CALIFORNIA
ENERGY COMMISSION

Energy Research and Development Division

FINAL PROJECT REPORT

Research and Development Opportunities for Offshore Wind Energy in California

Gavin Newsom, Governor
August 2020 | CEC-500-2020-053

PREPARED BY:

Primary Authors:
Amul Sathe
Andrea Romano
Bruce Hamilton
Debyani Ghosh
Garrett Parzygnot
Martins Paberzs

Guidehouse
101 California Street
San Francisco, CA 94111
guidehouse.com

Contract Number: 300-15-009

PREPARED FOR:
California Energy Commission

Silvia Palma-Rojas, Ph.D.
Project Manager

Jonah Steinbuck, Ph.D.
Office Manager
ENERGY GENERATION RESEARCH OFFICE

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Drew Bohan
Executive Director

ACKNOWLEDGEMENTS

The project team would like to thank the following technical advisory committee members for their invaluable assistance with this project:

- American Wind Energy Association
- Bureau of Ocean Energy Management
- California Energy Commission
- California Independent System Operator
- California Public Utilities Commission
- Ocean Protection Council

The project team would also like to acknowledge the contributions of interviewees from the following organizations:

- Aker Solutions, Asia Wind Energy Association, Audubon Society, Business Network for Offshore Wind, California Coastal Commission, California State Lands Commission, Castle Wind, Clean Power Alliance, DNV GL, EnBW, Equinor, GE Renewable Energy, MHI Vestas Offshore Wind, Monterey Bay Community Power, National Renewable Energy Laboratory, New York State Energy Research and Development Authority, Ørsted, Pacific Coast Federation of Fishermen's Associations, Pacific Gas and Electric Company, Pacific Ocean Energy Trust, Principle Power, RCAM Technologies, Redwood Coast Energy Authority, Schatz Energy Research Center at Humboldt State University, Siemens Gamesa, Sonoma Clean Power, Southern California Edison, Stiesdal Offshore Technologies, UC Berkeley Labor Center, University of Maine, U.S. Department of Energy, and Virginia Department of Mines, Minerals and Energy.

PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Research and Development Opportunities for Offshore Wind Energy in California is the final report for Contract Number 300-15-009 conducted by Guidehouse. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at 916-327-1551.

ABSTRACT

California's oceans hold energy resources that could contribute to meeting the renewable energy and low carbon energy goals outlined in Senate Bill 100. The National Renewable Energy Laboratory has identified that California has a technical resource capacity of 112 gigawatts of offshore wind. This capacity occurs primarily in deep waters that require floating platform technology to support wind turbines.

California faces various challenges with installing offshore wind turbines. These challenges include insufficient offshore wind historical-technical data and maturity of floating offshore wind technology, depth of offshore waters, high cost of floating technology, lack of information on the impact of these systems on sensitive species and habitats, strict environmental standards, and untested permitting processes.

Identifying ways to support technology innovation to address California-specific challenges will help with long-term development of cost-effective offshore wind projects. Supporting innovation and reducing costs will enable offshore wind to compete in the California energy market and the Western Energy Imbalance Market without subsidies.

The California Energy Commission funded this study to develop priority recommendations that would lead to cost-effective offshore wind projects. The study identifies 11 research, development, and deployment opportunities to remove or reduce technological, manufacturing, logistics, and supply chain barriers to deployment; lower the development risk of offshore energy projects; and identify opportunities for early pilot demonstration projects.

Keywords: California, offshore wind, floating offshore wind, offshore energy, offshore development, renewable energy, wind energy, RD&D

Please use the following citation for this report:

Sathe, Amul, Andrea Romano, Bruce Hamilton, Debyani Ghosh, Garrett Parzygnot (Guidehouse). 2020. *Research and Development Opportunities for Offshore Wind Energy in California*. California Energy Commission. Publication Number: CEC-500-2020-053.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Study Overview

Senate Bill 100 (De León) accelerates and expands California's clean electricity goals to 60 percent renewable electricity by 2030 and 100 percent renewable and zero carbon electricity by 2045. Achieving these goals will require a significant increase in renewable and carbon-free electricity generation.

Over the last four decades, California has helped pioneer land-based wind energy in the United States. As of 2019, the state has the fifth largest amount of wind capacity in the United States with 6 gigawatts of installed wind capacity. Although California has no offshore wind generation in place, the National Renewable Energy Laboratory has identified 112 gigawatts of offshore wind technical potential for California, which could be drawn upon in meeting the state's renewable and zero-carbon goals.

However, 96 percent of offshore wind resource potential is in water deeper than 60 meters where traditional offshore wind technologies are not suitable. California also faces unique challenges in installing and operating offshore wind turbines that include lack of technical history and maturity of offshore systems, deep coastal waters, high technology costs, sensitive habitats, and untested permitting processes for offshore energy generation.

The purpose of this project was to support development of cost-effective offshore wind projects by identifying research, development, and demonstration (RD&D) opportunities to remove or reduce technological, manufacturing, logistics, and supply chain barriers. Study objectives included:

- Understanding the current market state of floating offshore wind technology.
- Identifying specific barriers to commercial-scale offshore wind development in California.
- Developing technology and deployment research recommendations to advance offshore wind in the state.

Research Approach

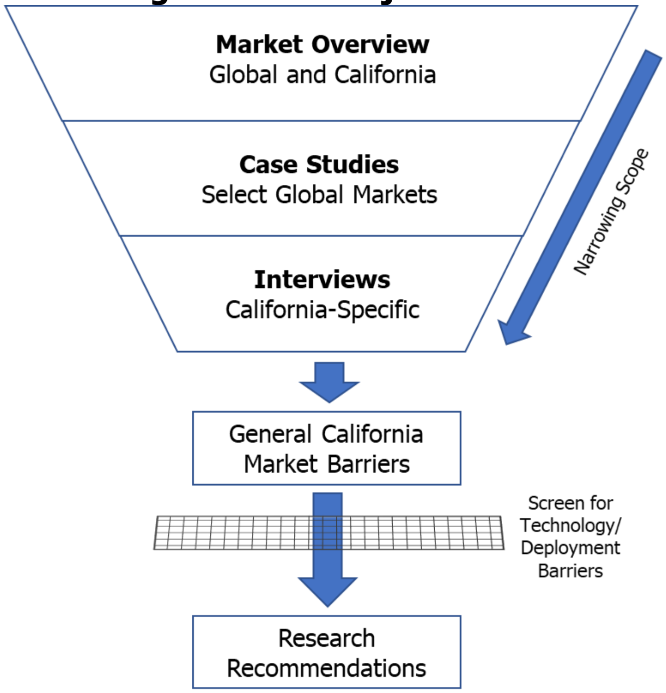
The project team used a five-step approach (Figure ES-1). The team began with a comprehensive literature review to provide an overview of global and California-specific offshore wind markets. Next, the team developed five case studies of global markets with relevant experiences applicable to California, informed by literature reviews and interviews with key market experts. The team also conducted 31 interviews with stakeholders from September 2019 and March 2020 to identify barriers and opportunities specific to the California market. The results of these three information-gathering steps helped synthesize a list of barriers to offshore wind development in California ranging from technical to infrastructure to policy issues. The team then focused on developing recommendations to address technical and deployment barriers identified during the process.

The research team presented its draft findings to a technical advisory committee and California Energy Commission (CEC) staff for further input before finalizing this report.

As part of the research, the team collected more than 200 studies that were compiled in a research database posted on the CEC's website, available at Offshore Wind Research and

Development Database. The database includes a wide range of reports but focuses on technical and market research conducted within the United States from 2017-2020.

Figure ES-1: Project Process



Source: Guidehouse, 2020

Barriers

The project team identified 10 key barriers to offshore wind energy development in California, briefly discussed below (in no particular order):

- There is limited capacity to transmit energy from offshore wind sites to load centers, particularly off the northern coast of California where the best wind resource is located. Power supply from offshore wind regions with good wind potential requires substantial investment in new transmission infrastructure or enhancements in existing transmission infrastructure.
- Statewide port capabilities must be assessed to identify improvements required and RD&D opportunities for large offshore wind projects. The infrastructure, layouts, and logistical capabilities of most existing ports in California do not fulfill the specific physical characteristics required for offshore wind projects. Offshore wind market development will require assessment of existing ports against specific criteria and enhancements in capabilities necessary for these ports to handle offshore wind projects.
- Uncertain market conditions restrict project development and supply chain investment. Project and technology developers see offshore wind project investments as risky without a planning target or specific state commitment and, therefore, hesitate to invest in offshore wind projects and supply chain infrastructure.
- Installation, operation, and maintenance of offshore wind projects are challenging because of the harsh and deep marine environment. No floating offshore wind platform system in the world operates in an environment (wind, wave, and depth combined)

directly comparable to California's northern and central coasts. It is unclear what, if any, complications these conditions will have on project cost or performance.

- Delays in federal leasing and untested California permitting processes present another challenge. It remains uncertain when the federal government will grant leases for California offshore wind areas. Additionally, state level permitting procedures are expected to require engagement with multiple stakeholders, posing delay risks for project developers.
- Limited data exists about potential negative impacts of offshore wind projects on commercial fisheries and offshore ecosystems in California. Ongoing analyses by multiple research institutions will help identify gaps in existing knowledge that can be filled through state-led or state-supported research efforts.
- There are uncertain cost trajectory and cost-competitiveness concerns with onshore resources. Limited commercialization of floating offshore wind technology and a nascent supply chain lead to uncertainties in levelized cost reduction trajectories and technology competitiveness with onshore renewable resources such as distributed and grid-scale solar, land-based wind, and small hydro.
- More complete understanding is needed about the total value proposition of offshore wind to California. The full macroeconomic benefits from offshore wind development (for example, jobs in coastal regions, economic growth, instate renewable energy, balancing and complementing solar generation) have not yet been fully assessed, which limits the value proposition from offshore wind projects.
- There are potential conflicts with military training and operations on the central and southern coasts. Existing and potential future areas for offshore wind projects are in proximity to multiple naval and air stations where current and future military testing and training are expected to be undertaken. The degree of offshore wind development compatible with United States Department of Defense operations is yet to be assessed.
- Limited data is available to support floating technology performance and project development at commercial scale. Floating platform technology has been proven to be technically viable, but because it is still relatively new, few large-scale operational projects exist globally. Projected deployment and operational efficiency of such projects could be affected by unforeseen challenges, such as logistical barriers, infrastructure failures, and supply chain constraints.

Research, Development, and Demonstration Recommendations

Overall recommendations to promote offshore wind development are in three broad categories: technology and infrastructure research; environment and resource research; and other. Recommendations in the first two categories align with the mission of the CEC's Energy Research and Development Division and the scope of the Electric Program Investment Charge scope and are discussed below. Other recommendations include considerations outside the scope of the Electric Program Investment Charge that could help advance offshore wind market development.

Technology and Infrastructure Research Recommendations

1. Expand and advance technologies for mooring, cabling, and anchoring: Specific research areas to improve the performance of cables in deep ocean and reduce the

total amount of cable used include: (1) studying the feasibility and durability of inter-array cabling webs that connect multiple turbine units to improve performance and lower costs; (2) supporting development of synthetic mooring lines with higher resilience and lower operation and maintenance costs; (3) evaluating options to shift floating platform positions by controlling tension and length of mooring lines; and (4) research dynamic wave motion effects on cables at depths proposed in California call areas. Studies could also support the design, manufacture, and installing low-cost anchors that maintain performance at extreme depths.

2. Develop technologies to ease operation and maintenance in extreme wind and wave conditions, including remote monitoring and robotic maintenance: Specific research areas to help lower capital and operation and maintenance costs in these conditions include application of remote monitoring software and sensor packages to send real-time performance data to onshore operations centers and application of robotic vessels to repair and replace components on the seafloor.
3. Develop technical solutions to integrate offshore wind to the grid, including facilitating technologies like green hydrogen and subsea storage: Research in this area would develop auxiliary technologies with offshore wind to maximize benefits. This could involve applied research, pilot demonstration or deployments of offshore and onshore hydrogen production using power generated by offshore wind, and a value study to quantify benefits from pairing offshore wind with storage.
4. Develop approaches to use and optimize existing supply chain and manufacturing or assembly solutions in California: This research would assess capabilities to use local materials and labor for offshore wind projects by: focusing on platform and tower technologies that can be produced in existing manufacturing facilities or using onsite manufacturing approaches in California; supporting floating offshore wind system research on integrated components supplied by a single manufacturer; and evaluating training programs to develop and enhance workforce capabilities for offshore wind projects.
5. Study the seismic vulnerability of floating platform mooring and anchoring systems: This research would evaluate whether the performance of mooring and anchoring systems could be affected by earthquakes and undersea slides prior to developing technical solutions to mitigate any seismic vulnerabilities that are identified.
6. Conduct a comprehensive study on port infrastructure in California and develop technical solutions to identified gaps: This study could assess the current state of port readiness and identify key deficiencies to support deployment of offshore wind projects (for example, lay-down space, water acreage, vertical clearance, need for additional dredging, competition for usage of port facilities). Such a study would help develop a port infrastructure enhancement plan, identify technical solutions, and estimate required investment.

Environment and Resource Research Recommendations

7. Conduct additional wind resource studies offshore of California: Collecting open access data on wind resource, generation profiles, and load shapes by placing additional buoy-mounting LIDAR (a technology similar to radar that uses light rather than sound) off the California coast in targeted locations would help improve characterization of the

resource. This in turn would inform the integrated resource planning model used by the California Public Utility Commission to help coordinate GHG reduction and clean energy expansion across load-serving entities. Accurate data would also help project developers formulate business cases for offshore wind investment.

8. Develop technologies to reduce wildlife impacts, including smart curtailment and deterrence: Research on advanced technologies such as smart curtailment (a sensor to stop turbine rotation when seabirds are in close proximity) and sonar deterrence (using sonar to prevent entanglement of marine animals with mooring lines and cabling) may help reduce negative effects on ecosystems from offshore wind projects.
9. Expand state-led environmental studies along the California coast to fill gaps in existing research: There are ongoing research efforts to study ecosystem effects of offshore wind farms in California, including research being conducted by Schatz Center, Point Blue Conservation Science, and the Conservation Biology Institute. The CEC could track findings from these gap analyses and fund additional studies to address identified needs. Many resulting research initiatives would likely involve studies encompassing both state and federal waters, potentially requiring collaboration with federal research agencies.

Other Research Recommendations

10. Assess the offshore wind installed capacity that complements solar generation and is feasible: This assessment could evaluate the potential of multiple levels of offshore wind development through various studies to clarify costs and benefits of transmission upgrades and identify cost and technical feasibility of long distance subsea high voltage direct current transmission, develop a guidebook on state permitting processes, and identify the potential or need for state-led mechanisms to reduce costs to ratepayers and developers for early projects.
11. Conduct a comprehensive study on the total value proposition of offshore wind development, including grid and macroeconomic benefits: This research would evaluate and quantify grid, employment, and environmental benefits of offshore wind for California in one comprehensive report. A complete valuation could improve the business case for investment and support further state-funded research, while facilitating the evaluation of offshore wind to other resources.

Conclusion

The project team concludes that there is a need for state funding and RD&D support to advance offshore wind in California. Numerous barriers to offshore wind industry development exist, including technology preparedness, infrastructure readiness, and non-technical issues like stakeholder concerns, data gaps, and untested planning processes. This report developed recommendations to help address technology and deployment barriers using CEC RD&D funds. The CEC may also be able to engage in a supporting role on initiatives to resolve barriers outside of this scope.

CHAPTER 1: Introduction

The California Energy Commission (CEC) contracted with Guidehouse Inc. to review and assess research, development, and deployment (RD&D) opportunities to support cost-effective offshore wind project development off the coast of California. This project focused on identifying RD&D opportunities to remove or reduce technological, manufacturing, logistical, and supply chain barriers to lower the development risk of offshore energy projects.

Project Purpose

Offshore wind may contribute to meeting the requirements outlined in Senate Bill 100 (De León, Chapter 312, Statues of 2018). SB 100 accelerates the renewables goal for California to 60 percent by 2030 and establishes a 100 percent renewable and carbon-free electricity goal by 2045.[1] California has helped pioneer land-based wind energy in the United States. As of 2019, the in-state installed wind capacity is the fifth largest in the United States, with installed capacity of 6 gigawatts (GW).[2] Opportunities to further expand land-based wind energy in California are limited due to spatial and onshore wind resource constraints. These onshore obstacles, combined with modeling showing significant offshore wind resource potential, have helped drive growing interest in offshore wind energy generation in California. The National Renewable Energy Laboratory (NREL) has identified that California has a technical resource potential of 112 GW of offshore wind. Of this resource potential, 96 percent (108 GW) is located in water deeper than 60 meters, where floating platform technology is more suitable to support wind turbines.[3]

In 2016, per the request of Governor Edmund G. Brown, Jr., the Bureau of Ocean Energy Management (BOEM) established the BOEM California Intergovernmental Renewable Energy Task Force to start planning for future renewable wind energy development in federal waters off the coast of California.[4] Since its formation, the task force has held over 80 meetings with elected officials, stakeholders, and the general public while supporting offshore site evaluation and data aggregation efforts. California faces unique challenges in the implementation of offshore wind turbines, including a lack of technical history and technological maturity of floating systems, deep coastal waters, high technology costs, sensitive habitats, and untested permitting processes.

---

[1] Online resource for SB 100 information.

[2] Per CalWEA WINDExchange, at least 5,842 megawatts (MW) of installed capacity are operating in the state, the fifth largest fleet in the United States.

[3] Referencing technical offshore energy potential per NREL's *Potential Offshore Wind Energy Areas in California* study from 2016.

[4] Per the California offshore wind databasin information portal.

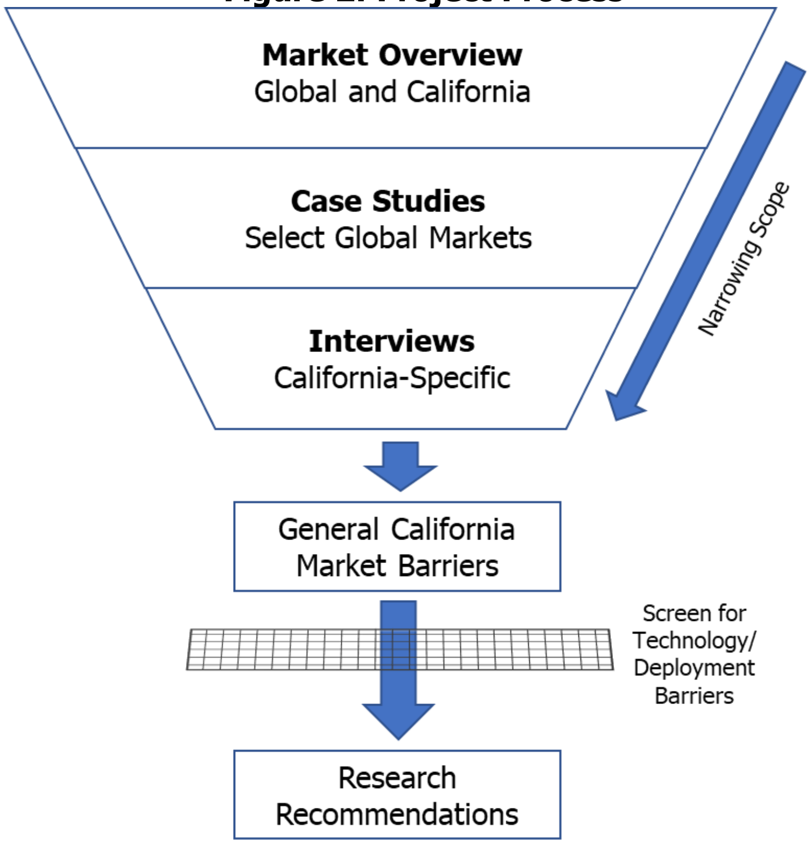
The purpose of this study is to support the development of cost-effective offshore wind projects and to identify RD&D opportunities to remove or reduce technological, manufacturing, logistics, and supply chain barriers. Objectives of this study include the following:

- Understand the current market state of floating offshore wind technology.
- Identify specific barriers to commercial scale offshore wind development in California.[5]
- Develop research recommendations to advance offshore wind in the state due to the following challenges: RD&D, project development, technology, manufacturing, installation, operating, transmission and permitting, and regulatory.
- Further evaluate RD&D funding to support technology development with a view toward future technological maturity.

Project Approach

The project team used a five-step process to understand the state of the offshore wind market as well as floating offshore wind technologies (Figure 2).

Figure 2: Project Process



Project team research process.

Source: Guidehouse, 2020

---

[5] Commercial scale is defined within this study as projects of at least 150 MW in size. The project team identified this figure through a variety of interviews; it also represents the minimum size of projects proposed off the coast of California.

An initial review of the global and California offshore wind markets provided context and allowed the project team to identify global trends, emerging markets, and industry leaders. The team then used case studies and interviews to glean in-depth perspective on the California market and floating technology research opportunities from stakeholders with direct industry knowledge. From these initial steps, the project team identified 10 overarching barriers to offshore wind development specific to California and developed 11 research recommendations to address technology and deployment barriers through RD&D funding.

The project team conducted 39 interviews, organized and met with a technical advisory committee (TAC), and attended the inaugural Pacific Rim Offshore Wind Conference in San Francisco to gain new insights.[6] The team also performed a detailed literature review to develop five market case studies. Initial research was conducted from August 2019 to February 2020. The list below details the goals and analyses conducted for each step of the project.

- Understand market: Before assessing various strategies, the project team conducted a literature review to characterize the market and status of floating offshore wind technologies. Market characterization started at the global level before focusing on the California market. The team used this step to further understand the barriers to, and potential benefits of, offshore wind in California and to frame future discussions with industry stakeholders.
- Conduct market case studies: The project team identified and developed five case studies to understand the drivers that led to the emergence of a successful offshore wind market in other states and countries. Four case studies focused on fixed and floating international markets including the United Kingdom and Scotland, East Asia (China, Taiwan, South Korea, and Japan), France, and the Netherlands; the fifth case study centered on the East Coast of the United States. The team chose markets to provide the most insight to California.
- Interview stakeholders: The project team interviewed key industry stakeholders from five market perspectives: project developers, technology developers, planning agencies and load-serving entities (LSEs), research institutes, and interest groups including environmental stakeholders and industry trade groups. Interviews focused on specific barriers and research opportunities regarding the California market.
- Analyze barriers: Using relevant literature and stakeholder interviews, the project team worked to identify and categorize barriers to commercial-scale floating offshore wind market development in the state of California. The team synthesized barriers most frequently identified by interviewees for inclusion. The 10 key barriers include technical, developmental, and external obstacles.
- Synthesize recommendations: Finally, the project team synthesized all information into a set of themes and opportunities for state involvement in the development of a

---

[6] Thirty-one interviews focused on report content and recommendations, while 8 further interviews supported case studies found in Chapter 3 and Appendix B. The Technical Advisory Committee consisted of the California Energy Commission, California Public Utilities Commission, Ocean Protection Council, Bureau of Ocean Energy Management, American Wind Energy Association, and the California Independent System Operator. Committee members were asked to review the report and provide preliminary feedback on project process and draft conclusions.

commercial offshore wind market in California. Recommendations focus solely on technology, environment, and deployment research opportunities. The team designed these recommendations to support RD&D funding initiatives that help deploy cost-effective offshore wind projects in California. Recommendations are tailored to help achieve a clean energy power system that ensures equitable, reliable, and safe services.

Research Database

As part of this research, the team collected more than 200 studies that are compiled in a research database posted on the CEC's website.[7] This database focuses on studies completed in the United States from January 2017 to January 2020, in addition to ongoing initiatives started during this period. Select studies conducted prior to 2017 or with a focus on wind energy areas outside of the United States were included if they contained findings that may be applicable to the California market. Studies are sorted into ten topical themes (for example, industry overview, environmental, or physical technology) based on the focus area of each report. This resource could be useful to support future studies in the area. The project team recommends periodic updates to this database to capture new research efforts and further developments in global markets that may provide lessons for California.

---

[7] This database can be accessed at Offshore Wind Research and Development Database.

CHAPTER 2:
Global and California Offshore Wind Market Overview

The global offshore wind industry has developed from nascency to commercial scale over the past decade. As offshore wind technologies have matured, they have strengthened the business case and justified regulatory support for further offshore wind energy development. In addition to technology advancement, a variety of factors have driven market expansion, including national and state targets and mandates, increased investment in projects and infrastructure, and an increasingly competitive levelized cost of energy (LCOE).[8] This chapter discusses offshore wind technologies, market drivers, and market opportunities.

Technology Overview

Offshore wind technology designs fall into two main categories: fixed and floating. Most fixed turbines are anchored to the seabed through a solid monopile, tripod, or jacket.[9] These designs prevent dynamic motion and do not allow the machine to move significantly in response to wave or wind pressures. Fixed foundations typically exhibit a maximum usable water depth of 50 meters to 60 meters; beyond this depth, fixed wind designs are not economically or technically feasible.[10] Floating platforms unlock offshore wind access in ocean waters with depths greater than 60 meters.

Off the coast of California, a steep continental shelf and increased wind speeds combine to make floating turbines the primary technically feasible option.

Platform Technology

Figure 3 illustrates the four primary types of floating platforms, which include semi-submersible, spar-buoy, tension leg, and barges. Several entities are developing hybrid technologies that fuse key elements of two or more of the four main platform designs.

---

[8] LCOE is a measurement of electricity cost that attempts to capture lifetime costs divided by projected energy production to achieve a cost per unit value. LCOE allows for the comparison of different technologies that may have different life spans, scales, and fixed and variable costs. This is further explained in this slide presentation from the Department of Energy.

[9] Solid monopile foundations are piles driven into the subsurface for stability. Jacket and tripod platforms involve three to four connection points with the subsurface. Iberdrola, a project developer, is one such source of information on these designs.

[10] U.S. Department of Energy, *2018 Offshore Wind Technologies Report*, 2019.

Figure 3: Floating Offshore Wind Designs

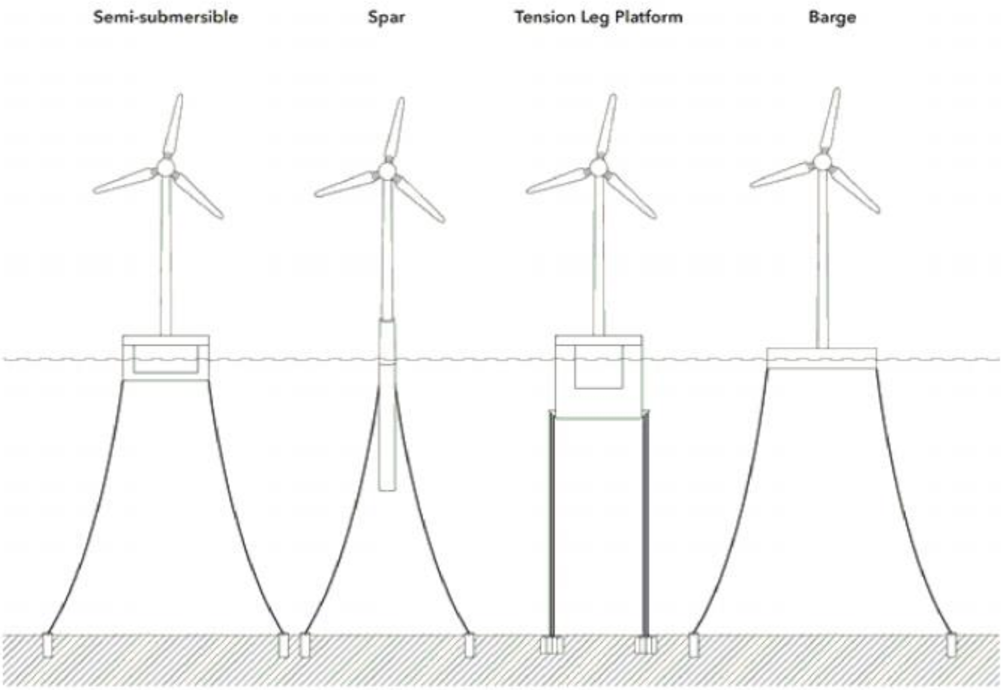


Figure illustrates four types of floating offshore wind platform designs: semisubmersible, spar, tension leg platform, and barge.

Source: DNV GL, *Floating Wind Turbine Structures* (2018)

Semi-Submersible

Semi-submersible platform technology uses a ballasted or anchored substructure that sits below the waterline when installed. Mooring can vary based on the substructure design. One prominent semi-submersible design, Principle Power's WindFloat, relies on three mooring cables anchored to the seafloor from each nexus of a triangular substructure. This design allows the platform to maintain relative stability in harsher conditions while still being able to move dynamically in response to wind and wave pressures. Many semi-submersible platforms, WindFloat included, are designed to be assembled quayside and towed by barge to project sites.[11] As of 2019, semi-submersible platforms represented 94 percent of the active and proposed floating project capacity.[12]

Spar-Buoy

Spar-buoy designs typically use a cylindrical, ballast-stabilized base with a high center of buoyancy. Such designs rely on this high center of buoyancy, which sits above the center of gravity, to help maintain stability. Spar-buoy system turbines are often assembled offshore, requiring naval heavy lift cranes and dynamic stabilization vessels. The first floating wind farm in the world, Hywind Scotland, implemented a spar-buoy platform system named Hywind,

---

[11] Quayside refers to a wharf or other built structure on the shore of a harbor and the land adjacent to it used for naval infrastructure and offshore construction.

