65	15.3%	14.9%	14.6%	14.2%	13.9%

Figure 21. WTIV Variation in NPV and IRR with day rate of $240k and Unit Sold after 10 years

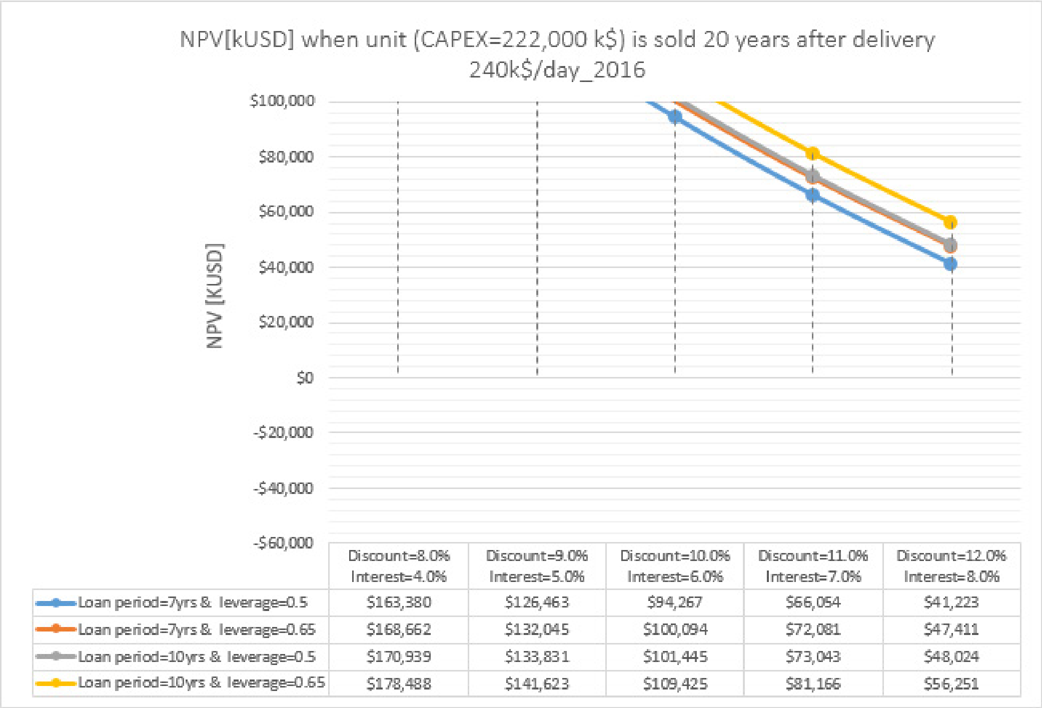

NPV[kUSD] when unit (CAPEX=222,000 k$) is sold 10 years after delivery 240k$/day_2016

	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7 yrs & leverage=50.0%	$112,794	$84,832	$60,019	$37,906	$18,121
Loan period=7 yrs & leverage=65.0%	$119,570	$91,681	$66,924	$44,851	$25,092
Loan period=10 yrs & leverage=50.0%	$120,353	$92,200	$67,197	$44,895	$24,921
Loan period=10 yrs & leverage=65.0%	$129,397	$101,259	$76,255	$53,936	$33,932

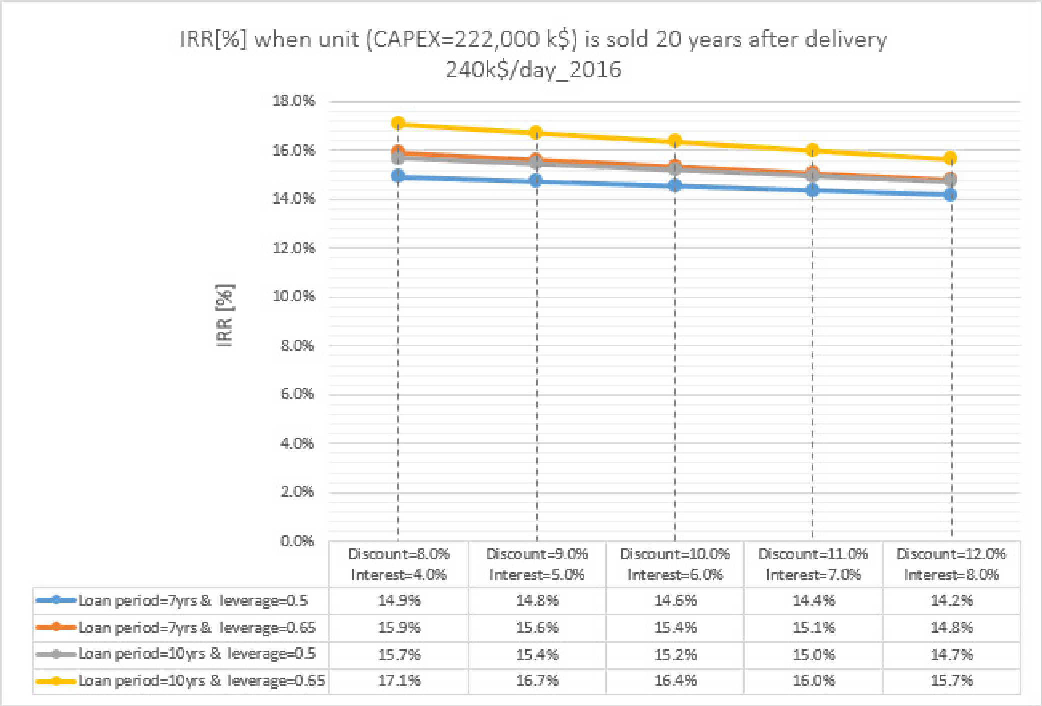

IRR[%] when unit (CAPEX=222,000 k$) is sold 10 years after delivery 240k$/day_2016

	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7 yrs & leverage=50.0%	12.1%	11.8%	11.4%	11.1%	10.8%
Loan period=7 yrs & leverage=65.0%	13.1%	12.6%	12.2%	11.7%	11.3%
Loan period=10 yrs & leverage=50.0%	12.9%	12.5%	12.1%	11.7%	11.3%
Loan period=10 yrs & leverage=65.0%	14.4%	13.8%	13.3%	12.7%	12.1%

Figure 22. WTIV Variation in NPV and IRR with day rate of $240k and Unit Sold after 20 years



	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7yrs & leverage=0.5	$163,380	$126,463	$94,267	$66,054	$41,223
Loan period=7yrs & leverage=0.65	$168,662	$132,045	$100,094	$72,081	$47,411
Loan period=10yrs & leverage=0.5	$170,939	$133,831	$101,445	$73,043	$48,024
Loan period=10yrs & leverage=0.65	$178,488	$141,623	$109,425	$81,166	$56,251



	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7yrs & leverage=0.5	14.9%	14.8%	14.6%	14.4%	14.2%
Loan period=7yrs & leverage=0.65	15.9%	15.6%	15.4%	15.1%	14.8%
Loan period=10yrs & leverage=0.5	15.7%	15.4%	15.2%	15.0%	14.7%
Loan period=10yrs & leverage=0.65	17.1%	16.7%	16.4%	16.0%	15.7%

10 Business Model for the Feeder Barge

A simple cash flow financial model was developed to assess the business case of the feeder unit considering the feeder strategy. This model tracks cash flow in and out of a vessel owner's account over the life of the unit. Like the model for the WITV, this is only for the vessel, not the overall project. Based on a larger analysis, a developer would need to answer questions such as the optimum number of feeder barges for their project based on specific data and circumstances. This report is only intended to supply data for a larger analysis of this type.

