California North Coast Offshore Wind Studies

Military Recommendation for Wind Farm Designs

This report was prepared by Mark Severy and Christina Ortega of the Schatz Energy Research Center. It is part of the *California North Coast Offshore Wind Studies* collection, edited by Mark Severy, Zachary Alva, Gregory Chapman, Maia Cheli, Tanya Garcia, Christina Ortega, Nicole Salas, Amin Younes, James Zoellick, & Arne Jacobson, and published by the Schatz Energy Research Center in September 2020.

The series is available online at schatzcenter.org/wind/

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Disclaimer

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About the Schatz Energy Research Center

The Schatz Energy Research Center at Humboldt State University advances clean and renewable energy. Our projects aim to reduce climate change and pollution while increasing energy access and resilience.

Our work is collaborative and multidisciplinary, and we are grateful to the many partners who together make our efforts possible.

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TABLE OF CONTENTS

1. BACKGROUND

The United States Coast Guard and Navy are currently engaged with the planning process of offshore wind in the California Outer Continental Shelf. Both are members of the Bureau of Ocean Energy Management's California Renewable Energy Task Force. Their interest is to make sure that development of offshore wind remains compatible with the military's operations. The Department of Defense (DoD) has a military presence off of the California Coast, which will require coordination and support between developers, BOEM, the State, and the DoD (BOEM, 2018). The DoD's interests lie in the ability to maintain access to training and testing areas in the airspace, sea surface, subsurface, and seafloor of California's Outer Continental Shelf where offshore wind may be present (Chung, 2018). The United States Coast Guard's mission is to ensure the Nation's maritime safety, security, and stewardship (Detwelier, 2018). One of the Coast Guards interests lies in the safety of navigation in waters of the Outer Continental Shelf, which includes assessing the risks of vessel collision due to the placement of new structures, like offshore wind turbines. They are also interested in the impacts that offshore wind farms may introduce to search and rescue missions (Kearns & West, 2018).

2. SUMMARY OF OUR INTERACTION

The Schatz Energy Research Center developed a technical description of potential offshore wind farm designs in the Humboldt Call Area based on preliminary engineering assessment as well as interviews with industry developers. The Schatz Center provided a copy of the technical description to the DoD and the US Coast Guard to receive their input and comments about potential compatibility issues with the scale, location, or technology of a future offshore wind development in the Humboldt Call Area. The technical description was sent to the military contacts on April 7th, 2020 via email. A copy of this report is provided at the end of this report in Appendix B.

3. DESCRIPTION OF THEIR RESPONSE

After review of the technical description provided, a DoD representative responded on May 15th, 2020 to say that the "DoD Regional Offshore Team has review the report and continue to find that offshore wind development within the Humboldt Call Area can be compatible with DoD's mission - as such, DoD does not have any questions with the regards to the content of the report" (Steve Chung, personal communication).

The Coast Guard responded to the technical description on June 22nd, 2020, stating that any establishment of structures will cause safety impacts for vessels in the waterway. The Coast Guard offered four recommendations for further development and planning. First, a formal navigational safety risk assessment will need to be completed for Coast Guard review. Second, dependent on the outcome of the navigational safety risk assessment, proper lights, labels, colors, and sound signals will need to be implemented. Third, a Search and Rescue and Pollution Prevention plan must be created and assessed by the Coast Guard Sector Humboldt Bay to determine the impacts on emergency responder missions. Last, Private Aids to Navigation (PAToN) permits, submitted to Coast Guard District Eleven Waterways Management Branch, will be required.

4. REFERENCES

[BOEM] Bureau of Ocean Energy Management. (Sept. 17, 2018). *BOEM California Intergovernmental Renewable Energy Task Force Meeting Summary*. < https://www.boem.gov/CA-Task-Force-Meeting-Summary/>

Chung, Steve. (Sept. 17, 2018). *Department of Defense Engagement Activities*. BOEM California Intergovernmental Renewable Energy Task Force Meeting. <https://www.boem.gov/California-Task-Force-Full-Deck/>.

Detwelier, George H. Jr. (Mar. 5, 2018). *United States Coast Guard Office of Navigation Systems.* BOEM's Offshore Wind and Maritime Industry Knowledge Exchange. <https://www.boem.gov/sites/default/files/renewable-energy-program/Navigational-Risk-Assessments-and-U-S-Coast-Guard-Responsibilities.pdf >.

Kearns & West. (Mar. 5, 2018). *Summary Report: Bureau of Ocean Energy Management's Offshore Wind and Maritime Industry Knowledge Exchange.* Bureau of Ocean Energy Management. < https://www.boem.gov/sites/default/files/renewable-energy-program/BOEM-Maritime-Meeting-Summary-FINAL-%281%29.PDF>.

APPENDIX A - LETTER FROM U.S. COAST GUARD

U.S. Department of Homeland Security
United States Coast Guard

Commander
Eleventh Coast Guard District

Coast Guard Island Building 50-2
1 Eagle Road
Alameda CA, 94501
Staff Symbol: D11 DPW
Phone: (510) 437-3801
Email: Ruth.A.Sadowitz@uscg.mil

Attn: Mr. Mark Severy
Schatz Energy Research Center
Humboldt State University
Arcata, CA 95521
115 McAllister Way

Dear Mr. Severy:

This letter is to inform you that I have reviewed the California North Coast Offshore Wind Study, dated March 2020. Coast Guard Eleventh District (D11) appreciates the opportunity to evaluate future waterway development projects. The Coast Guard has been delegated as primary agency with the duties of maritime law enforcement, saving and protecting life and property, and safeguarding navigation on the high seas and navigable waters of the United States per Title 33 Code of Federal Regulations (CFR) Chapter I, Subchapter A Part 1 (33CFR1.01-1). Any establishment of structures on the waterway will impact safety of navigation for all vessels. Specifically, the Humboldt Wind Farm proposal incorporates a large portion of the entrance to Humboldt Bay. D11 Waterways Management Branch's role is to provide guidance and review of any development proposal necessary to reduce the potential impacts on the Marine Transportation System. My recommendations for any future development or planning are the follows:

- A formal navigational safety risk assessment shall be completed by the applicant for Coast Guard evaluation. This assessment will identify risks, determine potential impact to navigation, and mitigating policies and procedures to ensure the safety, security, and efficiency of U.S. waterways.
- Proper lights, labels, colors, and sound signals will be used for navigation purposes to improve vessel navigation and avoid the hazards. The Coast Guard will determine the requirement after the navigational safety risk assessment have been completed and evaluated.
- Search and Rescue (SAR) and Pollution Prevention plan must be assessed, developed, and coordinated with Coast Guard Sector Humboldt Bay to determine impact on Coast Guard and other emergency responder missions and to enhance communications.
- Private Aids to Navigation (PAToN) permits will be required. PAtoN Application Form, CG-2554 must be submitted for approval to Coast Guard District Eleven Waterways Management Branch.

If you have any questions concerning these recommendations and future planning, please contact Ruth Sadowitz at (510) 437-3801, email: Ruth.A.Sadowitz@uscg.mil.

Sincerely,

T. L. CONNER
Acting Chief, Waterways Management Branch
U. S. Coast Guard
By direction

Below is the transcribed text from the letter for accessibility purposes. It was created via optical character recognition and may not be an exact replica.

U.S. Department of Homeland Security
Commander Eleventh Coast Guard District
Coast Guard Island Building 50-2
1 Eagle Road
Alameda CA, 94501
United States Staff Symbol: D11 DPW
Coast Guard Phone: (510) 437-3801
Email: Ruth.A.Sadowitz@uscg.mil

Attn: Mr. Mark Severy
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If you have any questions concerning these recommendations and future planning, please contact Ruth Sadowitz at (510) 437-3801, email: Ruth.A.Sadowitaz@uscg.mil.

Sincerely,
T. L. CONNOR
Acting Chief, Waterways Management Branch
U.S. Coast Guard
By direction

APPENDIX B - TECHNICAL DESCRIPTION OF NORTH COAST OFFSHORE WIND FARM

A technical description of a floating offshore wind farm in the Humboldt Call Area is described in the document below. This version was sent to the military for review.

California North Coast Offshore Wind Study

Technical Description of Offshore Wind Farm for Military Review

March 2020

Prepared for:

California Governor's Office of Planning and Research
California Military Energy Opportunity Compatibility Assessment Mapping Project (CaMEO CAMP)
Grant Agreement Number: OPR19100

Prepared by:

Mark Severy, Andrew Harris, Arne Jacobson
Schatz Energy Research Center
Humboldt State University
Arcata, CA 95521
(707) 826-4345

The potential for offshore wind energy generation is being investigated along the northern coast of California for six different scenarios that vary by wind array scale and electrical transmission route. This document provides a technical and spatial description of the wind farms scenarios that can be used by the military to assess compatibility between offshore wind and the military mission on the north coast of California.

This document begins with an overview of the different wind farm scenarios, including maps of the region, then presents the technical details that form the basis of analysis. The assumptions presented in this document were developed using publicly available reports and communication with developers.

Additional data and spatial information can be provided the facilitate a better assessment. Please let us know what information we should provide.

Table of Contents

1. INTRODUCTION

Future offshore wind development in northern California would include new infrastructure in three locations: 1) offshore for the wind farm, 2) in the Humboldt Bay Harbor for port operations, and 3) on land for electrical transmission upgrades. Development in each one of these areas may have different impacts or conflicts with the military mission.