[12] U.S. Department of Energy, *2018 Offshore Wind Technologies Report*, 2019.

designed and operated by Equinor. According to the U.S. Department of Energy (USDOE), Equinor's Hywind Tampen project is the only other spar-buoy proposal in development aside from the 2-megawatt (MW) Sakiyama test turbine in place off the coast of Japan.[13]

Tension Leg

Tension leg platforms connect semi-submerged platforms to the seabed through tensioned mooring lines. This design reduces dynamic capability of the platform, potentially increasing stability at the cost of placing significant pressure on the system's mooring and anchoring components. Final installation of tension leg platforms can still prove challenging due to final mooring requirements. Three pilot projects using tension leg designs have been proposed in Spain, Germany, and France, all of which have been approved.[14]

Barges

Barge designs typically involve a floating base made of metal or concrete. Unlike other designs, barge designs do not require complex substructures or active ballasting components. Barges have not gained significant traction in the market because the technology remains relatively less-developed than semi-submersible and spar-buoy designs for applications with larger turbines. According to the USDOE, Ideol's 2 MW Floatgen test project off the coast of France and the 3 MW Hibiki demonstrator off the coast of Japan remain the only installed barge platforms as of September 2019. Ideol's 24 MW Eolmed project remains the only other approved project identified using a barge design.[15]

Hybrid Technologies

A variety of hybrid technologies fusing components from two or more of the four key designs are under development or in the prototype phase. Among them is the Tetra system designed by Stiesdal Offshore Technologies; the design consists of a base capable of being altered for application within semi-submersible, spar-buoy, or tension leg platform designs. In February 2019, Stiesdal gained approval for a 3.6 MW TetraSpar demonstration project off Norway.[16] Other hybrid proposals include platforms capable of supporting multiple turbines and substructures that combine hydrokinetic or wave generation capability with wind generation. Multiple multi-turbine platform designs have reached the demonstration phase, but it remains unclear which systems incorporating multiple turbines or multiple generation technologies will prove to be technically feasible or cost-effective.

Turbine Technology

Land-based and offshore wind turbines have increased in size and power rating over the past 30 years. Current and proposed projects typically use turbines rated at 5 MW or higher, more than 10 times the power rating of the first offshore units installed in 1991. New projects benefit from these machines operating at previously unseen scales. Increased turbine size can

---

[13] U.S. Department of Energy, *2018 Offshore Wind Technologies Report*, 2019; table with proposed project pipeline on p. 33-34.

[14] U.S. Department of Energy, 2018 Offshore Wind Technologies Report, 2019

[15] U.S. Department of Energy, 2018 Offshore Wind Technologies Report, 2019; the Floatgen demonstrator went into operation in 2018.

[16] Stiesdal, Shell, and Innogy are partnering on the TetraSpar demonstration project.

contribute significantly to cost reductions at a project level due to higher turbine hub heights.[17] Higher turbine hub heights allow for access to better quality wind resources and reduced exposure to surface friction, helping generate higher capacity factors.[18] In addition to heightened capacity factors, supersized turbines reduce operational expenses through lower maintenance costs per megawatt of installed capacity and the potential to produce the same amount of electricity with fewer units. Public acceptance of these supersized turbines may be higher in offshore applications. Offshore turbines can reduce potential visual impact compared to land-based projects depending on the project's distance from shore. As turbine technology continues to develop, floating platforms may facilitate greater growth in the power rating of turbines on the market by improving access to better offshore wind resources.

The turbine manufacturer market is highly consolidated; Siemens Gamesa and MHI Vestas combined claim 70 percent of global capacity.[19] MHI Vestas has developed 8.4 MW and 9.5 MW rated turbines that are available, and Siemens Gamesa introduced the 10 MW generation capacity and 193 meter rotor diameter turbine, known as SG 10.0-193 DD, in 2019.[20] Other market players are working to introduce units with even higher ratings (12 MW+). GE Renewable Energy introduced one such system, the Haliade-X 12.0 MW rated turbine, in July 2019.[21] Units as large as 16 MW have been proposed, and it is unlikely this capacity rating represents an upper bound.

Global Market Overview

Since the first eleven 450 kilowatt (kW) turbines were installed at the Vindeby Wind Farm off the Danish coast in 1991, the offshore wind industry has experienced significant technological development and pipeline growth. According to the USDOE, 176 offshore wind projects operate around the world with a total capacity of 22,592 MW. An additional 838 projects are in various stages of development, including planning, site control, permitting, approval, financial close, and construction.[22] On hold, cancelled, and decommissioned projects are excluded for the purpose of this report.

The majority of projects in the global pipeline (55.9 percent) fall within the planning phase, wherein a proposal has been made, but no claims to a project site have been tentatively granted. Only around 39 percent of capacity-weighted projects, accounting for about 103 GW,

---

[17] Altitude at which the rotor, hub, and nacelle are positioned.

[18] Veers, Paul et al., "Grand Challenges in the Science of Wind Energy," *Science*, vol. 366, issue 6464, October 25, 2019. Capacity factors are generally defined as the percentage of theoretical maximum output a generation asset like a wind turbine achieves in a year. As described by the Department of Energy, this affects project economics and is considered a measure of reliability.

[19] U.S. Department of Energy, 2018 Offshore Wind Technologies Report, 2019.

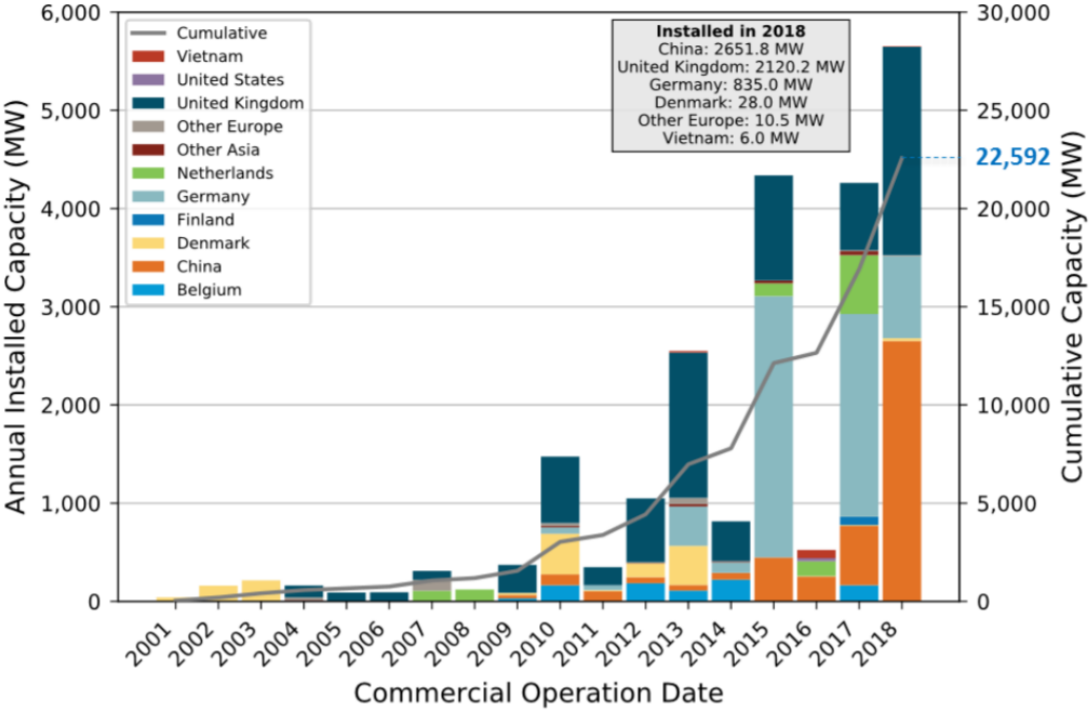
[20] For more detail, see Siemens Gamesa's product website page for the SG 10.0-193 DD. Siemens Gamesa, 2018.

[21] GE Renewable Energy's Haliade-X has an estimated 63 percent capacity factor and has a maximum height of 853 feet.

[22] U.S. Department of Energy, 2018 Offshore Wind Technologies Report, 2019.

have at least secured final approval. This value includes all installed capacity in operation or under construction. Figure 4 details the projects that have come online since 2001 by country.

Figure 4: Global Offshore Wind Installed Capacity by Year: 2001-2018



Global installed capacity of offshore wind energy has grown significantly over the past decade.
Source: USDOE, *2018 Offshore Wind Technologies Report* (2019)

A record capacity of 5,652 MW of offshore capacity was installed in 2018, and a global pipeline of an additional 838 projects with a capacity of 272,000 MW are spread across the remaining development phases. Three markets — the United Kingdom (UK), Germany, and China— account for 82.1 percent of the global installed capacity. Historical European dominance being challenged by rapid growth in Asia, led by China. At the end of 2018, 42.6 percent of global offshore wind projects under construction were sited off the coast of China, roughly equivalent to the ongoing construction in the UK and Germany combined.[23] It remains to be seen if development in new markets (for example, Poland and Portugal) can extend European leadership in the industry.

Global Floating Platform Market Pipeline

Around 58 percent of United States and 80 percent of European offshore wind resources exist in waters deeper than 60 meters, a depth beyond where fixed turbine technologies are traditionally viable.[24] The floating offshore wind industry remains nascent but is growing rapidly. Appendix A contains a database of floating offshore wind projects. As Table 1 shows, the array of proposed projects brings the total global pipeline to just under 5 GW.

---

[23] All statistics referenced are drawn from data included by the U.S. Department of Energy in the *2018 Offshore Wind Technologies Report*.

[24] As described in U.S. Department of Energy, *2018 Offshore Wind Technologies Report*, 2019, per NREL studies conducted on offshore wind resource potential.

Table 1: Global Floating Wind Project Pipeline

Project Status	Number of Projects	Proposed Capacity
Installed	8	46 MW
Approved	14	200 MW
Permitting	2	488 MW
Proposed	14	4,162 MW
Total	**38**	**4,896 MW**

The global floating offshore wind pipeline was just under 5 GWs in early 2019.
Source: USDOE, *2018 Offshore Wind Technologies Report* (2019)

Globally, interest in floating offshore wind has increased significantly in recent years following technical proof of concept, declining costs, and shifting political headwinds. Semi-submersible platform technologies leapt from the laboratory to the field through numerous successful pilots. Hywind Scotland, the world's first successful commercial demonstration project, achieved record capacity factors of around 65 percent in 2018.[25] Improved capacity factors, access to better wind resources, and increased turbine power rating combined to improve the cost projections of floating projects. Politically, the nuclear disaster at Fukushima in 2011 prompted both the Japanese and South Korean governments to explore the development of alternate clean energy sources, including accessing deep water offshore wind resources.[26] Each government has proposed commitments in excess of one GW floating capacity. Newly passed or increased renewable energy targets in multiple global markets (for example, Taiwan, UK, Germany, and Hawaii) have also helped incentivized a push toward the expansion of floating offshore energy generation.

United States Market Pipeline

The 30 MW rated Block Island Wind Farm off the coast of Rhode Island, the first offshore wind project in the United States, came online in 2016. In the years since, interest in fixed turbine project development along the East Coast and Great Lakes has greatly increased. A variety of actors, including state governments, utilities, and foreign and domestic technology and project developers, have pushed the expansion of the project development pipeline.

As of 2018, the project development pipeline in the United States stood at 25,824 MW, with 21,224 MW under exclusive site control (defined as a project that has, at minimum, secured the rights to its chosen project site) and 4,600 MW in unsolicited applications or proposals for areas that have not been leased.[27] Aside from Block Island, no projects have advanced to the stage of receiving final regulatory approval, as Figure 5 shows. The United States pipeline is

---

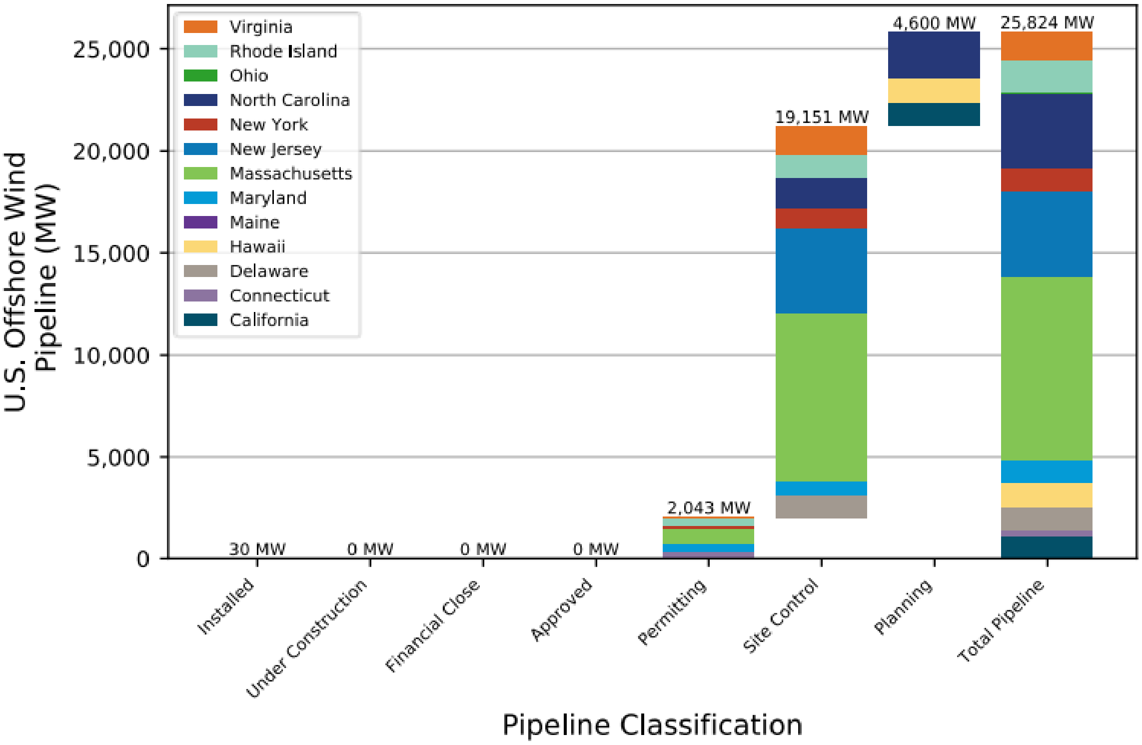
[25] Per a February 2018 Equinor press release.

[26] Reinforced through multiple stakeholder interviews and information gleaned from a case study of the East Asian offshore wind market.

[27] Exclusive site control is defined as a project that has, at minimum, secured the rights to its chosen project site. All numbers included in this section were derived from the 2018 Offshore Wind Technologies Report released in 2019 and may not reflect the current market status as of 2020.

being driven by a collection of eight states including New York, Massachusetts, and New Jersey, which combined account for at least 22.5 GW of project commitments through 2035.

Figure 5: United States Market Pipeline in 2018



The market pipeline in the United States stands at nearly 26 GWs as of 2018, though only 30 MWs have been installed.

Source: USDOE, *2018 Offshore Wind Technologies Report* (2019)

Nearly all project proposals are sited in federal waters and fall under the jurisdiction of the federal BOEM. In December 2018, BOEM auctioned three adjacent call areas off the coast of Massachusetts, garnering three winning bids of $135 million apiece from three separate parties.[28] Each individual bid represented a value more than three times the previous price record of $42 million proposed for a call area on the East Coast. Despite stakeholder criticism that this winner-takes-all bidding process could lead to increased costs passed to energy consumers and disincentivize local stakeholder engagement, these bids were held up as examples of the increased demand for offshore wind in the northeastern United States.[29] In total, the BOEM has designated 13 active call areas in the United States, which are estimated to have an energy resource potential of about 21 GW. As of December 2019, existing state commitments include no less than 22 GW in aggregate by 2035, implying the need for further call areas to satisfy existing demand and accommodate new or elevated targets.

---

[28] Call areas are regions of ocean designated by BOEM as potential areas for offshore wind development. These zones may be leased through an auction following a call for nominations, a process to gauge interest from potential developers. Wind energy areas (WEAs) may form a subset of a call area depending on which portions of ocean are contained in a winning auction bid. The full process is described through this presentation from BOEM.

[29] Based on interviews with industry experts conducted for this report.

California Market Pipeline

California's passage of SB 100 continued to change the landscape for clean energy development in the state and once again increased demand for new clean energy generation sources. The state has an estimated 112 GW of accessible offshore wind resources,[30] roughly 10 percent greater than the installed capacity of the entire land-based wind industry in the United States as of 2019.[31] This resource is largely inaccessible via traditional fixed-bottom offshore wind technologies due to the steep continental shelf on California's Pacific Coast.

Following the success of the Hywind Scotland project, two unsolicited proposals were submitted to BOEM in 2016 for project development off Humboldt Bay and Morro Bay. These projects, shown in Figure 6, were known as Redwood Energy and Trident Winds (now Castle Wind), respectively. BOEM responded to these unsolicited applications by opening three call areas off the coast of California on October 18, 2018, with a total resource potential of approximately 8.4 GW.[32] Two of these call areas encompass the sites targeted in the initial Redwood Energy and Castle Wind proposals, while the third is situated in proximity to the Diablo Canyon Nuclear Power Plant, which will be decommissioned in 2025.[33] Fourteen firms responded with interest to a BOEM call for nominations for one or more of the three call areas, which Table 2 outlines. Discussions between the BOEM California Intergovernmental Renewable Energy Task Force and stakeholders continue on adjustments or additions to the existing Call Areas.[34]

Interest was well distributed and relatively consistent across all three call areas; 10 firms provided nominations for part or all of Humboldt Bay compared to 11 for Morro Bay and Diablo Canyon. As of December 2019, BOEM has yet to grant site control to any entity and is preparing to hold lease auctions on call areas in 2020 or 2021.[35] This has not prevented respondents from engaging with local load-serving entities and community stakeholders. One such example is Castle Wind, which signed a non-binding memorandum of understanding with Monterey Bay Community Power in August 2019 to enter into a future power purchasing agreement (PPA) for their proposed 1,000 MW installation off of Morro Bay.[36] This agreement followed separate agreements secured between Castle and the City of Morro Bay and fishery

---

[30] Referencing technical offshore energy potential, per NREL's Potential Offshore Wind Energy Areas in California study from 2016.

[31] WindExchange, a product of the USDOE, estimates 97,963 MW of installed capacity in the United States as of Q2 2019.

[32] U.S. Department of Energy, 2018 Offshore Wind Technologies Report, 2019; per NREL studies conducted of offshore wind resource potential.

[33] From the PG&E website containing information on the PG&E Diablo Canyon Decommissioning Engagement Panel, 2019.

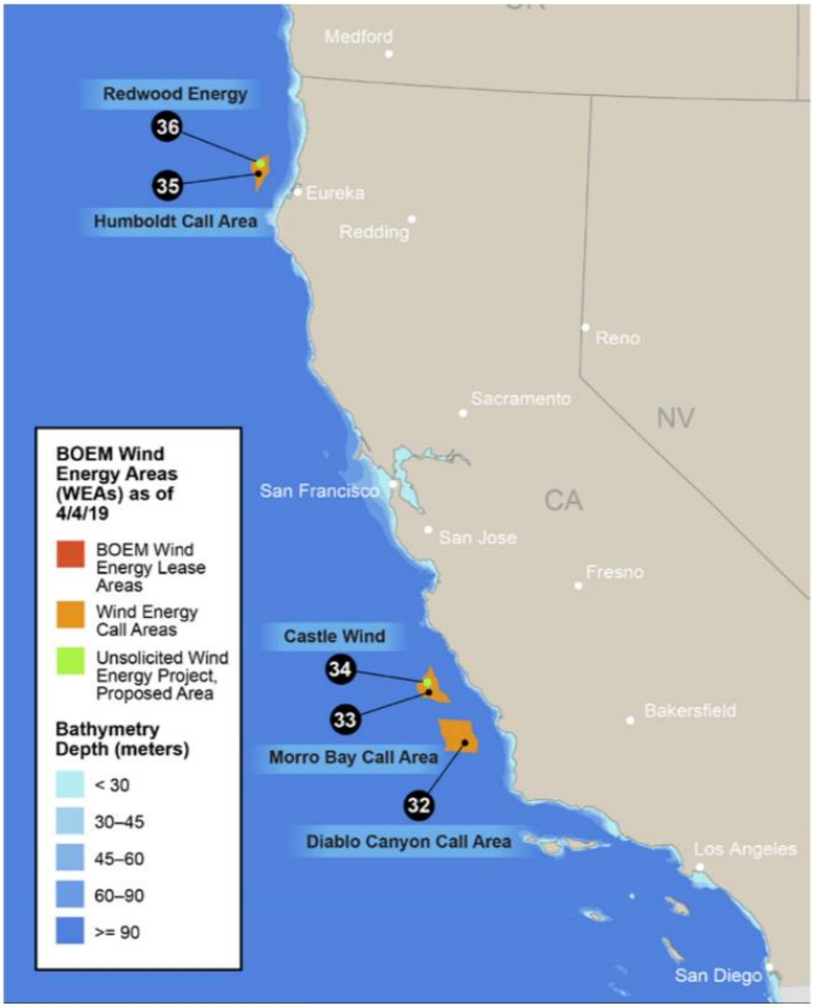
[34] Updates on workshops and Task Force proceedings can be found on the Offshore Renewable Energy portal on the California Energy Commission website.

[35] BOEM. The Path Forward for Offshore Wind Leasing. 2019.

[36] Various media sources, including "MBCP signs up for about 1,000 MW of California's future floating wind energy" from Windpower Engineering and Development, 2019.

organizations in 2018. It remains to be seen if these and other outreach efforts by prospective developers will be taken into consideration during BOEM's review process, which may award a final lease based either solely on highest bidder or on a collection of factors known as a multi-factor auction.

Figure 6: California Bureau of Ocean Energy Management Call Areas



Map illustrates the location of each of the three BOEM call areas off the coast of California.

Source: DNV GL, *Floating Wind Turbine Structures* (2018)

California Resource Planning Process

Multiple categories of load-serving entities operate in California, including large investor-owned utilities, municipal utilities, community choice aggregators (CCAs), and competitive retail service providers. The California Public Utilities Commission (CPUC), CEC, California Independent System Operator (ISO), and California Air Resources Board are the state agencies primarily responsible for facilitating long-term planning for California's electric sector and implementing related policy. In 2015, the passage of SB 350 (De León, Chapter 547, Statues of 2015) established greenhouse gas (GHG) reduction targets of 40 percent below 1990 levels and 50 percent renewable energy procurement by 2030 (later increased to 60 percent by SB 100).[37] SB 350 also mandated the establishment of an integrated resource planning (IRP) process to help coordinate GHG reduction and clean energy expansion across load-serving entities. The goal of IRP is to reduce the cost of achieving GHG emissions reductions by looking across individual load-serving entities and energy resource types to identify solutions to improve reliability and reduce overall cost.[38]

Table 2: Bureau of Ocean Energy Management California Call Area Nominations

No.	Nomination	Humboldt	Morro Bay	Diablo Canyon
1	Algonquin Power Fund	Partial		Partial
2	wdp Offshore Alpha	All	All	All
3	Avangrid Renewables	All	All	All
4	Castle Wind		All	
5	Cierco Corporation	All	All	All
6	EDF Renewables		All	All
7	EDP Renewables		All	All
8	EC&R Development	All	All	All
9	Equinor Wind	All	All	All
10	Mission Floating Wind		All	All
11	Northcoast Floating Wind	All		
12	Northland Power America	All	All	All
13	Redwood Coast Energy Authority	Partial		
14	Mainstream Renewable Power	Partial	Partial	Partial

Eleven firms requested control of the entirety of at least one call area, represented in this table as All, while three requested partial control of a subsection of at least one call area, represented in this as Partial.

Source: Bureau of Ocean Energy Management, *Call for Nominations* (2018)

The IRP operates on a 2-year planning cycle. The first year of the cycle is designed to evaluate the appropriate GHG emissions planning targets for the electric sector and load-serving entities informed by the California Air Resources Board's Climate Change Scoping Plan, and to identify the optimal mix of system-wide resources capable of meeting these GHG planning targets. CPUC decides on the appropriate GHG planning target for the electricity sector and creates the Reference System Plan (RSP) to meet this target. The CPUC uses this RSP to establish filing requirements for LSEs. The second year is designed to consider the suite of actions each load-serving entity proposes to take to meet these GHG targets. As each load-serving entity has its own local constraints and opportunities to consider, each files its own plan. The CPUC reviews,

---

[37] CPUC. Clean Energy and Pollution Reduction Act of 2015 (SB 350). Accessed 2020.

[38] 2019 IRP Proposed Reference System Plan slide deck, provided by the CPUC, 2020.

modifies, and aggregates these plans into a preferred system plan that achieves the same goals as the RSP. Based on the approved preferred system plan, the CPUC considers authorizing load-serving entities to procure resources within the next 1-3 years to meet GHG planning targets. The California ISO receives portfolio(s) from both the RSP and the preferred system plan as inputs into its transmission planning process.

Resource portfolios selected under the RSP in year one of the IRP process are determined through the CPUC's IRP model, RESOLVE.[39] RESOLVE is a capacity expansion model used to determine an optimal least-cost portfolio that meets forecasted electricity demand, reliability needs, and GHG targets given projected technology costs and other key assumptions. RESOLVE selects resources for the RSP from a list of candidate resources.[40] Candidate resources represent the electricity resources available to California to meet future grid needs and are characterized using publicly available data on technology cost, resource potential, and operations.

Offshore wind is an optional candidate resource for the 2019-2020 IRP cycle. It is not included in modeling as a default resource but may be added for selection in sensitivity analyses.[41] Two sensitivity analyses related to wind energy have been run in RESOLVE: one making offshore wind available for selection, in addition to the default 3 GW of out of state land-based wind from Wyoming and New Mexico on new transmission, and another in which offshore wind is available but the out of state wind is not.[42] When made available to RESOLVE, offshore wind is selected as part of the 2030 portfolio only in the most stringent GHG reduction scenario,[43] with approximately 1.6 GW of offshore wind selected by RESOLVE when out of state land-based wind is excluded. When out of state land-based wind is allowed, this value falls to just 6 MW.

As resource assumptions for offshore wind improve, inclusion as a default resource available for selection in IRP modeling may become appropriate.

Global Market Drivers

Multiple market drivers are supporting the early expansion of floating offshore wind energy, including new access to a large untapped resource, improved technological maturity, regulatory support, project cost-competitiveness, and a variety of potential environmental, economic, and visual benefits. Many of these factors expected to benefit expansion of the

---

[39] RESOLVE Model Overview, IRP Modeling Advisory Group, E3, 2016.

[40] IRP Offshore Wind Coordination with BOEM and NREL, presented at the CPUC on January 17, 2020.

[41] Optional candidate resources typically lack the robust data supporting cost and production estimates that support default candidate resources. They may become a default resource as more data is collected to inform the IRP evaluation process. Sensitivity analyses are unique model runs used to understand how alternate inputs and scenarios change the final portfolio selected.

[42] Out of state wind on new transmission is a default assumption in the 2019-2020 IRP cycle.

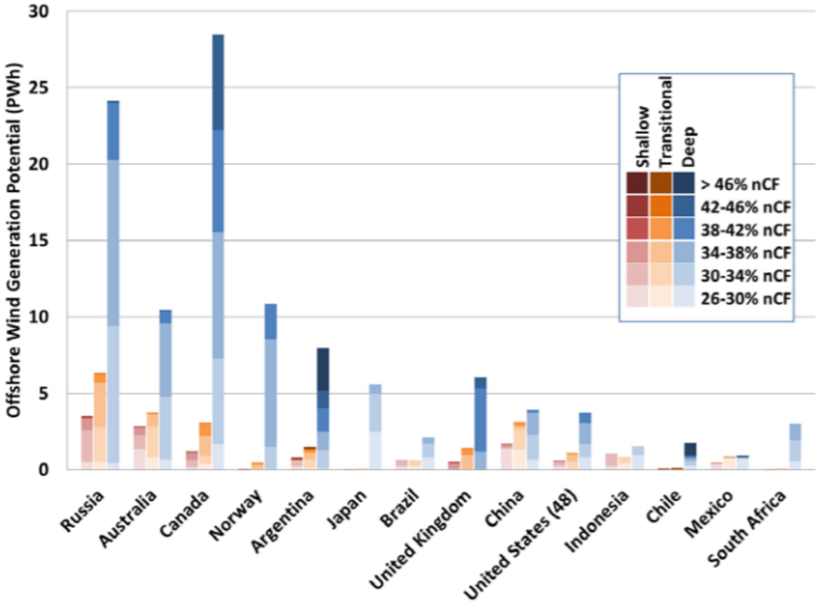
[43] California Air Resources Board GHG targets for the 2019-2020 IRP are set between 30 million metric tons (MMT) and 53 MMT by 2030. The most stringent allowance is defined as 30 MMT.

floating wind industry in the coming decade also supported development of the fixed offshore wind industry.[44]

Large Untapped Resource

The vast majority of global offshore wind potential exists in waters greater than 60 meters deep.[45] As Figure 7 shows, many nations of the world, including nearly all those bordering the Pacific Rim, exhibit significant deep water offshore wind potential within their 200 nautical mile exclusive economic zones.[46]

Figure 7: Offshore Wind Energy Potential in Select Nations



Significant offshore wind potential exists within the exclusive economic zones of many large countries as measured in petawatt hours (PWh) or million gigawatt hours (GWh).

Source: National Renewable Energy Laboratory, *An Improved Global Wind Resource Estimate for Integrated Assessment Models (2017)*

Deep water resource was largely inaccessible prior to the development of floating offshore wind technologies and remains untapped due to the nascency of the industry. Floating technology has the greatest potential in countries with limited onshore renewable resource potential that are experiencing significant growth in demand for generation capacity due to a developing economy, new renewable energy standards, or a combination of the two. This trend holds in the United States, as the two states generating the greatest interest from the floating offshore wind industry, California and Hawaii, have 100 percent renewable and zero-carbon and 100 percent renewable energy targets, respectively, and expensive land prices with limited remaining land-based wind opportunities. Despite increased solar, storage, and

---

[44] Based on a set of interviews with industry experts conducted for this report.

[45] National Renewable Energy Laboratory, An Improved Global Wind Resource Estimate for Integrated Assessment Models, 2017.