The cash flow model is assumed to begin when financing is in place. Construction is expected to last three years during which a vessel construction project team (on the owner's account) will be required to oversee construction and provide due diligence checks and oversight. A total of 12 people is estimated at an average total rate of $125k/year.

The unit is projected to begin work on wind farm installation immediately after leaving the shipyard and take 18 years of dedicated work completing turbine installations out to the 55 m contour line. Following the construction phase, it is assumed to be on wind farm maintenance at 40% utilization.

Insurance costs were fixed at 0.1% of CAPEX per year. All costs and revenues are corrected for inflation using a 2% rate of inflation. There are many other unknown details of the financial model such as future interest rates or possible tax credits.

These will be subjected to a sensitivity analysis where possible or conservative assumptions were made.

- Tax rate was left at 35% flat and no allowance made for tax credits or other forms of tax reduction in order to be conservative.
- No allowance was made for financing assistance from organizations such as the MARAD administered "Federal Ship Financing Programming" commonly known as Title XI.
- Net losses are not carried forward to offset future taxes.
- The unit is assumed to be fully depreciated over the life of the project and has a residual value of zero.

The loan is amortized over 10 years with interest rates ranging from 4% to 8% and discount rates range from 8% to 12% in the sensitivity study. Additionally, debt leverage ratios ranged from 50% to 65%.

The target day rate for the unit is $85,000 per day. This was subject to a sensitivity analysis of +/- $5k/day with the results shown in Figures 22 through 27 and results summarized in Tables 28 and 29. The values reported are for a discount rate of 9%.

Table 28. Summary of IRR for WTIV

MINIMUM IRR (%)		
day rate $k	10yr life	20yr life
80	7	10
85	8.1	11.2
90	9.2	12.1

With the target day rate, the unit can return an IRR of 8.1% if sold after 10 years, 11.2% if held for 20 years and the target IRR of 10% if sold after approximately 16 years.

Table 29. Summary of NPV for WTIV

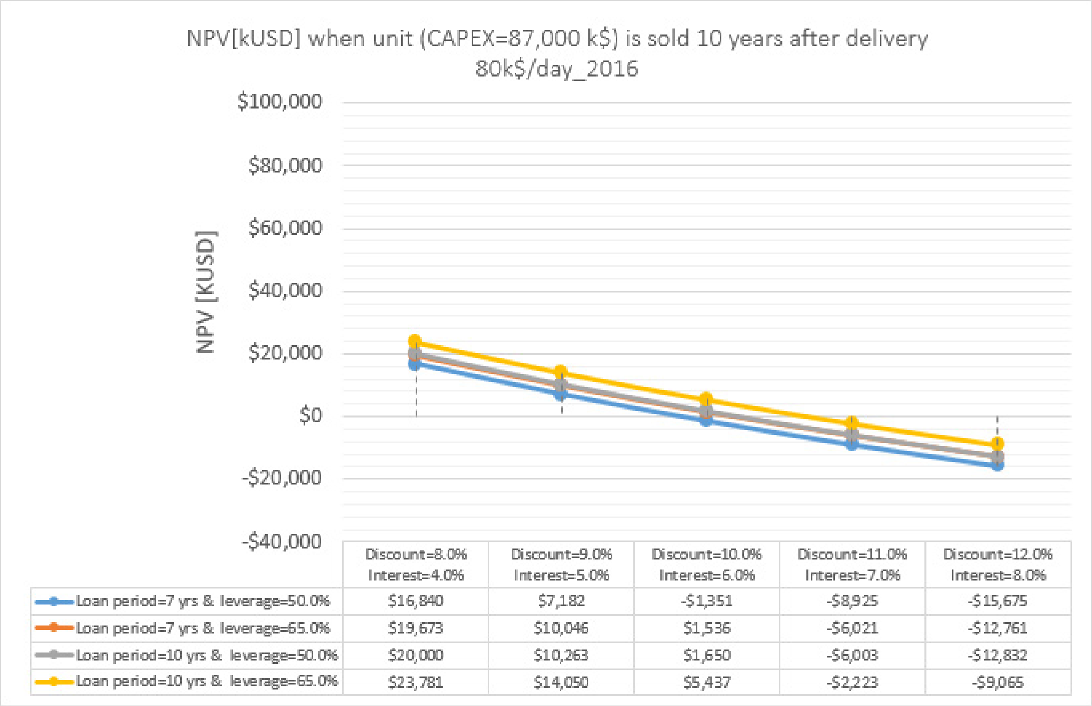
MINIMUM NPV ($million)		
day rate $k	10yr life	20yr life
80	7.2	11.6
85	13.4	19.9
90	19.6	28.2

Combining the target day rate with a discount rate of 9%, the unit can return an NPV of $13.4 million if sold after 10 years or an NPV of $19.9 million if held for 20 years.

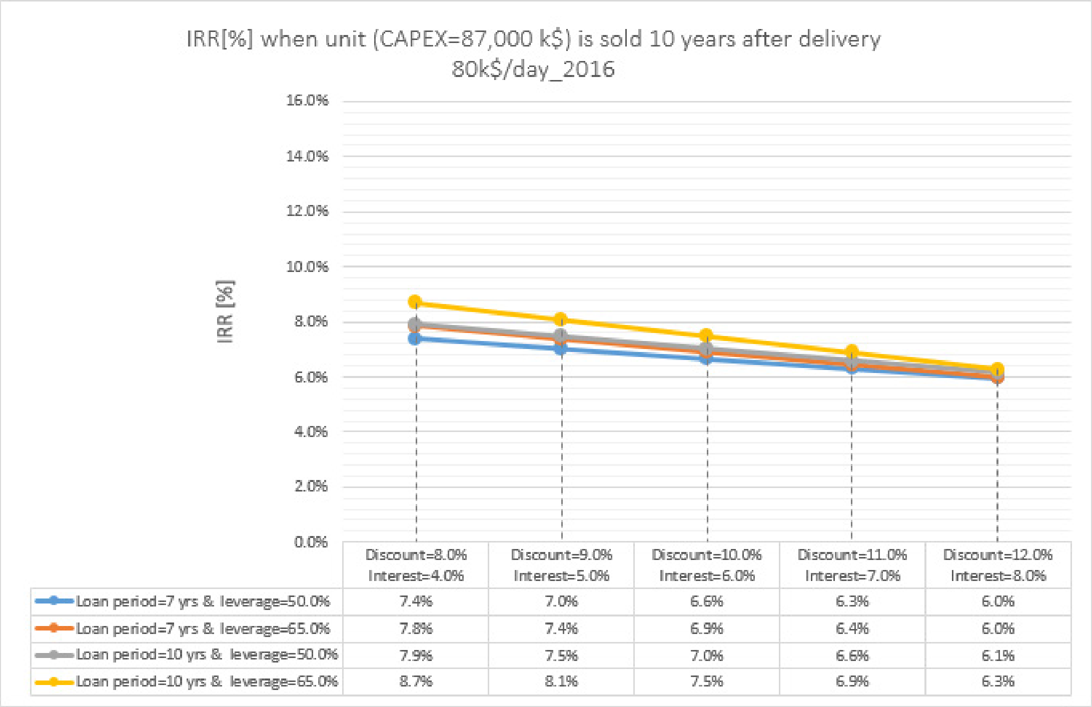
An item for future sensitivity studies is that the WTIV installation vessel for the feeder option may not need to be as big or as capable. Also, it is possible that several projects could share one feeder, which doubles as a wind farm maintenance unit and may improve the overall project economics.

