California North Coast Offshore Wind Studies

Description of Study Assumptions

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Disclaimer

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1. INTRODUCTION

The potential for offshore wind energy generation is being investigated along the northern coast of California for twelve different scenarios that vary by wind array scale, location, and electrical transmission route. This document provides a description of the wind farms scenarios in the North Coast Offshore Wind Study. This document begins with an overview of the different wind farms, 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.

2. OVERVIEW OF CHARACTERISTICS

The different options comprising a scenario are summarized in the list below. Each scenario contains a distinct combination of options as defined in Table 1 and shown in the maps in Figure 1 and Figure 2. 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).
  - Offshore Cape Mendocino (CM) - notional study area with high wind speeds. The CM area is roughly 6 - 40 km (3 - 20 nautical miles) offshore with an area of 532 km^2 (190 mi^2) and ocean depths between 100 to 1,100 meters (330 to 3,600 ft).
    Note: This area is being studied for comparative and modeling purposes only. This area has not been screened by any ocean user community and is not representative of a BOEM call area. BOEM has not indicated any interest in this representative area for wind development. Justification for the study of this area is provided in the Location section below.
- **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 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.[1] then transmitted to interconnection point with electrical grid within the San Francisco Bay.
- **Transmission Route**
  - Overland East - using existing utility right of way heading east
  - Overland South - using existing utility right of way heading south
  - Subsea - hypothetical subsea cable corridor heading south to the San Francisco Bay
- **Development Timeline**
  - Operation Date
    - 50 MW and 150 MW projects are assumed to be operational in 2026
    - 1,800 MW project assumed to be operation in 2028

[1] This adds cable length to send the export cable north from the Cape Mendocino area HVDC conversion. This choice simplifies the analysis rather than identifying another suitable location further south on the coast.

- System Lifetime - assumed to be 20 years

3. DESCRIPTION OF SCENARIOS

Twelve total scenarios are being evaluated, including seven in the Humboldt Call Area and five in the Cape Mendocino area (Table 1). For the Call Area, the project will study all three wind array scales with both overland transmission routes. In the Cape Mendocino area, the 150 MW and full build out scenario will be studied for overland transmission. The 50 MW scenario is deemed too small to warrant the longer transmission route from the Cape Mendocino. For both locations, the subsea transmission route will be studied only for the 1,800 MW scale scenario.

Table 1. Description of basic characteristics defining each scenario.

Scenario Name[a]	*Geographic Location*	*Wind Array Nameplate*	*Turbine Size*	*Transmission Route*	*Cable Landfall*	*Electrical Interconnection Location*
HB-50-East	Offshore Humboldt Bay (HB)	48 MW	12 MW	Overland, east	Landfall at South Spit of Humboldt Bay (HB)	Interconnection near Humboldt Bay Generating Station (HBGS)
HB-50-South				Overland, south		
HB-150-East		144 MW		Overland, east		
HB-150-South				Overland, south		
HB 1800-East		1,836 MW[b]		Overland, east		
HB-1800-South				Overland, south		
HB-1800-Subsea				Subsea, south	Two locations: 1) Landfall at South Spit for conversion to HVDC near HBGS 2) Landfall at subsea cable southern terminus (location tbd in Mendocino/Sonoma/SF Bay Area)	Subsea cable interconnection location tbd (Mendocino/Sonoma/SF Bay Area)
CM-150-East	Offshore Cape Mendocino (CM)	144 MW	12 MW	Overland, east	Landfall at South Spit of Humboldt Bay (HB)	Interconnection near Humboldt Bay Generating Station (HBGS)
CM-150-South				Overland, south		
CM-1800-East		1,836 MW[b]		Overland, east		
CM-1800-South				Overland, south		
CM-1800-Subsea				Subsea, south	Two locations: 1) Landfall at South Spit for conversion to HVDC near HBGS 2) Landfall at subsea cable southern terminus (location tbd in SF Bay Area)	Subsea cable interconnection location tbd in SF Bay Area

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

[b] A cost analysis will also be conducted for a 3,000 MW wind array using a south subsea transmission route.

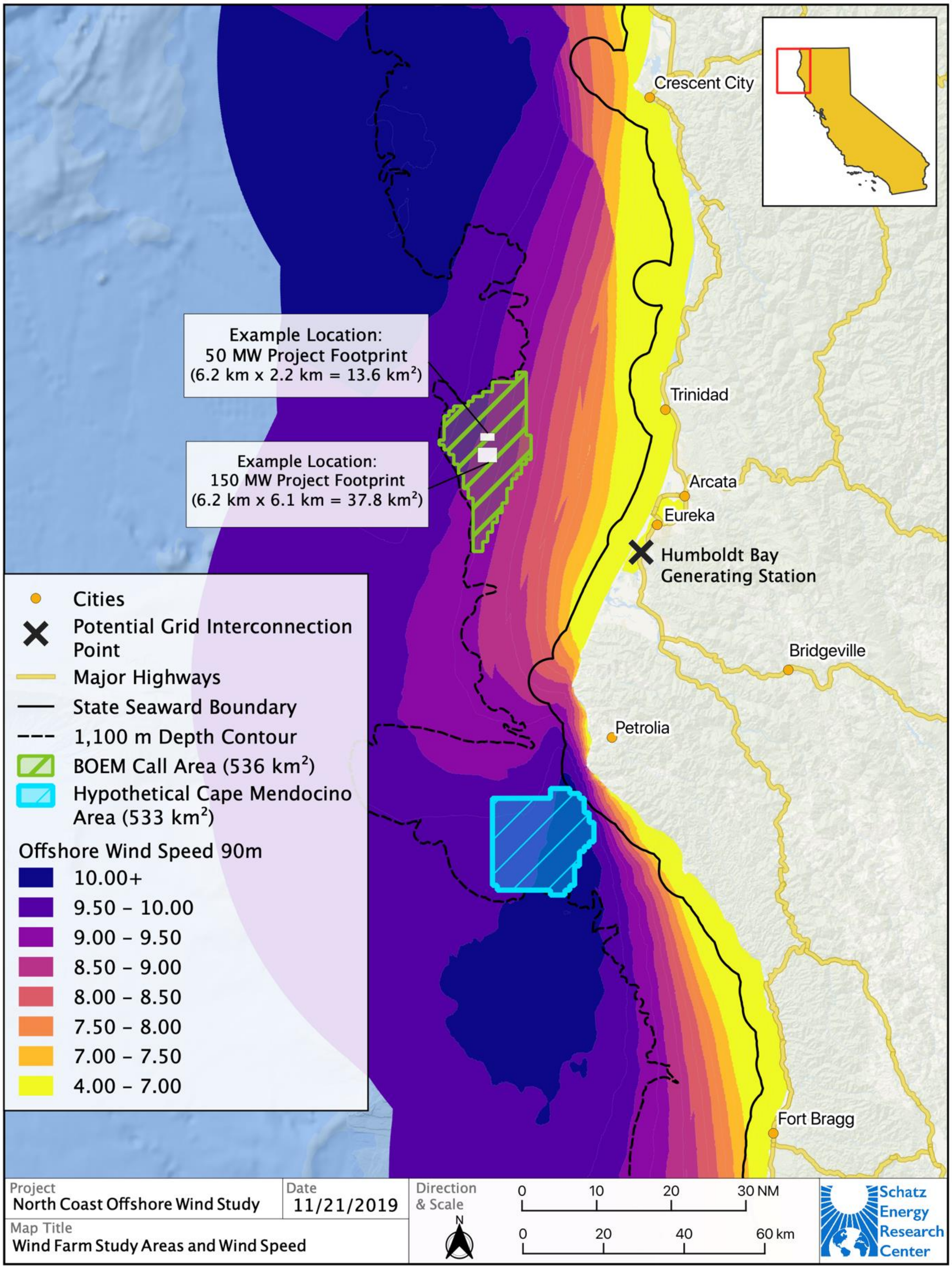

Figure 1. Map containing ocean wind speeds and potential wind array locations and sizes.