[46] Exclusive Economic Zones are oceanic areas within 200 nautical miles of a nation’s coastline within which that nation has sole right to conduct economic activities like resource extraction, fishing, and energy production.

onshore wind development in both states, there is uncertainty on which pathway will be least-cost to meet 100 percent renewable and zero-carbon energy in California or 100 percent renewable electricity in Hawaii without offshore energy development.[47]

Improved Technological Maturity

Floating offshore wind technology has matured rapidly since 2009. This progress can be seen through technology readiness levels (TRLs), a nine-step uniform metric that captures phases of technology development. Levels range from TRL 1, the ideation phase, to TRL 9, where a technology has been proven in applicable settings. Technology that achieves TRL 9 can be considered ready for commercial deployment.[48] As Figure 8 shows, spar substructures reached TRL 9 following the installation of the Hywind Scotland project in 2017, while semi-submersible structures and barges were projected to reach TRL 9 by the end of 2020. Certain types of semi-submersible and barge platforms, including the semi-submersible WindFloat by Principle Power and the Floatgen barge by Ideol, can already be considered to have reached TRL 9 following successful demonstration projects. Readiness of tension leg platforms and hybrid technologies (not included in Figure 8) remains on more distant timelines.

While the geographic range for spar technologies remains limited due to their need for deep ports with suitable draft depths of up to 250 feet, semi-submersible and barge technologies promise to expand the floating pipeline globally. Specific models of semi-submersible and barge substructures have already been proposed for use in the California market on projects within the Humboldt Bay and Morro Bay call areas.[49]

Mature floating offshore technology also exhibits technological characteristics that may eventually make it competitive or preferable to fixed turbines in certain locations, even with water depths accessible to both technologies.[50] Potential advantages identified in interviews with industry experts include lighter and portable base components, scalable quayside manufacturing and assembly, and simplified offshore installation. These advantages may allow floating platforms to scale through automated production in a way fixed technology cannot. Floating developers also have the opportunity to build off the knowledge base established by fixed-bottom developers over the past 30 years. According to the USDOE, these factors may contribute to floating technology achieving a steeper rate of cost reduction than fixed-bottom systems in coming years.[51]

---

[47] Based on interviews with industry experts conducted for this report.

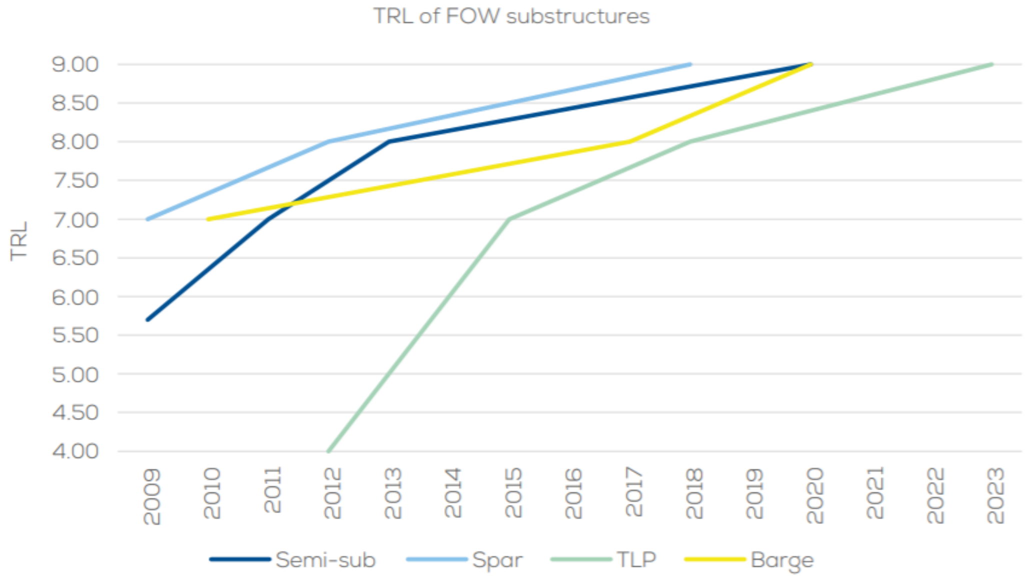
[48] As described by various sources, including WindEurope's 2017 Offshore Wind Energy Vision Statement and Cranfield University's 2018 Critical Review of Floating Support Structures.

[49] Based on interviews with industry experts conducted for this report.

[50] Based on interviews with industry experts conducted for this report.

[51] Per Beiter et al., 2016, as referenced in the U.S. Department of Energy *Offshore Wind Technologies Market Report*, 2019.

Figure 8: Technology Readiness Level of Floating Offshore Wind Substructures



Spar technology has reached TRL 9, described as proven in an operational environment, and can be considered ready for commercial deployment. Semi-submersible and barge technology was projected to reach this point in 2020.

Source: WindEurope, *Floating Offshore Wind Vision Statement* (2017)

Regulatory Support

High wind speed in deep waters and improved technology maturity have combined to generate significant interest in floating offshore wind from state and national governments around the world. As discussed earlier in this chapter, the global floating offshore wind pipeline has expanded to nearly 5 GW due to project proposals in Japan and South Korea.[52] Projects in these countries, as well as numerous commercial demonstrations and pilots in Europe, have garnered support from local and national regulators. As of January 2020, however, no state or country has committed to a target or carve-out mandating a specific installed capacity of floating offshore wind by a certain date. Chapters 4 and 5 briefly discuss regulatory mechanisms to support floating offshore wind. These topics are also addressed in the context of how such efforts spurred fixed offshore wind development over the past decade in multiple case studies included in Chapter 3.

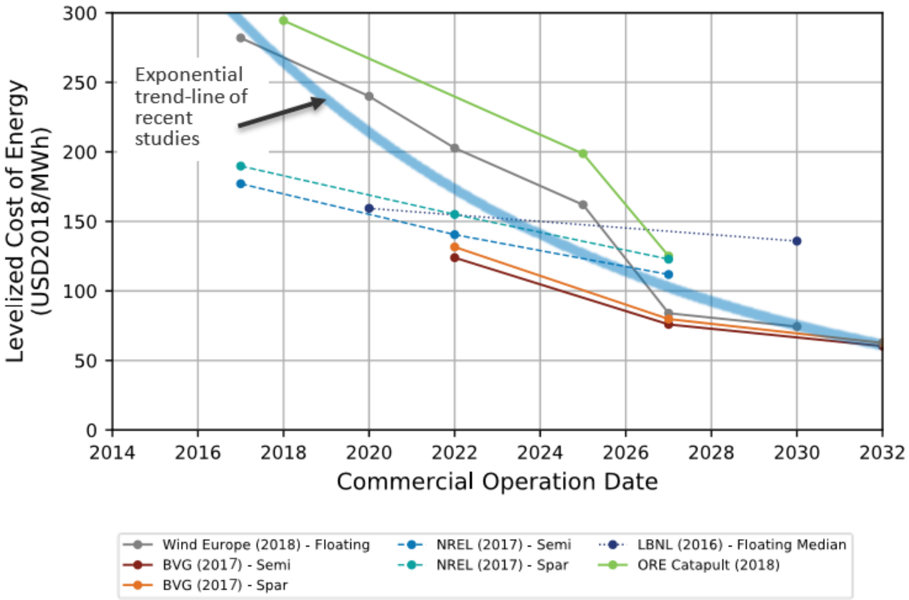
Projected Cost-Competitiveness

Many studies have forecasted the expected LCOE for floating offshore wind projects. The average LCOE of floating projects is estimated by the DOE at about $230 per megawatt-hour (MWh) as of 2019 and is expected to decrease to about $75/MWh by 2030, as Figure 9 shows.

---

[52] Developments of at least 1 GW each have been proposed separately off Ulsan City, South Korea, and Fukushima, Japan.

Figure 9: Floating Offshore Wind Levelized Cost of Energy Projections



LCOE projections for floating offshore wind follow a similar curve as they did for both fixed offshore and fixed land-based installations.

Source: USDOE, *2018 Offshore Wind Technologies Report* (2019)

The true cost of commercial-scale floating offshore wind energy remains unknown, as commercial-scale floating farms do not yet exist.[53] As of 2019, fixed offshore wind remains a more costly alternative to land-based wind, solar, and conventional generation in most locations.[54] The first commercial-scale floating offshore wind projects are projected to have a higher LCOE than fixed turbines due to a higher degree of financial and technical uncertainty, higher substructure costs, and a less established supply chain and manufacturing process.

Given similarities in the core technology, supply chain requirements, and proposed project scale, past fixed offshore project prices can still serve as a comparison point for the cost trends of future floating deployment. Past fixed offshore bidding processes produced winning auction values commonly known as strike prices.[55] The first offshore fixed-bottom wind projects in the United States, Vineyard Wind Phases One and Two, secured strike prices of $74/MWh and $65/MWh, respectively. After being adjusted for potentially biasing differences in the strike prices, including different contract lengths and revenue mechanisms unique to the United States market, the all-in or adjusted strike price for each phase of the project is about $100/MWh, as Figure 10 shows. These values sit in line with European projects of the same

---

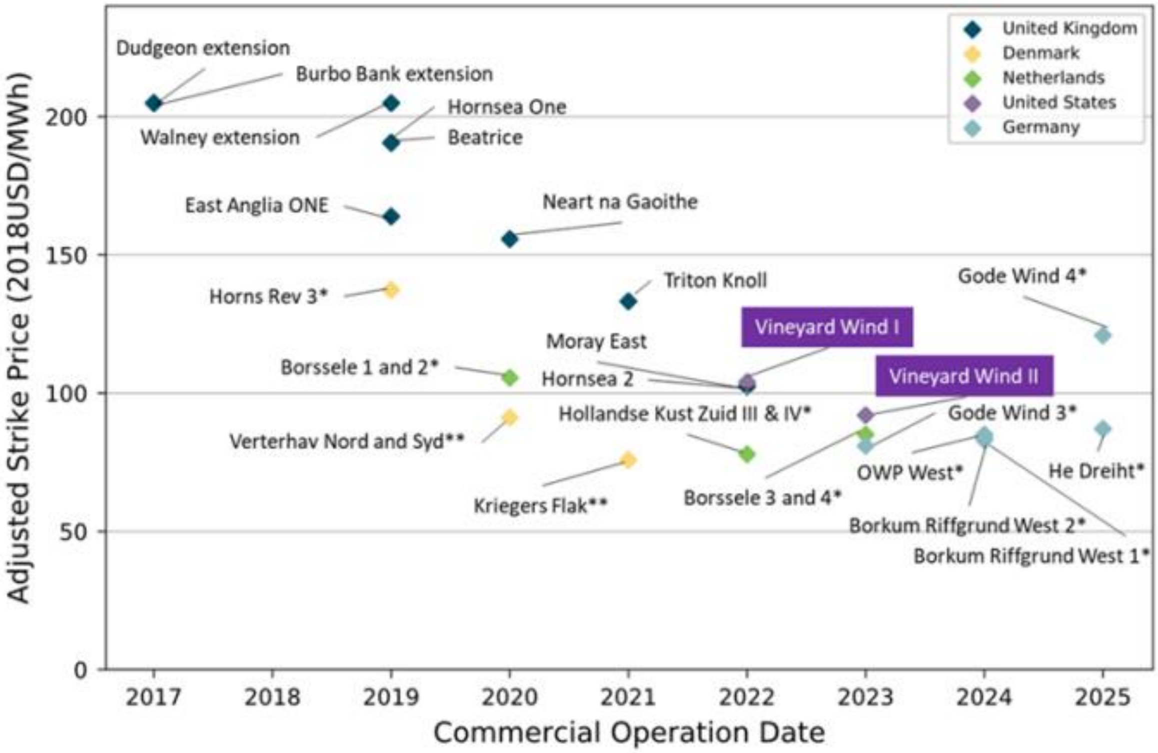
[53] Commercial scale is defined in this report as 150 MW or greater, which corresponds with the smallest project proposed (Redwood Energy) off the coast of California.

[54] U.S. Energy Information Administration, *Levelized Cost and Levelized Avoided Cost of New Generation Resources*, 2019.

[55] Strike prices are an agreed-upon price at which an option contract can be exercised as described by Merriam-Webster.

scale, despite having access to a far less established supply chain.[56] Floating offshore wind projects in the next 7-10 years are projected to bid at levels competitive with the first fixed offshore projects in the United States.[57]

Figure 10: Fixed Offshore Wind Adjusted All-In Strike Prices



Vineyard Wind Phase One and Phase Two strike prices are in line with European projects with similar projected commercial operation dates.

Source: USDOE, *2018 Offshore Wind Technologies Report* (2019)

Vineyard Wind was originally expected to have a much higher strike price due to it being the first project bid in the United States. A variety of factors contributed to lower than anticipated strike prices. The project benefited from experience and technology imported from Europe, including project experience from the parent company of one of Vineyard Wind's owners, Iberdrola, a Spanish-based developer. At 800 MW, it also achieved economies of scale by design and reduced financial risk by using large (MHI Vestas 9.5 MW) turbines. Perceived risk was further reduced by the favorable offtake conditions for electricity produced and the successful United States offshore technology pilot at Block Island just 3 years prior.[58] While it may be possible Vineyard Wind represents a strike price outlier in the United States' fixed-

---

[56] National Renewable Energy Laboratory, *The Vineyard Wind Power Purchase Agreement: Insights for Estimating Costs of U.S. Offshore Wind Projects*, 2019.

[57] Based on interviews with industry experts conducted for this report.

[58] U.S. Department of Energy Offshore Wind Technologies Market Report, 2019; p. 55 discussion of factors contributing to lowered prices for early market entrants in the United States. The act of purchasing electricity or another good is often described as off taking, and an agreement to purchase, like a power purchasing agreement, can alternately be called an offtake agreement.

bottom market, other East Coast projects have reached agreements for similar values.[59] It remains unclear whether these factors driving competitive prices for fixed-bottom projects in the United States will similarly lead to lower than expected LCOE in floating applications.[60]

Environmental, Economic, and Visual Benefits

Like other renewable energy developments, floating offshore wind energy offers several grid-related, macroeconomic, and environmental benefits aside from the value of clean energy produced. Table 3 outlines the potential benefits of floating offshore wind with relevance to the California market. [61]

Table 3: Potential Environmental, Economic, and Visual Benefits in California

Category	Benefit
Environmental	Limited seafloor disruption compared to fixed turbines
Environmental	Decreased coastal ecosystem interactions compared to fixed turbines placed closer to shore [62]
Macroeconomic	Revitalization of coastal port communities through direct investment in port infrastructure and full-time local job creation [63]
Macroeconomic	Higher potential for local content and local manufacturing supply chains through platform fabrication and final assembly
Visual Impact	Decreased visual impact compared to near-shore or onshore land-based wind turbines due to increased distance from shore

Potential benefits described in this table may help contribute to the value proposition of offshore wind in California.

Source: Guidehouse, 2020

If realized, these external benefits may contribute significantly to the value proposition of floating wind systems in California. Chapter 5 includes further discussion of value proposition studies.

Opportunities for Improvement

Through reviewing literature, interviewing industry experts, and case studying global markets, three essential areas of focus required to drive the market forward in California emerged:

---

[59] Park City Wind, also by Vineyard Wind, has reached an agreement to offer “a price lower than any other publicly announced offshore wind project in North America.” Ørsted also announced similar pricing for Ocean Wind off the coast of New Jersey and separately for Sunrise wind off the coast of New York.

[60] National Renewable Energy Laboratory, *The Vineyard Wind Power Purchase Agreement: Insights for Estimating Costs of U.S. Offshore Wind Projects*, 2019.

[61] Based on a set of interviews from industry experts conducted for this report.

[62] Biodiversity in coastal ecosystems is often concentrated near the shore; turbines farther from the shore may disrupt ecosystems relatively less than those closer to shore.

[63] UC Berkeley Labor Center, High Road for Deep Water: Policy Options for a California Offshore Wind Industry, 2017.

developing port infrastructure, planning for and constructing transmission, and supporting supply chain development.

Port Infrastructure

No single port in the state of California possesses the staging areas, weight ratings, vertical clearance, quayside draft, and assembly infrastructure required to host commercial-scale floating wind system assembly.[64] Cost-effective offshore wind energy project development hinges on having final assembly spaces in proximity to final project sites. Several ports near the BOEM call areas have been identified as potential hosting sites, but research and potentially significant investment is required to make any single port ready for commercialization.[65] Multiple ports may also be used for different parts of the project development life cycle to avoid the need for significant upgrades to a single port. The feasibility or formulation of a plan to overcome the limits to port availability and readiness in California requires further study.

Supply Chain

Individual wind projects at the pilot or commercial demonstration scale (<150 MW) are unlikely to produce energy that is cost-competitive with onshore renewable resources. Achieving commercial scale through a multi-GW pipeline is required to unlock cost-competitive project development.[66] To reach this scale, manufacturing infrastructure must be developed either domestically or internationally to supply project sites in California. Floating platforms and towers are the most likely components to be assembled within the state of California, though further research into manufacturing capacity will be required to assess current and needed infrastructure. Private investment in further infrastructure development is likely contingent on establishing a guaranteed market capacity.[67]

Transmission

The best wind resource in California exists off the north coast, from Mendocino County to the Oregon border, a region that includes the Humboldt Bay call area.[68] No large load centers exist within 100 miles of this stretch of coastline and no high capacity transmission lines are available to deliver power inland. The transmission capacity needed to send energy from proposed projects to more distant load centers in the central and southern parts of the state is also limited. If additional capacity is required, infrastructure would need to pass through high-risk fire zones. Similar challenges arise in the long-term at the Morro Bay and Diablo Canyon call areas despite their proximity to proposed offtake points (for example, Morro Bay Power

---

[64] Based on a set of interviews with industry experts conducted for this study.

[65] One developer committed approximately $100 million to port investment in Massachusetts, while NYSERDA separately announced $200 million in funding for proposed port infrastructure upgrades in October 2019. Ørsted has similarly committed to investing in over $100 million in steel fabrication and port upgrades in Maryland.

[66] Based on a set of interviews with industry experts conducted for this study. It is unlikely private investors will commit to the California market if return on investment is risky.

[67] Based on a set of interviews with industry experts conducted for this study.

[68] U.S. Department of Energy, WindExchange database, 2019.

Plant and Diablo Canyon Nuclear Power Plant) due to offshore resource potential exceeding the maximum available transmission capacity.[69] Injecting the 10 GW proposed by the offshore wind industry into the grid would require significant technical and policy solutions as well as significant investment under any scenario.[70]

---

[69] Based on a set of interviews with industry experts conducted for this study.

[70] Value proposed by Offshore Wind California advocacy coalition, as announced during the Pacific Rim Offshore Wind Conference in San Francisco in October 2019.

CHAPTER 3: Case Study Overview

The project team developed case studies for five key global offshore wind markets: the UK, France, Netherlands, East Asia, and the United States' East Coast. Research focused on identifying the drivers for offshore development, current market status, barriers faced, and lessons learned for California. This chapter summarizes key insights from each case study and overarching lessons learned. Appendix B includes the complete case studies.

Key Insights by Market

United Kingdom

- The UK is among the global leaders in fixed-bottom and floating offshore wind development. The first offshore wind turbine was installed in 2003 and the current installed capacity is 8.4 GW, with 11.7 GW capacity under development, which includes projects that are consented or under construction.[71]
- The UK leads the global fixed-bottom offshore wind market, and has set a target of 30 GW of offshore wind by 2030, driven by the UK Net Zero Emissions Law 2050.[72]
- Scotland has 30 MW of operational floating offshore wind capacity (Hywind Scotland) and an additional 50 MW under construction (Kincardine).[73] The most attractive sites for floating offshore wind are in Scotland due to the deep water, suitable geology, and sea climate conditions.[74] Scotland has an 8 GW offshore wind capacity target by 2030.[75]
- The first floating demonstration project, Hywind Scotland, used Spar-buoy technology by Equinor and had better-than-expected power generation efficiency. A 1 MW lithium battery-based pilot storage system is currently being developed for Hywind Scotland.[76] The 50 MW Kincardine project currently under development uses WindFloat semi-submersible platform by Principle Power, which is a more mature floating platform technology.
- The UK offshore wind market development has largely relied on expertise and equipment manufacturing capacities of other European countries. However, both the UK and Scotland have also utilized domestic oil and gas industry expertise and specialized suppliers (for example, foundation manufacturers and manufacturers of smaller components for wind turbine generators) to promote offshore wind development.

---

[71] The Crown Estate. Offshore Wind Operational Report. January to December 2018.

[72] Department for Business, Energy & Industrial Strategy. Offshore Wind Energy Revolution to Provide a Third of All UK Electricity by 2030. 2019.

[73] Offshore Wind Scotland web page. 2019.

[74] Carbon Trust. Floating Offshore Wind. Market & Technology Review. 2015.

[75] Offshore Wind Scotland. Scottish Offshore Wind Energy Council. Accessed 2020.

[76] Equinor (formerly Statoil). Statoil Launches Batwind: battery Storage for Offshore Wind. 2016.

- The UK auction system design allows the market to determine the most cost-competitive technology. Offshore wind projects compete for a government contract for differences against select renewable energy technologies (including biomass, geothermal, and tidal projects).[77] Wind farm developers bear the costs of grid connection, transmission, resource assessment, and the environmental impact assessment.[78]

France

- France has a target of 10 GW of installed offshore wind by 2028, most of which is expected to be fixed bottom. However, France will continue to invest in floating technology development.[79]
- France currently has 2 MW of floating wind installed at the Floatgen demonstrator project that began operation in 2019. In 2019, The European Commission approved four floating projects totaling 96 MW, each with an installed capacity of 24 MW.[80] Upon completion in 2021, France is expected to have the highest installed capacity of floating wind turbines in the world. These projects will pilot different floating platform technology types including a dampening pool design by Ideol, a semi-submersible steel platform by Naval Energy and Principle Power, and a modular steel platform by SBM Offshore and IFPEN.
- France has a strong onshore wind market that forms a supply chain for base components like towers, nacelles, and blades. It is an attractive market for offshore wind investment due to this supply chain, strong government support, and the presence of leading technology developers.
- France relies on a multi-factor tender system to evaluate offshore wind projects. Local content, stakeholder engagement, and project cost all are considered during the project review process. Desire to maximize local content in round 1 and round 2 tenders contributed to early project proposals being prohibitively expensive.[81] Cost, administrative complexity, and public opposition delayed offshore wind development for years. The French government reduced an initial target of 6 GW by 2020 to 3 GW in early tenders before increasing it to the current 10 GW target.[82]

---

[77] Contract for difference provides a 15-year guaranteed payment to the winner, determined as the difference between the auction price and a market reference price that represents the average cost of electricity in the UK market.

[78] A recent study by Navigant shows that when the costs are compared across selected EU countries, the UK model can result in higher overall costs. Navigant. Comparison of Offshore Grid Development Models. 2019.

[79] Warren, Ben. Renewable Energy Country Attractiveness Index, Ernst and Young. 2019.

[80] Durakovic, Adnan. EU Nods to Four French Floating Wind Farms. 2019. OffshoreWindBiz.

[81] Reuters. France Cuts Tariffs on Controversial Offshore Wind Projects. 2018.

[82] International Energy Agency, Renewable Energy technology Development. Comparative Analysis of International offshore Wind Development. 2018.

The Netherlands

- The Netherlands has 957 MW of current global fixed-bottom installed capacity with 3,000 MW under development.[83] As part of its 2030 Offshore Wind Energy Roadmap, it has set a target of 11.5 GW of offshore wind energy capacity by 2030, using the fixed-bottom technology.[84]
- The European offshore wind industry has a strong supply chain. MHI Vestas and Siemens Gamesa are the exclusive wind turbine generator suppliers for the Dutch offshore wind farms and are often contracted by developers to design, supply and install wind turbine generators. The Netherlands offshore wind supply chain is oriented around shipbuilding services, substructure manufacturing, and marine engineering. The country has very well-developed port infrastructure to support offshore wind development.
- Government support helped offshore wind achieve significant cost reductions through grid standardization, shortened project development timelines, and reduced investment risk. A feed-in tariff tender scheme is used to procure offshore wind where the lowest qualified bid is granted a 30-year operational permit and, prior to 2018, a 15-year subsidy guarantee.[85]
- As of April 2016, transmission system operator TenneT is responsible for developing and operating offshore transmission systems. This structure reduces cost to developers, de-risks development, and gives one central entity control over the transmission planning process. If TenneT fails to complete the offshore grid on the designated dates, it is liable for damages incurred by wind farm operators.[86]

East Asia

- The four east Asian countries studied were Japan, China, Taiwan, and South Korea. Among these four countries, Japan's experience with floating platform technology development and deployment is most relevant and applicable for California.

Japan

- Japan has been investing in floating substructure technology development for more than 20 years with a goal of becoming an exporter of floating technology and

---

[83] Navigant. Dutch Offshore Wind Market Update 2019. 2019.

[84] Netherlands Enterprise Agency. Offshore Wind Energy SDE+. Program closed in 2019, web page accessed 2020.

[85] Floating feed-in premium or SDE+ (in Dutch: Stimulering Duurzame Energieproductie) is an operating grant that the renewable energy generator receives when the cost of renewable energy is higher than the market price. The premium is adjusted annually based on market price development.

[86] International Energy Agency, Renewable Energy Technology Development. Comparative Analysis of International Offshore Wind Energy Development. 2017.

expertise.[87] It has an estimated offshore wind potential of 1,600 GW,[88] of which around 80 percent is located in depths greater than 100 meters.[89]

- As of February 2020, Japan has at least six installed prototype projects and remains the only market in East Asia with operational floating turbines.[90] The prototypes have provided up to five to seven years of data on their respective technology type, resilience, and environmental impact. Each project tested unique platform designs to optimize components and evaluate lowest cost options.
- Japan passed legislation in 2018 that outlined the process for offshore wind development in Japanese national waters. Eleven development zones were identified in 2019. At least five of these zones are under consideration for designation as wind energy areas.[91] Bidders are expected to be selected by the end of 2020 through public tenders and will receive feed-in-tariffs (FITs) guaranteed over 15 years.

China

- As of January 2020, China has the third largest installed capacity of fixed-bottom offshore wind in the world, with over 2.8 GW operational.[92] In 2016, the Chinese government established an ambitious national offshore wind target of 10 GW per year as part of the 13th Five-Year Plan for Renewable Energy.[93]
- The sole floating project under development is the single turbine 4 MW Shanghai Electric Floating Demonstrator by Shanghai Light.[94] All other projects installed and under construction use fixed foundations. Given the shallow average depth of the South China Sea, floating wind will likely not be required to meet national offshore wind targets by 2025.
- The Chinese offshore wind industry has had an exclusive local content requirement since the first installation of turbines in 2010 and is only open to Chinese-flagged installation vessels and local developers.

---

[87] Carbon Trust. Detailed Appraisal of the Offshore Wind Industry in Japan.

[88] JST Japan and Denmark Embassy. Recent Development and Challenges of Wind Turbine Technology. 2012.

[89] Per interviews with experts on the East Asian market.

[90] Carbon Trust. Floating Wind Joint Industry Project.

[91] Broehl, Jesse. Japan Passes Offshore Wind Legislation. Navigant Research. 2019.

[92] IEA. Offshore Wind Outlook 2019: World Energy Outlook Special Report.

[93] Asia Pacific Energy. China: 13th Five-Year Plan for Energy Development. Accessed 2020.

[94] Per interviews with experts on the Chinese market.

Taiwan

- Taiwan is an emerging market for offshore wind development. In 2017, the Taiwanese government established an offshore wind target of about 5.5 GW by 2025[95], which has already been awarded to ten developers (of which eight are international) for commissioning by 2025. Out of this, approximately 520 MW is expected to be complete by the end of 2020.
- The initial 5.5 GWs used a two-part process that first delegated 3.8 GWs for selection of bidders based on technical and financial capabilities and association with Taiwanese financial institutions.[96] The second 1.7 GW portion selected bidders primarily based on proposed feed-in-tariff price. Following the success of initial auctions, in 2019, Taiwan set an additional 10 GW offshore wind target by 2030.[97] Taiwan plans to emphasize local content requirements for future projects, which could raise project costs.

South Korea

- The South Korean government established a target of 12 GW installed capacity of offshore wind by 2030 as part of the Renewable Energy 2030 Implementation Plan released in 2017.[98] Five separate fixed-bottom projects, each 200 MW or greater, have been proposed.
- South Korea has a strong maritime and industrial sector with capabilities for subsea cable manufacturing, cable laying, installation, and substation manufacturing. The South Korean government is expected to restrict the use of international vessels and contractors to promote use of local content within the offshore wind supply chain.

United States East Coast

- Eight states on the U.S. east coast (for example, New York, Massachusetts, New Jersey, Connecticut, Virginia, Maryland, Rhode Island, and Maine) are promoting offshore wind development through a combination of targets, financial incentives, and RD&D support.[99] Fixed-bottom turbines are expected to dominate these markets in the near term due to the availability of strong wind resources in shallow water and the lower cost of fixed technology. The only proposed floating turbine project on the East Coast is the 12 MW New England Aqua Ventus I off the coast of Maine, which uses VolturnUS technology (developed at University of Maine).[100]

---

[95] Offshore Engineer. Taiwan Offshore Wind Market to Reach 5.5. GW by 2025. 2019.

[96] Wind Power Monthly. Taiwan Sets Out 5.5 GW Plan. 2018.

[97] Global Wind Energy Council (GWEC). From 0 to 15 GW by 2030: Four Reasons Why Taiwan is the Offshore Wind Market in Asia. 2020.

[98] Lee, Sanghoon. Revision2019. Renewable Energy 3020 Plan and Beyond. 2019.

[99] International Energy Agency (2019). Offshore Wind Outlook 2019. World Energy Outlook Special Report.