Also, the WTIV may not need as much design functionality if it remains in the field and is supplied by feeder barges. Consequently, it may be possible to optimize the design and reduce the direct cost of the WTIV.

Figure 23. Feeder Variation in NPV and IRR with day rate of $80k and Unit Sold after 10 years

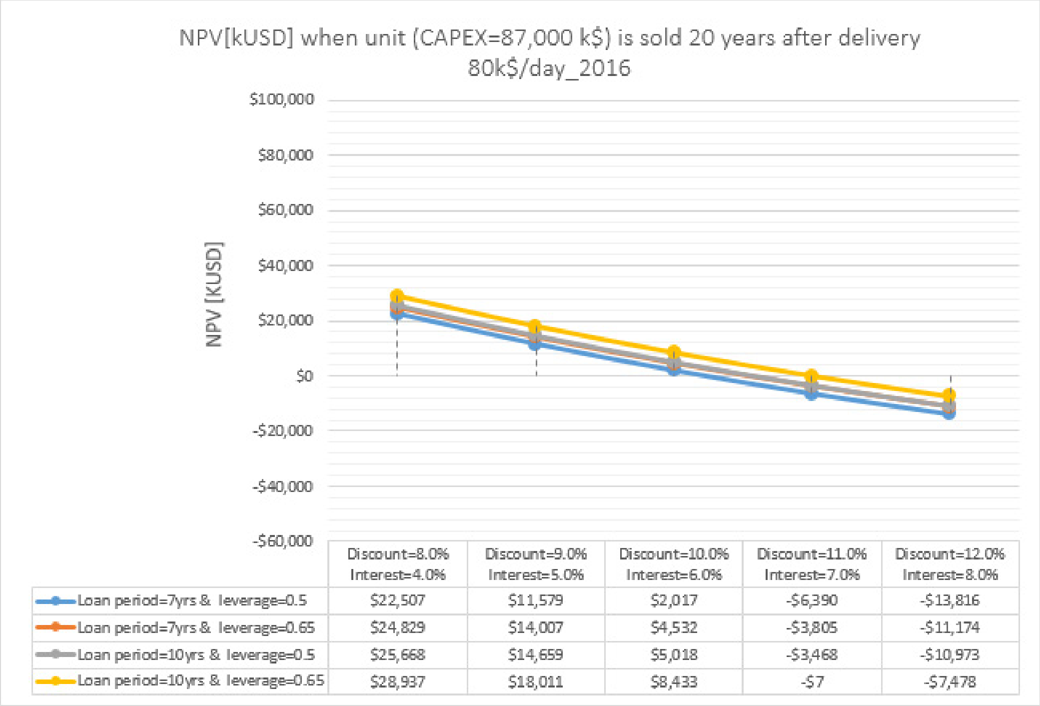


	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7 yrs & leverage=50.0%	$16,840	$7,182	-$1,351	-$8,925	-$15,675
Loan period=7 yrs & leverage=65.0%	$19,673	$10,046	$1,536	-$6,021	-$12,761
Loan period=10 yrs & leverage=50.0%	$20,000	$10,263	$1,650	-$6,003	-$12,832
Loan period=10 yrs & leverage=65.0%	$23,781	$14,050	$5,437	-$2,223	-$9,065

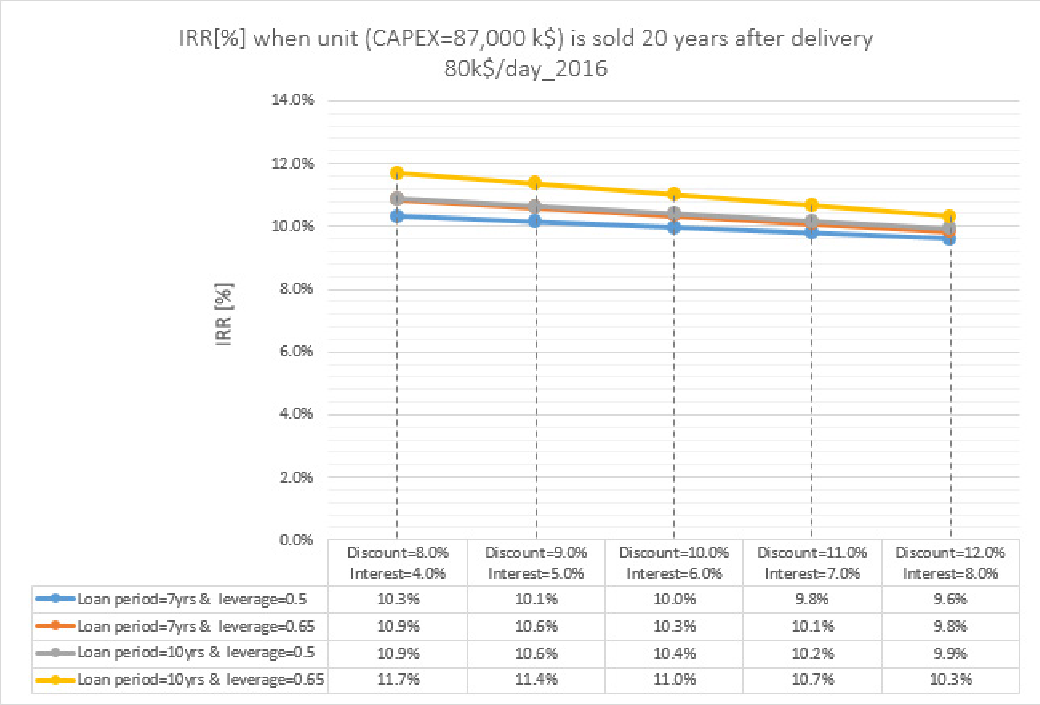


	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7 yrs & leverage=50.0%	7.4%	7.0%	6.6%	6.3%	6.0%
Loan period=7 yrs & leverage=65.0%	7.8%	7.4%	6.9%	6.4%	6.0%
Loan period=10 yrs & leverage=50.0%	7.9%	7.5%	7.0%	6.6%	6.1%
Loan period=10 yrs & leverage=65.0%	8.7%	8.1%	7.5%	6.9%	6.3%