2. PURPOSE

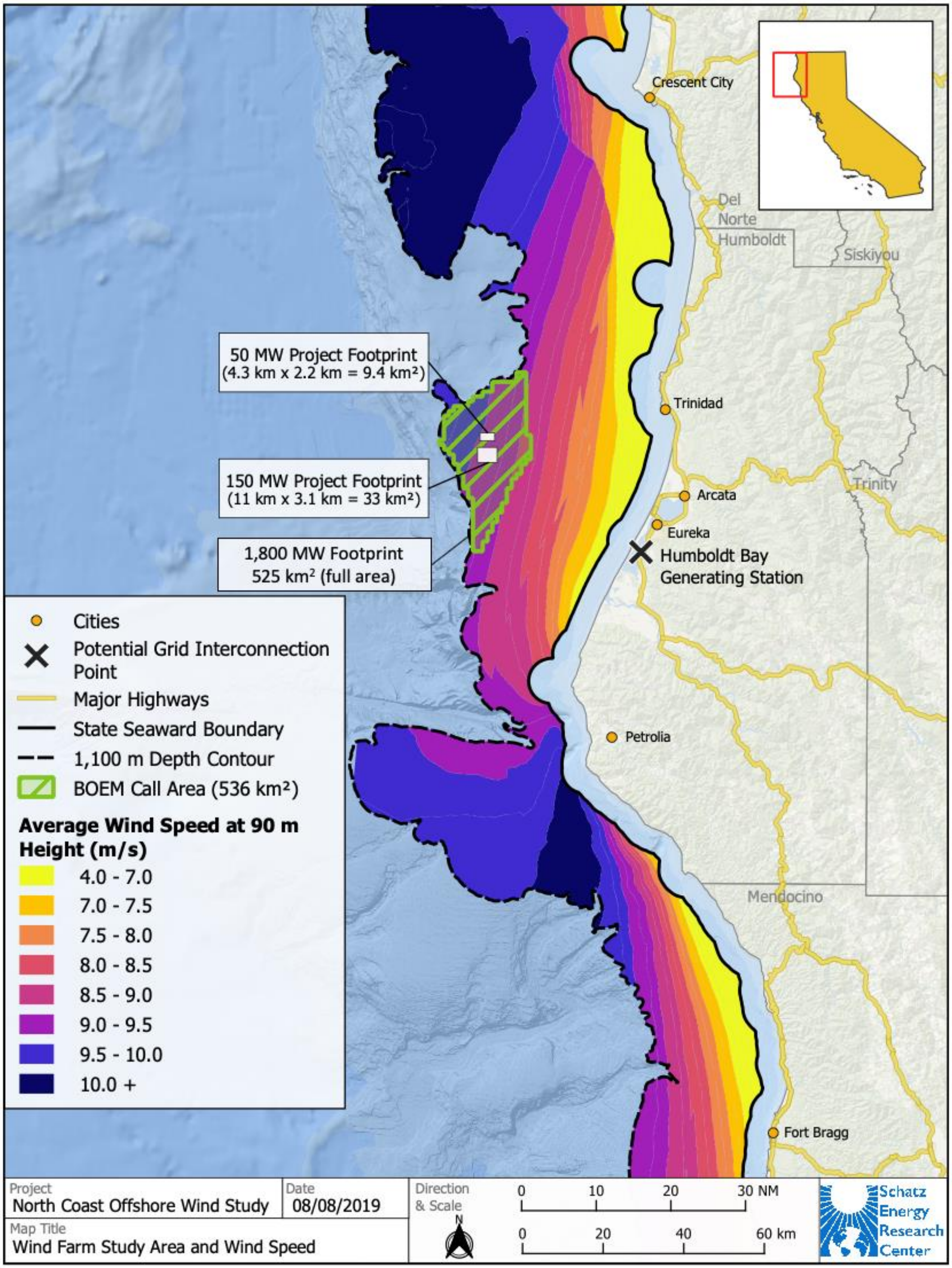
The purpose of this document is to provide a technical and spatial description of potential wind farm designs in northern California. This document will be shared with military representatives who will be asked to provide feedback about any technical design issues that would cause concern to their military operations. **During review, please let us know if there are any clarifying questions or additional details required in order to make an assessment. We expect this review to be an iterative process.**

3. OVERVIEW OF SCENARIOS

The different options comprising a scenario are summarized in the list below. Each option is described in greater depth in the Technical Descriptions in Section 4. .

- **Location**
  - Offshore Humboldt Bay (HB) – outlined by the Bureau of Ocean Energy Management (BOEM) Humboldt Call Area (BOEM, 2018). The HB area is roughly 40 - 55 km (20 – 30 nautical miles) offshore with an area of 540 km^2 (210 mi^2) and ocean depths between 500 to 1,100 meters (1,600 to 3,600 ft).
- **Wind Array Scale**
  - Pilot Scale - approximately 50 MW using 4 - 12 MW turbines (actually 48 MW)
  - Small Commercial – approximately 150 MW using 12 - 12 MW turbines (actually 144 MW)
  - Large Commercial – Full build out of study areas for a capacity of approximately 1,800 MW using 153 -12 MW turbines (actually 1,836 MW)
- **Cable Landfall**
  - The wind farm export cable will be horizontally directionally drilled (HDD) under the South Spit and Humboldt Bay with a vault for connecting two HDDs on the South Spit.
- **Interconnection Location**
  - Overland Transmission - interconnection at Humboldt Bay Substation near the Humboldt Bay Generating Station (HBGS).
  - Subsea Transmission – conversion to high-voltage, direct-current (HVDC) near HBGS then transmitted to an interconnection point with electrical grid within the San Francisco Bay.
- **Transmission Route**
  - Overland East - overhead transmission line using existing utility right of way heading east
  - Overland South - overhead transmission line using existing utility right of way heading south
  - Subsea, near - hypothetical subsea cable corridor heading south to the San Francisco Bay following a nearshore corridor
  - Subsea, far - hypothetical subsea cable corridor heading south to the San Francisco Bay following a deep-water corridor further from shore

Six scenarios are being evaluated that include three scales of development and different transmission upgrade options (Figure 1 and Table 1). The subsea transmission routes will be studied only for the 1,800 MW scale scenario.



Crescent City
Del Norte
Humboldt
Siskiyou
50 MW Project Footprint
(4.3 km x 2.2 km = 9.4 km²)
Trinidad
150 MW Project Footprint
(11 km x 3.1 km = 33 km²)
Arcata
Trinity
Eureka
1,800 MW Footprint
525 km² (full area)
Humboldt Bay Generating Station
Cities
Potential Grid Interconnection Point
Major Highways
State Seaward Boundary
1,100 m Depth Contour
BOEM Call Area (536 km²)
Petrolia
Average Wind Speed at 90 m Height (m/s)
4.0 - 7.0
7.0 - 7.5
7.5 - 8.0
8.0 - 8.5
8.5 - 9.0
9.0 - 9.5
9.5 - 10.0
10.0 +
Mendocino
Fort Bragg
Project
North Coast Offshore Wind Study
Date
08/08/2019
Direction & Scale
N
0 10 20 30 NM
0 20 40 60 km
Map Title
Wind Farm Study Area and Wind Speed
Schatz Energy Research Center

Figure 1. Map of Humboldt Call Area and annual average offshore wind speed at 90 m height.

Table 1. Description of basic characteristics defining each scenario.

<table>
<tr><th>Wind Array Capacity</th><th>Scenario Name[a]</th><th>Transmission Route</th><th>Cable Landfall</th></tr>
<tr><td>48 MW</td><td>50-East</td><td>Overland, east</td><td rowspan="4">Landfall at South Spit of Humboldt Bay (HB)</td></tr>
<tr><td>144 MW</td><td>150-East</td><td>Overland, east</td></tr>
<tr><td rowspan="4">1,836 MW</td><td>1800-East</td><td>Overland, east</td></tr>
<tr><td>1800-South</td><td>Overland, south</td></tr>
<tr><td>1800-Subsea-Near</td><td>Subsea, south Cable corridor nearshore</td><td rowspan="2">Two locations:
1) Landfall at South Spit for conversion to HVDC
2) Landfall at southern terminal in SF Bay Area</td></tr>
<tr><td>1800-Subsea-Far</td><td>Subsea, south Cable corridor far from shore</td></tr>
</table>

[a] Scenarios are label with naming convention *##-Aaa*, where '*##*' indicates the approximate wind array scale, and 'Aaa' indicates the transmission route.

4. TECHNICAL DESCRIPTION

The remainder of this document provides technical and design details about an offshore wind farm in northern California.

4.1 Location

The wind farm would be located within the Humboldt Call Area, as identified by the Bureau of Ocean Energy Management (BOEM, 2018). The area is located approximately 20-30 nautical miles west of Humboldt Bay (Figure 2). Descriptions and maps of the area are provided below and summarized in Table 2.

Table 2. Geographic specifications of the Humboldt Call Area.

Site name		*Humboldt Call Area*
General area		Offshore Humboldt Bay
West-East width		12 NM (22 km)
North-South width		25 NM (46 km)
Total area		207 mi^2 (537 km^2)
Perimeter		81 NM (150 km)
Centroid location	Lat.	-124.662°
	Lon.	40.965°
Distance to shore	Min.	17.4 NM (32.2 km)
	Max.	30.4 NM (56.3 km)
Average annual wind speed at 90 m height	Min.	8.875 m/s
	Mean	9.35 m/s
	Max.	9.875 m/s
Ocean depth	Min.	1,640 ft (500 m)
	Mean	2,673 ft (815 m)
	Max.	3,610 ft (1,100 m)

Site name		*Humboldt Call Area*
Construction and maintenance port	Name	Redwood Marine Terminal 1
	Lat.	40.817°
	Lon.	-124.182°
Centroid to port distance, approximate ship route		27 NM (50 km)
Interconnection point	Name	Humboldt Bay Generating Station
	Lat.	40.742°
	Lon.	-124.211°
Centroid to interconnection point distance, approximate cable route		25 NM (46 km)

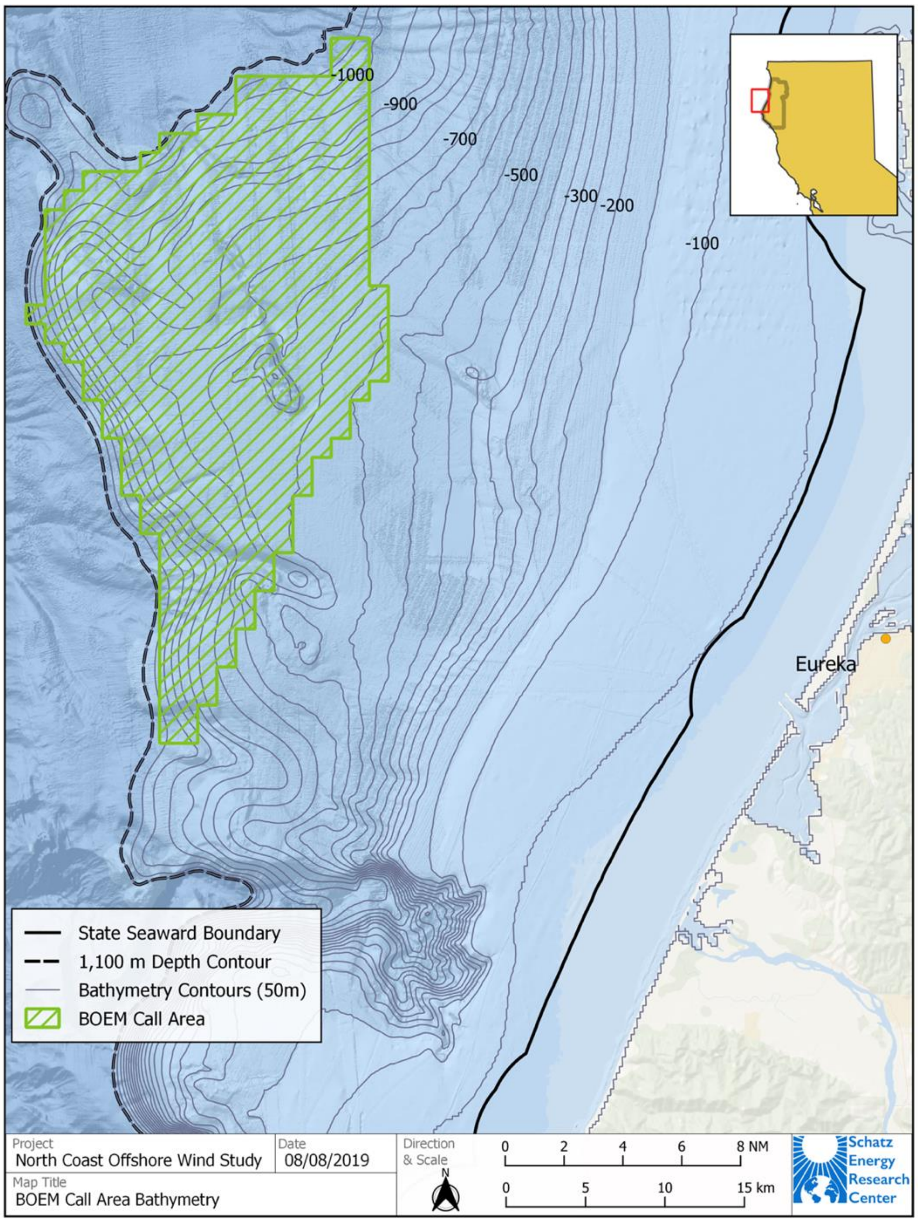


Figure 2. Humboldt Call Area with 50 m bathymetric contours.