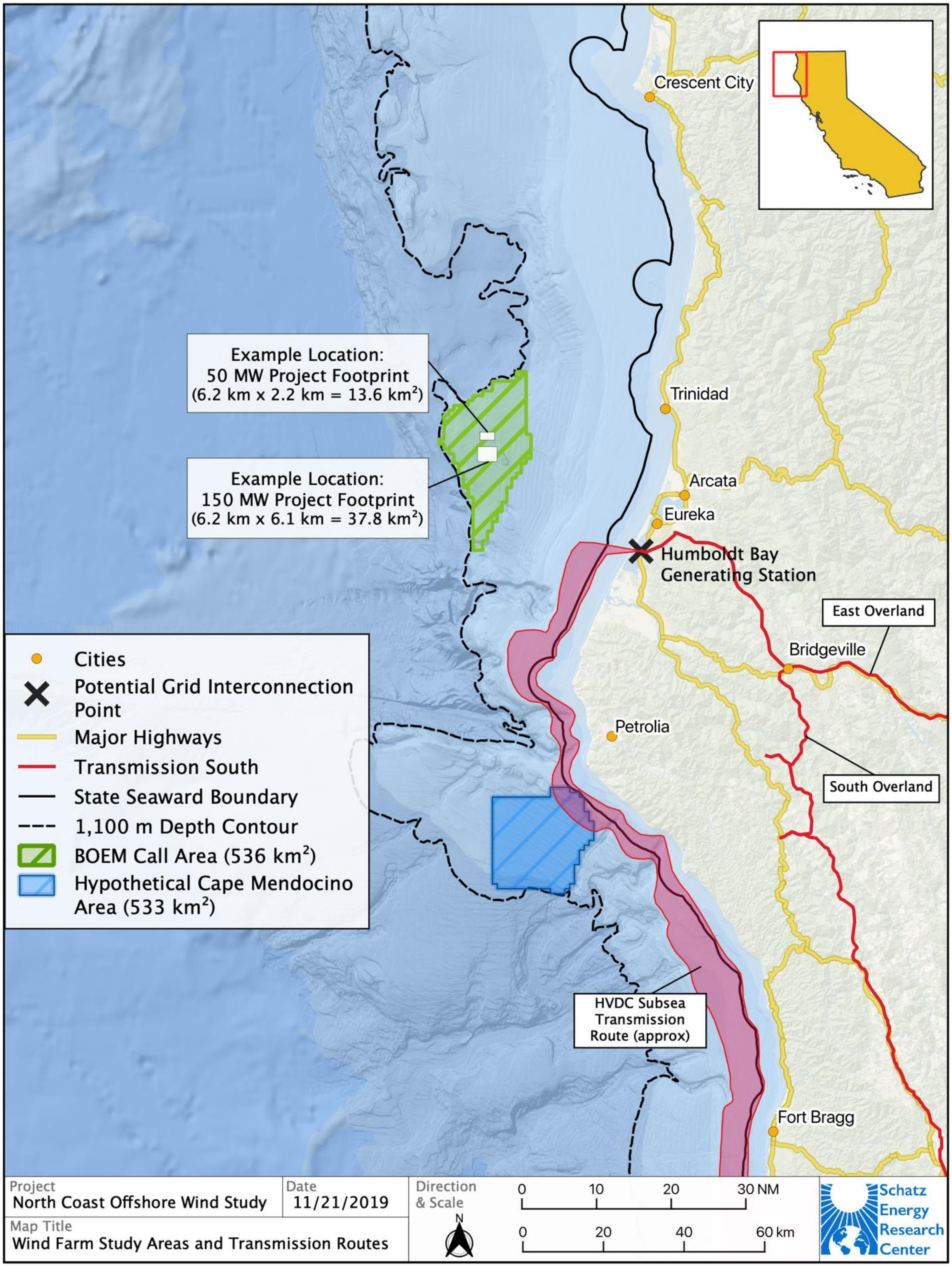

Figure 2. Map of the overland and subsea transmission line options for the two potential wind array areas.

4. TECHNICAL DESCRIPTION

The remainder of this document provides more details about the options that outline a scenario.

The characteristics that define each scenario are described in detail below.

4.1 Timeline

Offshore wind development is in the early stages of planning in California. The assumed timeline for development (Figure 3) will depend on the actual speed of leasing, permitting, development, and construction.

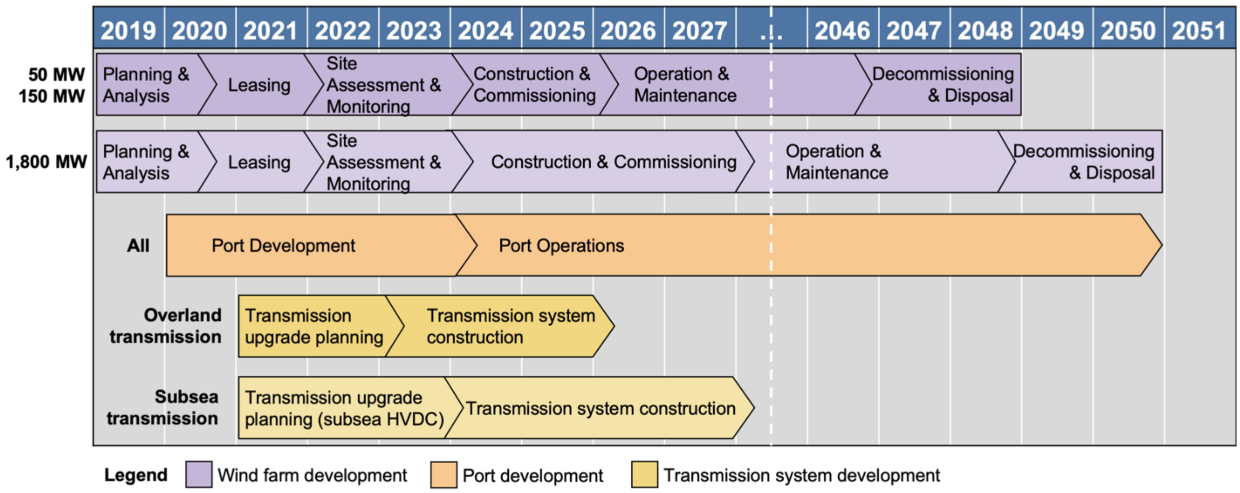

Figure 3. Assumed timeline of development.

BOEM (2019a) describes an approximately seven-year regulatory process of offshore wind development (see Table 2). The process in California is currently in the Planning and Analysis phase. The assumptions for the timeline are listed below:

- All scenarios, irrespective of location, capacity, and transmission route, have the same leasing and permitting timeline. The 1,800 MW wind array has longer construction phase to account for significantly more turbine installations.
- Wind array commissioning: 2026 (50 & 150 MW) or 2028 (1,800 MW)
- Wind array lifetime: 20 years
- Wind array start of decommissioning: 2046 (50 & 150 MW) or 2048 (1,800 MW)

Table 2. Timeline for development of offshore wind facility.

Table 3

Phase	*Description*	*Duration*	*Assumed Timeline*
Planning & Analysis [a]	• Intergovernmental Task Force • Call for Information and Nominations • Area identification • Environmental reviews	~ 2 years	until 2020

Phase	*Description*	*Duration*	*Assumed Timeline*
Leasing [a]	• Publish leasing notice • Hold competitive auction • Issue lease	~ 1-2 years	2020 - 2022
Site Assessment [a]	• Site Characterization • Site Assessment Plan	up to 5 years (assumed 2 years)	2022 - 2024
Construction & Commissioning [c]	• Construction and Operations Plan • NEPA and CEQA environmental review • Facility Design Report • Fabrication and Installation Report • Procurement • Assembly • Construction of wind farm • Commissioning of wind farm	~ 2 years (50 & 150 MW) ~ 4 years (1,800 MW)	2024 – 2026 2024 – 2028
Operation & Maintenance [c]	• Ongoing operations • Ongoing maintenance	20 years[d]	2026 – 2046 (50 & 150 MW) 2028 – 2048 (1,800 MW)
Decommissioning & Disposal [c]	• Decommissioning • Disposal	2 years	2046 – 2048 (50 & 150 MW) 2048 – 2050 (1,800 MW)
Port Development [b]	• Port development planning • Permitting process for port development • Port construction	4 years	2020 - 2024
Port Maintenance & Operations [b]	• Ongoing maintenance and operations of the port and harbor facilities	23 years	2024 - 2050
Transmission Upgrade Planning[b]	• Permitting • Planning • Engineering	2 years (overland) 3 years (subsea HVDC)	2021 – 2022 2021 – 2023
Transmission System Construction [b]	• Construction of transmission system	3 years (overland) 4 years (subsea HVDC)	2023 – 2026 2024 – 2028

[a] BOEM (2019a)

[b] Port and transmission system development is not a part of BOEM's regulatory process, but the timeline needs to be outlined for this study.

[c] BOEM (2019a) combines these phases into a single "Construction & Operation" phase. For the purposes of this study, we split this into three groups

[d] 25 years is the typical lease term (starting at the date of lease issuance). The lease tern could be longer than 25 years or extended for repowering purposes.

4.2 Location

Two locations will be investigated: the Humboldt Call Area located west of Humboldt Bay and another location offshore Cape Mendocino. Descriptions and maps are provided below and summarized in Table 4. The footprint occupied by the wind array is assumed to be an economic exclusive zone where other commercial users are legally excluded from fishing or transiting through the site.