Figure 24. Feeder Variation in NPV and IRR with day rate of $80k and Unit Sold after 20 years

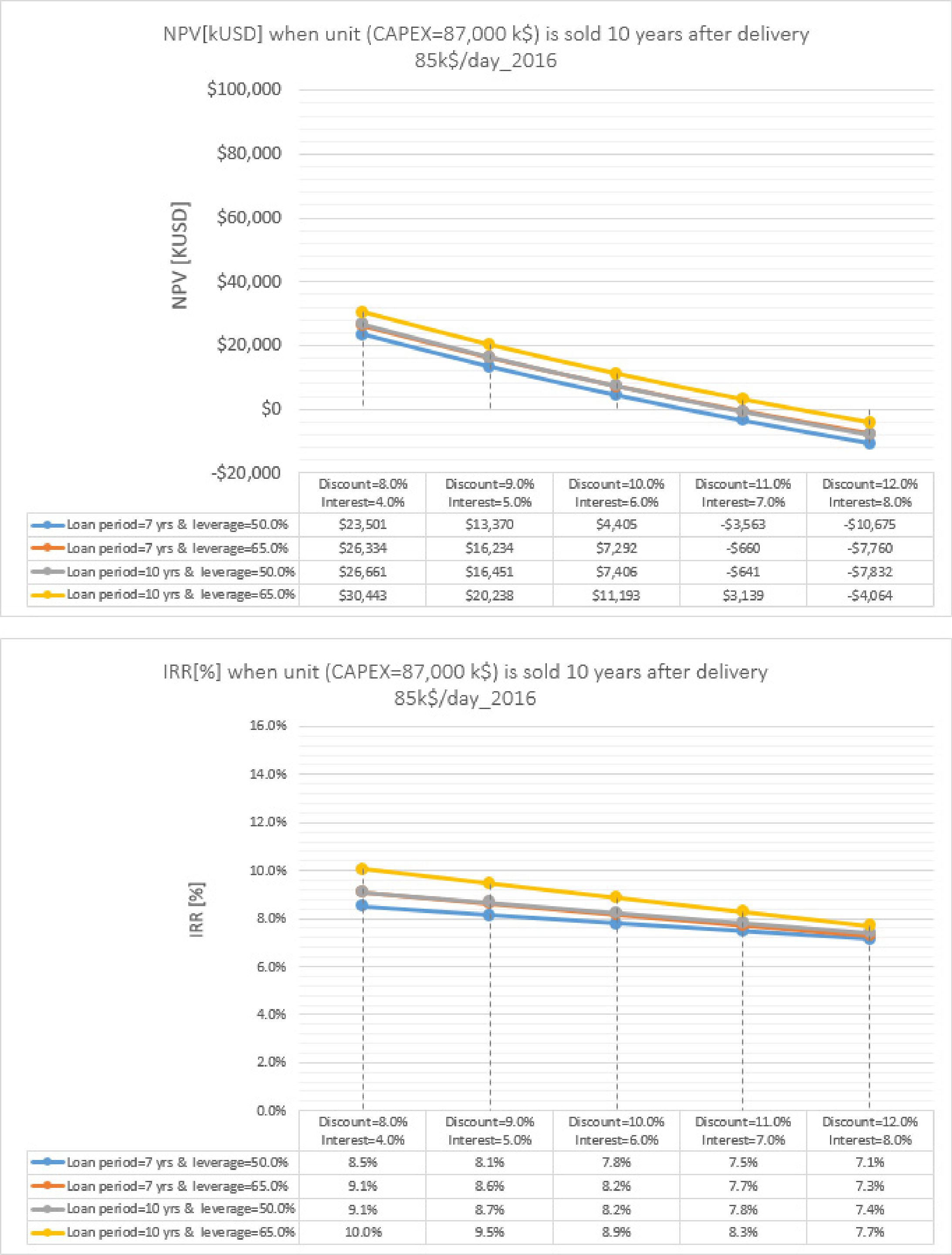


	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7yrs & leverage=0.5	$22,507	$11,579	$2,017	-$6,390	-$13,816
Loan period=7yrs & leverage=0.65	$24,829	$14,007	$4,532	-$3,805	-$11,174
Loan period=10yrs & leverage=0.5	$25,668	$14,659	$5,018	-$3,468	-$10,973
Loan period=10yrs & leverage=0.65	$28,937	$18,011	$8,433	-$7	-$7,478



	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7yrs & leverage=0.5	10.3%	10.1%	10.0%	9.8%	9.6%
Loan period=7yrs & leverage=0.65	10.9%	10.6%	10.3%	10.1%	9.8%
Loan period=10yrs & leverage=0.5	10.9%	10.6%	10.4%	10.2%	9.9%
Loan period=10yrs & leverage=0.65	11.7%	11.4%	11.0%	10.7%	10.3%

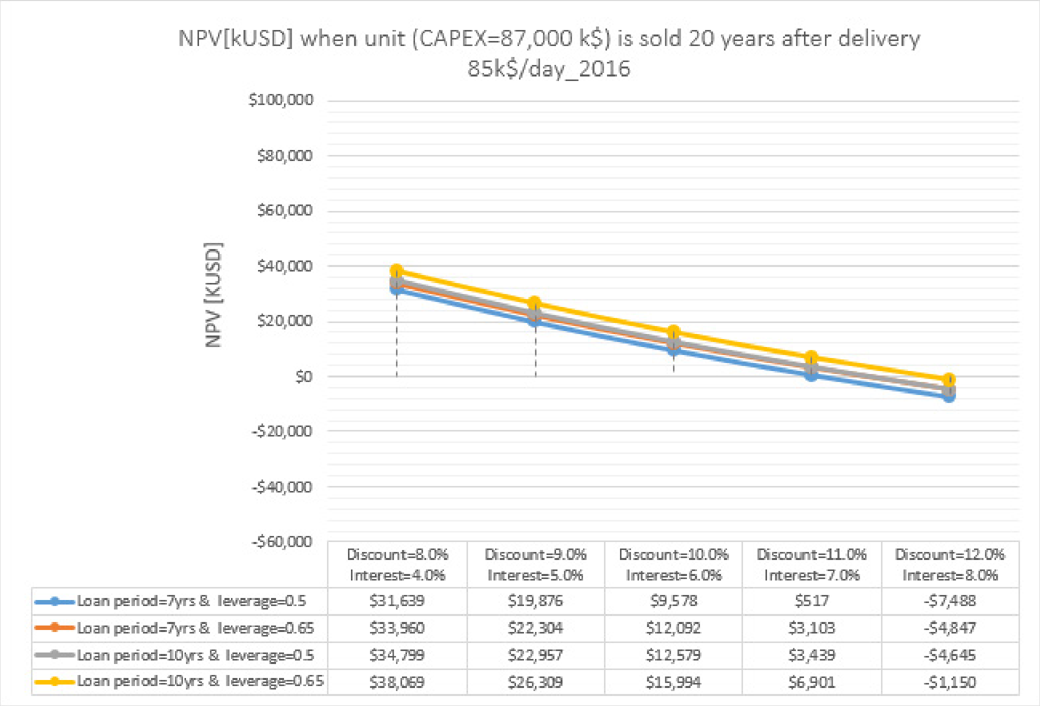
Figure 25. Feeder Variation in NPV and IRR with day rate of $85k and Unit Sold after 10 years