4.2 Equipment Description

This section provides technical details for the equipment that is likely to be used in an offshore wind farm. This section describes the turbines, floating substructure, mooring lines, and wind farm layout.

4.2.1 Wind Turbines

All wind turbines are expected to be rated at 12 MW. The dimensions of the turbine are pictured in Figure 3 with the specifications outlined in Table 3.

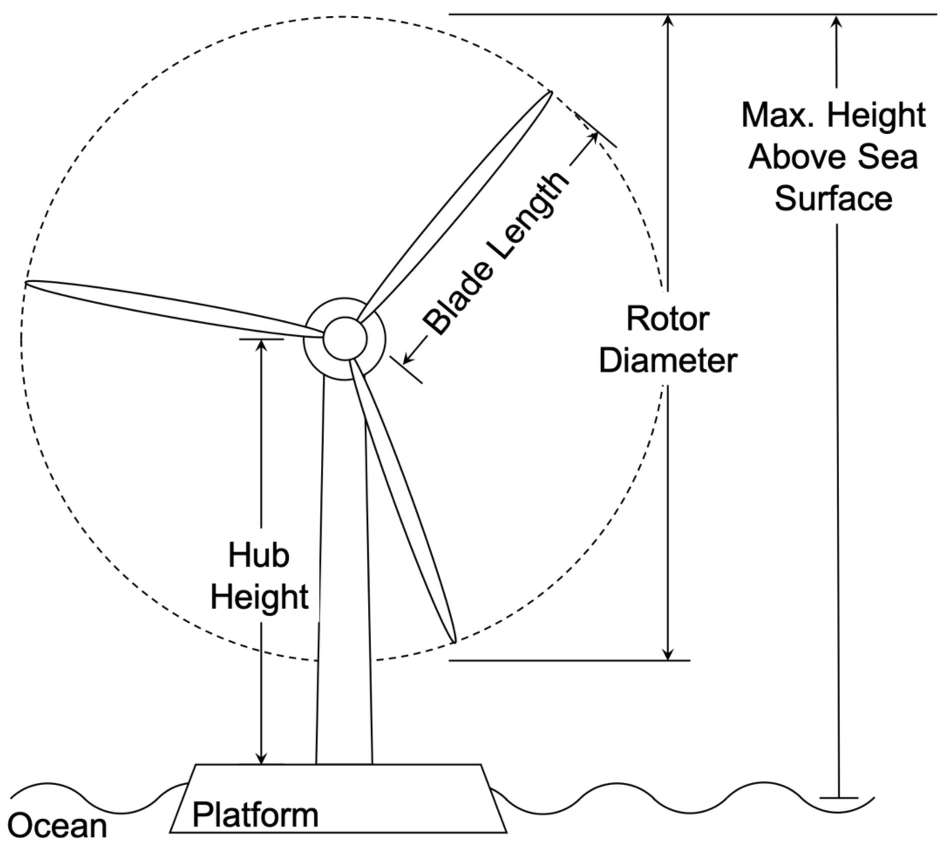


Figure 3. Dimensions of a wind turbine.

Table 3. Wind turbine dimensions

Wind Array Capacity	*Turbine Rated Power*	*Hub Height*	*Rotor Diameter*	*Blade Length*	*Max. Height Above Sea Surface*
50 MW	12 MW	136 m[a]	222 m[a]	107 m[b]	264 m
150 MW					
1,800 MW					

[a] Specifications based on a 12 MW reference turbine described by Musial et al., 2019
[b] Blade length based on GE Haliade-X 12 MW turbine (GE, 2019b).

4.2.2 Wind Farm Array

Three sizes of wind farms are being studied: a pilot scale, small commercial, and large commercial:

- Pilot Scale - approximately 50 MW wind array comprised of four 12 MW turbines (48 MW total)
- Small Commercial - approximately 150 MW wind array comprised of twelve 12 MW turbines (144 MW total)
- Large Commercial – Installation of turbines in the entire Humboldt Call Area, which can accommodate 153 turbines at 12 MW each for a 1,800 MW nameplate capacity (1,836 MW total)

The wind turbines are arranged within the array using four criteria:

1. 10D x 7D Spacing: Wind turbines have 10 rotor diameters (10D) of space in the North-South direction and 7D of space in the East-West direction. Spacing is increased in the North-South direction to minimize wake effects in the direction of the dominant winds. The critical dimensions of the turbines and wind array are described in Table 3.
2. Offset Rows: Rows in the wind array are offset perpendicular to the prevailing winds to minimize wind shading from the upstream row. Spacing dimensions are provided in Table 4 and Figure 4.
3. Mooring Line Overlap: Mooring lines from adjacent turbines cannot overlap. In deeper waters, mooring systems require a larger footprint on the ocean floor. This study assumes that the horizontal footprint of the mooring system is equal to the depth of the mooring lines (see Section 4.2.4). As the ocean becomes deeper and the mooring system footprint expands, the turbine spacing will increase to avoid overlapping mooring lines (see Figure 7 and Figure 8, for example).
4. Mooring Line Boundary: Mooring lines must be kept within the perimeter of the call area.

For the full build out scenario, turbines are placed with the spacing in Figure 4 unless deep water requires increased spacing to eliminate mooring line overlap. This layout allows for 153 of the 12 MW turbines to fit within the Humboldt Call Area (Figure 5), with a total capacity of 1,836 MW. Turbine coordinates for the 1,836 MW wind farm are provided in Table 5.

Turbine coordinates for the pilot-scale or small-commercial scale wind farms could occur at any location within the Call Area boundary.

Table 4. Specifications for the turbines and dimensions for the wind array grid layout.

Scale	*Wind Array Capacity*	*Number of Turbines*	N_{Column}	N_{Row}	*Array Width*	*Array Length*	*Array Area*
Pilot	48 MW	4	4	1	6.2 km	2.2 km	13.6 km^2
Small Commercial	144 MW	12	4	3	6.2 km	6.1 km	37.8 km^2
Large Commercial	1,836 MW	153	See map below for full build out arrangement				

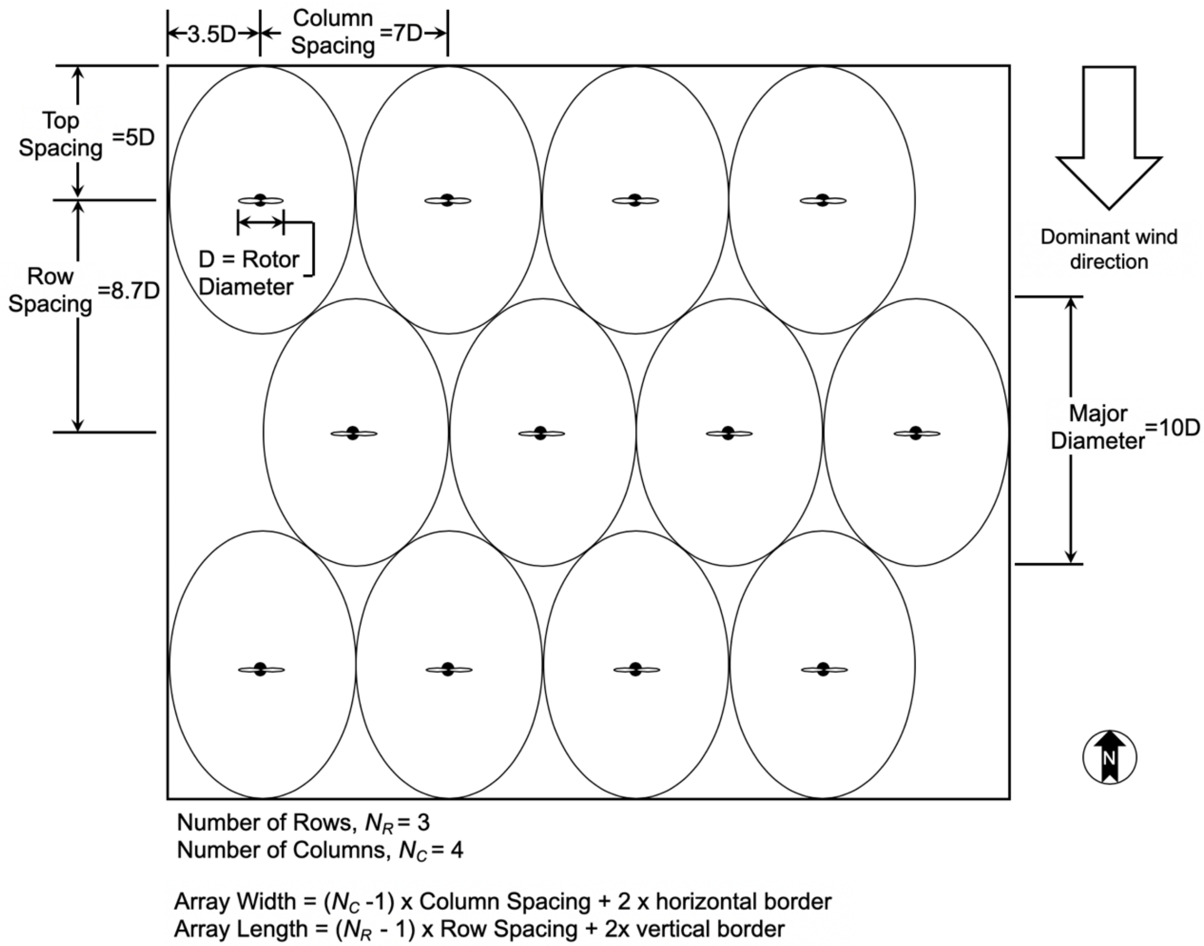


Figure 4. Dimensions of a wind array layout.