[100] VolturnUS is designed to use existing manufacturing processes and facilities available in the United States. Segmented modules capable of serial production make up the hull. Design allows for deployment out of port

- State targets, set through executive order or legislative process, are in effect in all eight states seeking to develop an offshore wind industry. State-level installed capacity commitments total at least 22.5 GW by 2035 and are expanding.[101] Timelines for commercial operation remain uncertain due to an extended environmental impact review at the federal level by BOEM and National Oceanic and Atmospheric Administration.
- State governments have sponsored a number of studies (for example, those conducted by NYSERDA[102]) assessing resource potential, and researching ecological and environmental impacts of offshore wind projects. They have additionally invested in port and transmission infrastructure development and initiated stakeholder engagement, especially with fisheries.
- Across the East Coast, offshore wind industry development is driven primarily by the technology's potential to decarbonize the power system and demand for low carbon resources near coastal load centers. The primary support for offshore wind project rollout in the United States was an investment tax credit (12 percent in 2019), that was extended through 2020 in late 2019.[103] Once qualified, the project has several years to reach completion. New legislation to extend the support for offshore wind until 2025 is being discussed in Congress.
- Supply chain and infrastructure on the East Coast remains nascent but is growing through investment. Multiple offshore wind developers, energy companies, and state authorities have invested in port, vessel, and manufacturing infrastructure to cater to the needs of offshore wind assembly and installation. As limited workforce development and Jones Act restrictions may raise costs of project development, no state has committed to local content requirements as of February 2020.[104]

Lessons Applicable to California

- Government support for new technologies: Offshore wind projects (especially floating) have relied on government support due to relatively high cost that makes initial projects non-competitive with other mature renewable energy technologies. Countries around the world have used alternate funding mechanisms to support development. Financial support was granted to fixed offshore wind during early development in multiple studied markets (for example, Netherlands, UK, East Coast), facilitating cost reductions. In Japan, floating technology trials since the 2011 Fukushima disaster have been supported by a consortium funded by the Japanese government.

---

facilities with as little as 27 feet of draft eligibility and includes ability to survive a 500 year storm. More information can be found through the University of Maine Advanced Structures and Composites Center website.

[101] International Energy Agency (2019). Offshore Wind Outlook 2019. World Energy Outlook Special Report.

[102] New York State. Studies and Surveys. Accessed 2020. NYSERDA.

[103] WindExchange. Production Tax Credit and Investment Tax Credit for Wind. Accessed 2020. United States Department of Energy.

[104] Gleaned through interviews with market experts conducted for this case study.

- Pipeline development: Establishing a project pipeline with government-support was vital in driving investment in supporting infrastructure and supply chain maturation. All seven countries and eight U.S. states included in case studies implemented an installed capacity target to support offshore wind. Target size and timeline varied based on local supply chain capabilities and the process undertaken for engaging with multiple stakeholders. Feed-in tariffs and renewable energy credits provided to winning bids helped offset high costs for initial projects and guaranteed a return for developers in many markets (for example, South Korea, Taiwan, and the East Coast).
- Transmission: Policies for interconnection and transmission development vary across markets. Offshore transmission infrastructure may be financed and owned by developers (for example, East Coast), financed by developers and owned by a third party (for example, UK), or both financed and owned by a third-party entity (for example, the Netherlands) depending on the market.
- Stakeholder engagement: Stakeholder and public opposition to offshore wind due to concerns about grid stability and visual impact significantly delayed project development in multiple markets (for example, France and the Netherlands). Engaging stakeholders in spatial planning helped minimize public opposition, project disruptions, and ecological damages. Engagement with, and education of, stakeholders (for example, fisheries) helped push markets forward through a focus on long-term planning.
- Local content: Even in markets with established onshore wind, offshore oil, or maritime industries and supply chains (for example, France, South Korea, Japan, and Taiwan), local content requirements led to concerns about high project cost and, in some cases, contributed to delays. Offshore wind developers rely on a global supply chain to keep project costs low; if access to this supply chain is inhibited by local content, bid prices are expected to rise in the short term.

CHAPTER 4: Interview Results

The project team conducted stakeholder interviews to characterize the state of the California offshore wind market, identifying important technology and infrastructure requirements to develop cost-effective offshore wind projects. The team conducted these interviews from August 2019 through May 2020. Outreach centered around five predefined stakeholder groups: project developers, technology developers, planning and procurement agencies, research institutes, and interest groups.[105] Table 4 lists the number of representatives interviewed from each group. Specific organizations chosen for interviews were identified through collaboration between the project team and the CEC. Appendix C provides the interview guides used to facilitate these conversations.

This chapter summarizes the viewpoints of researchers and stakeholders in the offshore wind industry obtained through conversations with interviewees. The content of this chapter should not be construed as the views of, or endorsement by, the project team or the CEC. All quotations and quoted phrases are directly attributed to interviewees. Any suggestions or recommendations contained in this chapter are solely those of the interviewees. TAC member organizations were not interviewed for this portion of the report, and findings outlined within should not be interpreted as representative of TAC member organizations.

Table 4: Stakeholder Interviews

Stakeholder Group	Number of Interviews
Research institutes	7
Technology developers	7
Project developers	4
Planning agencies and Load-Serving Entities	9
Interest groups	4
Total	31

Source: Guidehouse Offshore Wind Interviews, 2020

The project team asked interviewees questions on the state of the global floating offshore wind market and the barriers preventing the development of a floating offshore wind industry in California. The team asked interviewees to focus on technical RD&D barriers within floating platform technology or requisite infrastructure that the CEC can help mitigate through state-led research and Electric Program Investment Charge (EPIC) program funding. Although the primary objective of the interviews was to identify technical barriers, feedback from stakeholders naturally expanded to other types of barriers. The following sections describe each stakeholder group and summarize the team's interview findings from the perspective of those interviewed.

---

[105] Interest Groups representing all entities not easily defined by one of the primary four categories.

Research Institutes

The project team classified governmental, not-for-profit entities, and independent consultancies engaged in research around both fixed and floating offshore wind technologies as research institutes for this study. Groups interviewed included state and federal energy research divisions, academic institutions within the state of California, and private consultancies working in the renewable energy space. Specific expert focuses included technical research, energy engineering and infrastructure, and the macroeconomic impacts of renewable energy development.

The remainder of this section provides specific findings from the interviews with research institutes.

- Floating technology remains nascent. While not unanimous, research institutes were the only stakeholder group where a majority of interviewees stated concern over the readiness of floating technology and its applicability to the California market. They cited challenges with the technology itself, including mooring at extreme depths, operations and maintenance (O&M) in extreme wind and wave conditions, and scalability given physical infrastructure (for example, manufacturing, port, and vessel) constraints in California. Research institutes were generally less likely than other stakeholder groups (for example, project and technology developers) to agree that these challenges are easily solvable. Even if mitigated, multiple researchers feared that the cost of addressing these technical and infrastructure concerns could raise offtake prices for early projects to prohibitive levels.
- Port infrastructure and transmission consistently identified as top two barriers. As described by one research institute, each port has its own challenges, and there are significant seasonal variations to these challenges. Respondents felt studies should be conducted to understand what ports can be accessed at what times of the year for offshore wind development. For example, the Port of Humboldt Bay (proposed for use by projects in the Humboldt Bay call area) is only available for transit to offshore sites during part of the year due to seasonal sediment deposits from the Eel River. Projects would have to be completed and serviced on a seasonal basis, potentially raising upfront costs and limiting O&M activities during many months of the year. As stated by one researcher, a "reality check" for regulators and industry players on the severity of these port obstacles and the costs of mitigating them are needed.

  To reach the installed capacity scale of 10 GW proposed by some industry stakeholders, multiple suitable ports are needed up and down the California coastline. As of now, it is unclear which ports aside from the Port of Humboldt Bay could be used for final assembly. The cost of making more ports industry-ready is projected to be significant by all researchers surveyed.[106] Respondents believed no one will invest in these ports until a market is developed. Requisite transmission upgrades along the northern coast were seen as particularly cost-prohibitive, potentially "an order of magnitude or more" expensive than port upgrades. In the words of one researcher, questions of

---

[106] Multi-million dollar port infrastructure investments on the East Coast have been announced by multiple project developers, while NYSERDA has committed $200 million to port infrastructure upgrades for offshore wind in New York State.

transmission are "tied umbilically into" the setting of a state-level target for offshore wind.

- Setting an installed capacity target for offshore wind is viewed by respondents as vital. While acknowledging such a policy would be "a significant departure" from the status quo in California, all research institutes surveyed supported setting a target in the state, with one going as far as saying there would be "no way" to establish an offshore wind industry without one. The belief that offshore wind development would likely be necessary to meet SB 100 goals was also unanimous despite the associated costs and challenges. "Going carbon neutral by 2045 is not free," as one researcher stated, further explaining that all potentially accessible renewable resources need to be considered.
- Water depth off the coast of California is an understated challenge. No floating wind turbine demonstration has been tested at the 800 to 1,000-meter depth proposed at the Humboldt Bay call area. While this depth is unlikely to affect the platform or turbine components of a floating system, the mooring and interarray cabling process at these depths is entirely untested. In the event of routine replacement or a malfunction, O&M costs are expected to be much higher than in shallower water due to the extra material required to run mooring to the seafloor and the logistical complexity of operating at extreme depths. Multiple researchers hypothesized that transmission infrastructure, including high voltage direct current (HVDC) cables, installed at extreme depths would also prove challenging to repair and replace. While subsea HVDC cables are operating in other parts of the world, it is unclear if the laying, operation, and maintenance of these cables would be feasible or cost-effective off the coast of California due to the combination of depth, distance, seismic risk, and wind and wave conditions. Respondents identified this as an area for further research.
- Grid benefits of floating wind should be included in future cost-benefit discussions. Multiple researchers view offshore wind as a complementary resource to onshore solar power in California. Offshore wind generation tends to peak in the late afternoon and early evening, coinciding with the downward ramp of solar generation, and typically continues producing throughout the evening. These projections are based on models, not collected data. Researchers explained that they "need much better confidence in that curve" for offsetting the ramp and recommend placing additional LIDAR buoys to properly map this resource potential. Multiple researchers stated that the entire value proposition of offshore wind, including grid benefits, needs to be quantified to get a realistic picture of the technology's actual potential value. While cost-competitiveness with land-based wind and solar may take years to be fully realized, these researchers view that the auxiliary grid benefits of floating technology may help justify upfront investment.

Technology Developers

Technology developers are firms or organizations involved in the process of designing, fabricating, and assembling components of floating platforms, turbines, mooring systems, cabling, or other associated offshore wind technologies. The project team focused on interviewing turbine and platform technology developers because of the significant portion of project capital expenditures dedicated to these components.[107] The team conducted interviews with three of the largest global turbine manufacturers and four platform designers, including the designers of the two leading systems in terms of installed global capacity.

Multiple entities in this segment were also classified as project developers and commented from both stakeholder perspectives. The remainder of this section provides specific findings from the interviews with technology developers.

- Technology developers feel there is limited need for state support on platform, blade, and turbine component R&D. Technology developers did not see a need for state-led R&D activities in core technologies like platforms, blades, nacelles, and internal components. Most groups believed that these technologies are commercially viable for floating farms despite limited (<300 MW) installed global capacity. Where R&D could support core technology development, technology developers did not perceive any need for state-led interventions or co-funding given their internal capabilities to conduct needed research in these specific areas.
- Port infrastructure and assembly space remains an uncertainty. Turbine manufacturers were uncertain about the capability of California's ports to host the lay-down space needed for turbine blades. Multiple platform designers lacked clarity on which ports could provide the quayside length and draft required for dockside assembly.[108]
- Unclear path to developing transmission infrastructure connecting call areas to shore and to major load centers was a universally identified barrier. Multiple technology developers were uncertain which stakeholder would take the lead to address this challenge. Developers stated that because no incentive or clear path exists for private firms to invest in transmission planning or infrastructure development, they assumed they would not be involved in this process. Yet, all expressed that having a clear path to developing transmission was a necessity. Many in the industry view an HVDC backbone system, a subsea transmission line connecting projects to one another and running to load centers, as a potential means to avoid onshore transmission concerns. Despite being described as "very interesting" and "having potential," an HVDC backbone was also cited as impractical by multiple developers. According to one, HVDC backbone infrastructure is "not a new idea" that has "never materialized" due to the high cost, logistical difficulty, and increased risk of transmitting power from multiple projects through a single line.[109]
- Turbines are getting larger, though designs remain largely consistent across fixed and floating project applications. Developers stated little remains to be done to modify existing turbine designs (those primarily built for non-floating applications) for proposed floating farms. Both platform and turbine technology developers estimated turbines in

---

[107] A variety of sources confirm that turbine and platform capital expenditures represent a majority of system costs for floating offshore wind farms, including NREL's *2017 Cost of Wind Energy Review*.

[108] A draft is the vertical distance between the water line and the bottom of a floating platform, ship, or other naval vessel. Draft is used to determine the minimum depth of water required for the safe navigation of a vessel. Lay-down refers to the open space required to host components like blades, nacelles, and turbine towers.

[109] Logistical difficulty refers to challenges organizing relevant parties and designing and developing an HVDC backbone system itself given market and geographic conditions.

excess of 10 MW (12 MW-15 MW)[110] will be ready for commercialization by the projected operational dates (mid-2020s) proposed by project developers in California. Respondents suggested larger turbines, particularly those with access to stronger wind resources, will lower project LCOE due in part to increased electric generation per unit. The potential environmental effects of turbine scaling have been researched by at least one turbine manufacturer, who stated that "in most cases, a bigger turbine was better on most environmental parameters" than existing smaller systems from that manufacturer.[111]

- Respondents closely associated supply chain development with the industry-stated request for a state capacity target. Technology developers described the development of a California project supply chain without a business case supported through a state target or mandate as too risky due to the high upfront investment required. As one technology developer described it, "[technology developers] do not build a factory for one project." This aligns somewhat with the pull approach to developing and managing a supply chain rather than push. In a push strategy, manufacturers develop supply chains and product based on high confidence in the prediction for demand. A pull strategy responds to the market need, minimizing investment until necessary. Respondents suggest limited predictability in demand for offshore wind components in California is preventing investment—the industry is waiting for the market to pull.
- LIDAR wind data can be used to drive market interest and financing. Multiple interviewees suggested conducting LIDAR surveys of existing and future call areas to attract market interest and investors. As one technology developer stated, "having measured data from a LIDAR buoy is very good for financing" and may help spur capital flows that could help address other identified barriers.

Project Developers

Project developers are responsible for securing call areas and planning, financing, permitting, constructing, and interconnecting offshore wind projects. Upon completion of a project, project developers may operate, maintain, and eventually decommission the project. Some project developers are vertically integrated and conduct most operations across a project life cycle, while others partner with engineering firms and technology developers for planning, construction, and equipment procurement.

The project team reached out to select project developers that expressed interest in the California offshore wind market, including three of the 14 respondents to the BOEM California call for nominations. The team selected additional developers based on their experience in the fixed offshore wind market on the East Coast of the United States and key international markets.

---

[110] Turbines available on the market max out at 9.5 MW-10 MW. The largest unit under development, the 12 MW-rated Haliade-X by GE Renewable Energy, was unveiled earlier in 2019. Multiple interviewees from different stakeholder groups confirmed that even larger units are under consideration.

[111] These claims were made based on internal research from one turbine manufacturer and could not be separately corroborated by the project team. The reasons for, or magnitude of, reduced impacts were not shared with the project team. Further research in this area may be necessary to confirm purported environmental benefits.

The remainder of this section provides specific findings from the interviews with project developers.

- Project developers feel there is limited need for state support on platform or turbine technology RD&D though opportunities exist in mooring, cabling, monitoring, and supporting infrastructure. Respondents mentioned opportunities exist in the mooring, cabling, and supporting infrastructure RD&D space. There may also be opportunities for further cost reductions in the manufacturing space through next generation materials and processes. Respondents did not, however, cite any major R&D needs for platform or turbine technologies, and none expressed concern over the commercial readiness of core floating platform technologies (for example, blade, nacelle, tower, platform). In their view, "there are no show-stoppers" in terms of technical challenges to these core technologies that would require public R&D funding, and multiple semi-submersible and spar-buoy platform designs have reached TRL 9, although installed capacity remains limited.[112] Developers exhibited eagerness to prove floating technologies that are operational in pilot projects around the world (for example, Scotland, Japan, Portugal) at a commercial scale. Most project developers claimed to be technology-agnostic and avoided stating a preference for one floating platform technology over another. These firms held the view that multiple platform designs were ready for deployment in various parts of the world. Multiple project developers stated that the specific technology designs most suitable for the California market would have to be tested through the project development and permitting process.
- Port assembly space and associated infrastructure development remains a challenge. Both floating and fixed project developers expressed concern with regard to existing port infrastructure and the limited number of ports suitable for offshore wind development in California. Multiple project developers felt confident that they could help fund port infrastructure development given their financial backing—assuming there was certainty that large-scale projects would move forward. At least two of the project developers interviewed discussed their success in developing local infrastructure and supply chains in other global markets in recent years.
- Project developers believe an installed capacity target would be needed to create a market.[113] Project developers unanimously felt a target or other carve-out for offshore wind in California should be established to facilitate the development of operational projects in the state.[114] Interviewees identified that the investment risk for developing offshore wind in California is extremely high. They expressed that setting a target is

---

[112] Spar-buoy system Hywind reached TRL 9 with the installation of Hywind Scotland in 2017, while semi-submersible system WindFloat can be considered equivalent to TRL 9 through ongoing projects Kincardine and WindFloat Atlantic. Other systems, including Ideol's dampening pool barge technology, may be considered equivalent to TRL 9 due to multiple active full-scale pilots operational in deployment conditions.

[113] Offshore Wind California, the consortium promoting offshore wind development in California, announced its goal for 10 GW of installed capacity by 2030 in October 2019 at the Pacific Rim Offshore Wind Conference in San Francisco. This target was chosen as the consortium believed it to be both achievable and large enough to incentivize investment.

[114] A carve-out refers to the reservation of a specific percentage of energy generation under a renewable portfolio standard or other similar policy for a specific generation source like solar or wind.

"absolutely critical" to reducing this risk as it would create market pull that justifies investment. Respondents further cited how targets developed globally (Europe, Taiwan, United States East Coast) helped alleviate investment risk in those markets.

- Large project pipeline will drive down costs.[115] Without the ability to scale in a given market, the cost of individual projects will remain high. Multiple interviewees cited large-scale commercialization of offshore wind as one of the best opportunities to reduce costs in any market. Small demonstration or pilot projects would not facilitate the development of a supply chain in California that could drive down development costs for offshore wind. This supply chain would be required for offshore wind to have a chance to be cost-competitive with other renewable energy sources in California (for example, solar, land-based wind, geothermal).
- Local content requirements were cited as concerning because they could drive up costs.[116] All project developers, particularly the larger firms interviewed, described how they relied on established global supply chains for equipment to keep project costs low. Projects often used local engineering, procurement, and construction firms and vessel stock, but still relied heavily on inputs sourced from other markets. As viewed in the France case study in Chapter 3, local content requirements for equipment and inputs could prevent floating offshore wind projects from reaching cost-competitiveness by restricting developers' ability to rely on global material and labor sources for project development. Developers claimed that high wages and land costs within California would significantly raise the cost of labor and assembly or manufacturing space when compared with imported global alternatives.
- Respondents closely associated workforce development with the industry-stated request for a state commitment to offshore wind.[117] The degree to which local California labor can be used in early California offshore wind project construction is dependent on the scale of offshore wind projects. According to multiple developers, higher installed capacity targets (that is, more market pull) will lead to increased upfront investment in local workforce preparation and development of a local supply chain to support projects off the California coast. This local investment was described by multiple respondents as a key part of the total value proposition of offshore wind in the state. One developer cited the UK as an example. The UK was able to facilitate the building of "a new skills base" that "rejuvenated local economies" in part through the setting of installed capacity targets for offshore wind.
- Federal leasing process places weight on the highest monetary bid, minimizing importance of other important project success factors. Project developers unanimously view the BOEM process as a barrier to rapid development due to uncertain auction timelines. The highest monetary bid, winner-takes-all auction process for exclusive rights to lease areas was also identified as a cause of frustration among some

---

[115] A project pipeline includes all projects proposed, under construction, or in operation in a market.

[116] Local content requirements are laws that mandate a specific percentage of inputs or a portion of one type of input to a project must be sourced from local jurisdictions or companies.

[117] Offshore wind requires both standardized skills like welding and machine working as well as specialized capabilities for oceanic installation and turbine maintenance.

developers. Multiple interviewees felt this type of evaluation fails to consider other factors to project success like past offshore wind project development experience or ongoing efforts to engage with local stakeholders. Most project developers supported a revised auction system known as multi-factor auctions that would consider metrics like stakeholder engagement in addition to the highest monetary lease bid. Multiple project developers also expressed uncertainties surrounding potential delays due to the complicated California permitting process caused by the large number of regulating agencies in the state. However, they indicated barriers associated with federal approval as the primary challenge in the near term.

Planning Agencies and Load-Serving Entities

This group consists of state and federal government agencies, investor-owned utilities (IOUs), and Community Choice Aggregators (CCAs) near coastal call areas and major load centers. The state and federal agencies interviewed for this report are responsible for permitting and environmental protection, while selected IOUs and CCAs account for a large percentage of renewable energy procurement in California. At least two CCAs have engaged with offshore wind project developers, and the project team interviewed both of these organizations for this study. Inputs from the CEC, CPUC, and the California Independent System Operator (CAISO) were collected separately through the Technical Advisory Committee (TAC) review process and this section does not represent the views of the CEC, CPUC or CAISO.

The remainder of this section provides specific findings from the interviews with planning agencies and LSEs.

- Offtakers expressed need for better understanding of technology performance. Nearly all interviewees stated a need for better understanding generation profiles and cost-competitiveness of floating offshore wind in specific project sites with alternate renewable resources. LSEs described this information as critical to informing procurement decisions.[118] Cost projections from offshore wind projects would otherwise be too unreliable, preventing LSEs from entering into PPAs with developers. Even with greater cost certainty, however, multiple LSEs claimed that a new resource like offshore wind could be perceived as a higher-risk investment without a previous track record of success in the state. In order to gain better performance data and establish a track record for new offshore wind technology, multiple interviewees supported the concept of a pilot project.
- Demand for smaller, lower-risk projects utilizing more proven technologies is driven by procurement market structure. As the emergence of CCAs continues to fragment the California procurement market, power purchasing decisions will continue to be made by entities serving smaller slices of the state's load than traditional IOUs once did. LSEs indicated that with loads becoming more granular, offshore wind may not be a good fit for meeting LSE needs and instead they are likely to rely more on resources such as solar and batteries. Multiple agencies and IOUs expressed concern over whether smaller offtakers like CCAs could satisfy the capital or energy demand required to support large

---

[118] LSEs stated these data points would serve to improve IRP model inputs for offshore wind. This would help LSEs make more informed procurement decisions while allowing state agencies to evaluate whether a grid reliability need exists for offshore wind.

offshore wind projects. In acknowledgment of this challenge, multiple CCAs proposed aggregating demand across numerous LSEs or other offtakers like large private companies or government facilities to allow for the joint funding of pilots or commercial-scale projects by a wide set of parties. Sharing funding and offtake responsibility would help CCAs create a stable procurement demand in aggregate without assuming significant risk individually or being forced to pass large rate increases to customers.

- Majority support for improved regulatory certainty. Multiple agencies and LSEs included in this set of interviews believed that offshore energy development in California would be required to some degree to meet SB 100 goals. A majority of respondents cited regulatory uncertainty including potentially lengthy environmental permitting process for offshore energy generation, visual impact studies, and the lack of a state roadmap supporting offshore technology as significant barriers to development. Four interviewees supported the idea of a state-level carve-out or installed capacity target for offshore wind, with one suggesting an executive order to facilitate the process of setting a target. In contrast, one LSE expressed concern with a carve-out and countered that existing planning and procurement processes should be relied upon to select the most cost effective, viable resources needed. The remaining four interviewees did not express an opinion regarding carve-outs. Multiple interviewees suggested developing a permitting roadmap to clarify approval timelines for LSEs and developers. These views align with previously stated findings from other interviewees about the need for market pull in California. However, this finding does not incorporate the views of the CEC, CPUC or CAISO. The procurement track of the IRP has not yet evaluated the broader effects of such a state-level carve-out but might explore it in future studies.
- Prioritize infrastructure (ports and transmission) research and policy goals over platform and turbine R&D. This group of stakeholders did not offer specific suggestions on R&D opportunities associated with floating platform technology and instead focused on infrastructure challenges. Transmission was unanimously chosen as a top barrier with significant investment requirements for laying undersea cables. LSEs explained that offshore wind build-out near existing interconnection points like Diablo Canyon, Morro Bay, and Moss Landing may allow for interconnection of up to four GWs, but anything in excess would likely require extensive capacity upgrades to the existing grid (particularly between the northern coast and Central Valley). Interviewees did not expect CAISO to initiate planning for transmission from offshore wind supply without it being selected in the IRP preferred system plan or without a grid reliability need or policy directive like a carve-out for offshore wind. Multiple respondents indicated that the transmission planning and construction could take in excess of a decade depending on the location and proposed size of wind farms. Interviewees also widely agreed on the need to prioritize research on the state of ports (availability of quayside draft, assembly and lay-down space, potential seasonal variations in sediment and draft). Multiple respondents expressed uncertainty around the feasibility of upgrading ports quickly enough to host large blades and turbines along the mid-2020s timeline for commercial operation dates proposed by developers.
- Lease auction process timeline is uncertain and could cause delays in offshore wind deployment. The lack of an established timeline for bidding and leasing the three California call areas was identified as a potential cause of significant further delays (as

similarly experienced on the East Coast of the United States). Interviewees offered multiple stakeholder perspectives on the effects of these delays with respect to the California market. Many respondents were critical of the federal leasing process, stating that the pathway injects a high level of uncertainty into the permitting process due to the lack of clarity surrounding if or when leases will be awarded. At least two organizations framed potential delays positively, however, saying extra time would allow the state more flexibility to gather data and conduct environmental surveys. Multiple interviewees separately voiced disagreement with the current highest-bidder-take-all leasing system, fearing that this process would disincentivize project developers from engaging with local environmental and labor stakeholders since this due diligence would not factor into the final leasing decision.

- Fishery impacts should be evaluated and mitigated. Commercial fisheries remain a powerful industry in many coastal California jurisdictions. Engaging with these stakeholders early and incorporating them into the project planning process was described by multiple stakeholders as critical to gaining support or acceptance from the broader community in these places. While project developers could lead this engagement, multiple interviewees suggested that state planning agencies including the CEC should lead instead to ensure fishery impacts were duly considered. Macroeconomic benefits from wind energy development (for example, increased employment and investment in coastal jurisdictions) in the communities adjacent to offshore call areas may be blunted if local fisheries suffer. Only incomplete data on commercial fishers, including where, what, and how they fish, is available. Securing accurate information is important but non-trivial; fishers do not typically share their fishing zones or techniques for fear of exposing themselves to additional competition. Multiple interviewees identified overcoming this information barrier as a critical first step to fishery engagement in the offshore wind development process.
- U.S. Department of Defense (DOD) requirements may inhibit central coast development. U.S. DOD support for wind farms near military bases and testing areas in Central and Southern California will be required. All permitting and environmental protection agencies and CCAs interviewed expressed concern that the military would not allow for offshore development south of Monterey due to ongoing and proposed future testing activities in these areas. Should the U.S. DOD choose to support wind farms off the coast of Central and Southern California, "the whole [review and decision] process will take a lot longer than anyone expects," according to one stakeholder. This U.S. DOD decision process may prevent project developers from connecting projects to the grid by the mid-2020s as currently proposed. Lack of support from the military may limit offshore wind development to the northern coast.

Interest Groups

The project team defined interest groups as any organization not directly involved in the offshore wind project life cycle that may have a strong incentive to support or oppose the development of the offshore wind pipeline in California. Stakeholders interviewed for this category include wind industry trade organizations, environmental groups, and fishery associations. Whereas the project team targeted questions for the other four stakeholder groups to gain perspective on technology and supply chain readiness, interest groups were asked to focus on macroeconomic, environmental, and regulatory barriers and their effect on offshore wind industry commercialization in California.

The remainder of this section provides specific findings from the interviews with interest groups.

- Master planning can overcome existing barriers. Industry trade organizations were optimistic about offshore wind's success in California despite highlighting concerns over transmission capacity, port infrastructure, and supply chain readiness. Those interviewed voiced support for a state-level master plan for offshore wind development. As described in the interviews, a master plan could establish a framework and clear path forward to support offshore wind industry development in California. The plan may include a comprehensive review of deficiencies in manufacturing capacity, infrastructure, and the supply chain and guide targeted funding to address these issues. Respondents believed a plan could be used to support a state-level installed capacity target or, in the absence of a target, could be used separately to show the state's commitment to the industry. Groups were unsure which existing agency would take the lead on designing or enforcing a master plan, hypothesizing instead that a new entity may need to be created with some degree of oversight over various aspects of project planning, research, and financing.
- Environmental and fishery group respondents believe wildlife impact mitigation technologies should be the focus of additional research. Little is known about the potential ecosystem or migratory impacts of wind turbines at the distances from shore and depths proposed, as no farms of commercial scale exist under these parameters. Both environmental and fishery stakeholders cautioned against attempting to transfer knowledge from studies conducted in other countries to the ecosystems of California. Stakeholders see potential biodiversity impacts in California as more significant than those in the North Sea or other global fixed turbine project areas because of the high level of biodiversity and key migratory routes for birds and oceanic mammals off the coast of California. To solve specific offshore wind challenges with fish, birds, and marine mammals, respondents suggested data collection on ecosystems and species migratory routes is needed. This data would inform research into impact mitigation technologies like smart curtailment that deactivates turbines when protected species of birds are nearby or robotic mooring line cleaning to prevent lines from snaring nets and other debris that can trap sea mammals through secondary entanglement.[119]
- Environmental and fishery groups believe fishery and environmental impacts needs to be considered early in the planning process. Environmental and fishery groups supported the development of a more scientific engagement and planning process. Respondents suggested the potential impacts on fisheries and the environment cannot be adequately scoped or mitigated without collecting data. Multiple groups agreed that collecting this data early in the process would help inform constructive dialogue backed by evidence throughout a project's lifespan. Both environmental and fishery stakeholder types expressed uncertainty over what, if any, role they would play in the leasing,

---

[119] Smart curtailment focuses on curtailing during certain times of year, under certain weather conditions, and in response to highly threatened or legally protected species.

permitting, and project planning processes. Without their inclusion in these areas, they feared their concerns would not be properly considered.