4.2.1 Offshore Humboldt Bay (HB)

The Humboldt Call Area identified by the Bureau of Ocean Energy Management (BOEM, 2018) located west of Humboldt Bay approximately 20 to 30 nautical miles offshore (Figure 4).

4.2.2 Offshore Cape Mendocino (CM)

A second wind array location is considered for comparative purposes. A hypothetical wind array area offshore Cape Mendocino was outlined by the Schatz Energy Research Center to study the differences between this site and a wind array within BOEM's Humboldt Call Area (2018). This area has not been screened by any ocean user community and is not representative of a call area. BOEM has not indicated any interest in this representative area for wind development.

A notional wind array area was outlined in federal waters offshore Cape Mendocino (Figure 5). This general area was identified by Musial et al. (2016a) as a promising offshore wind area and we are studying this region for comparative purposes. The area to be studied in this project was defined by three simple assumptions: 1) including the highest average wind speeds in the region, 2) creating a boundary that will accommodate the same number of turbines as the Call Area for the full build out scenario, and 3) excluding any deep-water canyons. The area is defined in Figure 5 and characterized below.

Table 4. Geographic specifications of study locations.

Site name		*Humboldt Call Area*	*Hypothetical Cape Mendocino Area*
General area		Offshore Humboldt Bay	Offshore Cape Mendocino
West-East width		12 NM (22 km)	14 NM (25 km)
North-South width		25 NM (46 km)	15 NM (29 km)
Total area		207 mi^2 (537 km^2)	155.25 NM^2 (532.5 km^2)
Perimeter		81 NM (150 km)	55.6 NM (103 km)
Centroid location	Lat.	-124.662°	-124.496°
	Lon.	40.965°	40.090°
Distance to shore	Min.	17.4 NM (32.2 km)	3.1 NM (5.70 km)
	Max.	30.4 NM (56.3 km)	20.0 NM (37.0 km)
Average annual wind speed at 90 m height	Min.	8.875 m/s	9.625 m/s
	Mean	9.35 m/s	9.875 m/s
	Max.	9.875 m/s	10.125 m/s
Ocean depth	Min.	1,640 ft (500 m)	328 ft (100 m)
	Mean	2,673 ft (815 m)	2,140 ft (652 m)
	Max.	3,610 ft (1,100 m)	3,610 ft (1,100 m)
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)	55.5 NM (103 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)	45 NM (83 km)

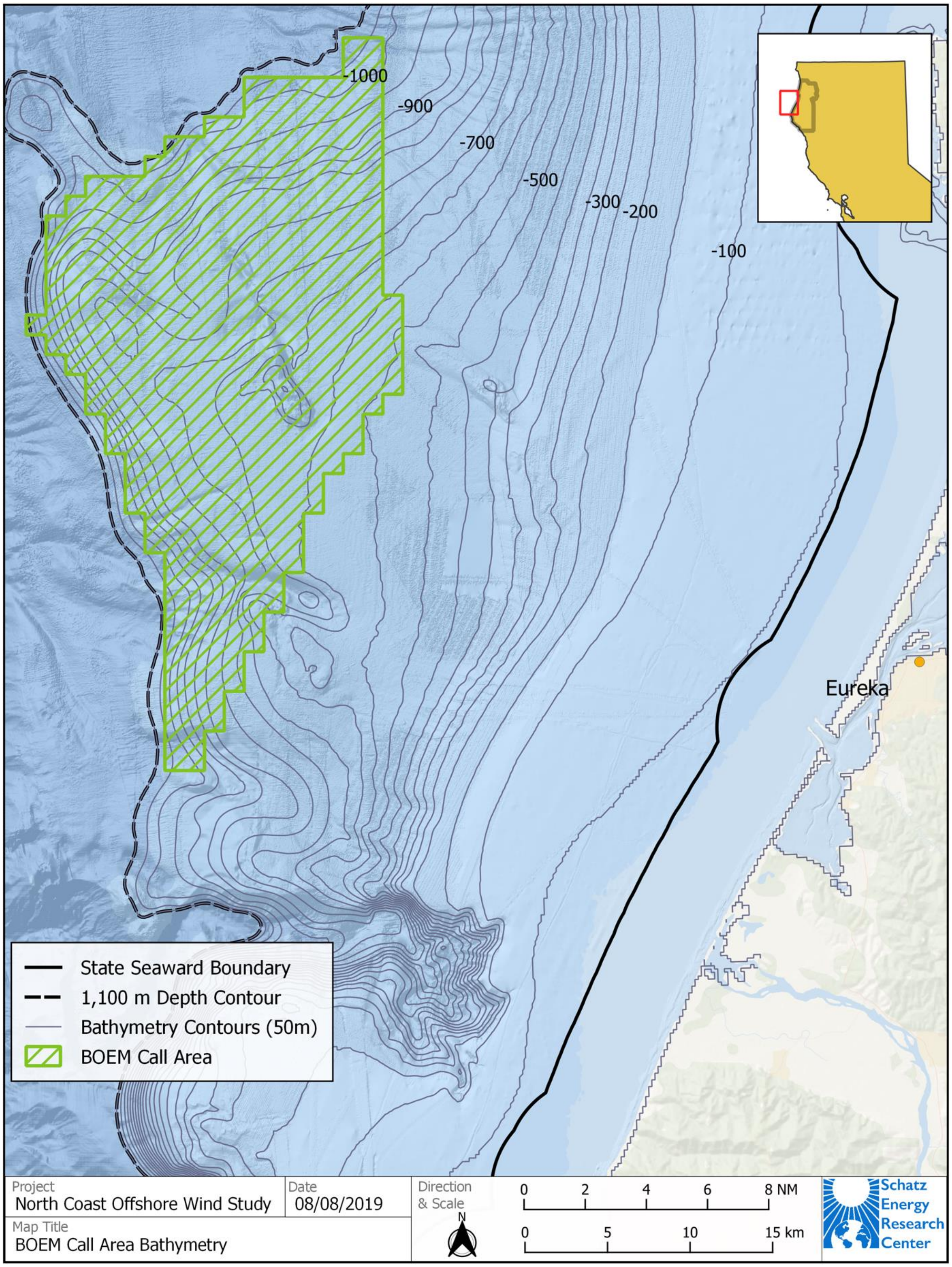

Figure 4. Humboldt Call Area with 50 m bathymetric contours.