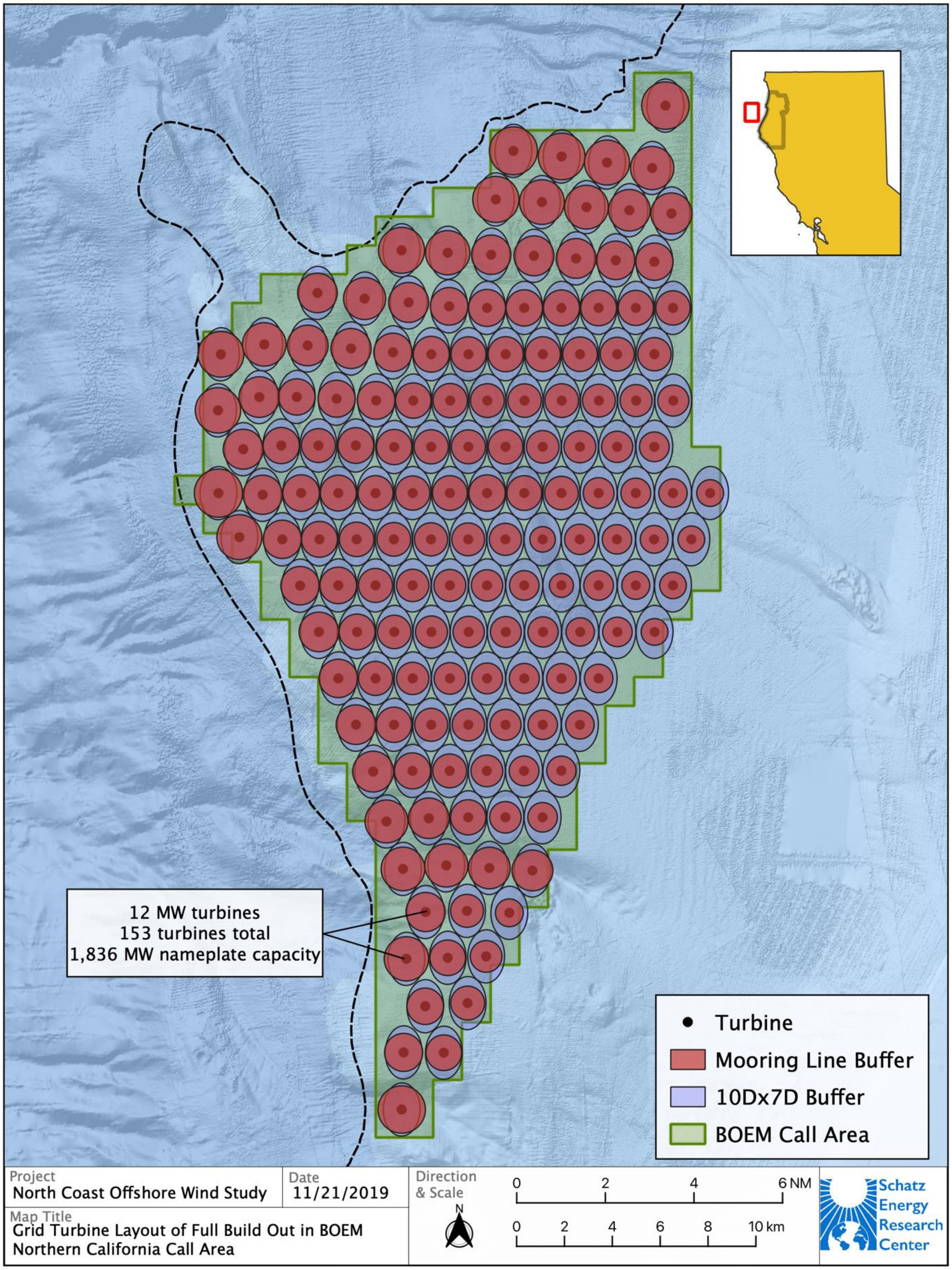


Figure 5. Turbine layout of full-build out scenario in Humboldt Call Area.

Table 5: Individual Turbine Coordinates for the Humboldt Call Area full build out scenarios.

Longitude	*Latitude*	*Depth (m)*	*Longitude*	*Latitude*	*Depth (m)*
-124.630296	40.836928	852.50	-124.673045	40.838215	903.85
-124.616874	40.874598	612.37	-124.682851	40.820565	819.95
-124.777834	40.992989	836.06	-124.671470	40.803532	744.19
-124.789693	40.976308	1,008.21	-124.661171	40.786674	708.89
-124.789878	41.028456	957.06	-124.672496	40.767858	746.30
-124.770368	41.012691	850.89	-124.654722	41.088652	964.77
-124.758988	40.994659	757.11	-124.656511	41.067854	823.49
-124.767713	40.976026	820.84	-124.639573	41.048115	758.73
-124.778864	40.959956	939.55	-124.648386	41.030598	734.03
-124.641362	40.820862	582.12	-124.638568	41.013315	700.35
-124.768448	41.032507	908.89	-124.629096	40.996086	681.10
-124.751732	41.013024	759.69	-124.637857	40.978597	726.79
-124.740520	40.994939	709.59	-124.646782	40.961078	672.12
-124.748637	40.976969	763.53	-124.655463	40.943651	656.35
-124.757533	40.959443	800.97	-124.645705	40.926314	644.42
-124.742508	41.052237	826.47	-124.654570	40.908728	644.30
-124.746846	41.032430	850.61	-124.644985	40.891443	648.28
-124.731944	41.012648	774.42	-124.653822	40.873996	663.46
-124.721943	40.995232	746.46	-124.644193	40.856705	658.59
-124.730175	40.977248	750.86	-124.651666	40.837557	870.24
-124.739075	40.959723	750.76	-124.662348	40.821311	689.43
-124.748233	40.942172	804.77	-124.652450	40.804338	663.35
-124.738423	40.924953	829.00	-124.646455	41.107018	1,003.29
-124.719029	41.050482	879.22	-124.631784	41.087982	934.92
-124.725284	41.031620	839.24	-124.635231	41.067741	836.10
-124.712297	41.012324	789.27	-124.621089	41.048377	753.29
-124.702880	40.994936	738.13	-124.629907	41.030861	731.96
-124.711695	40.977492	731.59	-124.620094	41.013577	704.54
-124.720617	40.960000	720.84	-124.610627	40.996345	667.55
-124.729278	40.942567	765.04	-124.619393	40.978858	701.92
-124.719501	40.925237	748.59	-124.628323	40.961341	533.53
-124.728346	40.907645	804.16	-124.637009	40.943914	618.39
-124.719153	40.890410	828.27	-124.627256	40.926576	632.51
-124.697090	41.049346	836.07	-124.636125	40.908991	627.41
-124.704415	41.030495	801.25	-124.626545	40.891705	615.33
-124.693858	41.012516	739.47	-124.635387	40.874259	622.79
-124.684502	40.995289	715.87	-124.625763	40.856966	618.71
-124.693248	40.977796	716.70	-124.622394	41.105236	977.38
-124.702159	40.960274	704.31	-124.609580	41.086391	915.20
-124.710825	40.942843	711.86	-124.614276	41.067070	832.46
-124.701053	40.925511	700.28	-124.602605	41.048635	747.62
-124.709902	40.907920	712.23	-124.611428	41.031120	721.91
-124.700303	40.890641	738.36	-124.601619	41.013835	685.33
-124.710172	40.872904	854.30	-124.592158	40.996602	653.15
-124.703083	40.854288	896.64	-124.600928	40.979115	642.88
-124.701115	41.068855	962.08	-124.609864	40.961600	634.78

Longitude	*Latitude*	*Depth (m)*	*Longitude*	*Latitude*	*Depth (m)*
-124.676933	41.048178	785.91	-124.618554	40.944175	500.33
-124.685343	41.030063	750.26	-124.608806	40.926835	592.27
-124.675515	41.012784	716.95	-124.617680	40.909251	620.40
-124.666034	40.995557	710.20	-124.608104	40.891963	595.02
-124.674785	40.978066	727.02	-124.571212	41.125059	991.42
-124.683700	40.960545	693.40	-124.599769	41.103288	941.21
-124.692371	40.943115	677.62	-124.588218	41.085530	869.47
-124.682604	40.925782	669.28	-124.594527	41.066618	806.92
-124.691458	40.908192	675.86	-124.584121	41.048891	734.11
-124.681864	40.890911	690.90	-124.592949	41.031377	710.35
-124.690691	40.873462	754.82	-124.583145	41.014090	670.40
-124.682160	40.855804	848.85	-124.573688	40.996855	621.67
-124.694453	40.836586	913.09	-124.582464	40.979370	624.71
-124.691911	40.802846	925.78	-124.591404	40.961856	615.38
-124.682137	40.785175	762.76	-124.600099	40.944433	619.47
-124.692398	40.767687	796.16	-124.590356	40.927091	617.09
-124.692805	40.746239	990.87	-124.599235	40.909508	594.29
-124.577260	41.101531	905.03	-124.567262	41.084590	859.11
-124.678156	41.068291	925.11	-124.575306	41.066383	778.97
-124.658056	41.047851	773.94	-124.565637	41.049144	717.89
-124.666864	41.030332	730.63	-124.574470	41.031631	695.98
-124.657041	41.013051	706.50	-124.564670	41.014343	649.28
-124.647565	40.995823	721.22	-124.790753	41.007396	949.59
-124.656321	40.978333	760.30	-124.563999	40.979622	593.07
-124.665241	40.960813	686.51	-124.572944	40.962110	580.92
-124.673917	40.943384	668.29	-124.581644	40.944687	583.14
-124.664155	40.926049	653.80	-124.571905	40.927344	559.87
-124.673014	40.908461	660.32	-124.545539	40.979872	560.51
-124.663424	40.891178	675.35	-124.554486	40.962359	557.82
-124.672256	40.873730	707.28	-124.563189	40.944939	556.11
-124.662623	40.856441	736.11			

4.2.3 Floating Substructure

Turbines are mounted on semi-submersible floating substructures. A generic substructure design comprises three semisubmersible columns connected in a triangular formation with the turbine mounted in the center (Figure 6) (design adopted from Musial et al. 2016a and 2019). Platform dimensions (Table 6) were determined using expert advice from developers and a basic design described in Robertson et al. (2014).

Two substructure sizes are identified, one large (Type A) and one small (Type B), that cover the range of potential substructure dimensions. The material of the substructure is either steel or concrete, but not specified for the purposes of this study.[1]

Table 6. Description of floating substructure.

	Type A Larger	*Type B Smaller*
Length (max)	91 m (300 ft)	61 m (200 ft)
Width (max)	91 m (300 ft)	61 m (200 ft)
Draft (unloaded)	7.6 m (25 ft)	5.5 m (18 ft)
Draft (in transit)	11 m (36 ft)	7.6 m (25 ft)
Draft (in operation)	18 m (60 ft)	18 m (60 ft)

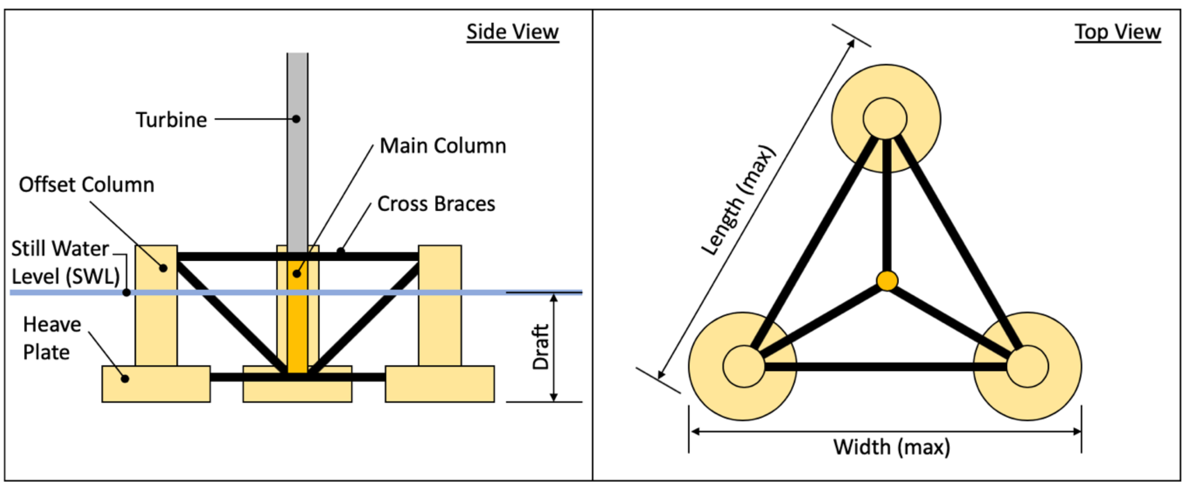


Figure 6. Dimensions of a floating platform. Generic design based on Robertson et al. (2014).