- Learning-by-doing is viewed as critical by the industry. This process includes improving efficiency in manufacturing, assembly, and installation through past project experience. Interviewees referenced the development of both fixed and floating technology in Europe as examples. After the first fixed-bottom projects were established, those firms gained a base of experience that was passed on to subsequent projects through knowledge sharing and improvements in technology, manufacturing, and installation. These improvements were developed through the experience of installing physical projects and collecting operational data (for example, energy generation, capacity factor, final cost, and environmental impact). A similar experience is being observed across early floating wind farms. This learning-by-doing process is expected to lead to cost reductions for floating platforms, both by identifying needed technology improvements and facilitating more efficient project development. Trade organizations also recommended learning from the fixed-bottom industry on the East Coast to further understanding of how factors like an untested permitting process for offshore energy generation led to delays.
- Setting an installed capacity target for offshore wind has strong support from trade organizations. Trade organizations representing the offshore wind industry voiced the strongest support for setting targets, explaining that such policies were instrumental in the facilitation of fixed offshore wind markets on the East Coast and in other nations around the world. While acknowledging the different challenges faced by the nascent floating wind industry, groups interviewed maintained the view that industry investment would follow the setting of a target.

CHAPTER 5:
Offshore Wind Deployment Barriers and Research, Development, and Demonstration Recommendations

This chapter presents offshore wind development and deployment barriers informed by interviews, a literature review, and case studies of the global offshore wind markets. It also discusses recommendations mapped to address these barriers, highlighting specific RD&D recommendations that the CEC could address.

Barriers

The project team identified 10 key barriers to offshore wind energy development off the coast of California. The remainder of this section describes these barriers in no particular order.

- Barrier 1: Limited infrastructure exists to transmit offshore wind generation to load centers, particularly on the northern coast. Capacity to transmit energy from offshore wind sites to load centers is limited, particularly on the north coast of California near where the best wind resource is located. Power offtake from call areas with good wind potential requires substantial investment in new transmission infrastructure and/or enhancement in existing transmission infrastructure. The Humboldt Bay call area is far from large load centers, potentially requiring new transmission lines or capacity upgrades spanning hundreds of miles. On the central coast, opportunity exists to build commercial development equivalent to the available capacity from the decommissioned Morro Bay power plant and Diablo Canyon power plant, which is still online and scheduled for decommissioning by 2025. Offshore development in excess of this available capacity will also require transmission capacity upgrades. The California ISO will conduct any new transmission planning for offshore development following direction from the IRP process. Offshore wind must be selected in the reference system portfolio in the IRP prior to California ISO undertaking transmission planning for power generated from offshore wind.[120]
- Barrier 2: Need to assess statewide port capabilities to identify improvements required and RD&D opportunities for large offshore wind projects. The infrastructure, layouts, and logistical capabilities of most existing ports in California do not fulfill the specific physical characteristics required for offshore wind projects. Floating offshore wind projects require ports with specific physical characteristics. Needs include significant lay-down space for towers and turbine blades, vertical clearance of up to 250 meters, and enough quayside length, weight-bearing capacity, and depth to host floating platform assembly. Expert interviews reinforced the notion that while individual ports in California are immediately suitable that may satisfy one or more of these requirements,

---

[120] The 2019-2020 IRP inputs and assumptions docket describes the mechanism for a resource's inclusion in the IRP process; offshore wind has not been used in the reference portfolio, though it has been modeled in framing scenarios.

the existing layouts of most facilities do not completely fulfill all requirements.[121] Therefore, offshore wind market development will require assessment of existing ports against specific criteria and enhancements in capabilities of these ports to handle offshore wind projects.

- Barrier 3: Uncertain market conditions restrict project development and supply chain investment. Project and technology developers interviewed for this study perceive risks in offshore wind project investments in the absence of a planning target and specific state commitment for offshore wind. These market actors indicated that they are hesitant to invest in offshore wind projects and supply chain infrastructure (for example, manufacturing capacity, ports, transmission infrastructure, and workforce development) without a capacity target or other indicator of state commitment to developing an offshore wind market.
- Barrier 4: Challenging installation, operation, and maintenance due to harsh and deep marine environment.[122] The combination of high wind and wave conditions and the depth of the water in the call areas presents a unique obstacle. No floating offshore wind platform system is operational anywhere in the world in an environment (wind, wave, and depth combined) that is comparable to California's northern coast. It is not clear what, if any, complications these conditions will have on project cost or performance.
- Barrier 5: Delays in federal leasing and untested California permitting processes. It remains uncertain when the federal government will grant leases for California call areas.[123] State-level permitting processes for offshore wind development in California require engagement with different agencies (for example, CEC, State Lands Commission, California Coastal Commission) that project developers may not have had to coordinate with in other states or countries.[124] The combination of uncertainty or unfamiliarity with both state and federal government processes could result in significant deployment delays.
- Barrier 6: Limited data on potential negative impacts on commercial fisheries and offshore ecosystems in California. Offshore wind is expected to negatively impact commercial fisheries by restricting where commercial fishing vessels may operate.[125] Some stakeholders indicated wind development could also affect migratory patterns of

---

[121] Multiple studies have provided a high-level view of California port infrastructure, including one from the BOEM in 2016. In-depth studies of eligible ports and the cost of upgrading port facilities have not been completed.

[122] The Energy Commission released the NextWind solicitation on September 30, 2019, which included up to $3 million in funding for technology research into offshore wind remote monitoring systems to reduce O&M costs.

[123] BOEM anticipates conducting California lease sales in 2020, but a specific date has not yet been established.

[124] California has over 200 state agencies, of which over 20 may be involved in some facet of offshore energy development. In contrast, other states and countries have as few as one entity with oversight over the process from start to finish. /

[125] Offshore wind energy development is described by stakeholders as an issue of "eminent domain" for fisheries; catching within floating wind farms will almost certainly be limited to avoid entanglement with subsea cabling and could potentially create exclusionary zones that are expected to harm certain commercial and recreational fishers.

different species (for example, blue whales, storm petrels, and sharks). The magnitude of potential impacts and the mitigation mechanisms remain uncertain. BOEM and the state are engaged in data gathering and stakeholder outreach to research impacts on both fisheries and coastal ecosystems.[126] Ongoing analyses by multiple research institutions will help identify gaps in existing knowledge that can be filled through state-led or state-supported research efforts.

- Barrier 7: Uncertain LCOE trajectory and concerns surrounding cost-competitiveness with onshore resources. Due to a nascent supply chain and limited technology commercialization, uncertainty exists around the trajectory of levelized cost reduction for floating offshore wind and the resource's competitiveness with the onshore renewable supply in California (for example, distributed and grid-scale solar, land-based wind, small hydro). Initial projects may not be cost-competitive on a $/MWh basis with alternate renewable generation assets. It is unclear if offtakers would be willing or able to enter into PPAs for electricity generated at a higher levelized cost than other renewable resources.[127]
- Barrier 8: Incomplete understanding of the total value proposition of offshore wind to California. Offshore wind offers a variety of potential benefits to California outside of the value of clean energy generated (for example, jobs in coastal regions, economic growth, in-state renewable energy). The IRP process does not take all of these components of the value proposition into account and may not properly assess the total value of offshore wind as a result. Total value proposition studies for offshore wind in California may consider these macroeconomic impacts to capture the full range of benefits offered.[128] This value is also dependent on the capacity of offshore wind installed and how this capacity may complement solar generation given their different electricity generation profiles. The IRP process already takes the effective load carrying capacity and varying generation profiles of different resource types into account when establishing system portfolios, though the value captured by this modelling is dependent on the data available. Continual improvements in modelling inputs through better data availability and additional value studies are needed to establish the specific contribution of various levels of offshore wind development in achieving a reliable, cost-effective, and low carbon energy system.

---

[126] The California Offshore Wind Energy Gateway serves as an aggregated source of existing environmental and fishery data. BOEM has completed stakeholder outreach and assessed key concerns for each group to be considered during additional research.

[127] *The Economic Value of Offshore Wind Power in California*, commissioned by Castle Wind and completed by E3, uses the RESOLVE model used in the IRP process to assess least-cost portfolios including offshore development. Even though the LCOE of offshore wind may initially be higher than alternative renewable supply options, this study finds that offshore wind is included within the least-cost portfolio by 2030 in California and has a progressively higher contribution in the state's least-cost portfolio as California's policy goals become more stringent to meet SB 100 targets. This study has not been reviewed by the CPUC to ensure consistency with the CPUC modeling process.

[128] Report titled *California Offshore Wind: Workforce Impacts and Grid Integration* co-released by the UC Berkeley Labor Center and E3 in September 2019 estimates the modelled economic and grid benefits of offshore wind development. This report could be used as a framework for a total value proposition study that incorporates new wind resource data and updated cost trajectories.

- Barrier 9: Conflicts with training and operation of the military on the central and southern coasts. The existing call areas at Morro Bay and Diablo Canyon, as well as other potential future call areas south of Monterey, are in proximity to multiple naval and air stations. Given current and potential military testing and training operations within these stretches of ocean, conflicts between offshore wind development and U.S. DOD activities may exist. As a main stakeholder and ocean user, the needs of the military must be considered in evaluating the degree of offshore wind development compatible with U.S. DOD operations.[129]
- Barrier 10: Limited data supporting floating technology performance and project development at commercial scale. Floating platform technology has been proven technically viable, but because of its nascency, limited large-scale operational projects exist globally.[130] The performance and viability of the technology is not yet demonstrated under California specific conditions. No floating farms in operation around the world as of January 2020 exceed 30 MW in size, far smaller than the scale of projects proposed off the coast of California (150 MW-1,000 MW+).[131] Although many similarities exist in the construction of a 30 MW versus a 1,000 MW project, it remains unknown what, if any, unforeseen obstacles commercial-scale project development in California may encounter (for example, port limitations, supply chain constraints, logistical issues) and how these obstacles may affect the value proposition.

Recommendations

This section presents recommendations grouped into three key themes to address the barriers discussed above:

- Technology and infrastructure research recommendations
- Environment and resource research recommendations
- Other recommendations

Technology and infrastructure and environment and resource research recommendations most directly fit within the mission of the CEC's R&D division and the scope of EPIC. Other recommendations include considerations outside the scope of EPIC that could help advance offshore wind market development. The CEC's R&D division may help facilitate these other recommendations even if other divisions or agencies spearhead them. Recommendations are split by key theme into three sections below. **Error! Reference source not found.**Tables within each section note which barriers are addressed by each recommendation, and all recommendations are discussed after each table in more detail.

---

[129] Federal statute 10 USC 183a: Military Aviation and Installation Assurance Clearinghouse for review of mission obstructions outlines the process through which a propose energy project may be evaluated for potential conflicts with military testing and operational activities.

[130] A small number of pilot or commercial demonstration projects are operational in multiple countries (Scotland, Japan, etc.), while others are under development (France, Portugal, Norway). That said, no farm with capacity greater than 30 MW is in operation, meaning field data on the performance of a large facility (>150 MW) does not exist.

[131] US Department of Energy, *2018 Offshore Wind Technologies Report*, 2019.

Technology and Infrastructure Research Recommendations

These recommendations identify new technologies that promote offshore wind deployment, reduce project costs, and assist with the installation, operation, and maintenance of floating offshore wind projects. Table 5 lists technology and infrastructure research recommendations.

Table 5: Technology and Infrastructure Research Recommendations

#	Technology and Infrastructure Research Recommendations	Barrier Addressed
1	Advance technologies for mooring, cabling, and anchors including interarray cabling webs and dynamic cabling.	4, 7
2	Develop technologies to ease O&M in extreme wind and wave conditions, including remote monitoring and robotic maintenance.	4
3	Develop technical solutions to integrate offshore wind, including facilitating technologies such as advanced hydrogen and subsea storage.	1, 8
4	Develop manufacturing approaches to use and optimize existing supply chain and manufacturing or assembly solutions in California.	3,7
5	Study the seismic vulnerability of floating platform mooring systems.	4
6	Conduct a comprehensive study on port infrastructure in California and develop technical solutions to identified gaps.	2, 3

Technology and infrastructure research recommendations include technologies that promote offshore wind deployment, reduce project costs, and assist with installation, operation, and maintenance of floating offshore wind projects.

Source: Guidehouse, 2020

- Recommendation 1: Advance technologies for mooring, cabling, and anchors including interarray cabling webs and dynamic cabling.[132] Research technologies and cabling designs that could reduce the length of cable needed and improve the performance of cables in deep offshore environments. This research has the potential to reduce the cost of installed capacity and improve the reliability and durability of installed systems. Specific opportunities and potential areas of research include the following:
  - Study the feasibility and durability of interarray cabling webs that connect multiple units to one another without needing to run individual mooring lines to the seafloor for each turbine. This design reduces the cost of cabling and mooring, while also lessening the chance of component failure at extreme depths by limiting the number of deep-sea lines needed.
  - Support the development of synthetic mooring lines (nylon, polyester, aramid, etc.) that could result in improved performance and reduced susceptibility to fatigue in dynamic ocean environments. Synthetic lines could reduce material costs compared

---

[132] The National Offshore Wind Research and Development Consortium selected an initiative on deep sea mooring research called DeepFarm (led by Principle Power) for a research grant in November 2019, presenting one opportunity for engagement.

    to standard steel and wire moorings while improving resilience and further cutting O&M costs.[133]
    - Evaluate the possibility to shift positioning of floating platforms by controlling the tension and length of mooring lines. This technology could adjust the distance between turbines to widen lanes for vessels to pass through and shift the arrangement of platforms to minimize wake effects in response to shifting wind conditions.
    - Research the effects of dynamic wave motion on cables at the depths proposed in the California call areas. Moving platforms place additional stress on cables that may otherwise only be used in stationary applications, affecting performance and increasing O&M costs. A better understanding of these effects could improve design and reduce O&M costs.
    - Support the design, manufacturing, and testing of low-cost anchors. Anchoring is one of the highest sources of capital expense for floating offshore wind systems. In California, anchors must also perform at depths and pressures previously untested in an active installation. Designing and testing anchors made of concrete or advanced composite materials may help reduce project costs and support deployment in deep sea environments.
    - Facilitate partnerships with out of state ocean and wave testing facilities to evaluate new technologies. Testing facilities that simulate oceanic conditions are limited within the state of California, posing a bottleneck for California-based technology developers. Partnerships with out of state facilities may be considered to support laboratory and field trials of technologies in support of California deployment.[134] These partnerships could include demonstrations of next generation platforms capable of hosting 12-15 MW turbines.
- Recommendation 2: Develop technologies to ease O&M in extreme wind and wave conditions, including remote monitoring and robotic maintenance.[135] Support the development of technologies that decrease capital cost and ongoing O&M costs for projects in California call areas with extreme wind and wave conditions. Specific opportunities and potential areas of research include the following:
    - Research application of remote monitoring software and sensor packages that could send real-time performance data to onshore operations centers. Remote monitoring could reduce the number of trips from land to offshore facilities for similar monitoring/inspections. The need to reduce O&M costs is not unique to offshore wind or floating foundations, but it becomes more significant as deeper waters lead

---

[133] As described in *Floating Wind Joint Industry Project - Summary Report Phase 1*, completed by an industry consortium led by the Carbon Trust.

[134] Example institutions include the Penn State Applied Research Laboratory, University of Minnesota MAST Laboratory, and University of Illinois Newmark Structural Engineering Laboratory.

[135] ARPA-E selected Principle Power's DIGIFLOAT in September 2019 to receive a $3.6 million grant to generate a digital representation of WindFloat Atlantic off the coast of Portugal. This model will be used to further understanding of system response to environmental conditions.

    to substructures and mooring becomes a more significant portion of total project costs.
  - Explore opportunities to repair and replace worn or damaged components, particularly those on the seafloor, with robotic vessels. Conditions on the open ocean will increase the complexity of servicing turbines. As California call areas are far offshore, larger and sturdier vessels may be required to service turbines in the absence of robotic maintenance, potentially increasing investment and O&M costs.
- Recommendation 3: Develop technical solutions to integrate offshore wind to the grid, including facilitating technologies like advanced hydrogen and subsea storage. Explore optimal pairings of auxiliary technologies with offshore wind to maximize benefits to the energy system. Specific opportunities include the following:
  - Develop partnerships and initiatives with research institutes studying storage opportunities unique to offshore wind. The Fraunhofer Institute, for example, recently piloted a subsea hydrogen storage system designed to pair with offshore wind farms.[136]
  - Research the technical feasibility of hydrogen production offshore or at suitable onshore facilities using power generated by offshore wind facilities. Hydrogen could be used to power industrial and mechanical processes that are otherwise difficult to decarbonize. Hydrogen production capability tied to offshore wind sites could mitigate the need for costly electricity transmission infrastructure upgrades and add value to offshore wind projects.
  - Conduct a value study quantifying potential benefits to the state grid from offshore wind plus storage. Existing and emerging storage technologies may reinforce the grid benefits of offshore wind by balancing intermittent power generation from onshore renewable resources.
- Recommendation 4: Develop manufacturing approaches to use and optimize existing supply chain and manufacturing or assembly solutions in California. Evaluate possible opportunities and challenges to supporting local content and local labor sourcing by examining capabilities within the state. Specific opportunities include the following:
  - Study existing manufacturing capacity and capabilities within California. Understand current supply chain constraints and opportunities by identifying existing facilities or potential future sites for fabrication, assembly, and deployment of towers and platforms. This information can support understanding which specific designs, technology types, or components are most feasible to develop in state.
  - Evaluate platform and tower technologies that allow for onsite manufacturing or production within existing manufacturing facilities in California. Reducing investment in new specialized facilities will lower production costs and support higher local content.
  - Support ongoing research into floating offshore wind systems with integrated components. Floating wind turbines combine technologies (for example, platform, tower, turbine) from multiple different manufacturers. A system designed and

---

[136] The Fraunhofer Institute StEnSEA pilot project ran from 2013 to 2017, concluding with successful operation of a test model (one-tenth scale). Further research opportunities may exist through a partnership.

    manufactured by a single entity may improve operational efficiency.[137] Such research would also have to assess the impact on LCOE.

    - Understand California's workforce capabilities and identify additional training programs the state can promote to support future local hiring for offshore wind projects. Developing a skilled worker base for these projects will help generate community support and reduce logistical complexity for project developers. Though training programs will not be necessary until project development timelines become more certain, early evaluation and design of these programs will facilitate accelerated rollout when the time comes.

- Recommendation 5: Study the seismic vulnerability of floating platform mooring systems. Evaluate whether mooring systems and anchoring systems will be negatively affected by earthquakes and undersea landslides and how these may impact system performance. Mooring systems are typically considered resilient to natural disasters by project and technology developers, but no floating turbine has been subjected to a major earthquake. If vulnerabilities are identified through such a study, develop technical solutions to reduce the seismic vulnerability of floating platform mooring systems.
- Recommendation 6: Conduct a comprehensive study on port infrastructure in California and develop technical solutions to identified gaps.[138] Utilize a gap analysis to identify the current state of port infrastructure in the state and research technical solutions to port barriers.
    - Conduct a statewide assessment of port capabilities to identify the upgrades and additional investment necessary to prepare port infrastructure to support offshore development and servicing.[139] The assessment would identify key deficiencies in port readiness (for example, lacking draft, lay-down space, water acreage, vertical clearance, need for additional dredging, competition for usage of port facilities) and opportunities to mitigate issues through state or private funding. Such a study would develop a list of necessary criteria for a port to successfully deploy offshore wind projects, compare current California ports against these necessary criteria and identify gaps, and assess additional investment needed to enhance the capabilities of ports to support offshore wind development. This study could also examine if using multiple ports in a multipart assembly process is more suitable than using a single port.
    - Develop technical solutions and estimate investment required to address identified deficiencies in ports. Upon completion of the above-mentioned port study, research technical solutions to the identified challenges and estimate required investment for ports to support offshore wind projects.

---

[137] NREL's SpiderFLOAT platform is designed to use a variety of materials efficiently to reduce system costs instead of relying on steel fabrication. A fully integrated system could be designed around SpiderFLOAT or another concept.

[138] The National Offshore Wind R&D consortium is collaborating with potential project developers in the northeastern states on port infrastructure studies. There could be similar collaboration opportunities in California.

[139] The Schatz Energy Research Center at Humboldt State University is evaluating the Port of Humboldt Bay for offshore wind development (including modeling seasonal variation and environmental constraints); similar studies should be be conducted for other potential OSW sites in California.

Environment and Resource Research Recommendations

The project team recommends conducting studies off the coast of California to evaluate offshore wind resources and the effect of wind farms on the natural environment and ecosystems. These studies are a first step to support research into technology solutions to mitigate any identified detrimental effects. Table 6 lists environment and resource research recommendations.

Table 6: Environment and Resource Research Recommendations

#	Environment and Resource Research Recommendations	Barrier Addressed
7	Conduct additional LIDAR wind resource studies offshore of California.	1, 7, 10
8	Advance technologies to prevent wildlife impacts, including smart curtailment and deterrence.	3, 10
9	Conduct state-led environmental studies along the California coast to fill gaps in existing research.	6

Environment and resource research recommendations include those to evaluate offshore wind resources and the effect of wind farms on the natural environment and ecosystems.

Source: Guidehouse, 2020

- Recommendation 7: Conduct additional LIDAR wind resource studies offshore of California. Place additional LIDAR buoys off the coast of California in targeted locations to gather accurate data on wind conditions.[140] State-funded LIDAR data would form a public resource that can be used by state planners (CEC, California ISO, CPUC), researchers at national laboratories, and prospective developers. Results of this study would de-risk the business case for offshore wind investment by improving the quality of wind resource data. This data could also provide higher quality input data to the IRP, which solely uses publicly available information and data.
- Recommendation 8: Advance technologies to reduce wildlife impacts, including smart curtailment and deterrence. Evaluate technologies that can reduce negative effects on birds and migratory sea mammals from offshore wind projects. Specific areas of research include the following:
    - Research smart curtailment by drawing on existing studies for land-based wind farms and evaluating their applicability to offshore environments. Smart curtailment could stop turbine rotation when sensors pick up protected seabirds in proximity to a floating unit, reducing bird fatalities from blade impact. Parameters for curtailment could consider species affected, migratory patterns, and prevailing weather conditions.
    - Research effectiveness and safety of sonar deterrence technologies on migratory marine mammals. Sonar deterrence may prevent incidents of subsea secondary entanglement with mooring lines and interarray cabling by alerting targeted marine mammals to the presence of a physical obstacle.

---

[140] Two LIDAR buoys have been allocated to the California coast by the USDOE, but many additional buoys could be placed to facilitate faster data sourcing on wind resource.

- Recommendation 9: Conduct state-led environmental studies along the California coast to fill gaps in existing research. Ongoing research efforts including a study by the Schatz Center and a gap analysis of existing data on the California Offshore Wind Energy Gateway by Point Blue Conservation Science and the Conservation Biology Institute[141] are seeking to identify the effects of wind farms on offshore ecosystems and migratory species in California. Results from these exercises will reflect on data quality and availability while clarifying gaps in knowledge that need to be filled. The CEC should engage with and review results from these ongoing studies and consider how the agency can help close these gaps by conducting or funding additional studies. Many resulting research initiatives would likely involve studies encompassing both state and federal waters, potentially requiring collaboration with federal research agencies.

Other Recommendations

The project team recommends additional actions to improve understanding of the value of offshore wind as a complementary resource in a cost-effective energy system. These are not recommendations related to technology or environmental research but rather studies that could support future planning and policy decisions. Such research may be conducted by other divisions of the CEC outside of RD&D or by other state agencies in concert with the CEC. Table 7 lists other research recommendations.

Table 7: Other Recommendations

#	Other Recommendations	Barrier Addressed
10	Assess the offshore wind installed capacity that is complementary to solar generation and feasible to support a reliable, cost-effective, and low carbon energy system.	1, 3, 5, 8
11	Conduct a comprehensive study on the total value proposition of offshore wind development, including grid and macroeconomic benefits.	7, 8

Other recommendations focus on opportunities to improve understanding of the value of offshore wind in California.

Source: Guidehouse, 2020

- Recommendation 10: Assess the offshore wind installed capacity that is complementary to solar generation and feasible to support a reliable, cost-effective, and low carbon energy system. Evaluate the role of multiple levels of offshore wind development toward supporting a more reliable and cost-effective grid. Various actions can be taken under this recommendation to facilitate greater understanding of the effects and processes of proposed offshore development, including the following:
  - Closely study the projected costs and benefits of transmission upgrades required for large-scale offshore development in California against alternatives including out of state wind.[142] Defining the scale of offshore development appropriate for California is

---

[141] Presentation titled Using Available Data to Identify Offshore Wind Energy Areas, presented at the Energy Commission/CPUC Integrated Energy Policy Report workshop in San Francisco on October 3, 2019.

[142] Identifying and planning transmission upgrades would be done in concert between the CPUC and CAISO through the IRP and Transmission Planning Process (TPP). CEC research support may possibly be used to evaluate technical specifications, requirements, and system risk and hardening opportunities to support offshore

  intrinsically tied into an understanding of the costs associated with transmission upgrades at various levels of installed capacity. Assessing transmission costs in a variety of scenarios will provide more accurate public data for use in various planning processes and inform discussion of the benefits of offshore development over different long-term scenarios.

  - Consider state-led mechanisms to reduce the cost to ratepayers and project developers of early projects. Topics of study may include the feasibility of direct financial incentives, means to improve offtake certainty, and the value of a centralized infrastructure development fund. Reducing financial barriers to offshore development could accelerate deployment and lead to increased cost reductions.
  - Evaluate the cost and technical feasibility of offshore HVDC transmission. Research on technical feasibility and projected costs for offshore transmission capacity and making that information publicly available can help support project development and resource or transmission planning.[143] If deemed feasible but cost-prohibitive, the CEC may choose to conduct research to mature and de-risk offshore HVDC technology. Research topics may focus on opportunities to ensure cable performance at extreme depths, options to reduce materials or manufacturing costs, and understand the effect of subsea transmission on various species.
  - Map out the permitting process and develop a handbook for developers trying to navigate California's regulatory environment for the first time.[144] This resource would help clarify the process, next steps, and projected timelines prior to project commissioning. Improving universal understanding of the permitting process could accelerate offshore wind deployment and help developers more easily engage with the proper state entities.
- Recommendation 11: Conduct a comprehensive study on the total value proposition of offshore wind development, including grid and macroeconomic benefits. Evaluate and quantify grid, employment, and environmental benefits of offshore wind for California in one study. Past studies have addressed some of the individual components of this total value proposition but have not attempted to quantify all added benefits in a means similar to studies conducted for other low penetration energy sources (for example, value of solar or value of storage studies).[145] An overarching and all-encompassing

---

wind development at varying scales. This recommendation is not intended to imply that CEC research would take the place of transmission planning and evaluation processes already in place.

[143] Current capacity expansion modeling in IRP does not enable specific transmission projects to be analyzed directly within IRP. It is only when IRP portfolios of generation and storage resources are provided as inputs to the annual TPP, that specific transmission projects get analyzed. The CPUC and CAISO could explore whether this is appropriate for subsea HVDC projects, or whether IRP modeling needs to be enhanced.

[144] A TAC member cited an ongoing effort within a California state agency to complete a permitting map for offshore wind; it is unclear what the status of this project is and when it may be made public. The Ocean Protection Council has organized a Marine Renewable Energy Working Group to facilitate discussion and inter-agency understanding of existing permitting processes and obstacles.

[145] Value proposition frameworks, outlined in this document from NREL, can be used to approximate the benefits of a given resource throughout the supply chain, extending to auxiliary benefits like grid health and employment gains.

state-led report could incorporate all other sources of information and be used by both planning agencies and developers. This valuation could also improve the business case for investment and support further state-funded research, while supporting a comprehensive comparison of offshore wind to other resources.

Conclusion

The project team concludes that there is a need for state funding and RD&D support to advance offshore wind in California. Numerous barriers to offshore wind industry development exist. Limited transmission capacity and suitable port facilities are each pressing obstacle to infrastructure readiness for commercial-scale development. The nascency of floating wind systems and manufacturing, installation, and O&M processes for these systems impacts cost-competitiveness with onshore resources. Non-technical issues like stakeholder concerns and competing ocean uses, data gaps, and untested planning processes for offshore energy in California may risk further delays once infrastructure and technology issues are resolved.

This report developed recommendations for CEC RD&D to help address technology and deployment barriers using funds. Each of these recommendations help address one or more barriers. The recommendations focused on technology and environment related research that fit the CEC Energy Research and Development Division’s role. The report provides a few additional recommendations covering areas outside the division in which the CEC may more broadly be able to engage in resolving barriers to help promote offshore wind development. Implementation of proposed research initiatives will help clarify the future path for offshore wind in California.