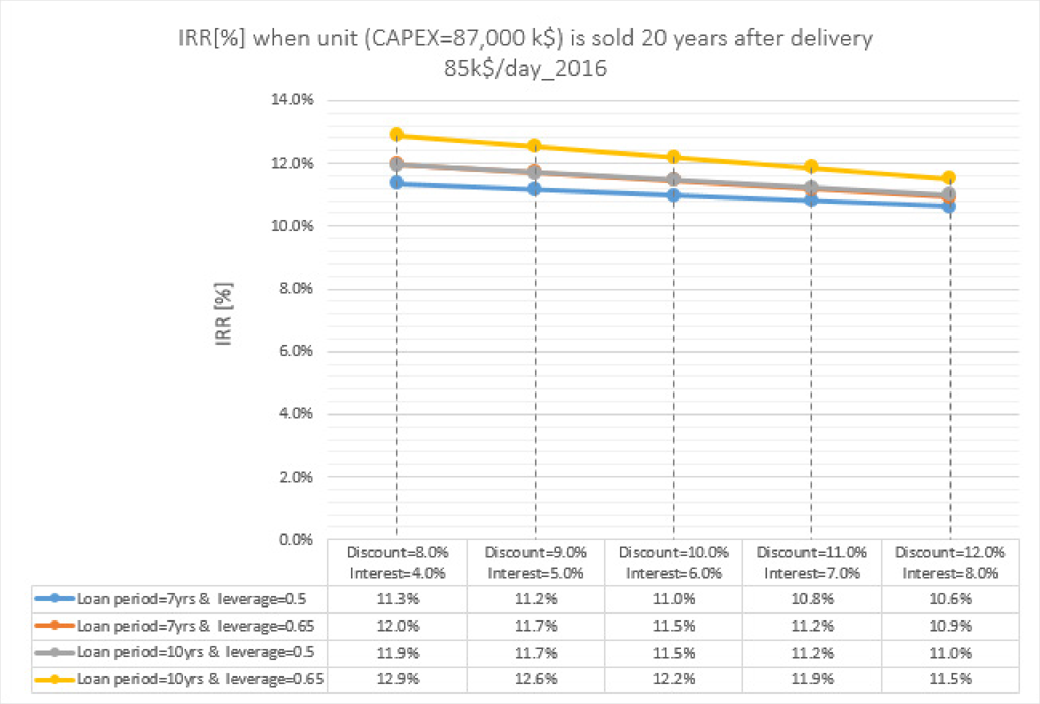
	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7 yrs & leverage=50.0%	$23,501	$13,370	$4,405	-$3,563	-$10,675
Loan period=7 yrs & leverage=65.0%	$26,334	$16,234	$7,292	-$660	-$7,760
Loan period=10 yrs & leverage=50.0%	$26,661	$16,451	$7,406	-$641	-$7,832
Loan period=10 yrs & leverage=65.0%	$30,443	$20,238	$11,193	$3,139	-$4,064

	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7 yrs & leverage=50.0%	8.5%	8.1%	7.8%	7.5%	7.1%
Loan period=7 yrs & leverage=65.0%	9.1%	8.6%	8.2%	7.7%	7.3%
Loan period=10 yrs & leverage=50.0%	9.1%	8.7%	8.2%	7.8%	7.4%
Loan period=10 yrs & leverage=65.0%	10.0%	9.5%	8.9%	8.3%	7.7%

Figure 26. Feeder Variation in NPV and IRR with day rate of $85k and Unit Sold after 20 years

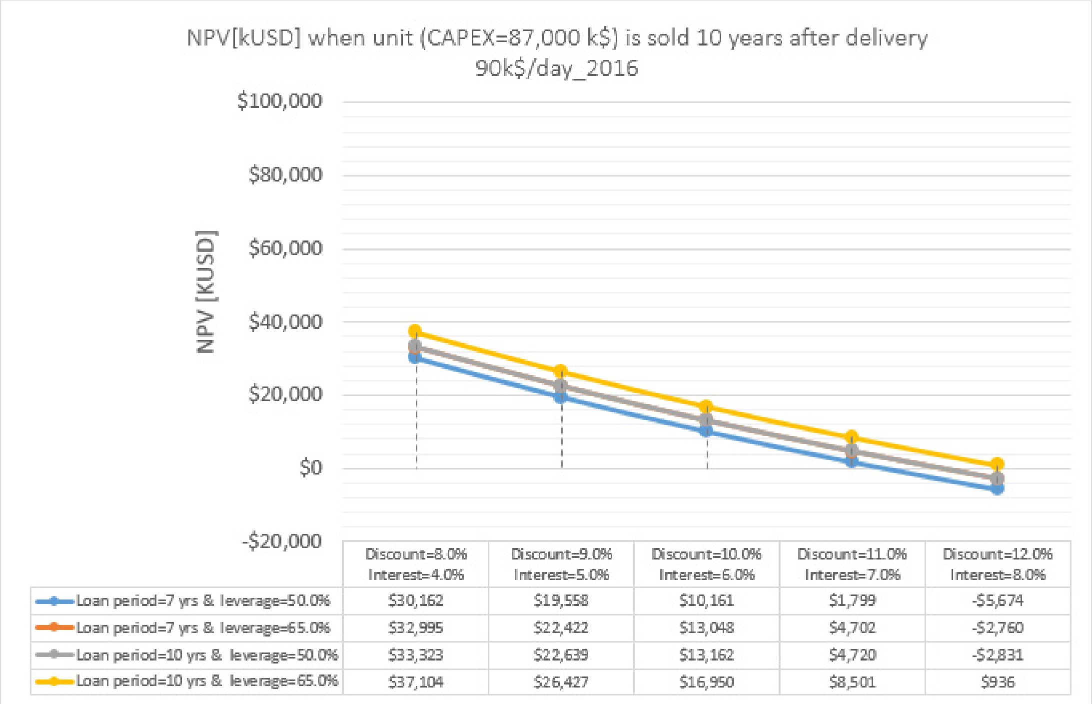


	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7yrs & leverage=0.5	$31,639	$19,876	$9,578	$517	-$7,488
Loan period=7yrs & leverage=0.65	$33,960	$22,304	$12,092	$3,103	-$4,847
Loan period=10yrs & leverage=0.5	$34,799	$22,957	$12,579	$3,439	-$4,645
Loan period=10yrs & leverage=0.65	$38,069	$26,309	$15,994	$6,901	-$1,150