4.2.4 Mooring Line and Anchor Description

Mooring and anchor systems will change based on ocean depth, bottom type, and other factors. For this study we cannot carry out a detailed mooring and anchor design, so a simple system was identified that would be suitable for water deeper than 600 m and would have a limited footprint on the ocean floor.

A three-line, taut-leg mooring system will connect to the bottom of the substructure with equal spacing from one another (Figure 7). The mooring line will be composed of high-modulus polyethylene (HMPE)

[1] Our goal is to be technology neutral; both steel and concrete platforms could be used.

starting at the connection point on the substructure and then transition to a steel chain close to the anchor (Copping & Greg, 2018). Anchor piles will be used to connect the mooring line to the seafloor.

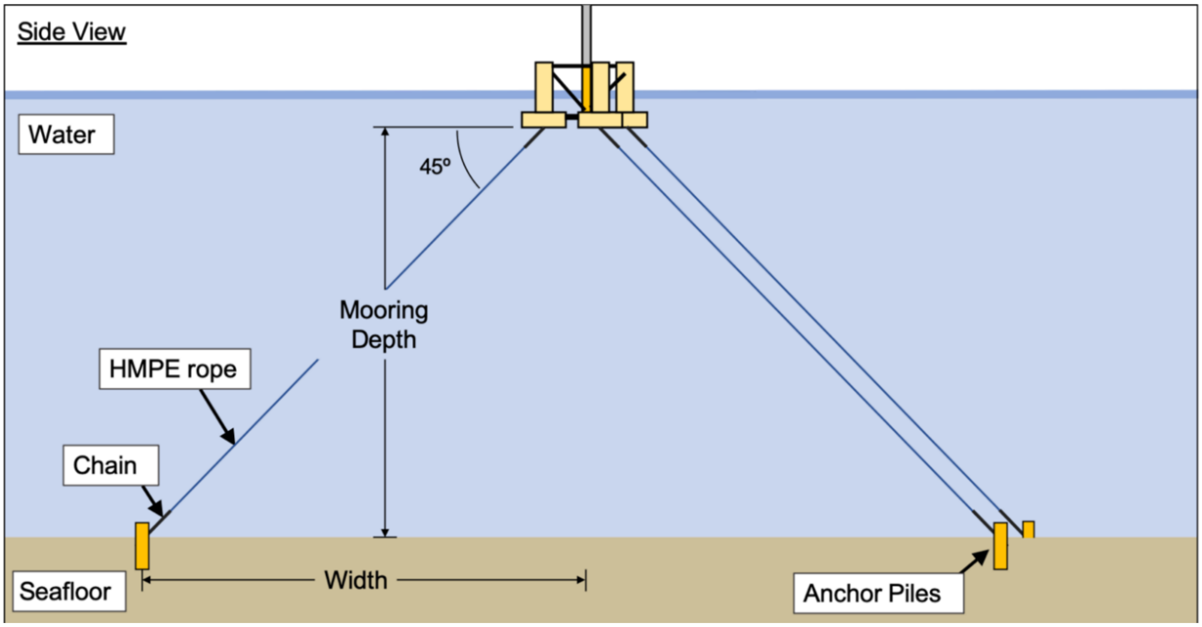


Figure 7. Side view of platforms with taut-leg mooring and anchor piles. Drawing not to scale.

The mooring lines extend radially away from the floating substructure and attach to the seafloor. The mooring line angle is 45 degrees to the surface. Thus, the footprint of the mooring on the seafloor is a circle with a radius equal to the mooring line length (i.e. the ocean depth minus the platform draft). See Figure 8 for an example layout.

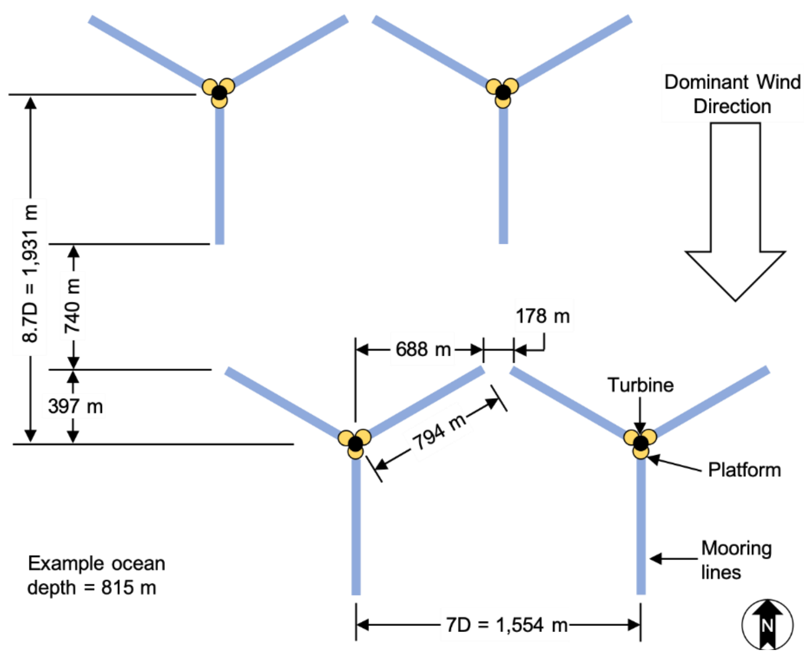


Figure 8. Top view of mooring lines with 12 MW turbine array. Footprint of mooring lines in this illustration is based on an 815 meter ocean depth, the average depth of the Humboldt Call Area.

The mooring system will have a larger footprint in deeper water. Using the offset 7D x 10D turbine spacing outlined in Section 4.2.2, above, mooring lines from neighboring turbines will begin to overlap at an ocean depth of 918 meters. To avoid overlap, the spacing turbine spacing will increase in waters deeper than 918 m.

Table 7. Mooring line and anchor specifications.

Parameter	*Value*	*Justification*	*Source*
Mooring type	Taut-leg mooring lines	Most suitable technology for deep waters between 600 and 1,000 m	Developer input
Connection points	On platform sides, 18 m below sea surface, three connection spaced equidistant from each other	Copied verbatim, with depth changed from 18 to accommodate substructure draft	Copping & Grear, 2018
Mooring line configuration	120° between each line with respect to the seafloor	Based on unsolicited lease requests and proven technology	Copping & Grear, 2018
Mooring line material	HMPE rope, transitioning to a chain near the anchor	HMPE is light and flexible. The chain will withstand more along the seabed.	Copping & Grear, 2018; Eriksson & Kullander, 2013
Mooring line diameter	112 mm	Based on unsolicited lease requests/copied verbatim. Unscaled from 5 MW turbine.	Copping & Grear, 2018
Mooring line mass	8.2 kg/m	Based on unsolicited lease requests/copied verbatim. Unscaled from 5 MW turbine.	Copping & Grear, 2018
Anchor type	Piled Anchors	Suitable for deep water. In-depth geologic study required to determine actual anchor type.	Developer input

4.2.5 Lighting and Markings

Lighting and markings on the turbines and structures must meet the requirements of the Federal Aviation Administration (FAA) per 14 CFR 77.7 and 14 CFR 77.9 and US Coast Guard (USCG) Aids to Navigation Manual Chapter 4 Section G. For this study, we are assuming the lighting and markings follow the guidelines outlined in BOEM’s (2019b) draft proposed recommendations. The specifications are repeated below (BOEM, 2019b):

- Aviation Obstruction Lighting
    - Each turbine outfitted with one light at the highest point on the nacelle and one light mounted mid-mast. The light specifications are:
        - Red LEDs (wavelength between 675 to 900 nm).
        - Photometric values of a FAA Type L-864 medium intensity obstruction light. Lighting most conspicuous to aviators. Lighting spread below the horizontal plane is minimal but still within photometric values of FAA Type L-864.
        - Flashing simultaneously at 30 flashes per minute.
        - Visible in all directions in the horizontal plane.
        - Lighting is most conspicuous to aviators. Lighting spread below the horizontal plane should be minimal but meet the photometric values of a FAA Type L-864.

        ▪ Using a photosensor, automatically reduce light intensity when it is safe based on meteorological visibility. Reduce lighting intensity to 30% when visitiblity is 3.1 mi (5 km) or greater and to 10% when visibility is 6.2 mi (10 km) or greater.
- Paint and Markings
    - Turbine and tower paint should be no lighter than RAL 9010 Pure White and no darker that RAL 7035 Light Grey.
    - Foundation base should be painted yellow.
    - Ladders at foundation base should be painted in a contrasting color from yellow to be easily distinguishable.
    - Each turbine has a distinct identifier painted on the unit.

Aircraft detection lighting systems and dimming technologies could be used but are not required.

4.3 Electrical Infrastructure

This section provides details about the electrical infrastructure including interarray cables, export cables, offshore substation, cable landfall location, interconnection point, and transmission route options. Figure 9 provides a visual representation of the various electrical equipment of an offshore wind farm delivering power via an overland transmission route.

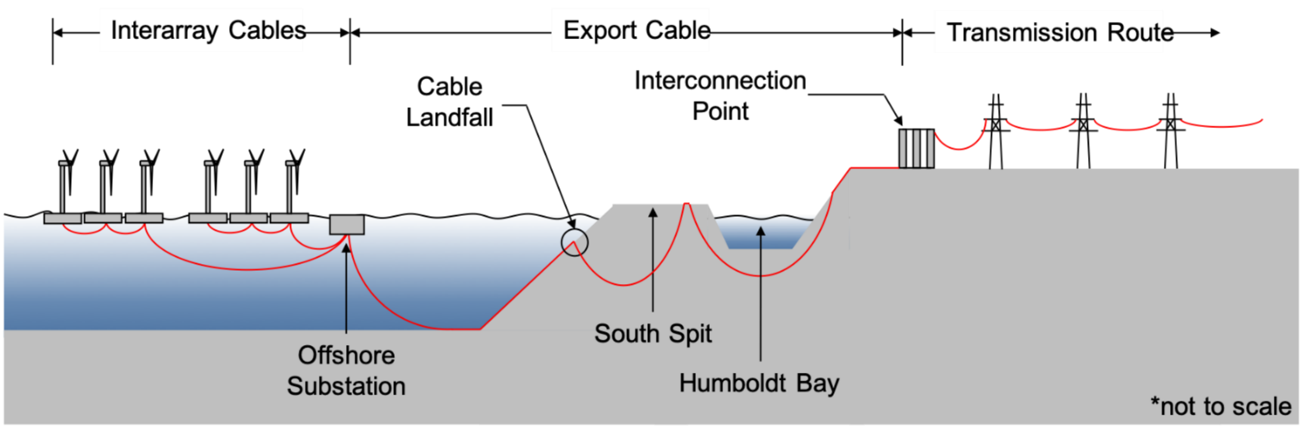


Figure 9. Generalized representation of electrical system locations for overland transmission routes.