LIST OF ACRONYMS

Term	Definition
BOEM	Bureau of Ocean Energy Management
California ISO	California Independent System Operator
CCA	Community Choice Aggregator
CPUC	California Public Utilities Commission
CEC	California Energy Commission
EPIC	Electric Program Investment Charge
EU	European Union
GBP	Great British Pounds
GHG	Greenhouse Gas
GW	Gigawatt
GWh	Gigawatt-hour
HVDC	High Voltage Direct Current
IRP	Integrated Resource Planning
kW	Kilowatt
LCOE	Levelized Cost of Energy
LSE	Load-serving entity
MHI	Mitsubishi Heavy Industries
MWh	Megawatt-hour
NREL	National Renewable Energy Laboratory
NYSERDA	New York State Energy Research and Development Authority
O&M	Operations and Maintenance
OSWInD	Offshore Wind Innovation and Demonstration Initiative
PPA	Power Purchasing Agreement
R&D	Research and Development
RD&D	Research, Development, and Deployment
ROC	Renewable Obligation Component
RSP	Reference System Portfolio
SB	Senate Bill
TAC	Technical Advisory Committee

Term	Definition
TRL	Technology Readiness Level
U.S. DOD	United States Department of Defense
USDOE	United States Department of Energy

REFERENCES

ABS. 2012. *BSEE TA&R 669 (Contract M11PC00004): Floating Wind Turbine.* American Bureau of Shipping on behalf of the Department of the Interior Bureau of Safety and Environmental Enforcement.

American Jobs Project. 2019. *The California Offshore Wind Project: A Vision for Industry Growth.* American Jobs Project.

Barter, Garrett. 2018. *Moving Toward Cost-Competitive, Commercial Floating Wind Energy.* National Renewable Energy Laboratory.

Banister, Kevin. 2017. *WindFloat Pacific Project Final Scientific and Technical Report.* Principle Power, Inc.

Beiter, Philipp, Paul Spitsen, Walter Musial, and Eric Lantz. 2019. *The Vineyard Wind Power Purchase Agreement: Insights for Estimating Costs of U.S. Offshore Wind Projects.* National Renewable Energy Laboratory.

Beiter, Philipp, Walter Musial, Levi Kilcher, Michael Maness, and Aaron Smith. 2017. *An Assessment of the Economic Potential of Offshore Wind in the United States from 2015 to 2030.* National Renewable Energy Laboratory.

Brown-Saracino, Jocelyn. 2018. *State of the Science: Technologies and Approaches for Monitoring Bird and Bat Collisions Offshore.* United States Department of Energy, Office of Energy Efficiency and Renewable Energy, Wind Energy Technologies Office.

Bureau of Ocean Energy Management. 2016. *Determining the Infrastructure Needs to Support Offshore Floating Wind and Marine Hydrokinetic Facilities on the Pacific West Coast and Hawaii.* Bureau of Ocean Energy Management.

Bureau of Ocean Energy Management. 2018. *California Call Areas Nominations.* Bureau of Ocean Energy Management.

Carbon Trust. 2015. *Floating Offshore Wind Market and Technology Review.* The Carbon Trust prepared for The Scottish Government.

Castro-Santos, Laura, Almudena Filgueira-Vizoso, Carlos Álvarez-Feal, Luis Carral. 2018. *Influence of Size on the Economic Feasibility of Floating Offshore Wind Farms.* Universidade da Coruña.

City of Morro Bay and Castle Wind. 2018. *Community Benefits Agreement Castle Wind Morro Bay Offshore Wind Farm Project.* City of Morro Bay.

Collier, Robert. 2017. *High Road for Deep Water: Policy Options for a California Offshore Wind Industry.* Center for Labor Research and Education, University of California, Berkeley.

Collier, Robert, Sanderson Hull, Oluwafemi Sawyerr, Shenshen Li, Manohar Mogadali, Dan Mullen, and Arne Olson. 2019. *California Offshore Wind: Workforce Impacts and Grid Integration.* Center for Labor Research and Education, University of California, Berkeley.

DNV GL. 2018. *Floating Wind Turbine Structures.* DNV-GL.

Energy and Environmental Economics. 2019. *The Economic Value of Offshore Wind Power in California.* Energy and Environmental Economics, Inc (E3).

Eurek, Kelly, and Patrick Sullivan, Michael Gleason, Dylan Hettinger, Donna Heimiller, and Anthony Lopez. 2017. *An Improved Global Wind Resource Estimate for Integrated Assessment Models.* National Renewable Energy Laboratory.

International Energy Agency. 2019. *Offshore Wind Outlook 2019.* International Energy Agency (IEA).

IRENA. 2016. *Floating Foundations: A Game Changer for Offshore Wind Power.* International Renewable Energy Agency (IRENA).

Kempton, Willett, Andrew Levitt, and Richard Bowers. 2017. *Industrializing Offshore Wind Power with Serial Assembly and Low-Cost Deployment.* University of Delaware.

Lazard. 2018. *Lazard's Levelized Cost of Energy Analysis – Version 12.0.* Lazard.

Massachusetts Clean Energy Center. 2017. *2017 Massachusetts Offshore Wind Ports and Infrastructure Assessment, Volume 2: Engineering Assessment of Potential Site Redevelopment and Reuse Scenarios.* Massachusetts Clean Energy Center.

Musial, Walter, Philipp Beiter, Suzanne Tegen, and Aaron Smith. 2016. *Potential Offshore Wind Energy Areas in California: An Assessment of Locations, Technology, and Costs.* National Renewable Energy Laboratory on behalf of Bureau of Ocean Energy Management.

Musial, Walter, Philipp Beiter, Paul Spitsen, Jake Nunemaker, and Vahan Gevorgian. 2018. *2018 Offshore Wind Technologies Market Report.* United States Department of Energy, Office of Energy Efficiency and Renewable Energy.

Myhr, Anders, Catho Bjerkseter, Anders Ågotnes, and Tor A. Nygaard. 2014. *Levelised Cost of Energy for Offshore Floating Wind Turbines in a Life Cycle Perspective.* University of Life Sciences (UMB), Department of Mathermatical Sciences and Technology.

National Offshore Wind Research and Development Consortium. 2018. *National Offshore Wind Research and Development Consortium: Research and Development Roadmap.* National OSW R&D Consortium.

Pacific Northwest National Laboratory. 2018. *Humpback Whale Encounter with Offshore Wind Mooring Lines and Inter-Array Cables.* Pacific Northwest National Laboratory prepared for the Bureau of Ocean Energy Management.

Redwood Coast Energy Authority. 2018. *Unsolicited Application for and Outer Continental Shelf Renewable Energy Commercial Lease.* Redwood Coast Energy Authority (RCEA).

Speer, Bethany, David Keyser, and Suzanna Tegen. 2016. *Floating Offshore Wind in California: Gross Potential for Jobs and Economic Impacts from Two Future Scenarios.* National Renewable Energy Laboratory prepared for the Bureau of Ocean Energy Management.

Skov, Henrik, Stefan Heinänen, Tim Norman, Robin Ward, Sara Méndez-Roldán, Ian Ellis. 2018. *ORJIP Bird Collision Avoidance Study Final Report.* The Carbon Trust.

United States Department of Energy and Department of the Interior. 2016. *National Offshore Wind Strategy: Facilitating the Development of the Offshore Wind Industry in the United States.* United States Department of Energy and United States Department of the Interior.

Wind Europe. 2017. *Floating Offshore Wind Vision Statement.* Wind Europe.

Wind Europe. 2018. *Floating Offshore Wind Energy: A Policy Blueprint for Europe.* Wind Europe.

APPENDIX A:
Floating Offshore Wind Project Table

This appendix includes a list of operational, planned, and proposed floating offshore wind projects. The majority of project data was provided by the USDOE 2018 Offshore Wind Technologies Market Report. Additional data was gleaned through interviews with industry stakeholders.

Key acronyms include:

- COD: Commercial Operation Date; the proposed or achieved date of grid interconnection for a completed project.
- TBD: To Be Determined; listed where project information on proposed scale, location, or substructure is not yet public or could not be verified.
- TLP: Tension Leg Platform; a type of floating platform substructure discussed in Chapter 2.

Table A-1: List of Operational, Planned, and Proposed Offshore Wind Projects

Project	Developer	Sub-structure	Status	COD*	Country	Region	Depth (m)	Project Capacity (MW)	Turbine Rating (MW)	Source
Hywind Demonstration	Equinor	Spar	Installed	2009	Norway	Europe	220	2.3	2.3	USDOE
VolturnUS 1:8 Demonstration	University of Maine	Semi-Sub	Installed	2013	United States	North America	0.02	0.02		Navigant 2020
Fukushima FORWARD Mirai Phase 1	Marubeni Corporation	Semi-Sub	Installed	2013	Japan	Asia	120	2	2	USDOE
Fukushima FORWARD Hamakaze Phase 2	Marubeni Corporation	Semi-Sub	Installed	2015	Japan	Asia	120	5	5	USDOE
Hywind Scotland	Equinor	Spar	Installed	2017	United Kingdom	Europe	100	30	6	USDOE
EOLINK 1/10 Scale	EOLINK S.A.S	Semi-Sub	Installed	2018	France	Europe	10	0.2	0.2	USDOE
Floatgen Demonstrator	Ideol	Barge	Installed	2018	France	Europe	33	2	2	USDOE
Kincardine Phase 1	Cobra	Semi-Sub	Installed	2018	United Kingdom	Europe	62	2	2	USDOE
Fukushima FORWARD Simpuu Phase 3	Marubeni Corporation	Semi-Sub	Installed	2018	Japan	Asia	120	7	7	Navigant 2020
Ulsan Floating Demonstration	Ulsan Consortium	Semi-Sub	Construction	2019	South Korea	Asia	15	0.75	0.75	USDOE
Sakiyama Floating Wind Turbine	TODA Corporation	Spar	Installed	2019	Japan	Asia	100	2	2	USDOE
Hibiki Demonstrato/	Ideol	Barge	Installed	2019	Japan	Asia	70	3	3	USDOE

Project	Developer	Sub-structure	Status	COD*	Country	Region	Depth (m)	Project Capacity (MW)	Turbine Rating (MW)	Source
Kitakyushu NEDO										
TetraSpar Demonstrator	Stiesdal Offshore Technologies/ Shell/ Innogy	Spar	Construction	2019	Norway	Europe	200	3.6	3.6	USDOE
WindFloat Atlantic	Principle Power	Semi-Sub	Installed	2019	Portugal	Europe	50	25	8	USDOE
DemoSATH - BIMEP	Saitec Offshore Technologies	Semi-Sub	Approved	2020	Spain	Europe	68	2	TBD	USDOE
Kincardine Phase 2	Principle Power/Cobra	Semi-Sub	Construction	2020	United Kingdom	Europe	62	50	9.5	USDOE
Dounreay Tri	Hexicon	Semi-Sub	Approved	2021	United Kingdom	Europe	76	10	5	USDOE
Groix Belle Ille	Eolfi	Semi-Sub	Approved	2021	France	Europe	62	24	6	USDOE
Provence Grand Large	EDF	TLP	Approved	2021	France	Europe	30	24	8	USDOE
Eolmed	Ideol	Barge	Approved	2021	France	Europe	62	24	6.2	USDOE
X1 Wind PLOCAN	X1 Wind	TLP	Approved	2021	Spain	Europe	62	TBD	TBD	USDOE
Floating Power Plant PLOCAN	FPP	Hybrid	Approved	2021	Spain	Europe	62	TBD	8	USDOE
GICON Schwimmendes Offshore Fundament SOF Pilot	GICON	TLP	Approved	2022	Germany	Europe	37	2.3	2.3	USDOE
Shanghai Light Demonstrator	TBD	TBD	Approved	2022	China	Asia	TBD	4	4	Navigant 2020
New England Aqua Ventus 1	University of Maine	Semi-Sub	Proposed	2022	United States	North America	100	12	6	USDOE

Project	Developer	Sub-structure	Status	COD*	Country	Region	Depth (m)	Project Capacity (MW)	Turbine Rating (MW)	Source
Les Eoliennes Flotantes du Golfe du Lion	Engie/EDPR	Semi-Sub	Approved	2022	France	Europe	71	30	10	USDOE
Hywind Tampen	Equinor	Spar	Construction	2022	Norway	Europe	110	88	8	USDOE
AFLOWT	European Marine Energy Centre	Semi-Sub	Approved	2022	Ireland	Europe		TBD		Navigant 2020
NOAKA	Equinor/Aker	TBD	Proposed	2023	Norway	Europe	130	TBD	TBD	USDOE
Hitachi Zosen	Equinor	TBD	Proposed	2024	Japan	Asia	TBD	400	TBD	USDOE
Redwood Coast Energy	EDPR/Principle Power	Semi-Sub	Proposed	2025	United States	North America	550	150	8	USDOE
Macquarie Japan	Macquarie	TBD	Proposed	2025	Japan	Asia	100	500	TBD	USDOE
Floating W1N	Eolfi/Cobra	TBD	Proposed	2025	Taiwan	Asia	TBD	500	TBD	USDOE
Ulsan Parcel One	Shell/Coens/ Hexicon	Semi-Sub	Proposed	2027	South Korea	Asia	TBD	200	TBD	USDOE
Ulsan Parcel Two	Macquarie	TBD	Proposed	2027	South Korea	Asia	TBD	200	TBD	USDOE
Ulsan Parcel Three	CIP/SK E&S	TBD	Proposed	2027	South Korea	Asia	TBD	200	TBD	USDOE
Ulsan Parcel Four	Principle Power/KFWind	TBD	Proposed	2027	South Korea	Asia	TBD	200	TBD	USDOE
Oahu North	AW Wind	Semi-Sub	Proposed	2027	United States	North America	850	400	6	USDOE
Oahu South	AW Wind	Semi-Sub	Proposed	2027	United States	North America	600	400	6	USDOE
Progression Wind	Progression Wind	Semi-Sub	Proposed	2027	United States	North America	650	400	6	USDOE
Morro Bay	Castle Wind	Semi-Sub	Proposed	2027	United States	North America	900	1000	8	USDOE
Donghae KNOC	Equinor/KNOC	TBD	Proposed	2027	South Korea	Asia	TBD	TBD	TBD	USDOE

Project	Developer	Sub-structure	Status	COD*	Country	Region	Depth (m)	Project Capacity (MW)	Turbine Rating (MW)	Source
VolturnUS Commercial Farm	University of Maine	TBD	Proposed	TBD	United States	North America		300	TBD	Navigant 2020

***Based on source data published in 2019**

Sources: USDOE: U.S. Department of Energy, *2018 Offshore Wind Technologies Report*, 2019; Navigant 2020: Interviews conducted by Navigant during the conduct of this study

APPENDIX B:
Case Studies

This appendix presents case studies on offshore wind market development and progress from the following areas:

- United Kingdom (UK) and Scotland
- France
- Scotland
- East Asia (including Japan, China, Taiwan, and South Korea)
- United States East Coast

United Kingdom and Scotland

Market Overview

- The UK, including Scotland, is among the global leaders in fixed-bottom and floating offshore wind development.[146]
- The first offshore wind turbine was installed in 2003 and the current installed capacity is 8.4 GW, with 11.7 GW capacity under development (projects that are consented or under construction).[147]
- The UK and Scotland auction system design allows the market to determine the most cost-competitive technology to gain government support. In the auction, offshore wind projects (fixed bottom and floating) compete for a government contract for difference against a variety of other renewable energy technologies (for example, biomass, combined heat and power, geothermal, tidal and wave projects). Contract for difference provides the project with a 15-year guaranteed payment, which is the difference between the auction strike price and market reference price.[148]
- The wind farm developer bears the costs of grid connection, transmission, resource assessment, and environmental impact assessment.
- The national electricity transmission systems operators (National Grid in the UK, Scottish Power in Scotland) assess and finance the onshore grid reinforcement requirements.
- Transmission assets are later sold to a separate entity that operates the offshore transmission asset, the offshore transmission owner, through a competitive auction (organized by the government regulator for electricity and gas, the Office of Gas and Electricity Markets).

---

[146] 4C Offshore Wind Database

[147] The Crown Estate. Offshore Wind Operational Report. January to December 2018.

[148] The Oxford Institute for Energy Studies (2019). Auctions for Allocation of Offshore Wind Contracts for Difference in the UK.

- The third auction round in the UK and Scotland cleared in September 2019 with a record-low bidding price of 39.65 £/MWh (USD 49.08) for commercial operation date in 2023/2024 and 41.61 £/MWh (USD 51.50) for 2024/2025.[149]

United Kingdom Summary

- The UK leads the global fixed-bottom offshore wind market with 7.9 GW installed capacity.
- The UK industry members aim to generate one-third of the country's electricity from offshore wind by 2030 (equivalent to 30 GW).[150] To support this ambition, the UK's government signed a deal with the industry stakeholders, The UK Sector Deal for Offshore Wind.[151]
    - The deal stipulates that the government invests up to 557 million Great British Pounds (GBP) in state subsidies, while the industry stakeholders invest up to 250 million GBP into supply chain development.[152]
- Key drivers behind the 30 GW target include the following:
    - Government plan to close all coal-fired power plants by 2025[153]
    - Decline of the UK's nuclear plans[154]
    - Passing of Net Zero Emissions Law 2050, a law that requires to bring emissions to net zero in the UK by 2050[155]

Scotland Summary

- Scotland has 30 MW of operational floating offshore wind capacity (Hywind Scotland) and a further 50 MW under construction (Kincardine).[156]
- The most attractive sites for floating offshore wind are in Scotland due to deep water, suitable geology, and sea climate conditions.[157]

---

[149] Department for Business, Energy & Industrial Strategy (2019, Oct 11). Contracts for Difference (CfD) Allocation Round 3: Results – Published 20 September 2019, Revised 11 October 2019.

[150] Department for Business, Energy & Industrial Strategy. Offshore Wind Energy Revolution to Provide a Third of All UK Electricity by 2030. 2019.

[151] Offshore Wind Sector Deal, Her Majesty's Government

152 Department for Business, Energy & Industrial Strategy (2019, Mar 7). Policy Paper, Offshore Wind Sector Deal.

[153] Power Stations of the UK. Coal Countdown.

[154] Kennedy, Will, Carr, Mathew (2019). Britain's Failing Nuclear Plan Poses Huge Questions for Power.

[155] UK Government (2019). UK Becomes First Major Economy to Pass Net Zero Emissions Law.

[156] Offshore Wind Scotland web page. 2019.

[157] Carbon Trust (2015). Floating Offshore Wind. Market & Technology Review.

- In response to the UK Sector Deal for Offshore Wind, Scotland introduced a target of 8 GW offshore wind capacity by 2030 in addition to the 30 GW UK target.[158]

Market Players and Value Chain

The UK and Scotland offshore wind capacity has been largely developed by using the expertise and equipment manufacturing capacities of other European countries, such as Denmark, Germany, the Netherlands, Norway, Poland, and Spain. The wind turbine and foundation manufacturing in the UK is led by Siemens Gamesa and MHI Vestas for large offshore wind turbine generator manufacturing and Sif and Bladt Industries for foundation and substructure manufacturing. The largest subsea cable providers for the UK and Scottish markets are JDR, Prysmian (cable provider for Kincardine floating offshore project), and Nexans (cable provider for Hywind floating offshore wind project).[159] The floating substructures for the Hywind Scotland floating wind projects were manufactured by the Spanish state-owned shipbuilding company Navantia and transported to the assembly site in Norway. Navantia has also been selected to manufacture the floating substructures for Kincardine floating project.[160]

The UK and Scotland historically have a strong North Sea oil and gas exploration industry. The existing synergies in marine engineering experience, marine project development, and port and manufacturing infrastructure support substructure manufacturing and O&M activities. The UK also has number of specialized suppliers (commonly referred to tier two and three suppliers—for example, foundation manufacturers and manufacturers of smaller components for wind turbine generators) that provide various components for wind turbine installation offshore and services to original equipment manufacturers, project developers, and operators.

The leading offshore wind project developers in the UK and Scotland are companies that are committed to expanding their renewable energy portfolios, such as Ørsted, E. ON, Innogy, Equinor, Vattenfall, and SSE Renewables.[161]

Drivers

Historically, the UK and Scotland depended on the Renewables Obligation Component (ROC) scheme that obliged electricity suppliers to buy a specific proportion of their energy from renewable sources. ROCs would vary by the type of technology, allowing the government to define their renewable energy technology mix. In addition, Scotland provided "enhanced ROCs for innovative foundation technologies," which supported the development of the Hywind floating pilot project with higher subsidies.[162] The aim of enhanced ROCs was to provide higher funding for precommercial technology development before it can compete with established

---

[158] Offshore Wind Scotland. Scottish Offshore Wind Energy Council.

[159] Offshore Wind Industry Council. The UK Offshore Wind Industry: Supply Chain Review.

[160] Navantia approximated that 1,250,000 person-hours will be needed for the production process in addition to 15,000 tons of steel in this article from Wind Power Monthly. 2019.

[161] The Crown Estate (2018). Offshore Wind Operational Report 2018.

[162] International Energy Agency, Renewable Energy Technology Development. Comparative Analysis of International Offshore Wind Energy Development. 2017.

fixed-bottom technology projects under the same incentive scheme. The ROC scheme was cancelled in 2017, which posing risks for floating projects.

Current support mechanisms for the UK and Scotland include the government contract for difference scheme and power purchase agreements (PPAs) between generators and commercial entities. Contract for difference is the government's main support mechanism for low carbon projects. Renewable energy generators apply for contract for difference by submitting a flat rate bid (sealed format) during scheduled auction rounds for the electricity they will produce. The successful bidder receives a flat rate payment (indexed) over a period of 15 years from the government-owned Low Carbon Contracts Company. The flat rate is the difference between the strike price (a fixed winning bid) and reference price (a variable measure of the average electricity price in the UK and Scotland). When the reference price is lower than strike price, the generator will receive revenue for selling their electricity to the market and the Low Carbon Contracts Company will pay a generator the difference (that is, the top-up price). When the reference price is higher than the strike price, the generator will pay the difference back to Low Carbon Contracts Company.

Under the contract for difference scheme, viable floating offshore wind sites need to compete economically with fixed-bottom offshore wind energy sites elsewhere in the UK or Scotland. The levelized cost of energy (LCOE) for a 30 MW floating offshore demonstration project is estimated at roughly 200 GBP/MWh[163] (~262 USD/MWh) which does not compete with fixed-bottom price levels (~65 GBP/MWh or ~85 USD/MWh[164]).

The Crown Estate in the UK and Crown Estate Scotland in Scotland are the public bodies responsible for identifying and leasing offshore development sites and managing the offshore site leasing rounds under the contract for difference auction system. The most recent leasing round tender opened in both the UK during fall 2019 (for example, round 4 in the UK and the first ScotWind tender in Scotland). Crown Estate Scotland's Sectoral Plan for Offshore Wind energy remains technology-neutral, allowing the technology preference to be determined by the market.[165] Tracking the developments of ScotWind tender round (opened during fall 2019) could present valuable insights for California because of the similarity of Scotland's technology-neutral energy strategy. In the UK, the next auction round will encourage technology innovations. No discrete support mechanisms for floating offshore wind are expected to be introduced.

---

[163] ORE Catapult. Macroeconomic Benefits of Floating Offshore Wind in the UK. 2018.

[164] CarbonBrief. Analysis: UK Auction Reveals Offshore Wind Cheaper than New Gas. 2018.

[165] The Crown Estate Scotland (2019). New Offshore Wind Leasing for Scotland. Discussion Document.

Technological Solutions

Floating Technology

The first floating commercial demonstration project (10+ MW), Hywind Scotland, had better-than-expected power generation efficiency due to the floating system's (platform equipped with a turbine) response to wind and wave conditions and a site location with good wind resource.[166] To lower costs, the Hywind developer emphasizes the need to focus on four key aspects:

- Optimizing floating platform design to reduce the costs per metric ton
- Increasing project and turbine size (10 MW-15 MW) to lower infrastructure and logistics costs
- Developing installation and operations and maintenance (O&M) methods
- Developing and pairing projects with energy storage technology[167]

To store electricity from the floating wind turbines, Hywind Scotland is developing a 1 MW lithium battery-based pilot storage system.[168]

Table B-1 summarizes the technology characteristics of floating offshore wind projects in Scotland.

---

[166] Carbon Trust (2015). Floating Offshore Wind: Market and Technology Review.

[167] Bringsvaerd, Sebastian. Industrialization, Scale and Next Generation Technology Will Cut Costs. 2018.

[168] Equinor. Statoil Launches Batwind: battery Storage for Offshore Wind. 2016.

Table B-1: Floating Offshore Wind Projects in Scotland

Project	Installed Capacity	Floating Wind Technology Concept	Technology Parameters
Hywind Scotland pilot project	30 MW	Spar-buoy by Equinor	• Maximum advertised depth of 500 meters (130 meter depth for this project) • Validated platform technology in operation since 2009 • 70 meter-90 meter draft requirement • Catenary three-line mooring system using steel chains • Adaptable ballast to support larger turbines • Exact dimensions and mass of the spar-buoy are site-dependent • Recent Hywind pilot project results presented 65 percent capacity factor (well above fixed-bottom offshore wind) [169] • Specified manufacturing facilities and vessels required (based on floating foundation dimension and weight: heavy lifting equipment, mooring dock)
Kincardine floating project	50 MW (Proposed)	WindFloat semi-submersible platform by Principle Power (under construction)	• One of the more mature floating platform concepts • Stability performance allows for use of existing offshore turbine technology • Can support most three-blade turbines with minor design modifications • Catenary three-line mooring system using steel chains and polyester lines • Specified manufacturing facilities required

Source: Guidehouse, 2020

The UK and Scotland offshore wind industry place floating wind technology development among the highest innovation opportunities. Increasing the number of test sites and demonstration sites in the UK and Scotland is challenging due to high capital costs for the private sector. Future market visibility and a clear UK policy for floating wind would attract more international players and drive innovation local the UK market.

---

[169] Froese, Michelle. World's First Floating Wind Farm Delivers Promising Results. 2018.

Grid Connection

The development and construction of offshore transmission assets in the UK can be undertaken either by a developer or an offshore transmission owner.[170] Due to European unbundling requirements,[171] the developer cannot hold generation and transmission assets after completion, resulting in transmission assets being sold to offshore transmission owner. To date, the construction of offshore transmission assets has only been performed by wind farm developers. Following the UK experience, Denmark is implementing a similar grid connection regime for the upcoming tender round in 2020.

Developer-led grid connection allows the developers to minimize interface risks and optimize the planning and construction process of generation and transmission assets. A developer-led approach also results in limited coordination between different sites and relatively high project costs. In contrast to the UK, other countries such as Germany, the Netherlands, and France have mandated the national transmission system operators to construct and operate the grid connection to focus on offshore grid coordinated development and site de-risking. A recent study by Navigant shows that when the costs are compared across selected EU countries, the UK model can result in higher overall costs.[172] In the UK, National Grid examines grid connection applications from wind developers and assesses the required onshore transmission network reinforcements for a stable connection of new offshore wind farms. Once the construction of the transmission assets is completed, the assets are sold through a competitive tender to an offshore transmission owner. Ofgem manages the offshore transmission owner tenders, and the regulator in the UK grant the operating licenses for the new offshore transmission assets. The developer pays Ofgem for running the offshore transmission owner tender. The offshore transmission owner is responsible for O&M and availability of transmission assets. The developer is entitled to compensation from offshore transmission owner in case of revenue loss due to grid unavailability.

Policy Outlook

The UK (including Scotland) is the global offshore wind leader in terms of installed capacity (fixed bottom and floating). Maintaining this market position will likely depend on an open trading relationship with the post-Brexit European Union (EU) since funding from the EU has been integral to realizing the current floating wind projects.[173] In the absence of previous ROC support mechanism, the future of floating wind projects in the UK remains uncertain because of relatively higher technology costs and the need for government support.

---

[170] Navigant. Comparison of Offshore Grid Development Models. 2019.

[171] Unbundling is the separation of energy supply and generation from the operation of transmission networks. Third energy package. European Commission. 2019.

[172] Navigant. Comparison of Offshore Grid Development Models. 2019.

[173] European Technology and Innovation Platforms Smart Networks for Energy Transition. New EUR 10 Billion Innovation Fund for Low Carbon Technologies. 2019.

Lessons for California

1. **Local content:** While becoming the global offshore wind leader, the UK industry has capitalized on experiences and capacities from other EU countries. This has been done without applying minimum local content requirements that could limit project realization. Conversely, France introduced high local content requirements in the early stages of offshore industry development, which contributed to stagnation in project development and high project costs.[174] California should maintain caution in driving offshore wind market development with an emphasis on local content requirements.
2. **Government support:** In Scotland, the first floating wind project was heavily dependent on the availability of enhanced government support (ROCs). As the cost of floating wind technology is still relatively high and cannot compete directly against more mature renewable energy technologies like solar and land-based wind, California would need mechanisms to lower project costs and de-risk technology deployment.

France

Market Overview

1. France is the fourth most attractive renewable energy investment market following China, the United States, and India for new deployment opportunities;[175] the market is driven by strong government support for offshore wind and favorable geographic conditions.[176]
2. France is the leading floating offshore wind market globally, partly due to the presence of several leading floating platform technology developers (such as Ideol, Eolfi, and Naval Energies[177]) and the recent announcement the EU Commission approved investment and operation aid to support four demonstration projects with a total capacity of 96 MW in the Atlantic Ocean and Mediterranean.[178]
3. Current installed capacity: 2 MW (Floatgen demonstration project by Ideol), that began operation in 2019.
4. Capacity in development (consented projects at different stages of development)**:** 3,000 MW fixed and 96 MW floating demonstration projects.
5. France has a target of developing 10 GW of floating and fixed-bottom offshore wind energy by 2028.

---

[174] Described after the conclusion of this case study for France.

[175] Windpower Monthly, France. 2020.

[176] Warren, Ben. Renewable Energy Country Attractiveness Index, Ernst and Young. 2019.

[177] Carbon Trust. Floating Offshore Wind. Policy Appraisal. 2017.

[178] Durakovic, Adnan. EU Nods to Four French Floating Wind Farms. 2019.