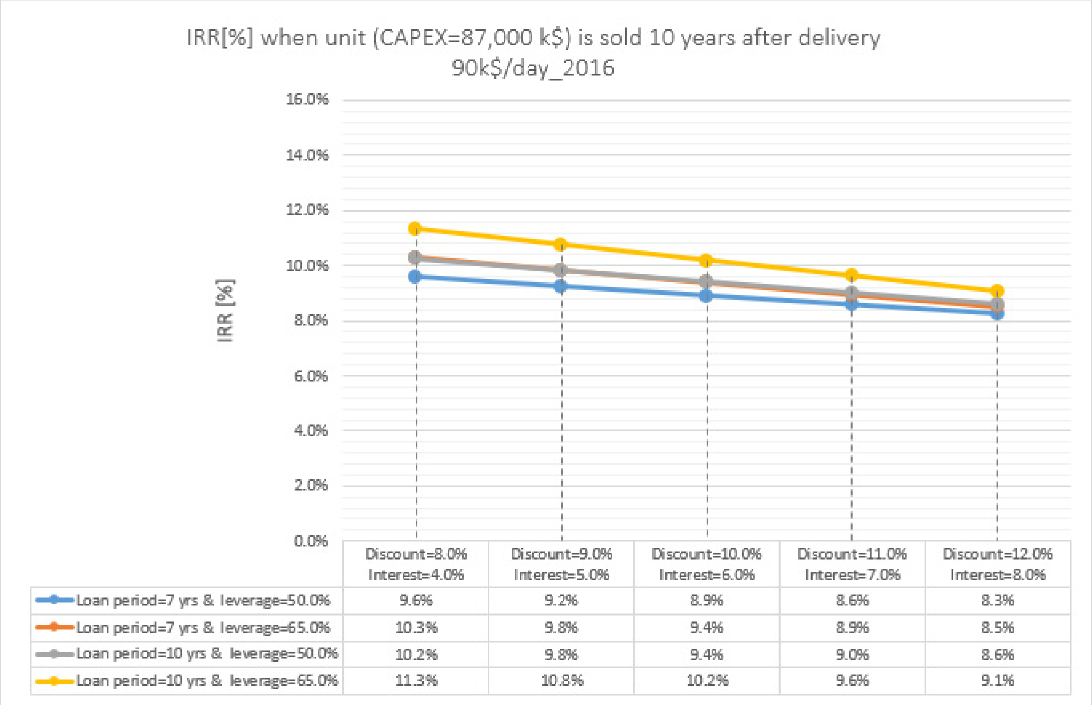


	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7yrs & leverage=0.5	11.3%	11.2%	11.0%	10.8%	10.6%
Loan period=7yrs & leverage=0.65	12.0%	11.7%	11.5%	11.2%	10.9%
Loan period=10yrs & leverage=0.5	11.9%	11.7%	11.5%	11.2%	11.0%
Loan period=10yrs & leverage=0.65	12.9%	12.6%	12.2%	11.9%	11.5%

Figure 27. Feeder Variation in NPV and IRR with day rate of $90k and Unit Sold after 10 years

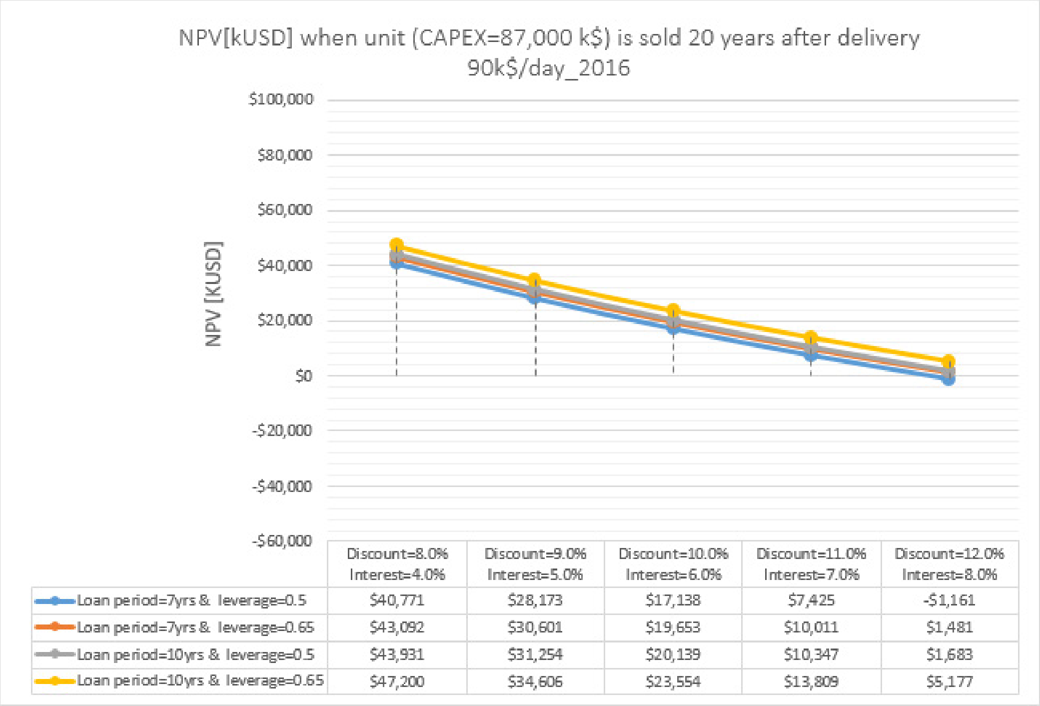


	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7 yrs & leverage=50.0%	$30,162	$19,558	$10,161	$1,799	-$5,674
Loan period=7 yrs & leverage=65.0%	$32,995	$22,422	$13,048	$4,702	-$2,760
Loan period=10 yrs & leverage=50.0%	$33,323	$22,639	$13,162	$4,720	-$2,831
Loan period=10 yrs & leverage=65.0%	$37,104	$26,427	$16,950	$8,501	$936