4.3.1 Interarray Cables

The wind farm electrical system configuration is a radial string design with cross-linked polyethylene (XLPE), interarray cables rated for 66 kV. The turbines will be connected in a daisy-chain. A buoyancy cable floating system will be used to route the interarray cable through the water column at depths from 100-150 meters to connect a string of turbine platform to the floating substation (Figure 10).

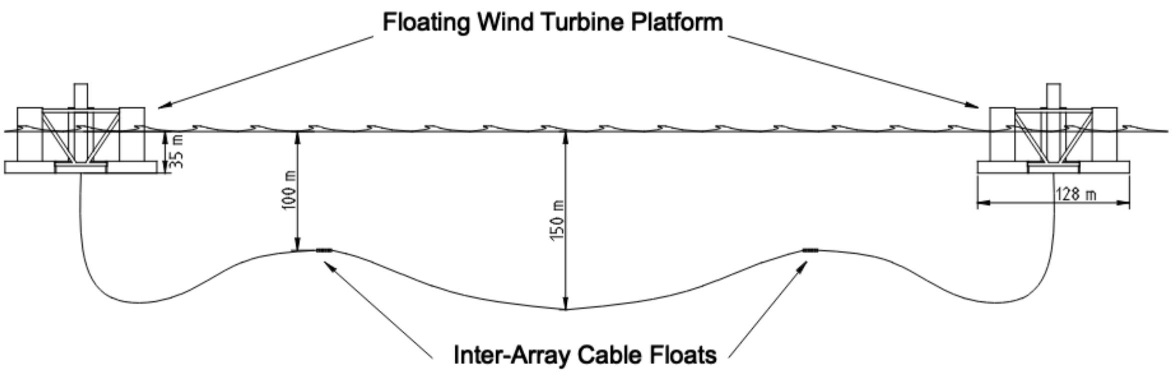


Figure 10. Interarray cable dimensions.

4.3.2 Offshore Substation

The offshore floating substation is the electrical connection point for the interarray cables. The interarray cables will be combined at the offshore substation and sent back to shore in an export cable. The offshore substation will house electrical equipment such as a collector bus, protective switchgear, a step-up transformer, and power quality equipment.

4.3.3 Export Cable

High voltage, alternating current (HVAC), cross-linked polyethylene (XLPE) cables will be used to export power from the offshore substation to the interconnection point near the Humboldt Bay Substation (Table 8). The subsea cables will be buried 1.5 meters under the ocean floor while traversing back to shore until the water reaches 9 meters depth, where cable landfall will begin.

Table 8. Export cable specifications based on cables from ABB (2019).

Wind Farm Scale	*No. of cables/cores*	*Nominal cable voltage*	*Cross sectional area of conductor*	*Outer Diameter of Cable*
Pilot Scale (50 MW)	1 cable x 3 core	66 kV	300 mm^2	134 mm
Small Commercial (150 MW)	1 cable x 3 core	132 kV	800 mm^2	194 mm
Large Commercial (1,800 MW)	6 cable x 3 core	275 kV	1,600 mm^2	265 mm

4.3.4 Cable Landfall and Interconnection Locations

The export cable coming from the wind farm will landfall on the North or South Spit of Humboldt Bay (Figure 11), then cross underneath the bay to an interconnection point near Humboldt Bay Generating Station.

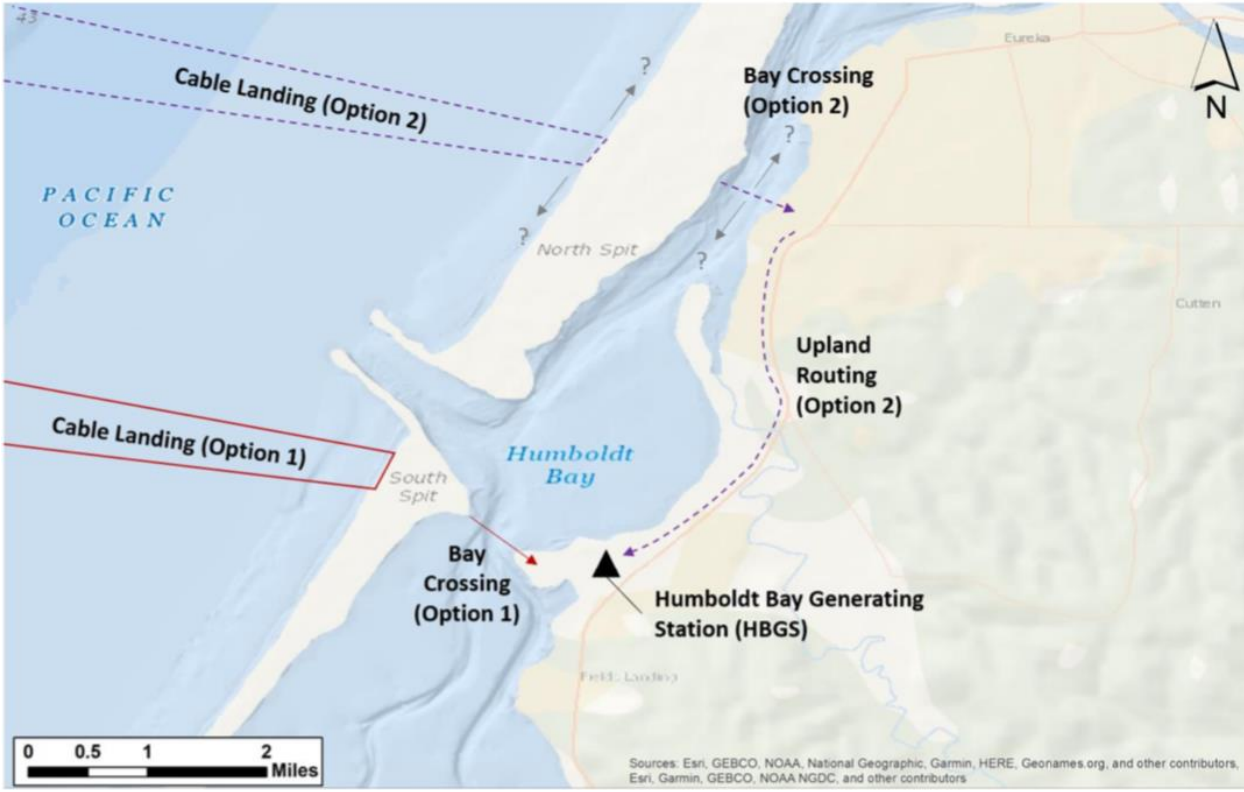


Figure 11. Cable landing location options.

The installation will use two horizontal directional drilling (HDD) bores to bring the export cable 1) from ocean onto the peninsula and 2) from the peninsula underneath the bay to the interconnection locations (Figure 12). Horizontal directional drilling (HDD) to bring the export cable onshore will begin at an ocean depth of 9 meters offshore. The HDD will connect to a cable vault located on the spit. A second HDD is then used to route the cable from this vault under the floor of Humboldt Bay to another vault located near the HBGS. The necessary electrical switchgear and equipment including a transformer will be located at a substation near HBGS where power conditioning and synchronization will occur before exporting power to the electrical utility grid.

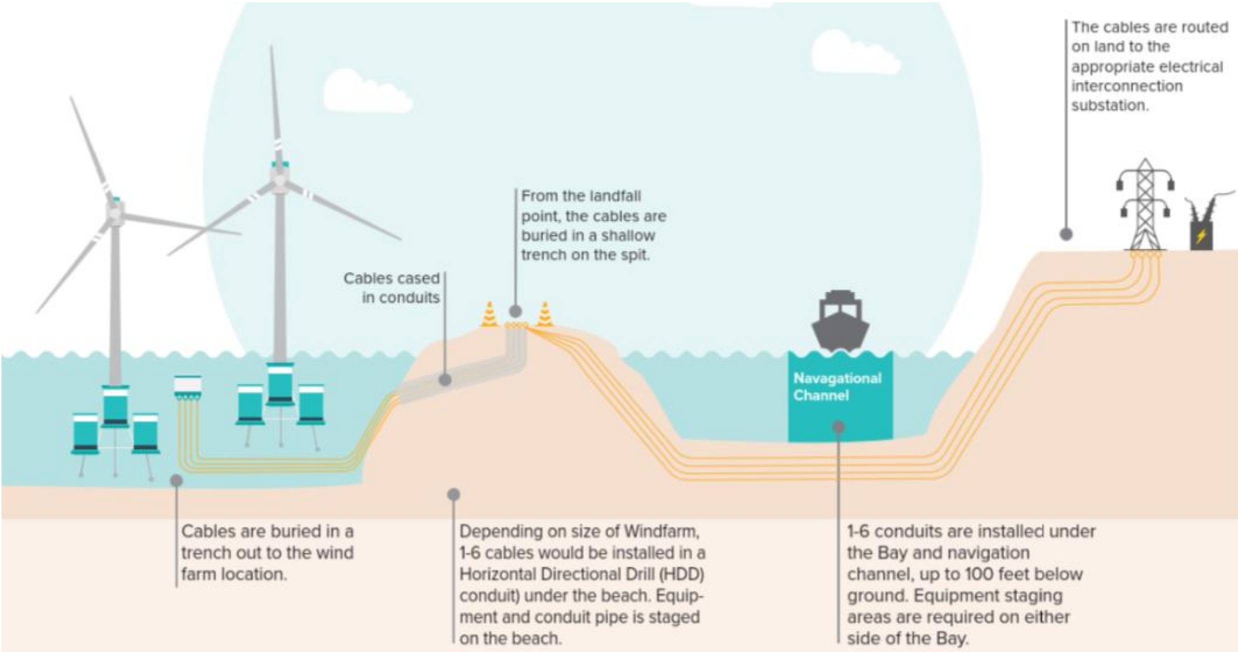


Figure 12. Cable landfall overview.

Potential alignment of the export cable landfall is shown in Figure 13, alongside other infrastructure constraints in and around Humboldt Bay.

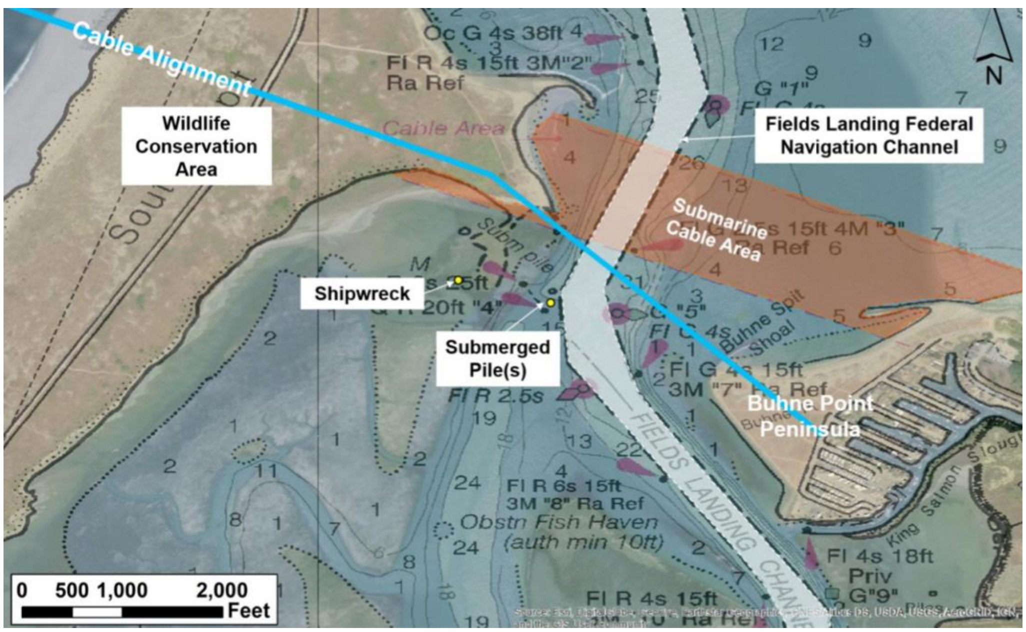


Figure 13. Potential cable alignment and existing infrastructure constraints for South Spit landfall.