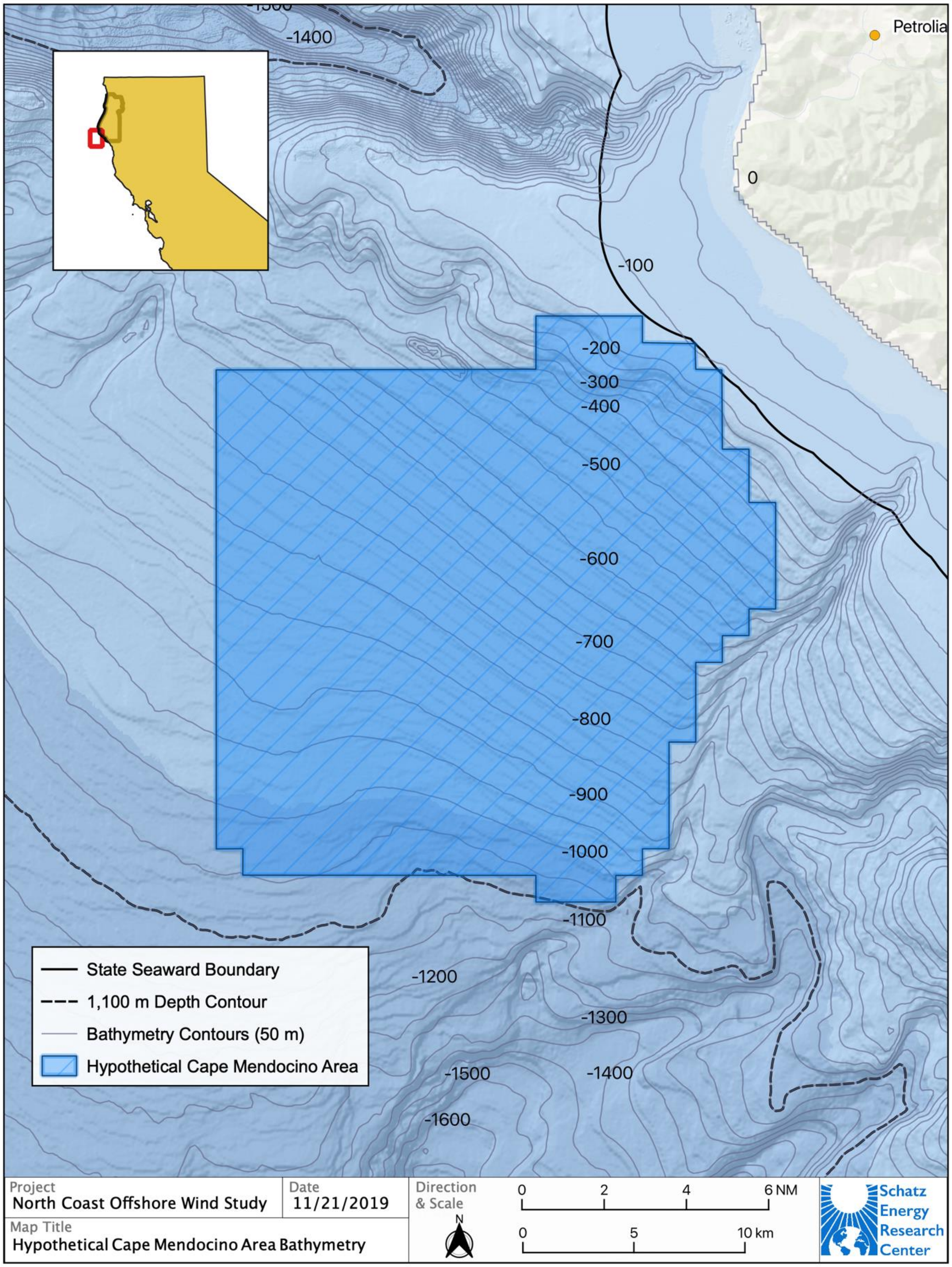

Figure 5. Notional Cape Mendocino area with 50 m bathymetric contours

4.3 Equipment Description

This section provides technical details for the equipment assumed in this study. This section describes the turbines, floating substructure, mooring lines, and wind farm layout.

4.3.1 Wind Turbines

All wind farms are assumed to use a 12 MW turbine. The specifications for this turbine are derived from the standard reference turbine developed by the National Renewable Energy Laboratory (NREL). The dimensions of the turbine are pictured in Figure 6 with the specifications outlined in Table 5. The power curve is shown in *Figure 7*.

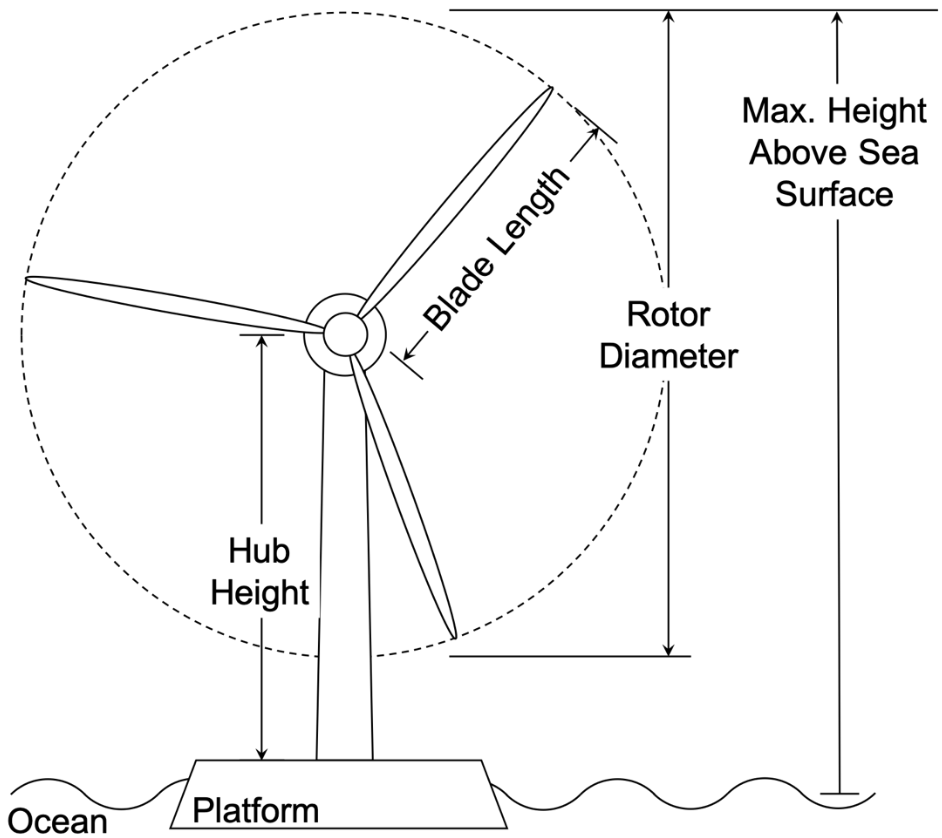

Figure 6. Dimensions of a wind turbine.

Table 5. Specifications of wind turbines in this study. Specifications are subject to change based on developer outreach.

Wind Array Capacity	*Turbine Rated Power*	*Hub Height*	*Rotor Diameter*	*Blade Length*	*Max. Height Above Sea Surface*	*Source*
50 MW	12 MW	136 m	222 m	107 m[a]	264 m	Musial et al., 2019
150 MW						
Full Build						

[a] Blade length based on GE Haliade-X 12 MW turbine (GE, 2019b).

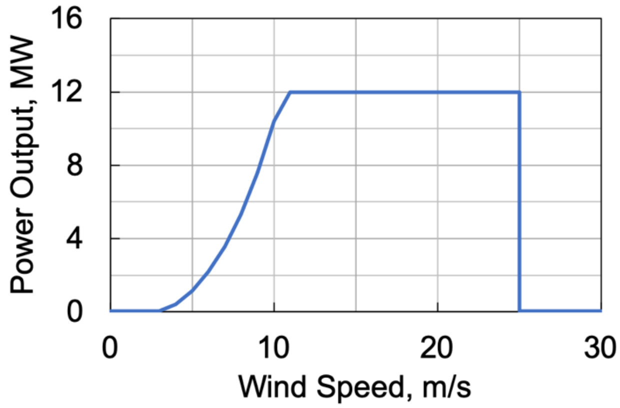

Figure 7. Power curves for 12 MW NREL reference turbines from Musial et al. (2019).

4.3.2 Floating Substructure Description

A semi-submersible floating substructure will be used for this analysis following Musial et al. (2016a and 2019). The basic substructure design comprises three semisubmersible columns connected in a triangular formation with the turbine mounted in the center (Figure 8). Platform dimensions (Table 6) are 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.[2]

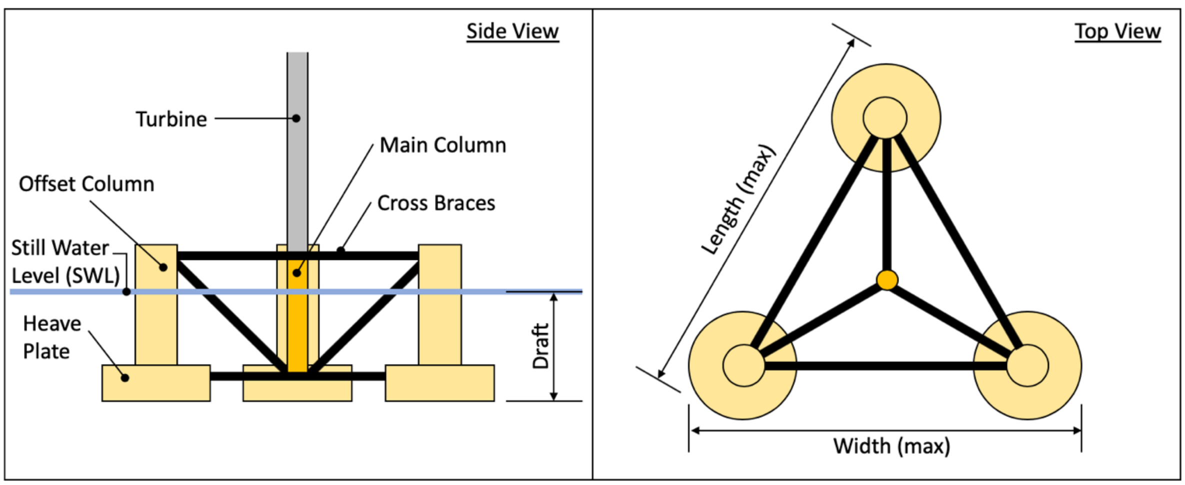

Figure 8. Dimensions of a floating platform. Generic design based on Robertson et al. (2014).

[2] Our goal is to be technology agnostic. Both steel and concrete platforms could be used.

Table 6. Description of floating substructure.