6. According to the Multiannual Energy Programme,[179] in 2024, France will have a tender for between 250 MW and 500 MW of floating offshore wind.[180]

Market Players and Value Chain

With around 15 GW of land-based wind, France has a strong land-based wind supply chain, consisting of 1,000 small to large industrial companies located throughout the country. During the 2012 to 2014 rounds of offshore wind project awards, government policy required a high degree of local content, with the goal of developing a national offshore wind turbine supply chain through state-owned firms like Alstom and Areva. France's main energy regulator, the Energy Regulatory Commission, opposed high support tariffs, set at around €200/MWh (USD 221/MWh), which led to offshore wind project stagnation.[181] GE and Siemens Gamesa subsequently took ownership of state-owned Alstom and Avera, opening access to greater investment and an established global supply chain. In 2019, GE's LM Wind Power opened the first blade manufacturing facility and started prototyping the 107-meter-long blades to be installed in Haliade-X 12 MW turbine. GE also produces Haliade-X nacelles in Saint-Nazaire near France's Atlantic coast to supply the regional markets.[182]

France has favorable conditions for floating offshore wind market development including local harbor facilities and a local naval and offshore oil and gas industry capable of providing manufacturing, installation, and O&M services to the floating wind market. The only installed floating offshore wind demonstration project is Ideol's 2 MW Floatgen, a pilot of a dampening pool semi-submersible floating structure made of concrete and steel that began operation in 2019. The Floatgen platform was built in the port of Nantes-Saint Nazare using typical concrete building technology and tugboats for transporting the structure. This floating platform design allows for the structure (including the turbine) to be built onshore or in dry docks and transported to the site location through relatively shallow water due to the low draft of the dampening pool. The dampening pool concept limits installation costs and upfront investments for manufacturing by reducing the need for specialized facilities. Ideol has deployed a similar floating structure in Japan in the Hibiki 3 MW demonstration project. These semi-submersible platforms tend to have higher wave-induced motions, which can reflect negatively on the power generation performance of the turbine.[183]

The European Commission recently approved financial support for the construction and operation of four floating wind demonstration projects totaling 96 MW, which are in development and detailed in Table B-2.

---

[179] Multiannual Energy Programme is the official government policy document of 2018, which lays out the development trajectory for the next 10 years.

[180] Durakovic, Adnan. France to Tender up to 6 GW of Offshore Wind by 2028. 2019.

[181] Reuters. France Cuts Tariffs on Controversial Offshore Wind Projects. 2018.

[182] Renewable Energy News (2019). GE Cracks on With Saint-Nazaire Turbine Assembly. 2019.

[183] International Renewable Energy Agency. Floating Foundations: A Gamechanger for Offshore Wind Power. 2016.

Table B-2: European Commission Approved Floating Projects in France

Project Name	Installed Capacity	Floating Tech and Turbine Type	Pros and Cons	Expected Operation Year
EolMed demonstration project	24 MW	Dampening pool by Ideol, Senvion 6 MW turbine	• Can be built onshore or in site docks • Manufactured in concrete or steel • Manufacturing lead time up to 14 months • Easy towing to site location • Can be built by construction service providers	2020
Groix and Belle-Ile demonstration project	24 MW	Semi-submersible steel platform by Naval Energy, MHI Vestas 9.5 MW turbine	• Steel columns connected to a central concrete base • Can be manufactured at most ports using local steel and concrete manufacturing facilities • Using the same concrete technology as used in bridges and dams • Structures can be assembled in port rather than in open sea and brought back to port for heavy maintenance	2021-2022
Provence Grand Large demonstration project	24 MW	Modular steel platform by SBM Offshore and IFPEN, 8 MW undisclosed turbine type	• Tension leg platform • Light structure • Limited draft allowing quayside installation • Assembly with standard yard means • Modular fabrication, use of local supply chain	2021

Project Name	Installed Capacity	Floating Tech and Turbine Type	Pros and Cons	Expected Operation Year
Golfe du Lion demonstration project	24 MW	Semi-submersible steel platform by Principle Power, GE Haliade 6 MW turbine	• Full assembly onshore and towed to offshore site • Quayside fabrication • Drag embedment anchors permit installation in various soil conditions including mud, clay, sand, and layered soils • Low weather dependency for installation	2021

Source: Guidehouse, 2020

Energy market players such as Eolfi, ENGIE, EDPR, EDF EN, Caisse des Depots, Quadran, and China Guangdong Nuclear are key investors behind the four-demonstration floating offshore wind projects in France.

Drivers

Following the Paris Agreement, the initial 2020 offshore wind targets set forward by the French government were driven by the Renewable Energy Directive of the European Union.[184] The Directive stipulated EU member states increase the renewable share in their energy strategy to fulfill the binding requirements. The requirements differ for each member state based on their renewable energy capacity starting point and each country's economic capability to increase it. To achieve their binding target, France set out an expected trajectory for gradually increasing the offshore wind energy share in their energy mix from 2010 to 2020.[185]

Although the French government initially set a target of 6 GW of fixed-bottom offshore wind by 2020, a combination of challenges continually delayed commercial project construction that had been approved in the 2012 and 2014 tenders.[186] In its first two offshore wind tender rounds, France placed a high emphasis on maximizing the domestic economic benefits from offshore wind development by requiring local content, which contributed to high development costs of around €200/MWh.[187] In the tender evaluation process, offshore wind farm environmental impact was weighted at 20 percent, while the local content share and proposed

---

[184] European Commission. 2020 Climate and Energy Package. Webpage for original legislation set in 2007 and 2009 by the European Commission.

[185] Republic of France. National Action Plan for the Promotion of Renewable Energies 2009-2020. Webpage on national renewable energy action plans 2020.

[186] Barthelemy, Christophe. CMS Expert Guide to Offshore Wind in Northern Europe. 2018.

[187] Windpower Monthly, France. 2020.

project prices were each weighted at 40 percent. As it became apparent that the 6 GW capacity would not be installed by 2020, the government downgraded their target to 3 GW of installed capacity by 2023, as part of the multi-annual energy plan.[188] In June 2018, the French government finally approved the construction of six of the previously approved offshore wind projects after the government renegotiated with developers to cut the feed-in tariff from €200/MWh to around €150/MWh (USD 161/MWh).[189] Later in 2018, the government presented updated plans for the 2030 timeline to increase the target from 3 GW to 5.2 GW. The new target faced criticism by industry stakeholders for not being high enough and underutilizing offshore wind's potential contribution to developing a low carbon economy.[190]

For its round 3 call in 2019, France changed the tender requirements and removed local content as one of the evaluation criteria, focusing primarily instead on lowering costs.[191] Round 3 included an initial preselection of bidders based on technical and financial criteria, followed by competitive dialogue with all bidders that the French government introduced to clarify specifications and sharing of responsibilities during construction and operation phases.[192] After the dialogue, selected candidates were invited to place their bids.

After the round 3 tender resulted in less than a €50/MWh[193] (USD 55.7/MWh) tariff, the French Prime Minister confirmed increasing the target from around 600 MW to approximately 1 GW per year, aggregating to a 2028 target of 10 GW.[194]

French transmission systems operator Réseau de Transport d'Électricité finances and builds the offshore wind grid connection assets except the offshore substation, which is built by the developer. A transition from developer-built to transmission system operator-built grid connection took place from 2015 to 2017 through multiple changes in the law. The law 2017-1839 of December 2017 stipulates that the transmission system operator should bear all costs of grid connection as defined in the tender or by the Minister of Energy. The prior grid connection mechanism, where development costs and associated risks are fully borne by the wind farm developer, resulted in an increased electricity purchase price. The change was aimed at facilitating project financing by lowering the developer risk.[195]

---

[188] International Energy Agency, Renewable Energy technology Development. Comparative Analysis of International offshore Wind Development. 2018.

[189] Reuters. France Cuts Tariffs on Controversial Offshore Wind Projects. 2018.

[190] OffshoreWindBiz. France Sets 2030 Offshore Wind Target, Industry Not Impressed. 2018.

[191] Foxwell, David. Top-Down Approach to Local Content 'Drove Costs Up' in France. 2019. Riviera.

[192] OffshoreWindBiz. France Pre-Selects 10 Dunkerque Offshore Wind Bidders. 2017.

[193] Renews Biz. EDF Wins 600MW Dunkirk Offshore Wind Farm. 2019.

[194] Durakovic, Adnan. France to Set 1GW Annual Offshore Wind Tendering Target. 2019

[195] Kind and Spalding. Good News At Last for the Development of Offshore Wind Projects in France. 2018.

Barriers

The French offshore wind industry has faced a variety of challenges that have stagnated industry development for many years. One of the major challenges has been the administrative complexity—developers have to acquire various authorizations from public authorities to begin project development. Due to strong public opposition to offshore wind, the authorizations have been challenged by various parties, including environmental organizations and energy worker trade unions. The opposition to wind energy in France is mainly associated with pro-nuclear groups and the public's dissatisfaction with the wind turbine effect on the natural landscape.[196] Recent court decisions have dismissed various challenges, and authorities have implemented measures to shorten the public challenge proceedings.[197,198]

The high costs of offshore wind projects as initiated in 2012 and 2014 were attributed to unfavorable seabed conditions in France, project risks due to unclear stakeholder roles during construction and operation, and high taxes and local content requirements. During this period between rounds 1 and 2, international offshore wind prices (for example, UK, Germany, Denmark) declined by more than 50 percent.[199] The round three offshore wind tender in 2019 saw high interest from international developers due to the improved French regulatory framework. A consortium consisting of the French Utility EDF, German renewable developer Innogy, and Canadian energy company Enbridge (operating offshore wind in the EU), won the tender, leveraging offshore wind farm development and operation experiences from the UK and German markets.

Lessons for California

California may use the following lessons learned from France's offshore wind market experience:

1. **Government financing support:** The cost of floating offshore wind projects remains much higher than fixed-bottom projects in France. Realization of the four floating wind demonstration projects designed to test floating technologies by Ideol, Naval Energy, SBM, and Principle Power on a commercial demonstration scale is possible due to funding provided by the European Commission for projects furthering innovation in offshore wind foundation technologies. Because of the high cost of floating wind technology, demonstration project developers cannot compete with fixed-bottom projects for financial support under standard offshore wind tender rounds in the country, so government financial support is critical to promote further market development.
2. **Project pipeline:** Defining a government-supported, transparent project pipeline was vital to invite investment in supporting infrastructure and supply chain, which was achieved through the Multiannual Energy Programme.

---

[196] Pech, Marie-Estelle. The Anti-Wind Battle is Gaining Momentum. 2018.

[197] Kind and Spalding. Good News At Last for the Development of Offshore Wind Projects in France. 2018.

[198] Bryant, Liza. Winds of Change: France Faces Challenges as It Embraces Offshore Wind Power. 2017.

[199] Reuters. France Cuts Tariffs on Controversial Offshore Wind Projects. 2018.

3. **Technology choice:** Choice of optimal floating technologies in France will be driven by each floating wind system's motion stability (platform design) and differences in each platform's cost to build, install, and maintain. France's first installed test project (the Floatgen dampening pool by Ideol) focused on unit manufacturing near the installation site.[200] Dampening pool technology is one example of a platform technology that can be built in dry docks or onshore using conventional construction methods and common materials including concrete. The four test projects approved in 2019 by the European Commission are each intended to test new technologies. California could track these projects and assess which aspects might be applicable to its conditions.

The Netherlands

Market Overview

- First fixed-bottom turbine in the Netherlands was installed in 2007 and the current installed capacity is 957 MW, with 3,000 MW in development.[201]
- The Netherlands has a target of 11.5 GW of offshore wind energy capacity by 2030, all of which is based on fixed-bottom technology.[202]
- The government uses a floating feed-in premium tender scheme[203] to procure offshore wind. Successful companies with the lowest bid price that meet all specified requirements[204] from the government win a 15-year subsidy grant (zero subsidy in 2018 and 2019 auction rounds) and a 30-year permit to build, operate, and decommission the wind farm.
- A centralized government body, the Netherlands Enterprise Agency (RVO), executes all offshore wind farm tenders and related activities on behalf of the Dutch government.[205] TenneT, the national transmission system operator, holds the mandate to develop and operate all offshore grid transmission assets built after 2016. The first two subsidy-free

---

[200] A larger demonstrator of dampening pool technology was installed by Ideol in Japan (3 MW Hibiki Demonstration project), where it operates in demanding weather conditions.

[201] Navigant. Dutch Offshore Wind Market Update 2019. 2019.

[202] Netherlands Enterprise Agency. Offshore Wind Energy SDE+. Program closed in 2019, web page accessed 2020.

[203] Floating feed-in premium or SDE+ (in Dutch: Stimulering Duurzame Energieproductie) is an operating grant that the renewable energy generator receives when the cost of renewable energy is higher than the market price. The premium is adjusted annually based on market price development.

[204] Qualification criteria as set out in the Dutch Offshore Wind Energy Act and Ministerial Order: (1) Demonstrate that project is technically, financially and economically achievable; (2) Bidder's assets shall amount to at least 20 percent of the total investment costs; (3) Bidders need to demonstrate commencement of the project construction within four years after receiving the permit.

[205] Navigant. Dutch Offshore Wind Market Update 2019. 2019.

concessions in the Netherlands were awarded to the Swedish power company Vattenfall in 2018 and 2019.[206]

Market Players and Value Chain

The European offshore wind industry has a strong supply chain with manufacturing centers in Denmark, Germany, Spain, and the UK, all with access to the North Sea and proximity to the leading offshore wind energy markets in Europe. The majority of European offshore wind turbine generator components are manufactured in Denmark (blades and control systems), Germany (nacelles, blades, assembly), and Spain (gearboxes, blades, generators and towers). MHI Vestas and Siemens Gamesa are the exclusive wind turbine generator suppliers for the Dutch offshore wind farms and are often contracted by developers to design, supply and install wind turbine generators.

The Netherlands offshore wind supply chain is oriented around shipbuilding services, substructure manufacturing, and marine engineering. Key Dutch companies include Sif Group (foundation manufacturing), Ballast Nedam (engineering and construction), Van Oord (marine engineering and construction), and Mammoet (heavy lifting and installation).

The Netherlands has been a leading sea power in Europe for multiple centuries. The country has a well-developed port infrastructure with seven deep-water North Sea ports, with open access to sea and inland areas and low tidal ranges, which are important for installation activities with jack-up vessels. The following port facility attributes are typically associated with successful bottom-fixed offshore wind project operations:[207]

- Space to accommodate equipment storage and assembly with jack-up possibilities
- Heavy cargo storage and equipment
- Facilities for manufacturing and synergies with other industrial manufacturers
- Good position in relation to offshore wind farms
- Ports with minimal congestion or tidal impact
- Space for O&M hub development and heliport landing capabilities
- Future infrastructure for possible energy storage projects

Dutch-based companies Nuon, Shell, and Eneco led the early rounds of offshore wind development in the Netherlands. They were followed by international developers Northland Power, Ørsted, and Vattenfall, which have entered the market.

Drivers

Similar to other EU member states, the offshore wind target in the Netherlands was driven by the Paris Agreement and EU's climate and energy legislation (EU Directive 2009/28/EC). To achieve its binding target, the Netherlands set out an expected trajectory for gradually increasing the offshore wind energy share to 14 percent of its energy mix by 2020.[208] In 2013,

---

[206] Lee, Andrew. Vattenfall Wins 760 MW of Dutch Zero-Subsidy Offshore Wind. 2019. Recharge News.

[207] TKI Wind Op Zee. Holland: Your Portal to Offshore Wind. Government of Holland. Accessed 2020.

[208] Republic of France. National Action Plan for the Promotion of Renewable Energies 2009-2020. Accessed web page 2020.

the Dutch Ministry of Economic Affairs and Climate Policy established the Energy Agreement, identifying offshore wind as a key technology to reach decarbonization goals and setting a target to develop 4.5 GW by 2023.[209] In 2019, this target was revised to 11.5 GW by 2030 in the Offshore Wind Energy Roadmap 2030.[210] With support from the government, the Dutch offshore wind industry achieved significant cost reductions through grid connection standardization,[211] shorter project development timeframes, and lowered investment risks through achieving higher investment security from continued market growth. The tender scheme reduces risks for developers by awarding the winning project developer with a building permit, access to offshore and onshore grid connection points, and in some tender rounds a 15-year subsidy grant. RVO executes the offshore wind energy subsidy and permit tenders on behalf of Ministry of Economic Affairs and Climate Policy. RVO also carries out preparatory site studies and surveys of identified wind energy areas.

Barriers

The Netherlands has been looking to become a global leader in wind energy since the early 1980s, with a specific focus on offshore generation due to land constraints.[212] Implementation has encountered many problems driven by local opposition and the danger that wind unpredictability could cause the energy system to lose stability. Implementation problems were also related to discrepancies in national objectives related to wind energy targets for climate change policies and possible benefits on the local level. Development of the first offshore wind farm experienced significant delays due to permit procedures, negotiations with environmentalists, and lack of certainty over financial support. Due to policy changes in 2003 and rapidly increasing consumer demand for low carbon electricity, which local supply could not meet, renewable energy imports significantly increased, causing Dutch tax money to flow to international suppliers. After introducing the first fixed feed-in tariff to renewable electricity producers, the government had to scale down its plans because of much higher priced proposals for new offshore wind farms than anticipated. Only two offshore projects subsequently secured government financial support (through the feed-in tariff).

Transmission Structure

In April 2016, a transmission system operator -built grid development model was implemented in the Netherlands, where TenneT was appointed to develop and operate the future offshore transmission system. Prior to that, all offshore grid connections were built by developers. This model is used in Germany, the Netherlands, Denmark, Belgium, and France, where government agencies or transmission system operators are responsible for all stages of the offshore transmission asset life cycle, from site development to construction and operation. If the transmission system operator fails to complete the offshore grid on the designated dates,

---

[209] Navigant. Dutch Offshore Wind Market Update 2019. 2019.

[210] Minister of Economic Affairs and Climate Policy. Letter to Parliament on Offshore Wind Roadmap 2030. 2018.

[211] The Dutch TSO TenneT is mandated by the government to construct five identical 700 MW high voltage alternating current offshore wind substations that will result in substantial reduction of construction and maintenance costs.

[212] Ogg, Frits. World Wind Energy Association. The Netherlands. 2018.

it is liable for damages incurred by the wind farm operators.[213] The producers of wind energy are entitled to compensation for damages and revenue losses in case of construction delays and in the case of restricted grid availability once the offshore project is commissioned. Such unforeseen costs are partially socialized through transmission tariffs for electricity consumers after formal approval by the regulator, while the transmission system operator funds other unforeseen costs.

Lessons for California

California should consider the following lessons from the Netherlands:

1. **Political and policy buy-in:** The Netherlands developed a short-to-medium term project development roadmap with appropriate policy levers to meet deployment targets, maximizing stakeholder interest. Maximizing buy-in from a wide range of government departments helped mitigate risk of policy changes.
2. **Permitting:** A structure (one-stop-shop) for tendering and permitting helped streamline project development and facilitated planning between offshore wind farm areas while contributing to an overall shorter permitting process. California does not have significant authority over site permitting due to siting in federal waters, though the state does have permitting responsibility over near-shore and onshore assets.
3. **Stakeholder engagement:** Securing broad engagement in spatial planning helped minimize public opposition, project disruptions, and ecological damages. This engagement helped push the market forward through a focus on long-term planning, including the protection of marine biodiversity.

East Asia

This case study includes a summary of offshore wind industry progress, drivers, and next steps in four leading East Asian markets: Japan, China, Taiwan, and South Korea.[214]

Japan

Drivers

Japan is primarily an energy importer, meeting over 90 percent of its primary energy needs through imported fossil fuels.[215] In the interest of establishing energy security and furthering carbon dioxide emissions reduction goals, in 2010, the Ministry of Economy, Trade, and Industry committed to increasing Japanese energy self-sufficiency to 70 percent by 2030. Initially, it was anticipated much of this clean domestic capacity could come from nuclear power. Prior to 2011, Japan sourced nearly 30 percent of its electricity from a fleet of 54 nuclear reactors, compared to about 1 percent from non-hydro renewable energy.[216] In 2011,

---

[213] International Energy Agency, Renewable Energy Technology Development. Comparative Analysis of International Offshore Wind Energy Development. 2017.

[214] This case study is to be further enhanced through interviews with experts from the East Asian markets prior to publication of the final report.

[215] World Nuclear Association, Nuclear Power in Japan. August 2019, accessed 2020.

[216] International Energy Agency. Data and Statistics for Japan. 2020.

the Great East Japan Earthquake and subsequent Fukushima-Daiichi nuclear disaster served as a turning point for nuclear energy generation in Japan and opened the door for greater investment in renewable energy. To support renewable energy expansion, the Japanese government initiated a feed-in tariff in July 2012 that mandated utilities to purchase generation from renewable resources at a fixed price for 20 years.

Long before Fukushima, offshore wind was identified as a candidate resource for future expansion, with a particular focus on floating technology. Japan has the sixth largest sea space of any country in the world and an estimated offshore wind potential of 1,600 GW.[217] Around 80 percent of Japan's offshore wind resource is located in depths greater than 100 meters.[218]

Market Status

Japan has been investing in floating substructure technology development for more than 20 years with a goal of becoming an exporter of floating technology and expertise.[219] Between 2012 and 2016, three floating test turbines were installed off the coast of Japan as part of the Fukushima FORWARD offshore wind demonstration area: Fukushima Mirai (2 MW), Fukushima Simpuu (7 MW), and Fukushima Hamakaze (5 MW).[220] As of February 2020, Japan has at least six installed prototype projects and remains the only market in East Asia with operational floating turbines.[221] Tested technology concepts include the following:

- A semi-compact submersible by Mitsu Engineering, installed 2013
- An advanced spar by Japan Marine United, installed 2013
- A hybrid spar by Toda Construction, installed 2013
- V-shaped semi-submersible by MHI, installed 2015
- Hybrid wind and wave platform by MODEC, installed 2015
- Concrete barge design by Ideol, installed 2018

A multi-turbine platform concept from Kyushu University remains in development. Prototypes have provided up to five to seven years of data apiece on their respective technology type, resilience, and environmental impact. Turbines installed at the Fukushima FORWARD testing site have survived harsh environmental conditions and multiple typhoon events without notable damage. Each project tested unique platform designs to optimize components and evaluate lowest cost options. For example, Mitsu Engineering's semi-submersible prototype, the first unit installed in 2013, used a heavy steel base that raised capital costs. This design was further optimized into the lower-cost V-shaped design by MHI that was installed in 2015. Toda Construction, meanwhile, designed a hybrid spar technology using a steel top and concrete bottom to reduce costs and maximize local content. Japan Marine United instead

---

[217] JST Japan and Denmark Embassy. Recent Development and Challenges of Wind Turbine Technology. 2012.

[218] Per interviews with experts on the East Asian market.

[219] Carbon Trust. Detailed Appraisal of the Offshore Wind Industry in Japan.

[220] Pamphlet for Fukushima FORWARD. Fukushima Floating Offshore Wind Farm Demonstration Project. 2012. Fukushima Offshore Wind Consortium.

[221] Carbon Trust. Floating Wind Joint Industry Project.

developed a conventional steel spar with a shorter body capable of shallow water deployment. This platform technology was also chosen to support the world's first floating substation, which was installed at the Fukushima FORWARD site in 2015.

In part due to continued pressure to diversify away from nuclear energy, legislation passed in 2018 outlined the process for offshore wind development in Japanese national waters. Eleven development zones were identified in 2019. At least five of these zones are under consideration for designation as wind energy areas.[222] Upcoming public tenders will be used to select bidders for each selected zone, perhaps as soon as by the end of 2020. Winners will receive a feed-in tariff of 36 Japanese Yen (JPY) per kWh (USD 0.319/kWh) guaranteed over 15 years. Japan is the only East Asian market that has not established a target specific for offshore wind development. Instead, a target for all wind including land-based and offshore development was established in July 2019 to promote 10 GW by 2030. It is likely initial offshore development (up to 10 GW) will focus on fixed-bottom technologies due to the maturity of the technology and industry.[223] Limited area for shallow near-shore seabed will force the commercial deployment of floating wind farms after shallow capacity is full.

Japan faces similar challenges to many other Asian markets considering offshore development, including opposition from powerful industries (for example, fisheries, shipping, conventional energy) and insufficient grid capacity. These and other barriers also closely mirror those seen in California. Both markets share a deep seabed close to shore and require technologies able to withstand routine exposure to extreme wind and wave conditions. Like California, Japan requires comprehensive environmental impact assessments prior to project approval. Japan also has a shortage of installation vessels and port infrastructure for offshore wind project construction despite many of the ports being along the coastline.[224] As of 2020, all floating capacity installed in Japan (<20 MW) consists of demonstration projects. Due to a small cumulative capacity, Japanese firms have a limited offshore wind development history. Foreign developers such as Ørsted, Equinor, Windpal, wpd, and Copenhagen Investment Partners all have established branch offices in Japan.

China

Drivers

China has an established land-based and offshore wind market with a robust turbine manufacturing industry and project development capabilities.[225] Demand for offshore wind in China is driven primarily by rapidly expanding load and the distribution of renewable resources in the country. Most load in China resides in the eastern portion of the country, with hundreds

---

[222] Broehl, Jesse. Japan Passes Offshore Wind Legislation. Navigant Research. 2019.

[223] Per interviews, Japan has around 10 GWs of accessible offshore wind resource in water shallow enough to accommodate fixed turbine technology. Given the lower cost of fixed turbines as of 2020, interviewees expected Japan would focus on fixed bottom installation where possible.

[224] Panticon. Policy coherence developments to finally unleash Japan's offshore wind market.

[225] Global Wind Energy Council. Latest Update on China Offshore Wind. 2019.

of millions of people living within 100 miles of the Pacific coast.[226] This load is projected to continue increasing at a rate of over 2.5 percent per year.[227] In contrast, the majority of solar and wind resource and available land sits to the west, 500 miles or more from megacities like Beijing and Shanghai. Distance and demand for local generation have increased the cost of transmitting renewable energy and supported the construction of polluting coal and gas facilities in populated areas. Aside from nuclear power, offshore wind represents the only clean energy source that can be constructed at scale near load centers in eastern China due to limited land availability.

China initially included targets for offshore wind in the 12th Five-Year Plan for Renewable Energy released in 2011. Conflicting motivations and limited coordination between central and provincial government entities contributed to China falling short of the goals established in the 12th Five-Year Plan. While the central government desired to keep costs low by building close to shore, provincial governments were concerned about placing near-shore wind facilities near major coastal population centers.[12] After delays and the re-siting of contested farms, provincial governments moved to increase support for offshore wind.

Market Status

As of January 2020, China has the third largest installed capacity of fixed-bottom offshore wind in the world, with over 2.8 GW operational.[228] In 2016, the Chinese government established an ambitious national offshore wind target of 10 GW per year as part of the 13th Five-Year Plan for Renewable Energy.[229] In 2018, China established a feed-in tariff for offshore wind of CYN 0.8/kWh (USD 0.11/kWh) for 2019 and CYN 0.75/kWh (USD 0.11/kWh) for 2020.[230] This tariff is set to expire in 2021. Barring an extension, projects must begin construction during 2020 to be eligible for financial support.

As of early 2020, the sole floating project under development is the single turbine 4 MW Shanghai Electric Floating Demonstrator by Shanghai Light.[231] All other projects installed and under construction use fixed foundations. Given the shallow average depth of the South China Sea, floating wind will likely not be required to meet national offshore wind targets by 2025.

Offshore wind industry observers have highlighted shortcomings in vessel stock and turbine production capacity as constraints that may prevent China from achieving its target of constructing 10 GW per year. Due to China’s political and trade relationships with other countries, the market is only open to Chinese-flagged installation vessels and local developers, with the top three being China General Nuclear Power Corporation, China Energy Investment Corporation, and China Three Georges. The Chinese offshore wind industry has had an

---

[226] Li, Minmin Et al. Study on Population Distribution Pattern at the County Level of China. 2018.

[227] Asia Pacific Energy. China: 13th Five-Year Plan for Energy Development. Accessed 2020.

[228] IEA. Offshore Wind Outlook 2019: World Energy Outlook Special Report.

[229] Asia Pacific Energy. China: 13th Five-Year Plan for Energy Development. Accessed 2020.

[230] 4C Offshore Wind. China Unveils New Feed-In Tariff Scheme. 2019.

[231] Per interviews with experts on the Chinese market.

exclusive local content requirement since the first installation of turbines in 2010. As offshore wind farms move further away from shore, the market has begun acquiring international engineering and development experience to support rapid growth in new areas and deeper waters, but still remains closed to international developers and suppliers.

Taiwan

Drivers

Taiwan is an emergent market for offshore wind that is open to international developers. Following the Fukushima nuclear meltdown, the Taiwanese government pledged to become nuclear-free by 2025. As part of this pledge, the government committed to investing tens of billions of US dollars in renewable energy technology, including $22.7 billion in wind energy.[232] As in other East Asian countries, Taiwan benefits from the proximity of offshore wind sites to coastal load centers. Each of the four largest metropolitan areas in Taiwan sit within 20 miles of the Taiwan Strait, the shallow body of water that separates Taiwan from mainland China. This implies that all of the offshore wind projects in Taiwan can be based on fixed-platform technology.

Market Status

In 2017, the Taiwanese government established an offshore wind target of about 5.5 GW by 2025.[233] In 2018, the government awarded all 5.5 GW of this target to ten developers for commissioning by 2025. Approximately 520 MW of this initial 5.5 GW are expected to be completed by the end of 2020. As of January 2020, there are no active floating offshore wind projects in Taiwan due to the low cost of fixed-bottom turbines and the shallow average depth of the South China Sea. Eolfi, a French developer, and Cobra Conseciones, a Spanish manufacturer, have expressed interest in the Taiwanese market, however, and submitted a tentative proposal for a 500 MW installation that remains under evaluation.[234] Future decarbonization scenarios may lead to greater interest in floating technology.