4.3.5 Transmission Routes

There are several transmission route options being considered depending on the size of the wind farm.

- **Pilot Scale, 50 MW**
  - <u>Overland Transmission, East</u>

- Build new 115 kV transmission line from Humboldt Bay Substation to Cottonwood following an existing right of way along Highway 299 (120 miles)
- Build new 115 kV transmission line between Bridgeville and Garberville No. 2 Substation following an existing right of way (36 miles)

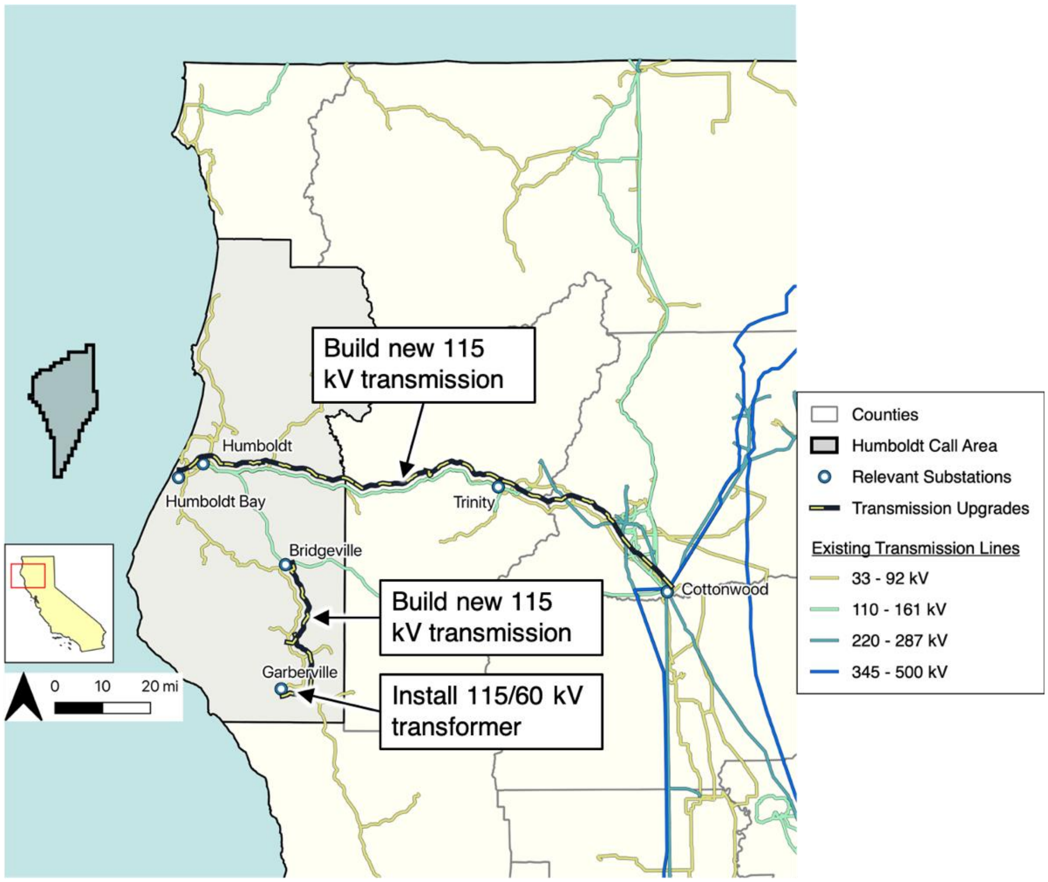


Figure 14. Transmission upgrades for 50 MW Pilot Scale (Source: PG&E).

- **Small Commercial, 150 MW**
  - Overland Transmission, East
    - Build new transmission as identified for Pilot Scale, 50 MW scenario.
    - Reconductor existing 115 kV transmission lines from Humboldt Bay Substation to Cottonwood (120 miles)
    - Reconductor existing 60 kV transmission lines from Humboldt Substation to Bridgeville to Garberville to Laytonville to Willits (129 miles)

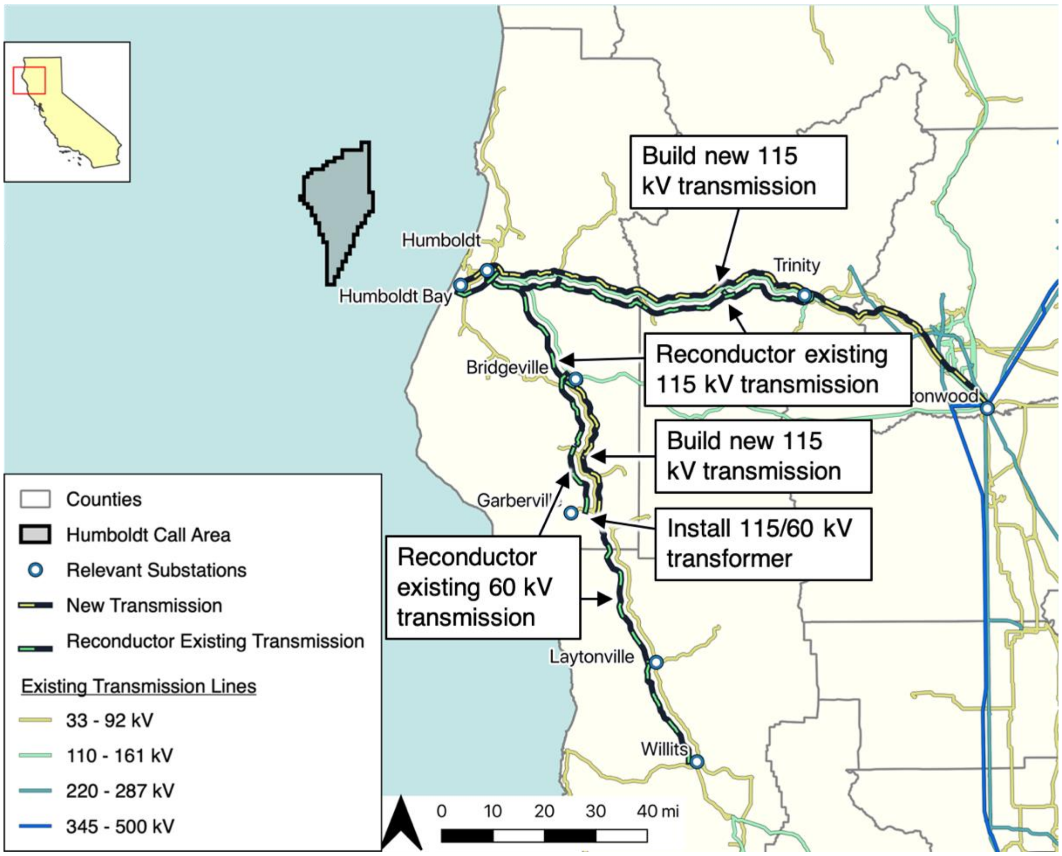


Figure 15. Transmission Options for 150 MW Small Commercial Scale (Source: PG&E)

- **Large Commercial, 1,800 MW**
  - Option 1: Overland Transmission, East
    - Build new 500 kV transmission line from Humboldt Bay and Round Mountain Substation (150 mile), Round Mountain to Table Mountain (89 miles), Table Mountain to Vaca-Dixon (83 miles), and Vaca-Dixon to Tesla Substation (57 miles)
  - Option 2: Overland Transmission going South
    - Build new 500 kV transmission line from Humboldt Bay to Vaca-Dixon Substation (260 miles)
    - Build new 500 kV substation in Collinsville, CA
    - Build new 500 kV transmission line from Vaca-Dixon to Collinsville Substation
    - Perform several upgrades and reconductor a few lines around Pittsburg, CA area.

- Option 3: Subsea Transmission, Nearshore
  - Build new HVDC subsea cable from Humboldt Bay to a fictitious interconnection point in the Bay Area. The cable corridor is routed close to shore.
  - Install HVDC converter station in Bay Area
  - Distribute power to Potrero, East Shore, and Los Esteros Substations
- Option 4: Subsea Transmission Deepwater
  - Same as Option 3, but the subsea cable is routed further from shore at a depth near 2,000 meters.