Parameter	*Type A*	*Type B*
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)

4.3.3 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 9). The mooring line will be composed of high-modulus polyethylene (HMPE) 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.

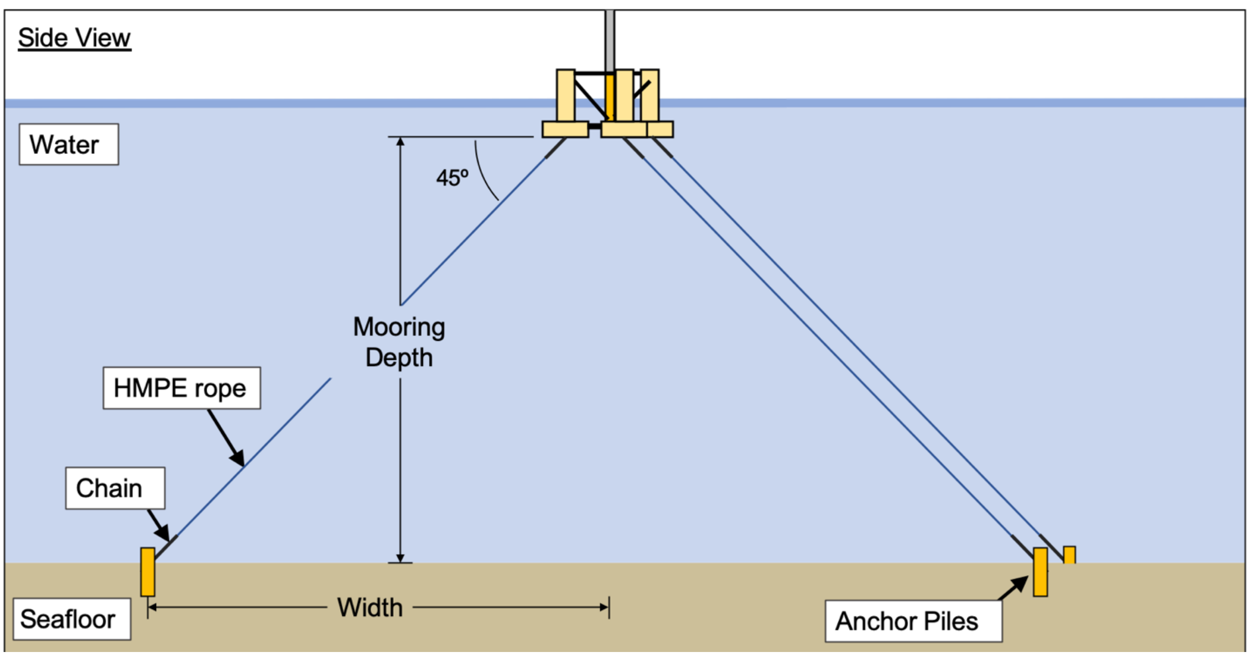

Figure 9. Side view of platforms with taut-leg mooring and anchor piles. Drawing not to scale.

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 10 for an example layout. Mooring line and anchor specifications are presented in Table 7.

The mooring system will have a larger footprint in deeper water. Using the offset 7D x 10D turbine spacing outlined in Section 4.3.4, below, 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.

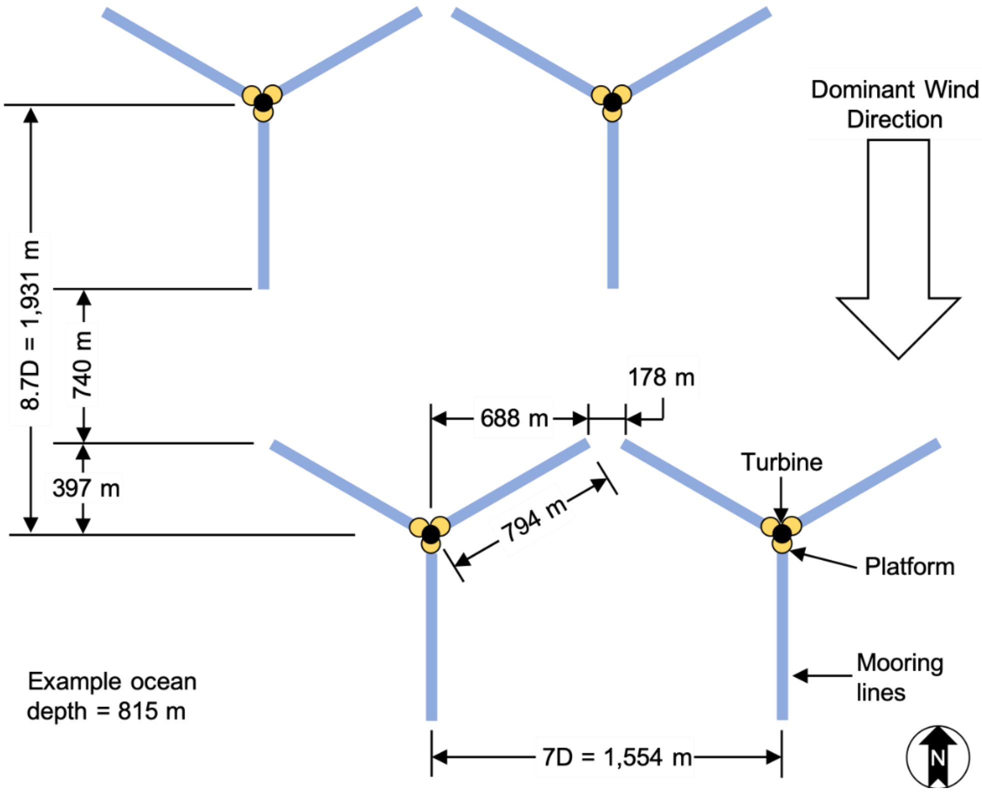

Figure 10. Top view of mooring lines with 12 MW turbine array. Footprint of mooring lines in this illustration is based on an 815 meter ocean depth, the average depth of the Humboldt Call Area.

Table 7. Mooring line and anchor specifications. Subject to change based on developer outreach.

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

Parameter	*Value*	*Justification*	*Source*
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

4.3.4 Wind Farm Array

Three wind array scales will be studied: 50, 150, and 1,800 MW, as described below. A 12 MW turbine will be used in all wind arrays.

- 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. <u>10D x 7D Spacing:</u> 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 spacing is determined by establishing an elliptical area around each turbine. The major diameter, 10D, of the ellipse is in the direction of the prevailing wind, and minor diameter, 7D, perpendicular to it. The spacing was established following Musial et al. (2016b) and using input from developers. The number of rows and columns of turbines depends on the total power capacity of the wind array. The critical dimensions of the turbines and wind array are described in Table 8.
2. <u>Offset Rows:</u> 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 Figure 11 and Table 8.
3. <u>Mooring Line Overlap:</u> 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 4.3.3). As the ocean becomes deeper and the mooring system footprint extends, the turbine spacing will increase to avoid overlapping mooring lines (see Figure 12 and Figure 13, for example.
4. <u>Mooring Line Boundary:</u> 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 11 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 12), with a total capacity of 1,800 MW. The boundary of the Cape Mendocino study area was created to accommodate the same number of 12 MW turbines for full build out (Figure 13).