Of the ten project leases chosen in phase one, eight were granted to international developers: Ørsted, wpd, Northland Power, Copenhagen Infrastructure Partners, Macquarie, Mitsui & Co, and Swancor. Following the success of initial auctions, in 2019, officials increased the initial 5.5 GW target to accommodate an additional 10 GW by 2030.[235]

To support offshore wind, the Taiwanese government developed a two-tiered financial support scheme.[236] In the initial 5.5 GW tender, 3.8 GW were granted through a project selection process that considered technical capabilities like engineering design and O&M planning as

---

[232] Grant Thornton. Winds of Change: Navigation risk in the offshore wind sector.

[233] Offshore Engineer. Taiwan Offshore Wind Market to Reach 5.5. GW by 2025. 2019.

[234] U.S. Department of Energy, 2018 Offshore Wind Technologies Report, 2019.

[235] Global Wind Energy Council (GWEC). From 0 to 15 GW by 2030: Four Reasons Why Taiwan is the Offshore Wind Market in Asia. 2020.

[236] Jones Day. Taiwan Offshore Wind Farm Projects: Guiding Investors through the Legal and Regulatory Framework.

well as financial capabilities including the bidder's financial strength and associations with Taiwanese financial institutions.[237] The remaining 1.7 GW were included in an auction 2 months later, with a feed-in tariff bid price considered as the primary factor. This combination of selection and auction processes was designed to establish an industrial supply chain and facilitate rapid market development. The initial feed-in tariff rates were subsequently decreased by the Taiwanese government following criticism from local agencies that the guaranteed rates were too high.

Taiwan does not have a large domestic turbine manufacturing industry to supply projects. Developers rely primarily on international technology manufacturers. One such manufacturer, Siemens Gamesa, signed memorandums of understanding in 2018 to supply turbines to Taiwanese projects and expand local tower manufacturing capabilities. Other suppliers, including MHI Vestas and Hitachi, have also engaged with project developers that were granted contracts in phase one.

Upon completion of this first phase, Taiwan will be the second largest offshore wind market, after China. Increasing local content is a stated goal of the Taiwanese administration, making it unclear whether low auction prices seen in phase one ($60-$70/MWh) will be achieved in further bidding rounds.[238] Taiwan is looking to subsidize manufacturing and supply chain infrastructure to deal will higher local content desirability and the need to keep tariffs low.

South Korea

Drivers

In 2017, South Korea committed to increase its share of electricity generated from renewable sources to 20 percent by 2030.[239] Due to land constraints on the Korean Peninsula and the availability of wind resources in shallow waters near coastal load centers, offshore wind was selected as a primary resource to develop. Interest in offshore wind technology in South Korea first increased following the Fukushima-Daichi nuclear disaster in Japan in 2011. In the aftermath of this event, the South Korean government faced public pressure to evaluate and decommission nuclear power facilities. This pressure intensified following a corruption scandal that began in 2012, in which Korean Electric Power Corporation was found to have colluded with parts suppliers to forge safety certifications for reactor components. Fourteen of the 23 active reactors in the country were implicated as having potentially unverified parts.[240] Three were subsequently scheduled for decommissioning. A feed-in tariff was put in place to support renewable energy development and was subsequently replaced in 2016 by a renewable portfolio standard. This updated policy requires large power companies with over 500 MW of

---

[237] Wind Power Monthly. Taiwan Sets Out 5.5 GW Plan. 2018.

[238] Based on interviews with experts on the East Asian wind market.

[239] Reuters. South Korea Likely to Miss its 2030 Renewable Energy Target. 2019.

[240] New York Times. Scandal in South Korea Over Nuclear Revelations. 2013.

demand in their portfolio to maintain a minimum proportion of renewable energy generation or renewable energy credits.[241]

Market Status

The South Korean government established a target of 12 GW installed capacity of offshore wind by 2030 as part of the Renewable Energy 2030 Implementation Plan released in 2017. Five separate fixed-bottom projects, each of 200 MW or greater, have been proposed in South Korean wind development areas.[242] In 2019, data collection on these sites began with the launch of a LIDAR buoy. On confirmation of the wind resource and projected value of clean energy generated, the South Korean government will commission chosen projects to begin construction.

South Korea has a strong maritime and industrial sector. Leading South Korean turbine manufacturer, Doosan Heavy Industries, provides a 5.56 MW turbine model and plans to develop an 8 MW class by 2022.[243] Multiple South Korean companies offer strong capabilities for subsea cable manufacturing, cable laying, installation, and substation manufacturing, including LS Systems, KEPCO, and CS Wind. While this may eventually aid in facilitating cost-effective development, the South Korean government is expected to restrict the use of international vessels and contractors, raising projected costs.

Lessons for California

California should consider the following lessons from East Asian markets:

1. **Learning from Japan's floating platform experience:** Floating wind research is more developed in Japan than perhaps anywhere else in the world. Platform prototypes have been operational off the coast of Japan since 2013, supported by a consortium of government and industry leaders. Pilot projects were used to gain information on the performance of multiple platform types prior to committing to a policy target. Prototypes have provided up 5-7 years of data on their respective technology type, resilience, and environmental impact. Turbines installed at the Fukushima FORWARD testing site have survived harsh environmental conditions and multiple typhoon events without notable damage. Each project tested unique platform designs to optimize components and evaluate lowest cost options. Tracking these projects and learning from the protype development and testing experiences will be useful for California to consider as it embarks on offshore wind development.
2. **Financial support:** Feed-in tariffs are a common support mechanism across three of the four East Asian markets studied and are used to facilitate early development of a wind industry supply chain by guaranteeing return on investment. Only South Korea uses a renewable energy certificate scheme that gives a variable benefit based on the market price for these certificates.

---

[241] Korea Energy Agency. Renewable Portfolio Standard (RPS) of Korea. Accessed 2020.

[242] Lee, Sanghoon. Revision2019. Renewable Energy 3020 Plan and Beyond. 2019.

[243] Richard, Craig. Doosan's 5.56MW Turbine Validated. 2019. Wind Power Offshore.

3. **Policy buy-in:** As of 2019, all East Asian markets studied have some form of target supporting offshore wind development, except Japan. Japan has committed 10 GW of land-based and offshore wind development by 2030. Japan identified a few wind development zones and will issue public tenders to select bidders for each selected zone with a feed-in tariff to the winner guaranteed over 15 years.

United States East Coast

General Market Overview

East Coast first mover states total up to 22.5 GW planned capacity by 2035. The specific targets[244] by state are:

- New York: 9 GW installed by 2035
- Massachusetts: 3.2 GW by 2035
- New Jersey: 3.5 GW by 2030
- Connecticut: 2 GW by 2030
- Virginia: 2.6 GW by 2028
- Maryland: 1.2 GW by 2030
- Rhode Island: 1 GW by 2025

Fixed-bottom turbine technology is expected to dominate the East Coast market in the near term due to the availability of strong wind resources in shallow water. The United States East Coast market estimates fully commissioning 1 GW-2GW of fixed-bottom offshore wind capacity per year in 2021 and 2022.[245] Current predictions are unclear due to ongoing delays for the 800 MW Vineyard Wind project off the coast of Massachusetts.[246] In August 2019, BOEM announced the initiation of a broad impact assessment of offshore development, including Vineyard Wind, in response to stakeholder comments and concerns. A new permitting schedule released in February 2020 outlines expected final decisions for clean air and water permits by March 2021, a 15-month delay from the previous target.[247] Despite lingering uncertainties, demand for East Coast wind energy areas remains strong and appears to be strengthening. Three Massachusetts lease areas auctioned in December 2018 saw prices nearly double on a per-square-kilometer basis since the first round of auctions in January 2017 from \$132k/km^2 to \$258k/km^2. Increased lease bids have been paired with decreasing PPA prices. The first PPA for a United States wind farm was contracted in 2014 between Deepwater Wind and National Grid for power from Block Island Wind Farm at a levelized cost of

---

[244] International Energy Agency (2019). Offshore Wind Outlook 2019. World Energy Outlook Special Report.

[245] New Energy Update. US Offshore Wind.

[246] Stromsa, Karl-Eric. Two Months Later, Vineyard Wind's Delay Still Clouds US Offshore Picture. 2019. Greentech Media.

[247] Bureau of Ocean Energy Management. Vineyard Wind Offshore Wind Facility One Federal Decision Permitting Timeline. 2020.

electricity of $244/MWh over 20 years.[248] In contrast, PPA prices for Vineyard Wind submitted in mid-2018 fell to $65/MWh for the second phase of the project. More recent agreements, including a $58.46/MWh PPA for Mayflower Wind in February 2020, have continued to demonstrate this downward trend.[249]

All East Coast offshore project proposals are contained within wind energy areas designated by BOEM. Potential for further expansion of existing wind energy areas remains strong given increased developer interest, falling project electricity costs, and increasing state targets. The Gulf of Maine, for example, has 156 GW of untapped offshore wind potential and may be able to host additional New England wind energy areas.[250] About 89 percent of this resource exists in deep waters near shore, which reaches over 60 meters after three nautical miles. Maine Aqua Ventus GP LLC is leading the first floating wind demonstration project in the East Coast, called New England Aqua Ventus I.[251]

State-Level Market Overview

The section below provides an overview of offshore wind development in three states: New York, Massachusetts, and Virginia. New York and Massachusetts are two of the top three markets in North America in terms of offshore targets. Virginia represents the southernmost market and may serve as a model for military engagement.

New York

New York has the largest installed capacity target for offshore wind of any sub-national government in the world. This figure represents a significant increase from the original target of 2.4 GW set by Governor Andrew Cuomo in 2018. Two projects, Empire Wind and Sunrise Wind, totaling 1.7 GW won the state's first solicitation in 2019.

In 2018, New York released a master plan outlining research needs in the environmental, infrastructure, resource evaluation, and stakeholder engagement spaces. Subsequently, the New York State Energy Research and Development Authority (NYSERDA) funded more than 20 studies assessing challenges in these areas. Studies completed to date focus on collecting geospatial information, projecting socioeconomic impacts, and examining environmental and ecological conditions.[252] NYSERDA also deployed two LIDAR buoys in the summer of 2019 to improve wind resource projections. The state expects to see significant economic gains from offshore wind, including the accrual of over 10,000 jobs and billions of dollars or direct investment. Over the past 2 years, New York has committed substantial funding to offshore wind development, including $200 million to port infrastructure to help accelerate local supply chain growth and $20 million for workforce development. Separately, NYSERDA facilitated the development of the National Offshore Wind Research and Development Consortium through a

---

[248] Beiter, Phillip Et al. The Vineyard Wind Power Purchasing Agreement: Insights for Estimating Costs of U.S. Offshore Wind Projects. 2019. National Renewable Energy Laboratory.

[249] Renews.biz. Mayflower Wind to deliver $58/MWh power. 2020.

[250] The University of Maine. Offshore Wind in Maine. 2016.

[251] Aqua Ventus Maine. New England Aqua Ventus 1 information homepage. Accessed 2020.

[252] New York State. Studies and Surveys. Accessed 2020. NYSERDA.

$20 million grant to support technical research initiatives nationwide. Studies from NYSERDA and the consortium have been included in the research database attached to this report.

Massachusetts

Interest in offshore wind has been spurred by climate change and, more recently, the retirements of fossil fuel and nuclear facilities. Utilities in Massachusetts are required to procure offshore wind energy under the Massachusetts Energy Diversity Act passed in 2016 and most recently updated in 2018. As of 2020, Massachusetts has committed to requiring offtake of at minimum 3.2 GW of offshore wind by 2035, up from an initial commitment of 1.6 GW in 2016.[253] Massachusetts has a long history with offshore wind proposals, dating back to the initial Cape Wind project proposal in 2001. Following years of delays, Cape Wind finally failed in 2017 after a long array of legal challenges from local residents and fishery stakeholders concerned over visual impacts due to the farm's proximity to shore and potential effects on local fisheries. These same concerns originally delayed construction of Vineyard Wind, the first commercial-scale project in the United States to secure a PPA, despite it being sited further offshore.[254]

To avoid many of the same concerns that contributed to the abandonment of Cape Wind, Massachusetts has invested time over the past 10 years facilitating early engagement with stakeholders, engaging in wind energy area identification, and aiding market and supply chain creation. Special working groups were organized around habitat and fishery topics. Feedback and data collected during these working groups clarified the specific needs of stakeholders in affected industries and identified optimal locations for offshore development. State agencies like the Massachusetts Clean Energy Center took leadership on environmental research efforts including aerial surveys of migratory mammals like the North Atlantic Wright Whale, of which at least five have been completed to date.[255] Transmission studies began as far back as 2014 to identify potential grid interconnection points and required upgrades to the land-based system.[256] Because Massachusetts operates a generator lead line approach, developers are responsible for the construction of offshore transmission infrastructure. Early research into transmission helped accommodate this design by de-risking projects and lowering PPA prices in the state.

Virginia

In 2012, the USDOE selected Dominion Resources' Virginia Offshore Wind Technology Advancement Project to receive a $4 million grant as part of the national Offshore Wind Innovation and Demonstration Initiative (OSWInD).[257] This initiative sought to accelerate cost-effective commercial offshore wind development in the United States. Funding was primarily

---

[253] American Wind Energy Association (AWEA). U.S. Offshore Wind Industry Status Update for December 2019. Accessed 2020.

[254] All existing or proposed call areas off the coast of Massachusetts are at least twelve nautical miles from shore.

[255] Based on a set of interviews with industry experts conducted for this report.

[256] Studies are ongoing, and can be found through the MassCEC webpage

[257] United States Department of Energy. Technical Report: Virginia Offshore Wind Technology Advancement Project (VOWTAP) DOE EE0005985 Final Technical Report Rev 1a. 2017.

used to prepare for future demonstrations of offshore wind technologies through technology research and completion of geospatial and marine surveys. Three years later, the Virginia Offshore Wind Technology Advancement Project was selected to receive up to $47 million in additional funding from OSWInD to develop a 12 MW two-turbine demonstration project. The first wind energy lease in federal waters was subsequently granted to the Virginia Department of Mines, Minerals and Energy by BOEM in March 2015 to support this demonstration project. OSWInD funding was subsequently suspended following adjustment of the project's proposed commercial operation date to 2020. The Virginia Offshore Wind Technology Advancement Project, or the Coastal Virginia Offshore Wind project as it is currently known, remains in a pending status as of February 2020, but lessons learned from preliminary research helped support Virginia's increased commitment to offshore wind development.

As of 2020, Virginia has a goal of approximately 2.6 GW by 2028, set through a state planning target tied to the projected capacity of Virginia's wind energy area.[258] This wind energy area is split into three parcels of approximately 850 MW a piece. State agencies are considering requesting the addition of a second wind energy area to accommodate increased demand, and the Virginia Legislature passed a bill in February 2020 to increase the state's offshore wind target to 5.2 GW by 2034, pending Governor Ralph Northam's signature.[259] Initially, there was concern that Virginia's significant military presence would inhibit offshore development. Virginia is home to the Port of Norfolk, the largest military port in the world and a docking location for much of the United States Navy. To mitigate concerns, military stakeholders were engaged early in the siting process and included in taskforce meetings. Regular meetings and communication helped determine and optimal design and scale of offshore development compatible with military activities.

Drivers

Across the East Coast, offshore wind industry development is primarily driven by the technology's potential to decarbonize the power system and the initiative of developers to increase the project pipeline in the United States market. Market experts also point to the low cost of offshore wind energy and projected increases in electricity demand due to electrification of buildings and transportation as significant contributing factors.[260] State targets, whether set through executive order or legislative process, are in effect in all seven states seeking to develop an offshore wind industry. Independent state policy commitments to offshore wind capacity escalated in 2017 and in 2019 reached 22.5 GW by 2035.[261] This string

---

[258] Confirmed through interviews and legislative dockets, including Virginia Senate Committee on Commerce and Labor, Labor Subcommittee. 2020.

[259] Confirmed through interviews and legislative dockets, including Virginia Senate Committee on Commerce and Labor, Labor Subcommittee. 2020.

[260] New Energy Outlook (2019). US Offshore Wind in 2019. Sizing Up the Markets in US Offshore Wind.

[261] International Energy Agency (2019). Offshore Wind Outlook 2019. World Energy Outlook Special Report.

of commitments has attracted international developers as well as financial institutions with interest in claiming a share of the market.[262]

As with California, BOEM is responsible for overseeing renewable energy project development in federal waters and holds the mandate to execute auctions to lease development zones. The primary support for offshore wind project rollout in the United States is the investment tax credit worth 12 percent in 2019, which is set to be phased out in 2020 yet once qualified the project has several years to reach completion.[263] New legislation to extend the support for offshore wind until 2025 is being discussed in Congress.[264]

Supply Chain Development

The East Coast does not have a sufficient supply chain to manufacture most offshore wind components locally. Unlike developed European markets, no offshore wind turbine manufacturing capacity exists within a reasonable distance of installation locations. Capabilities for foundation manufacturing are much greater due to the existing United States oil and gas manufacturing facilities in the Gulf of Mexico.[265] The standardization of offshore wind foundations requires serial production unlike the unique structures built for oil rigs.[266] Commercialization of turbine bases does not yet exist on the East Coast. Offshore wind industry leaders generally agree on the need to escalate the development of a United States supply chain which includes a qualified workforce, foundation and tower manufacturing capacity and assembly ports to reach established installed capacity targets at an optimal cost. Fixed turbine farms often benefit from local production of towers and bases to reduce transportation costs. To achieve high local content in these components, a local workforce and regional supply chain must be developed. As the industry matures, local content can be mandated through local content requirements, but as of February 2020, no East Coast state has a local content requirement to prevent high United States labor costs from increasing the offtake price of electricity.[267]

Installation and other purpose-built vessel availability is another concern due to Jones Act requirements, which allows only US-flagged vessels to operate between US ports. Lack of United States-flagged offshore wind vessels can lead to extended timelines for reaching offshore wind targets and inhibit cost reductions. Despite multiple new vessel announcements

---

[262] Asian Power. Japanese Banks to Raise USD 270 million for Overseas Offshore Wind Fund. 2019.

[263] Froese, Michelle. Offshore Wind Tax Credit Extension Will Jumpstart U.S. Industry. 2019. Wind Power Engineering and Development.

[264] Offshore Wind Biz. U.S. Offshore Wind Act Gets Another Go. 2016.

[265] U.S. Department of Energy. National Offshore Wind Strategy. Facilitating the Development of the Offshore Wind Industry in the United States. 2016.

[266] McClellan, Stephanie A. University of Delaware. Special Initiative on Offshore Wind. Supply Chain Contracting Forecast for U.S. Offshore Wind Power 2019.

[267] Gleaned through interviews with market experts conducted for this case study.

from large shipbuilders in 2018 and 2019 (for example, Falcon Global and Fred Olsen,[268] Zentec and Renewable Resources International[269]), deficient United States vessel stock remains a barrier to rapid deployment.

Port infrastructure development is also ongoing. Multiple offshore wind developers, energy companies, and state authorities have invested in port infrastructure to cater to the needs of offshore wind assembly and installation in the East Coast. These commitments include the following:

- Vineyard Wind lease of New Bedford Commerce terminal in Massachusetts as its deployment base. The terminal is a 29 acre heavy-lift facility designed to support the construction, assembly, and deployment of offshore wind projects.[270]
- $650 million investment by Anbaric and a commercial partner in Brayton Point's Commerce Center in Massachusetts to turn a cola plant into a logistics port and offshore wind power hub. The project will incorporate development of 1,200 MW HVDC converter station, battery storage, turbine assembly sites, and installation vessel maintenance docks.[271]
- $93 million investment by Ørsted, Connecticut Port Authority, and terminal operator Gateway in the State Pier of New London in Connecticut to develop and offshore wind hub. The project will include upgrading current pier infrastructure and heavy lifting equipment to support loading and unloading of offshore wind components.[272]
- $13 million investment by Ørsted in Tradepoint Atlantic global logistics center in Baltimore County, Maryland. The investment will establish a 50-acre staging center for laydown and assembly of components for the Skipjack offshore wind farm construction.[273]
- Ørsted signing lease for use of the Port of Norfolk to supply the Virginia wind energy area.

Other infrastructure development efforts focus on transmission. Grid interconnection for the United States East Coast is comparable to that of the UK, where a developer or third party must fund construction of offshore transmission capacity as part of the project cost. Optimizing long-term transmission capacity and avoiding costly buildouts of interconnection points for individual projects is a main priority for state governments. In New York and New

---

[268] Business Wire. Fred Olsen Windcarrier and Falcon Global Announce Cooperation Agreement in Offshore Wind. 2017.

[269] Runyon, Jennifer. First US Offshore Wind Installation Vessel to be Built with Oil and Gas Expertise. 2017. Renewable Energy World.

[270] OffshoreWindBiz. Vineyard Wind Books New Bedford Marine Commerce Terminal. 2018.

[271] Informational page about the Brayton Point Commerce Center. 2019. Accessed 2020.

[272] Scott-Smith, Brian. New London Offshore Wind Project Gets USD 93 Million Investment. 2019. WSHU Public Radio.

[273] Ørsted U.S. Offshore Wind. Tradepoint Atlantic Partner and Maryland's First Offshore Wind Energy Center. 2019. Ørsted.

Jersey, BOEM has announced a request for competitive interest following an unsolicited bid by Anbaric Development Partners to build out an offshore transmission system.[274]

The only proposed floating turbine project on the East Coast is the 12 MW New England Aqua Ventus I off the coast of Maine. This proposal uses a design named VolturnUS that was developed and patented by the University of Maine.[275] The University of Maine has been engaged in offshore wind research for more than a decade, since before a one-eighth scale version of VolturnUS became the first grid-connected offshore wind project in the United States in 2013. In the 7 years since, the University of Maine has collected environmental data and invested research into next generation materials and manufacturing processes to facilitate VolturnUS deployment and clear obstacles to the Aqua Ventus I project.

The USDOE granted Aqua Ventus I a $10 million grant in 2018 to support a full-scale demonstration project, which is based on VolturnUS technology. The demonstration project will deploy two undisclosed 6 MW turbine models mounted on the VolturnUS concrete semi-submersible floating platform connected to the seabed with three mooring lines apiece. Platform and turbine tower components will be manufactured in a nearby industrial facility, assembled in Seaport, Maine, and towed to the offshore installation site.[276] The Governor of Maine boosted the development of New England Aqua Ventus I by signing legislation that requires the state's public utilities commission to sign a PPA with the project consortium.[277] Without this guaranteed offtake, the projected cost of energy produced may have delayed grid interconnection further.

Lessons for California

1. **Learning by doing:** The East Coast markets were able to exceed expectations for pipeline growth and come in below projected PPA prices by leaning on experienced developers and proven technologies and de-risking project investment through the setting of targets. Pilot projects (for example, Block Island Wind Farm, New England Aqua Ventus I) were used to supplement this knowledge and test new technologies but maintained higher costs and faced delays similar to much larger projects.
2. **Interconnection responsibility:** Project developers and financiers are generally responsible for developing offshore transmission infrastructure on the East Coast between an offshore project site and onshore substation. While project sites are typically closer to shore than those proposed off the coast of California, this transmission capacity has been rolled into the cost of East Coast projects without prohibitively increasing PPA price.

---

[274] Gerdes, Justin. Who Should Build the Coming U.S. Offshore Grid. 2019. Greentech Media.

[275] Per the University of Maine Advanced Composites Center webpage, VolturnUS is designed to use existing manufacturing processes and facilities available in the United States. Segmented modules capable of serial production make up the hull. Design allows for deployment out of port facilities with as little as 27 feet of draft eligibility and includes ability to survive a 500 year storm.

[276] The University of Maine, Advanced Structures and Composites Center. New England Aqua Ventus 1. Accessed 2020.

[277] Greentech Media. Maine's Floating Offshore Wind Project Anticipates New Investor This Year. 2019.

3. **Research support:** East Coast governments assisted by de-risking projects, participating in siting processes, and engaging with stakeholders. Research plans, including the New York master plan, focused on conducting extensive environmental research. Environmental studies including aerial surveys, resource studies, and fishery assessments aided regulators and developers alike by assessing the impact of development and establishing public data resources to support future study. State governments did not engage directly in research into core system technologies but helped improve the value proposition for developers and stakeholders by filling in information gaps related to deployment and project impact. Many East Coast states are separately engaged with the National Offshore Wind R&D Consortium to support technology research.
4. **Stakeholder engagement:** East Coast states typically engaged with stakeholders early to preempt concerns, delays, and legal challenges. While some delays remained, work with BOEM, fisheries, environmental advocates, and the military allowed states to understand and include unique challenges faced by each party in the planning process. Organization of working groups, participation in BOEM task forces, and completion of data collection and environmental studies in advance of the planning process all supported rapid pipeline growth. Engagement with fisheries in particular helped define acceptable areas for offshore development and protect vital industries including scallop farmers off the coast of Massachusetts.[278]

---

[278] Based on interviews conducted to inform the East Coast case study.

APPENDIX C: Interview Guides

General Introductory Questions

1. Please briefly describe your role at your organization.
2. Is your firm currently involved in any facet of the offshore wind industry? If yes, please describe your involvement and geographic focus. If not, what is your relation to the industry or is there a reason you are not directly involved?
3. What do you see as the biggest technical challenges to building offshore wind in California?
4. What role can the Energy Commission and other state agencies play in reducing the current barriers?
5. What is needed (ports, vessels, infrastructure, etc.) to support floating offshore wind in California, including deployment of supersized blades and tall towers?
    1. *a.* Do you feel these infrastructure demands are different than in other offshore wind call areas in other countries? If yes, how?
    2. *b.* What is the readiness level of this infrastructure in California?
6. As you know, the technical energy potential in deep water is significant in California, Therefore, California wind energy projects might focus on floating platforms. Which proposed floating systems or types of systems (spar-buoy, semi-sub, tension leg, etc.) appear to be the most promising, both in general and specifically for the coastal conditions off California? What is the readiness of this technology?
7. What are the greatest levers (including R&D levers) to lowering the levelized cost of energy and increasing the capacity factor of offshore wind energy projects in California?
    - a. What is the levelized cost of a long-term PPA ($/kWh) required to be competitive with other renewable electricity options in California?
        - i. Does this figure include delivery of the electricity to a major load center or is this the PPA price at the project interconnection site?
8. Rank your top three challenges out of the following obstacles:
    - a. R&D Funding & Support, Project Finance & Risk, Permitting/Regulatory, Technology, Manufacturing, Installation, Operational, Transmission, community opposition for visual impacts.
    - b. Why do these come to the top of the list and what can be done about them? What role can agencies and stakeholders within California play?

Stakeholder-Specific Inquiries

<u>Project Developers</u>

1. What are the permitting requirements unique to offshore wind in California, and how can the regulatory framework support cost competitiveness? Any special observations for just floating platforms?

2. What are the technical barriers due to the challenging seabed conditions in California and which, if any, changes in the anchoring or mooring designs have been identified to overcome these challenges?
3. What are the R&D opportunities to use HVDC lines as the transmission system in offshore energy farms in California, including use of "backbone" transmission connecting multiple projects?
4. Do you view floating offshore wind as a risky *long-term* investment which will require a prohibitively higher rate of return?
    a. If yes, how can state regulators help facilitate project investment in the floating offshore wind space to reduce project risk and improve financier's willingness to fund projects?
5. Is the workforce available in California prepared to develop offshore wind projects in California? What is the strategy of your company to develop the first offshore wind projects in California, workforce wise? Are R&D projects enough to prepare the workforce?

<u>Technology Developers</u>

1. How do you view the development of higher MW rated units (10+ MW) in both the context of how these larger units will interact with existing platform technology and how it will affect the business case for floating offshore wind?
2. What are the emerging manufacturing approaches or advanced composite materials that can be suitable for California offshore applications?
    a. How can those innovations contribute to lower cost and accelerate offshore energy developments?
3. What are the technical barriers due to the challenging seabed conditions in California and which, if any, changes in the anchoring or mooring designs have been identified to overcome these challenges?
4. What are the R&D opportunities to use HVDC lines as the transmission system in offshore energy farms in California, including use of "backbone" transmission connecting multiple projects?

<u>Planning Agencies and Load Serving Entities</u>

1. To your knowledge, were any noteworthy factors used to determine the call areas chosen (aside from resource potential, proximity to grid connection points, and deep-water ports)?
2. Of the transmission challenges unique to offshore wind, which do you view as the biggest barrier(s)? What transmission mechanism(s) do you view as most efficient and practical?
3. Are you projecting offshore wind to be a significant component of the energy mix in California going forward? If yes, are there any specific preparations you are making?
4. What role can the Energy Commission and other planning agencies play in making sure offshore wind meets its potential over the next decade?
5. What are the R&D opportunities to use HVDC lines as the transmission system in offshore energy farms in California, including use of "backbone" transmission connecting multiple projects?

6. Is there any analysis being conducted in your agency that includes offshore wind in the process of meeting SB 100 goals? Could you share the focus of the analysis?
7. Any specific wildlife impact that your agency is looking at or concerned about due to offshore wind deployment?

Research Institutes

1. What research is still needed to support technical offshore wind and floating offshore wind development and shorten the timeline to market of commercially scalable systems?
2. Do you anticipate the positive macroeconomic impact of floating offshore wind development will be significant enough to generate organic support from local and municipal entities, or do state incentive programs need to be involved to drive adoption?
3. What are the emerging manufacturing approaches or advanced composite materials that can be suitable for California offshore applications?
    a. How can those innovations contribute to lower cost and accelerate offshore energy developments?
4. What are the technical barriers due to the challenging seabed conditions in California and which, if any, changes in the anchoring or mooring designs have been identified to overcome these challenges?
5. Any specific wildlife impact that your institution is studying due to potential offshore wind deployment in California? Any preliminary results that you can share? Is there any need of more research focused on wildlife impact?

Interest Groups

3. In what ways will floating offshore wind development impact local ecosystems? Are there any species or populations at specific risk, and how can these risks be mitigated by project and technology developers? What role can the Energy Commission or other state agencies play?
4. How can state agencies, including the California Energy Commission, work with trade organizations and industry stakeholders to support technology research and deployment?
5. Is there any need for more research focused on wildlife impact that you are aware of?