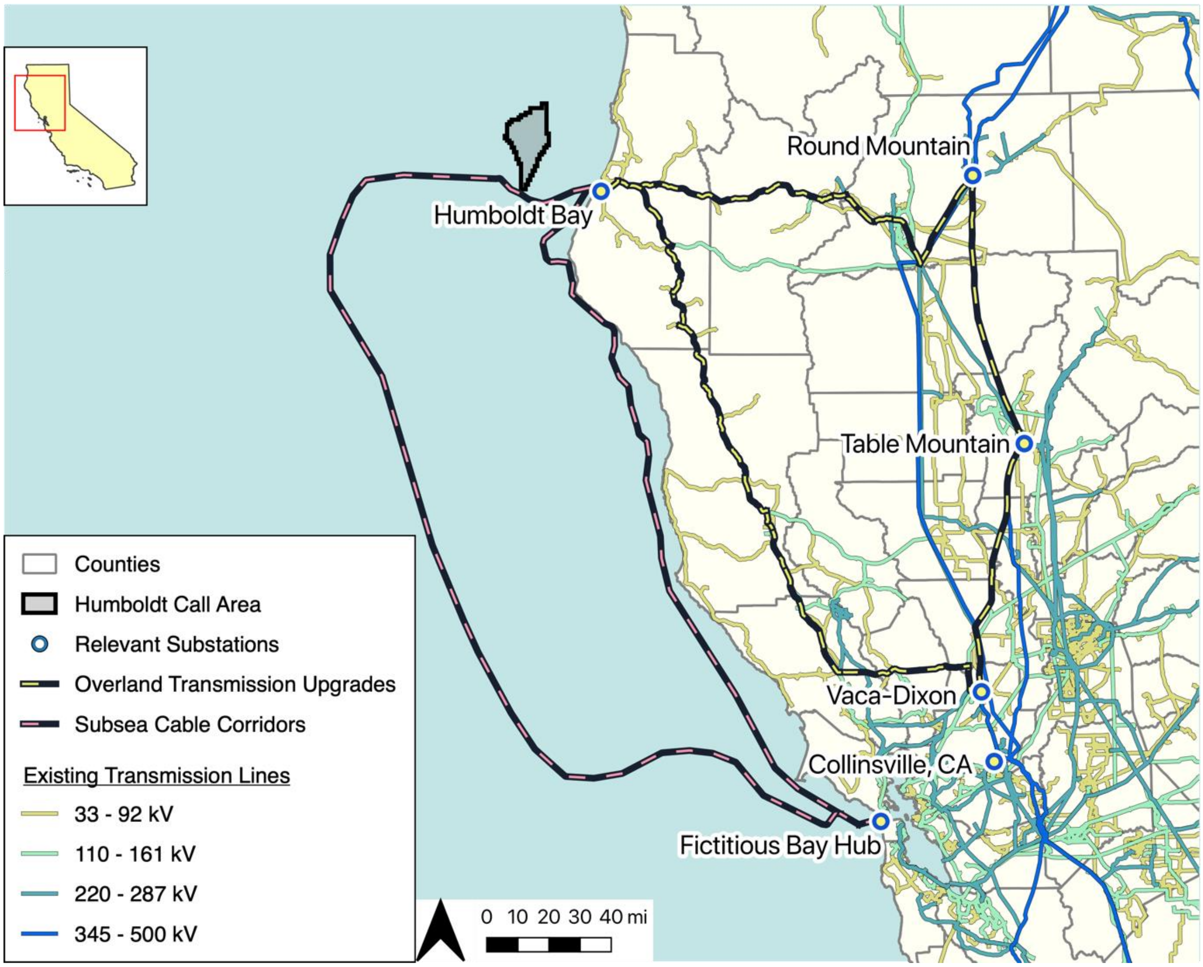


Figure 16. Transmission options for 1,800 MW Large Commercial Scale

4.3.6 Subsea HVDC Transmission Cable

Two potential cable corridors were identified to connect wind farms in the Humboldt Call Area to electric load centers in the San Francisco Bay Area. Each cable corridor faces a variety of different challenges between the nearshore and further from shore route. The corridors were created by taking into consideration seismic activity, ocean depth, vessel traffic, bedrock locations, subsea canyons, Marine Protected Areas, existing subsea cables, ocean disposal sites, and steep slopes. Not all challenges can be avoided for the different corridors, and designing the cable route would be complex. The cable corridors identified here were designed to minimize the hazards, but the feasibility of either route has not been confirmed.

4.4 Construction and Maintenance

Construction, maintenance, and operation occur as part of three phases described below: assembly and installation; operations and maintenance; and decommissioning.

4.4.1 Assembly and Installation

A preliminary list of equipment that is likely required for assembly and construction is provided in Table 9. This list will be revised based on input from experts and developers during this study.

Table 9. Assembly and construction equipment preliminary assumptions – will be revised during analysis.

Parameter	*Value*	*Justification*	*Source*
Farm site equipment	Anchor Handling Tug Supply vessel (AHTS), Remote Operated Underwater Vehicle (ROV), Cable laying vessel (CLV)	Based on installation process assumptions	Beiter et al (2016)
Port equipment	2 Crawler cranes *(capacity of at least one >500 tonnes)*, assembly area, storage area	Installation process assumptions	Beiter et al (2016)
Transport equipment	AHTS, 2 smaller tugs for assistance	Installation process	Beiter et al (2016)
Cable landfall equipment	Horizontal drill rig (onshore), jack-up barge	Based on expected coastal regulations	

4.4.2 Operations and Maintenance

The preliminary assumption is that O&M is based out of the Humboldt Bay and that semi-submersible platforms can be towed to and from port for major maintenance activities. Potential vessels for use in O&M activities are: a crew transfer vessel (CTV), a large anchor handling tug supply vessel (AHTS), smaller assist tugs, and a remote operated underwater vehicle (ROV) or a dive-support vessel that can be commissioned when necessary. Other equipment such as a larger “mother ship” for support or a helicopter may be considered as part of the O&M plan depending on the results from developer outreach.

Table 10. Operations and maintenance preliminary vessel assumptions – will be revised during analysis.

O&M plan	*Vessels*	*Justification*	*Source*
Port-based	AHTS, CTV, assist tugs	Described O&M plan based on ECN’s O&M tool	Beiter et al (2016)

Until more information is collected, repairs are assumed to occur using the schedule and failure rates outlined by Ioannou (2018, p. 413), which includes assumed failure rates, average repair time, and material costs for repair and replacement of major components. The impact of local metocean conditions on the O&M procedures are currently unknown for the study areas and will be incorporated into this study if and when this information becomes available.

4.4.3 Decommissioning

During the Construction and Operation Phase of the project, a Construction and Operations Plan (COP) is submitted to BOEM that must describe all activities related to the project including decommissioning and site clearance procedures. A detailed project-specific description and explanation of the general concept and proposed decommissioning procedures for all installed components and facilities must be provided (BOEM 2016).

The major steps for decommissioning an offshore wind farm include:

- turbine/foundation assembly removal,
- mooring line and anchors removal,
- electrical cable removal,
- scour protection to prevent damage to the seafloor, and
- salvage or disposal of all materials.

5. WORKS CITED

ABB. (2019). *XLPE Submarine Cable Systems: Attachment to XLPE land cable systems user's guide.* Rev 5. 12 pgs.

Beiter, P., Musial, W., Smith, A., Kilcher, L., Damiani, R., Maness, M., ... & Scott, G. (2016). *A Spatial-Economic Cost-Reduction Pathway Analysis for U.S. Offshore Wind Energy Development from 2015-2030*. Technical Report NREL/TP-6A20-66579. National Renewable Energy Laboratory. Golden, CO.

Bjerkseter, C., & Ågotnes, A. (2013). *Levelised costs of energy for offshore floating wind turbine concepts*. (Master's thesis). Norwegian University of Life Sciences, Ås, Norway. Retrieved 9 July 2019 from https://nmbu.brage.unit.no/nmbu-xmlui/bitstream/handle/ 11250/189073/Bjerkseter,%20C.%20&%20%C3%85gotnes,%20A.%20(2013)%20-%20Levelised%20Costs%20of%20Energy%20for%20Offshore%20Floating%20Wind%20Turbine%20Concepts.pdf?sequence=1

[BOEM] Bureau of Ocean Energy Management. (2016). Guidelines for Information Requirements for a Renewable Energy Construction and Operations Plan (COP), Version 3.0. Retrieved on 18 June 2019 from https://www.boem.gov/note10222014/

[BOEM] Bureau of Ocean Energy Management. (2018). *Northern California Call Area*. Retrieved on 26 April 2019 from https://www.boem.gov/Humboldt-Call-Area-Map-NOAA-Chart/

[BOEM] Bureau of Ocean Energy Management. (2019a). *Regulatory Framework and Guidelines*. Retrieved on 3 June 2019 from https://www.boem.gov/Regulatory-Framework/

[BOEM] Bureau of Ocean Energy Management. (2019b). *Draft proposed guidelines for providing information on lighting and marking of structures supporting renewable energy development*. Retrieved on 6 November 2019 from https://www.boem.gov/Lighting-and-Marking-Guidelines/

Code of Federal Regulations. (2011). Part 585 Subpart I of Volume 30 of the Code of Federal Regulations (C.F.R.) - Renewable energy and Alternate Uses of Existing Facilities on the Outer Continental Shelf

Copping A., and Grear, M. (2018). Humpback whale encounter with offshore wind mooring lines and inter-array cables. Technical Report PNNL-27988 / BOEM 2018-065. Retrieved on 8 July 2019 from https://www.boem.gov/BOEM-2018-065/

Eriksson, H., & Kullander, T. (2013). Assessing feasible mooring technologies for a Demonstrator in the Bornholm Basin as restricted to the modes of operation and limitations for the Demonstrator. BOX-WIN Technical Report No. 4. ISSN 1400-383X. Göteborg University, Göteborg, Sweden. Retrieved 9 July 2019 from: https://studentportal.gu.se/digitalAssets/1461/1461314_c98.pdf

[GE] General Electric. (2019a). *Haliade 150-6MW Offshore Wind Turbine.* Retrieved on 14 May 2019 from https://www.ge.com/renewableenergy/wind-energy/offshore-wind/offshore-turbine-haliade

[GE] General Electric. (2019b). *Haliade-X Offshore Wind Turbine Platform.* Retrieved on 14 May 2019 from https://www.ge.com/renewableenergy/wind-energy/offshore-wind/haliade-x-offshore-turbine

Ioannou, A., Angus, A., Brennan, F. (2018). A lifecycle techno-economic model of offshore wind energy for different entrance and exit instances. *Applied Energy, 221*, 406-424.

Kim, H., Choung, J., and Jeon, G.-Y. (2014). "Design of Mooring Lines of Floating Offshore Wind Turbine in Jeju Offshore Area." ASME Proceedings | Ocean Renewable Energy, American Society of Mechanical Engineers. Retrieved on 12 July 2019 from https://proceedings.asmedigitalcollection.asme.org/proceeding.aspx?articleid=1912177.

Musial, W., Beiter, P., Tegen, S., & Smith, A. (2016a). *Potential Offshore Wind Energy Areas in California: An Assessment of Locations, Technology, and Costs*. Technical Report NREL/TP-5000-67414. National Renewable Energy Laboratory. Golden, CO.

Musial, W., Heimiller, D., Beiter, P., Scott, G., & Draxl, C.. (2016b). *2016 Offshore Wind Energy Resource Assessment for the United States*. Technical Report NREL/TP-5000-66599. National Renewable Energy Laboratory. Golden, CO.

Musial, W., Beiter, P., Nunemaker, J., & Spitsen, P. (2019). *Oregon Offshore Wind Site Feasibility and Cost Study. Version 1.0*. National Renewable Energy Laboratory. Golden, CO. Unpublished Report

Musial, Walter, Philipp Beiter, Jake Nunemaker, Donna Heimiller, Josh Ahmann, and Jason Busch. (2019). *Oregon Offshore Wind Site Feasibility and Cost Study*. Technical Report NREL/TP-5000-74597. National Renewable Energy Laboratory, Golden, CO. Retrieved 5 Nov 2019 from nrel.gov/docs/fy20osti/74597.pdf.

Müller, K., Matha, D., Karch, M., Tiedmann, S., and Proskovics, R. (2017). Deliverable 7.5 Guidance on platform and mooring line selection, installation and marine operations. LIFE50+, 22, 46. Retrieved on 12 July 2019 from https://lifes50plus.eu/results/.

Myhr, A., Bjerkseter, C., Agotnes, A., Nygaard, T. (2014). Levelized cost of energy for offshore floating wind turbines in a life cycle perspective. *Renewable Energy, 66*, 714-728.

Porter, A. and Phillips, S. (2016). *Determining the Infrastructure Needs to Support Offshore Floating Wind and Marine Hydrokinetic Facilities on the Pacific West Coast and Hawaii*. US Department of the Interior, Bureau of Ocean Energy Management, Pacific OCS Region, Camarillo, CA. OCS Study BOEM 2016-011. 238 pp.

Renewable Energy and Alternate Uses of Existing Facilities on the Outer Continental Shelf, 30 C.F.R. § 585 Subpart I (2011).

Robertson, A., Jonkman, J., Masciola, M., Song, H., Goupee, A., Coulling, A., & Luan, C. (2014). *Definition of the Semisubmersible Floating System for Phase II of OC4*. Technical Report NREL/TP-5000-67414. National Renewable Energy Lab. Golden, CO.