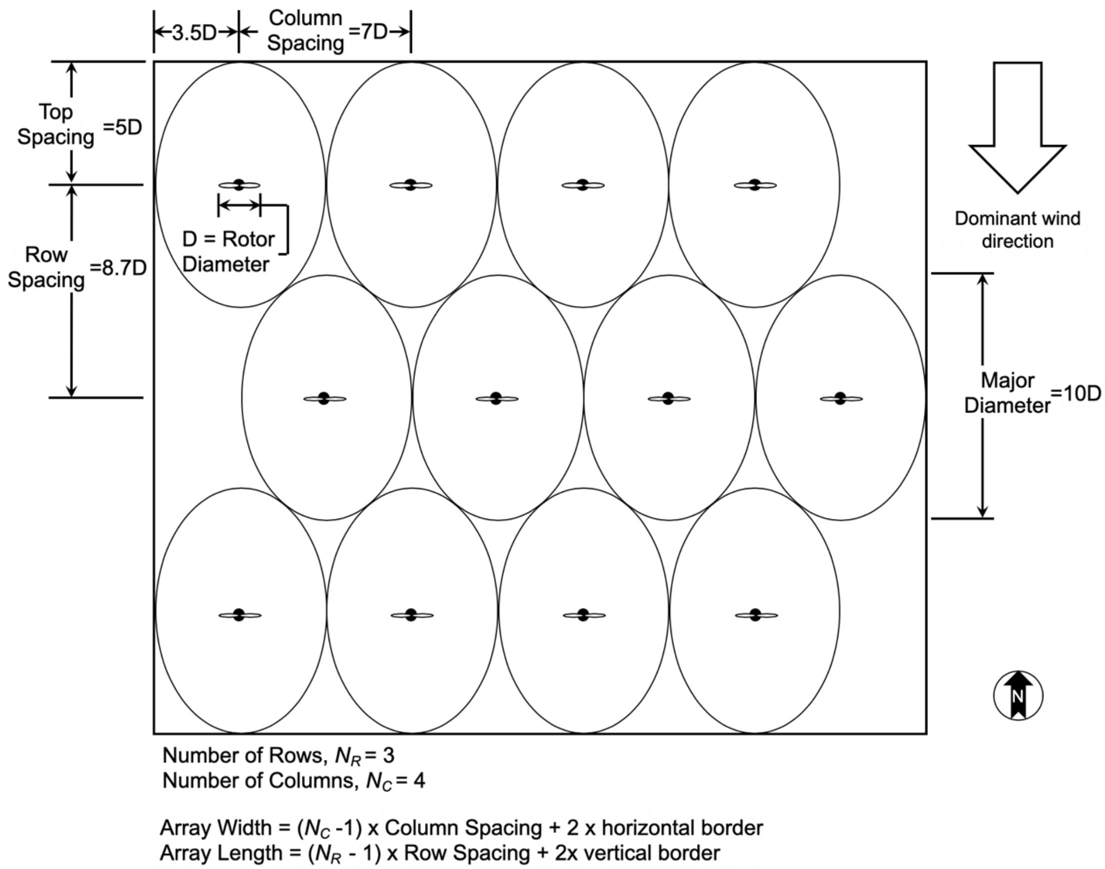

Figure 11. Dimensions of a wind array layout.

Table 8. Specifications for the turbines and dimensions for the wind array grid layout.

Wind Array Capacity	*Number of Turbines*	N_{Column}	N_{Row}	*Array Width*	*Array Length*	*Array Area*	*Calculated Specific Power, MW/km²*
48 MW	4	4	1	6.2 km	2.2 km	13.6 km^2	3.5 MW/km^2
144 MW	12	4	3	6.2 km	6.1 km	37.8 km^2	3.8 MW/km^2
1,800 MW	153	See maps below for full build out arrangement					~4.0 MW/km^2 [a]

[a] The specific power is slightly different between both study areas because the areas are slightly different.

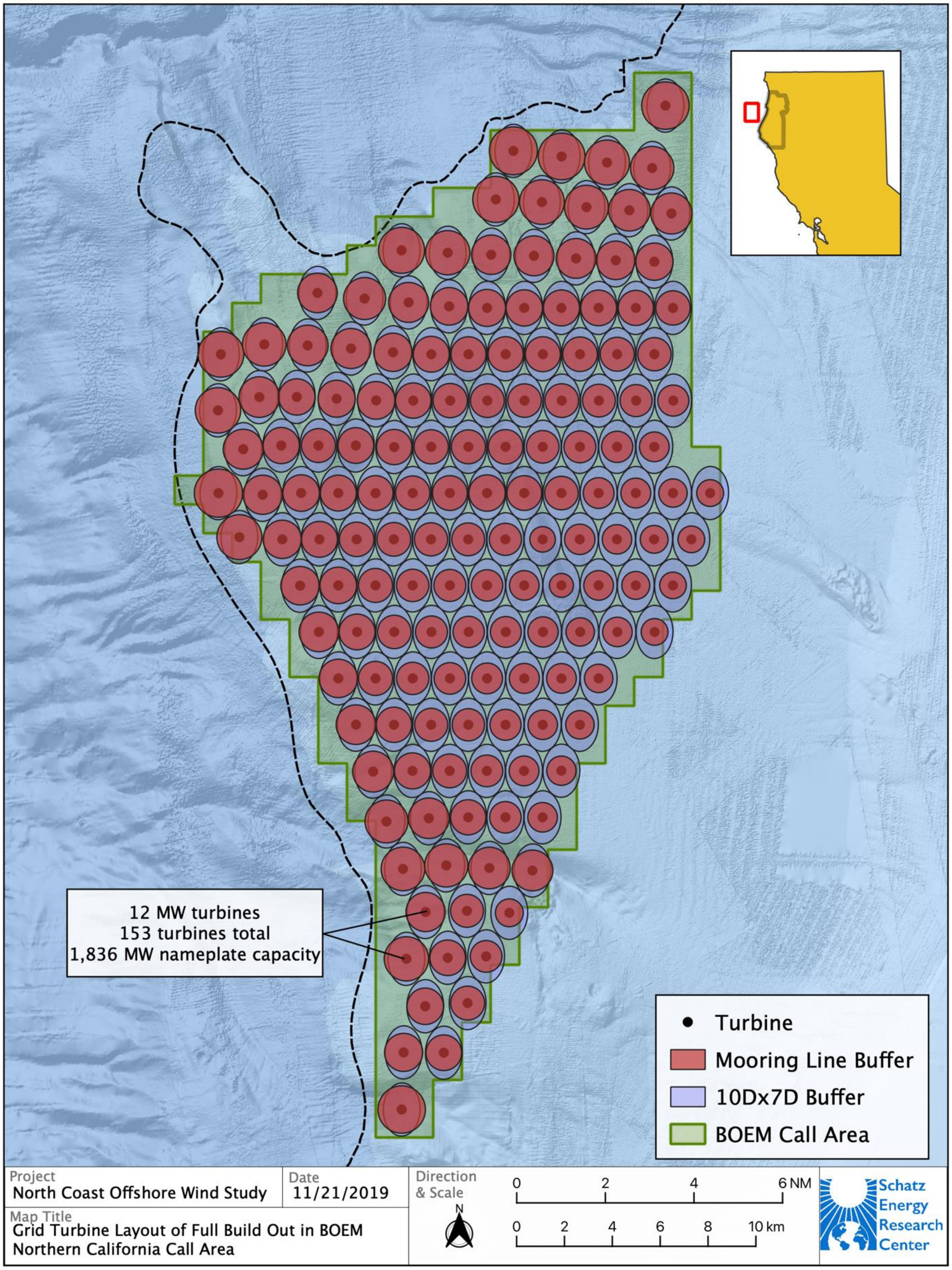

Figure 12. Turbine layout of full-build out scenario in Humboldt Call Area.