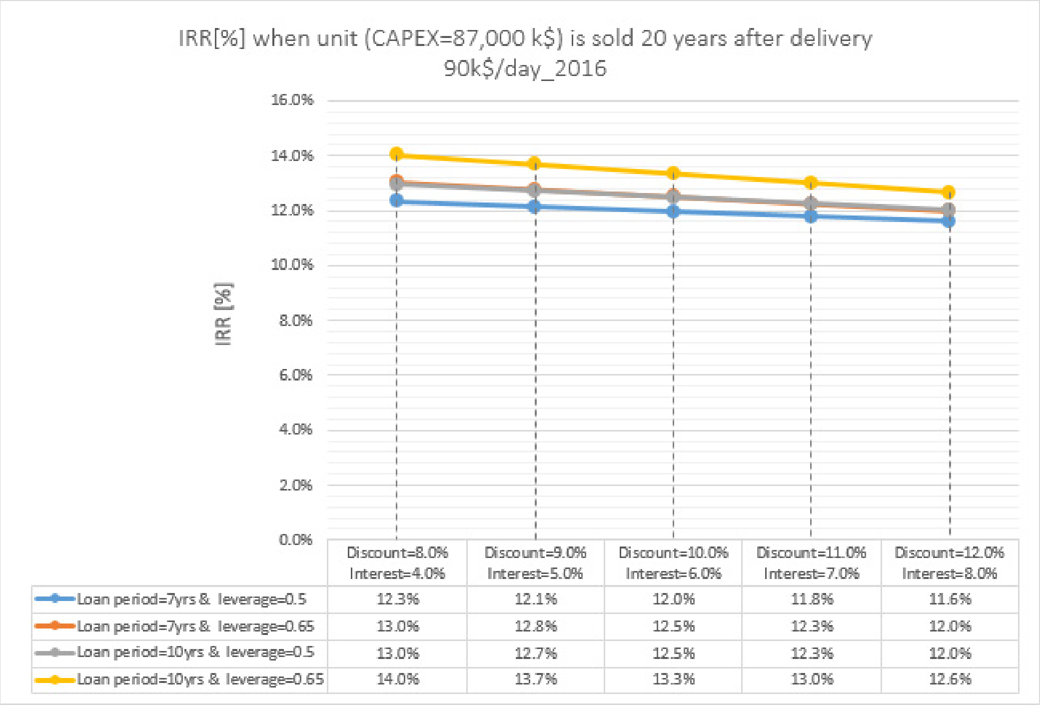


	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7 yrs & leverage=50.0%	9.6%	9.2%	8.9%	8.6%	8.3%
Loan period=7 yrs & leverage=65.0%	10.3%	9.8%	9.4%	8.9%	8.5%
Loan period=10 yrs & leverage=50.0%	10.2%	9.8%	9.4%	9.0%	8.6%
Loan period=10 yrs & leverage=65.0%	11.3%	10.8%	10.2%	9.6%	9.1%

Figure 28. Feeder Variation in NPV and IRR with day rate of $90k and Unit Sold after 20 years



	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7yrs & leverage=0.5	$40,771	$28,173	$17,138	$7,425	-$1,161
Loan period=7yrs & leverage=0.65	$43,092	$30,601	$19,653	$10,011	$1,481
Loan period=10yrs & leverage=0.5	$43,931	$31,254	$20,139	$10,347	$1,683
Loan period=10yrs & leverage=0.65	$47,200	$34,606	$23,554	$13,809	$5,177



	Discount=8.0% Interest=4.0%	Discount=9.0% Interest=5.0%	Discount=10.0% Interest=6.0%	Discount=11.0% Interest=7.0%	Discount=12.0% Interest=8.0%
Loan period=7yrs & leverage=0.5	12.3%	12.1%	12.0%	11.8%	11.6%
Loan period=7yrs & leverage=0.65	13.0%	12.8%	12.5%	12.3%	12.0%
Loan period=10yrs & leverage=0.5	13.0%	12.7%	12.5%	12.3%	12.0%
Loan period=10yrs & leverage=0.65	14.0%	13.7%	13.3%	13.0%	12.6%

11 Conclusions

This study took a sample of potential offshore wind development areas in the Northeast between New York and Massachusetts where existing commercially available bottom fixed technology may be used. Data on bathymetry, wind, wave, current, and soil conditions was identified. Eight-MW turbines were laid out in a 9 x 9 rotor diameters grid and the number of turbines that could theoretically be installed were tallied according to water depth range.

Installation methodologies and timelines were synthesized to define the functional requirements of the WTIV and feeder barge. Based on the requirements, a WTIV with a main crane capacity of 1500te (1645 ST) and a beam of 42m (138 ft.) was designed. Estimating packages were prepared and submitted to U.S. shipyards resulting in an average estimated cost of $222 million and a build time of 34 months.

Likewise, a feeder barge with a variable load capacity of 3400te (3740 ST) and a beam of 38m (125 ft.) was designed to support a field-bound WTIV. Estimating packages were prepared and submitted to U.S. shipyards resulting in an average estimated cost of $87 million and a build time of 25 months.

A basic financial model was created to track cash flows for a vessel owner over the life of the unit. To achieve a reasonable combination of day rates ($220,000) and internal rate of return (10%), at least 10 years of firm work is required for the WTIV. For the feeder barge, approximately 16 years of work at a day rate of $85,000 is required to generate an internal rate of return of 10%.

This will require a group of states and developers coordinate on an identified pipeline of projects. However, if the full potential of the offshore wind areas on the East Coast is realized, several vessels may be justified for areas not considered in this study.

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Appendix A – Product Brochure – NG-9800C-US

NG series jack-up vessels

Type NG-9800C-US

Description

The GustoMSC NG series is a range of multi-purpose self-propelled jack-up vessels. The NG-9800C-US is especially designed for the US Wind Turbine Installation market and is a further development of the successful NG-9000C. This self-propelled unit undertakes voyages and positioning for jacking operations without tug assistance. The four legs with the continuous speed jacking system and the diagonal pre-loading allow for easy and faster jacking installations.

The increased width of the unit creates a wider deck space for positioning large jacket foundations on deck and enables a large capacity crane in jacked-up mode.

The NG-9800C-US is able to accommodate a 1,500t leg crane located on top of the jack-house and revolves around the aft jack-up leg. The main deck of 3,450 m² is locally reinforced for the transportation of wind turbine parts or other heavy components. The NG-9800C-US is intended for use in water depths of up to 55 m survival in a US East-Coast type environment.

In addition the vessel has the ability to work in the Offshore Oil & Gas sector. This product sheet describes the standard unit. and modifications to suit the client's requirements can be considered.

Main particulars

Principal dimensions

Hull length (main deck)	127.8 m
Hull width	42.0 m
Hull depth	10.0 m
Hull draft	5.8 m
Leg length max. (incl. spudcan)	92.0 m
Leg length under hull (max.)	± 69.0 m

Classification, regulations

ABS, DNV GL or equivalent

Power generation

4 diesel generator sets of 4,200 ekW plus 1 of 1,960 ekW
1 emergency diesel generator set of 1,000 ekW

Propulsion

Propulsion for transit and DP is provided by
3 * 3,500 kW propulsion azimuthing thrusters aft
2 * 1,800 kW ccp tunnel thrusters
1 x 2,000 kW azimuthing thrusters forward

Speed

Transit speed with aft thrusters only	11 kn

The Netherlands
Karel Doormanweg 35, 3115 JD, Schiedam
P.O. Box 687, 3100 AR Schiedam

Telephone +31 (0)10 2883 000
Telefax +31 (0)10 2883 001

www.GustoMSC.com

GustoMSC

Variable load

Variable load	6,400 t
Deck load	10 t / m²
Deck area	± 3,450 m²

Accommodation

An accommodation deckhouse suitable for 90 persons is located on the forward end of the vessel.