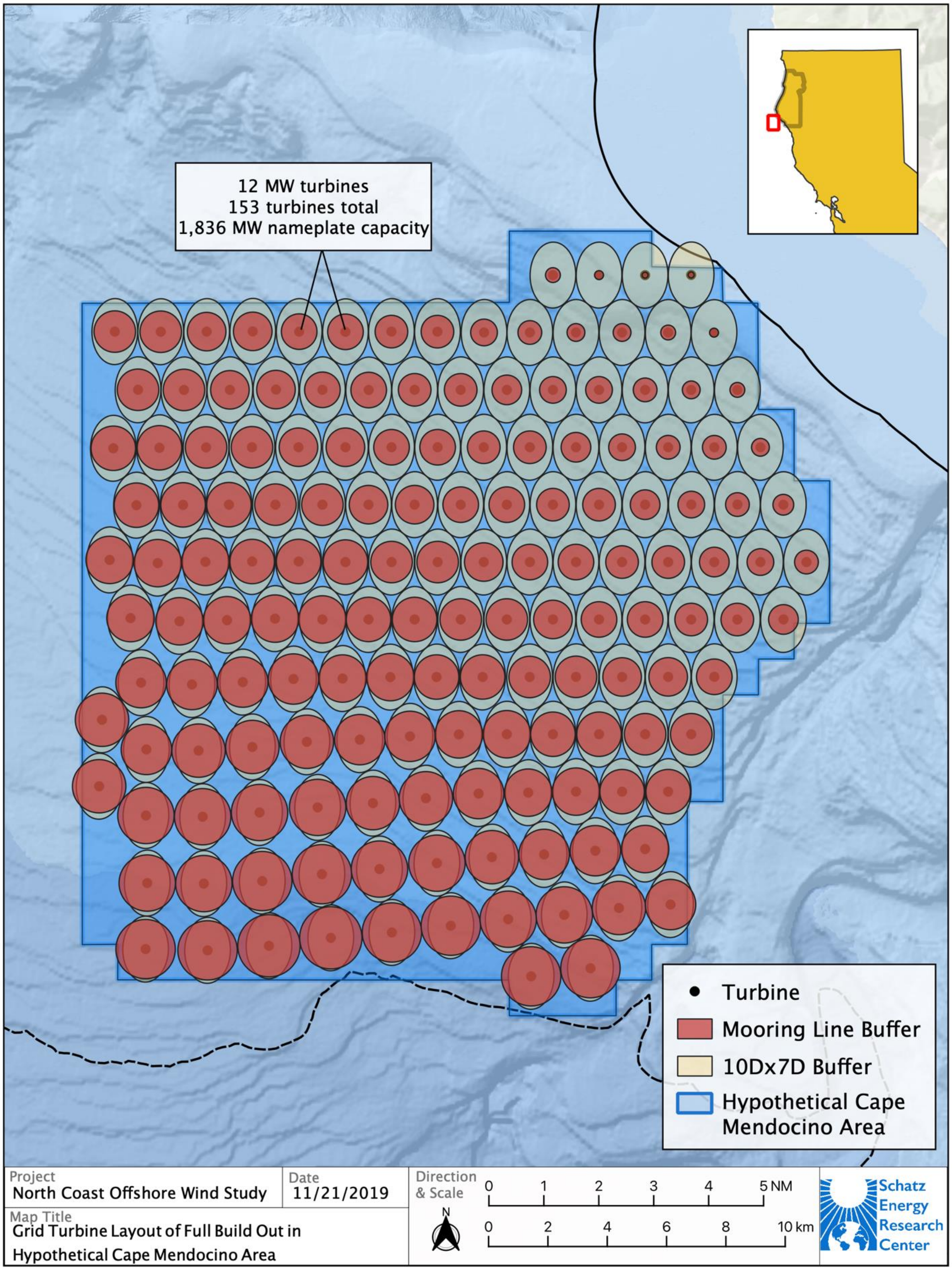

Figure 13. Turbine layout of full build out scenario in notional Cape Mendocino area.

4.3.5 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 are not included in the assumed installation.

4.4 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 14 provides a visual representation of the various electrical equipment of an offshore wind farm delivering power via an overland transmission route.

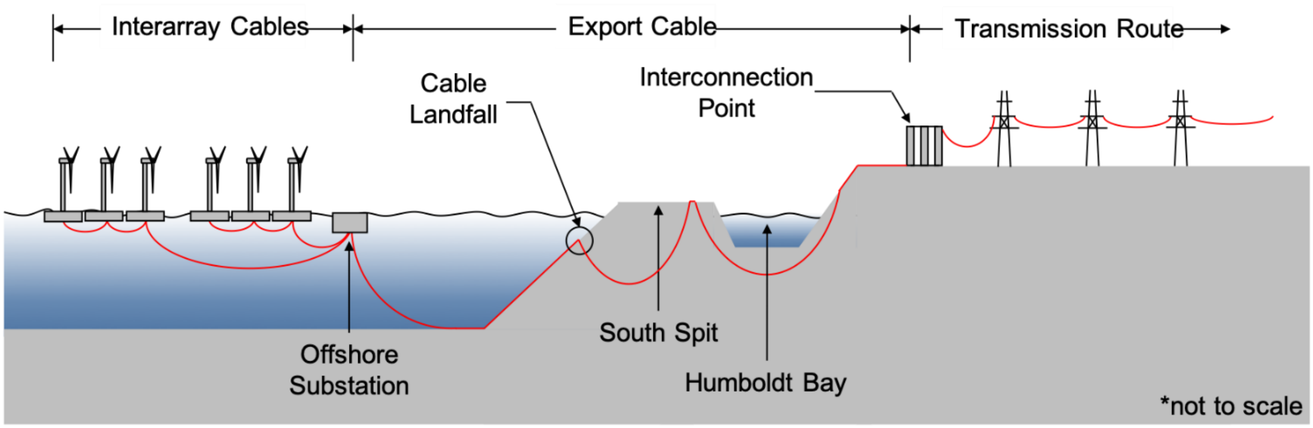

Figure 14. Generalized representation of electrical system locations for overland transmission routes.

4.4.1 Interarray Cables, Offshore Substation, and Export Cable

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 from the bottom of each turbine platform and then to a floating substation.

The offshore floating substation is the electrical connection point for the array cables and will house the necessary electrical equipment such as a collector bus, protective switchgear, a step-up transformer, and power quality equipment (e.g. shunt reactors). The AC transformer will step-up the voltage for the export cable back to shore and a shunt trip reactor may be needed to adjust for voltage variations and compensate for reactive power within the 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 at the Humboldt Bay Generating Station (Table 9). 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 9. Export cable specifications based on cables from ABB (2019).

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

4.4.2 Cable Landfall and Interconnection Locations

The export cable landfall will be in the northern section of the South Spit of Humboldt Bay (highlighted area on the left in Figure 15). The landfall and interconnection approach being studied is described below.

Horizontal directional drilling (HDD) to bring the export cable onshore will begin at an ocean depth of 9 meter on the Pacific coastline. The HDD will connect to a cable vault located within this area. A second HDD is then used to route the cable from this vault under the floor of Humboldt Bay to another vault located on Buhne Point (highlighted area on the right in Figure 15), located adjacent to HBGS. The necessary electrical switchgear and equipment including a transformer will be located at HBGS where power conditioning and synchronization will occur before exporting power to the electrical utility grid.

Figure 15. General areas for cable landfall.

4.4.3 Subsea HVDC Transmission Cable

For the preliminary subsea transmission concept, landfall and the wind farm export cable routing under the spit and bay to the HBGS are the same. However, for the subsea transmission scenarios, the HVAC export cables will connect to a HVDC conversion station at or near the HBGS. Once converted, the HVDC submarine transmission cable will be routed back under the bay and spit for subsea transmission to the south. The southern terminus landfall location is unknown at this time, but will be in the San Francisco Bay Area.

The subsea transmission concept will also look at HVDC conversion near the HBGS, but this preliminary decision was made to simplify the analysis and look at one interconnection point rather than trying to identify another suitable HVDC conversion location further south on the coast.

4.4.4 Transmission Routes

The Humboldt region electricity system has a modest 100 MW average load and a transmission system that has limited capacity to export power into the broader California grid. Installing a gigawatt-scale generator in the region will far exceed any local demand and will require construction of a new high-voltage transmission line to export power from the offshore wind farm to the rest of California. New transmission will need to connect with California's 500 kV transmission lines (solid blue lines in Figure 16). Pacific Gas and Electric Company (PG&E), who owns the transmission lines, determined four potential transmission options, including two overland and two subsea (Figure 16). Based on power flow modeling of the transmission system, summaries of the upgrade options are provided below.[3]

[3] Details about the technical specifications of the upgrades and associated costs are provided in the Transmission Power Planning Study report (forthcoming).