Helideck (optional)

A helicopter landing deck suitable for a Sikorsky S61N/S92A (9.3 t) of 22.2 m is provided.

Design criteria

Positioning / Jacking / Pre-loading condition

The dynamic positioning system is executed for DP notation. The jack-up is able to position, jack and pre-load whilst meeting DP requirements in the following conditions:

	DP1	DP2
max significant wave height	1.8 m	1.5 m
tidal current (surface)	1.03 m/s	1.03 m/s
wind velocity	10.8 m/s	5.14 m/s

Elevated operational conditions on request.

Elevated survival condition

	summer	*year round*
Water depth	55 m	50 m
Airgap	9 m	14 m
Wave height (Hmax)	12.5 m	19.5 m
Surface current	1.2 m/s	1.2 m/s
Wind velocity (1 min sust)	38 m/s	38 m/s
Spudcan penetration	5 m	5 m

Jacking system

The vessel is equipped with the GustoMSC 9800C continuous hydraulic positive engagement jacking system

Max. holding capacity	9,800 t per leg
Platform lifting speed	22 m/hr
Platform lowering speed	27 m/hr
Leg handling speeds	up to 40 m/hr

Main crane

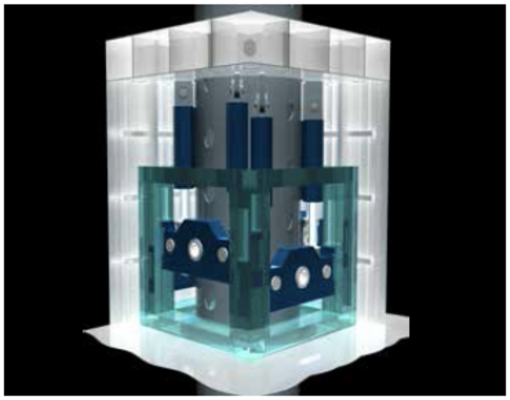
The vessel is equipped with a leg encircling crane. The crane is located on top of the port side aft Jack-house and revolves around the Jack-up Leg of the vessel.

Main hoist	1,500 t @ 32 m
Minimum outreach	15 m
Max. hook height (ref. main deck)	approx. 115 m
Aux. hoist	150 t
(Aux. cranes (3x)	12.5 t @ 30 m)

Metric system

Weights [t] and forces [tf] are in the metric system.

Data presented in this product sheet is for information only and subject to change without notice.



Appendix B – Product Brochure – NG-3750C

NG series jack-up vessels

Type NG-3750C-FEEDER

Description

The GustoMSC NG series is a series of multi-purpose self-propelled jack-ups that undertake transit and positioning offshore without tug assistance.

This NG-3750C-FEEDER is specially designed for transporting wind turbine components from Ports to larger installation Jack-up vessels offshore that are not able to enter the Ports due to their dimensions and/or height restrictions. The accommodation is placed on port side in order increase the deck space (1,800 m^2), carry longer items on deck and the deck is locally reinforced for the transportation of heavy components.

Within this FEEDER design future modifications to a Wind Turbine Maintenance Jack-up vessel are taken into account. Some of the modification considerations are: installation of a 400t crane and extension of the accommodation. This conversion to a NG-3750C-WTM reduces CAPEX as the unit can be operated during the life time of the Wind farm or as an Oil & Gas Support & Maintenance Jack-up.

The NG-3750C-FEEDER is intended for use in water depths of up to 50 m in a harsh North Sea type of environment and has a leg length under the hull of approx. 68 m. This unit is equipped with well-balanced DP2, increasing maneuvering capability and a robust, continuous positive engagement hydraulic jacking system for fast, frequent and secure jacking operations and with a high built-in redundancy.

This product sheet describes the unit for the above mentioned services and can be modified to suit the client's requirements.

Main dimensions

Hull length	70.5 m
Hull width	38.0 m
Hull depth	6.5 m
Leg length max. (incl. spud-can)	86.0 m
Leg length under hull (max.)	± 68.0 m

Classification

ABS, DNV GL or equivalent

Power generation

4 diesel generator sets of 1,600 kW
1 emergency diesel generator set of 500 kW

Propulsion

Propulsion for transit and DP is provided by:
2 x 1,650 kW propulsion azimuthing thrusters aft
1 x 1,650 kW retractable azimuthing thruster forward
1 x 1,650 kW CPP tunnel thruster

Speed

Transit speed	6 - 7 kn

Variable load and deck

Maximum variable load	approx. 3,400 t
Deck load	10 t/m^2
Deck area	± 1,800 m^2

Productsheet
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The Netherlands
Karel Doormanweg 35, 3115 JD, Schiedam
P.O. Box 687, 3100 AR Schiedam
Telephone +31 (0)10 2883 000
Telefax +31 (0)10 2883 001

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Accommodation

An accommodation deckhouse on port side suitable for 12 persons, public facilities for 28, located on the forward end of the vessel.

Design criteria

Positioning / Jacking / Pre-loading condition

The dynamic positioning system is executed for DP notation. The Jack-up is able to position, jack and pre-load whilst meeting DP requirements in the following conditions;

	DP-1	DP-2
Signifcant wave height	1.5 m	1.0 m
Current	1.03 m/s	1.03 m/s
Wind	10.8 m/s	5.14 m/s

Elevated condition

The jack-up is designed to withstand the following combination of survival conditions;

	operation	survival
Water depth	50.0 m	50.0 m
Max wave height	3.0 m	11.0 m
Current	1.0 m/s	1.0 m/s
Wind	20.0 m/s	30.0 m/s
Air gap	8.0 m	8.0 m
Leg penetration	5.0 m	5.0 m

Jacking System

The vessel is equipped with a positive engagement GustoMSC continuous hydraulic "Pin in Hole" jacking system.

Max. Holding capacity	3,850 t per leg
- Platform lifting speed	24 m/hr
- Platform lowering speed	30 m/hr
- Leg handling speeds up to	40 m/hr

GustoMSC services

GustoMSC provides basic design services to obtain Class approval. GustoMSC provides associated equipment like Jacking System.

Metric system

Weights [t] and forces [tf] are in the metric system.

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For more information about this report, please contact NYSERDA

New York State
Energy Research and
Development Authority

17 Columbia Circle
Albany, NY 12203-6399

toll free: 866-NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov

U.S. Jones Act Compliant Offshore Wind Turbine Installation Vessel Study
A Report for the Roadmap Project for Multi-State Cooperation on Offshore Wind

New York State Energy Research and Development Authority
Massachusetts Clean Energy Center
Massachusetts Department of Energy Resources
Rhode Island Office of Energy Resources
Clean Energy States Alliance

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