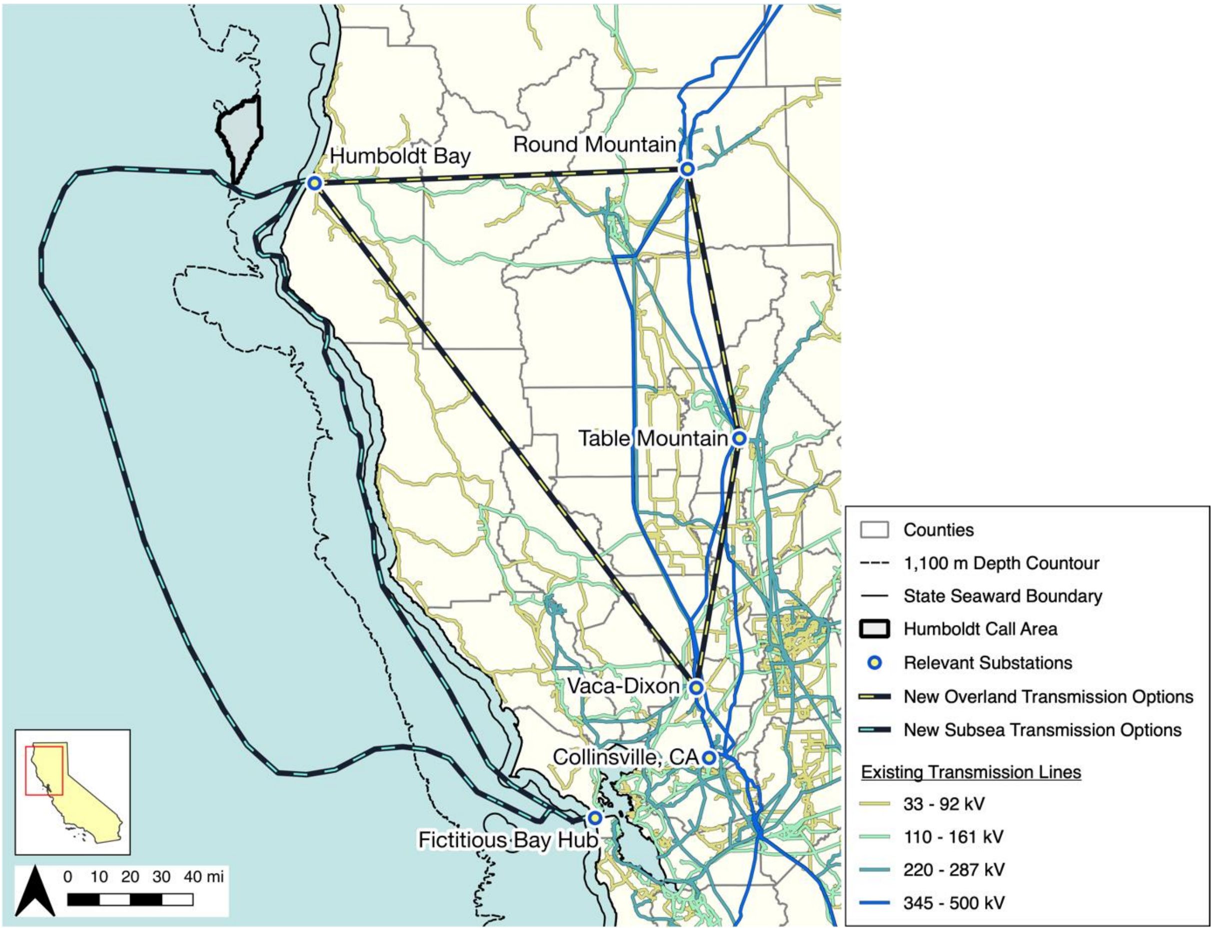

Figure 16. Transmission upgrade alternatives for 1.8 GW of offshore wind from the Humboldt Call Area.

Overland East

A new 500 kV HVAC transmission line would connect between Humboldt Bay Substation and Round Mountain Substation. The transmission pathway follows a utility right of way for an existing 115 kV transmission line alongside California Highway 36. This alternative would require:

- Construct new 500 kV substation near Humboldt Bay Substation
- Build new 500 kV transmission line from Humboldt Bay to Round Mountain; Round Mountain to Table Mountain; and Table Mountain to Vaca-Dixon
- Reconductor some auxiliary transmission lines and make upgrades to impacted substations

Overland Southeast

A new 500 kV HVAC transmission line would connect between Humboldt Bay Substation and the Vaca-Dixon Substation. The transmission pathway follows a utility right of way for an existing 60 kV transmission line that runs alongside the Eel River and California Highway 101 into Lake County then heading east towards Vacaville. This alternative would require:

- Construct new 500 kV substation near Humboldt Bay Substation
- Build new 500 kV transmission line from Humboldt Bay to Vaca-Dixon
- Construct new 500 kV substation near Collinsville, CA
- Reconductor some auxiliary transmission lines and make upgrades to impacted substations

Subsea Transmission Cable

A high-voltage, direct-current (HVDC) subsea cable will connect between Humboldt Bay and the San Francisco Bay Area. Power from the wind farm will be converted into HVDC at a converter station near the Humboldt Bay Substation. Once converted, the subsea transmission cable will be routed back to sea and toward the San Francisco Bay Area. There are two possible cable corridors, one nearshore and one further from shore. The southern terminal of the cable is at a generic point in the San Francisco Bay Area, "Fictitious Bay Hub". The Bay Hub will connect into several transmission networks because no single network in the Bay Area can accept this much additional capacity. This alternative would require:

- Construct new AC to DC converter station near Humboldt Bay Substation
- Build new HVDC subsea cable between Humboldt Bay the San Francisco Bay Area.
    - Two possible subsea cable corridors have been identified.
- Construct new 230/500 kV DC Bay Hub Substation at an undetermined location in the Bay Area
- Construct six new 230 kV cables that would connect the Bay Hub to different transmission networks in the Bay Area

  Reconductor some auxiliary transmission lines

4.5 Construction and Maintenance

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

4.5.1 Assembly and Installation

As part of this project, a port infrastructure assessment will be performed for Humboldt Bay to determine where the construction activities may take place. This feasibility-level evaluation will identify port-side and navigation infrastructure needs, inventory existing port facilities, and determine the necessary upgrades to support the development of an offshore wind farm. Based on a previous pre-screen analysis, Humboldt Bay can be classified as a quick reaction port and an assembly port, and further analysis of the supply chain will be required to determine if Humboldt is a suitable port for fabrication and construction activities (Porter and Phillips, 2016).

For this preliminary description of construction and installation activities, it is assumed that fabrication and construction of the components will occur at another port or facility outside of Humboldt County and components will be shipped to Humboldt Bay for assembly. However, specific local fabrication activities may be investigated based on the results of industry outreach. Assuming components are fabricated outside Humboldt Bay, the components will be stored in a lot upon arrival in Humboldt Bay. Among other factors, the size capacity of the upland storage and staging areas will influence the scheduling of assembly (e.g. whether all components are delivered first or the assembly process will take place in parallel to deliveries to ensure space is available for future components). The port-side assembly process is complex and requires specific infrastructure, equipment and vessels, which will be determined during the course of this project. The preliminary assumption is that assembly will take place quayside and equipment testing will take place in protected waters to identify any faulty components before towing the substructure and turbine unit to the site.

The Humboldt Bay Harbor Recreation and Conservation District has expressed interest in an offshore renewable energy port to be located at Redwood Marine Terminal I in Samoa, California (HBHRCD, 2019). Improvements to this port terminal will be necessary in order to support the storage, assembly, and operation and maintenance of components for an 1,800 MW offshore wind development. Potential specifications of the port include three vessel berths, an ultra-high capacity wharf for the tower and nacelle, and access piers to move equipment between the upland storage and fabrication areas onto the wharves (Figure 17).

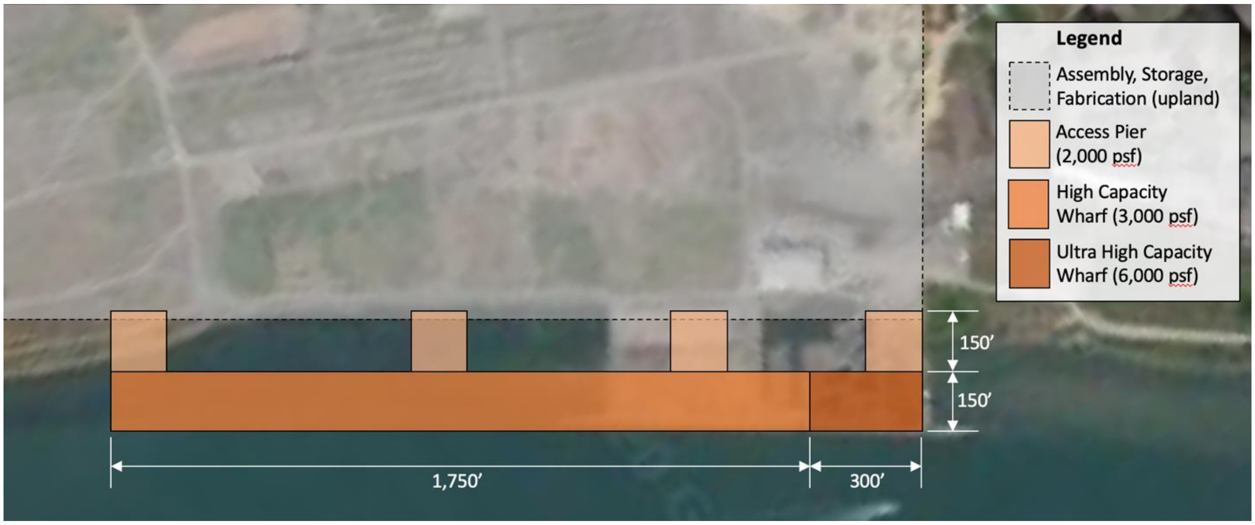

Figure 17. Example port facility for offshore wind development.

A preliminary list of equipment that is likely required for assembly and construction is provided in Table 10. This list will be revised based on input from experts and developers during this study.

Table 10. 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	

4.5.2 Operations and Maintenance

The operation and maintenance (O&M) plan will be developed in more detail as this study progresses. The O&M plan will be developed by Mott MacDonald as part of the port infrastructure assessment. The list of O&M tasks will be used to evaluate the port infrastructure requirements, economic costs, and environmental impacts of the maintenance activities.

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 (Table 11). 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 11. Operations and maintenance preliminary vessel assumptions.

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.

4.5.3 Decommissioning

During the Construction and Operations 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.
-

These activities are required to be completed within 2 years following termination of the lease. Prior to decommissioning, the developer is required to submit a decommissioning application and receive approval from BOEM. Additional regulations can be found in 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 (2011).

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