CALIFORNIA OFFSHORE WIND: Workforce Impacts and Grid Integration

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Page 10 photo: Assembly of wind turbine components at a Nordex factory in Jonesboro, Arkansas. *Credit: U.S. Department of Energy,* https://www.flickr.com/photos/departmentofenergy/8056998248/.

Page 54 photo: Turbine assembly at port in Norway prior to being towed to Hywind Scotland, the world's first floating offshore wind farm. *Credit: Equinor.*

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Preface: Disclaimer required by the California Public Utilities Commission

This report includes material prepared by E3 for the University of California at Berkeley Labor Center. This material is separate from and unrelated to any work E3 is doing for the California Public Utilities Commission. While E3 provided technical support to the UC Berkeley Labor Center in preparation of this report, E3 does not endorse any specific policy or regulatory measures as a result of this analysis. The California Public Utilities Commission did not participate in this project and does not endorse the conclusions presented in this report.

The E3 material uses E3's California-wide RESOLVE model developed under California Energy Commission contract number EPC-14-069. Versions of this model have previously been used by E3 for projects completed on behalf of the California Energy Commission and the California Air Resources Board. These California state agencies did not participate in the project and do not endorse the conclusions presented in this report. The RESOLVE model used for this project is distinct from the RESOLVE model developed for the CPUC's 2017-2018 Integrated Resource Planning proceeding (R.16-02-007). The following table summarizes the major differences in the RESOLVE model version used for this study and the version used in the CPUC's IRP proceeding.

Key differences in RESOLVE input assumptions as compared to CPUC IRP proceeding

Category	Assumption for This Study	Difference from CPUC IRP 2017-2018 Cycle Assumption
Geography	California Independent System Operator (CAISO) + Sacramento Municipal Utilities District (SMUD) + Los Angeles Depart-ment of Water and Power (LADWP)	California Independent System Operator (CAISO)
Natural gas fixed O&M costs	Going-forward cost to maintain existing natural gas generation set to $50/kW-yr	Included in total fixed costs
Natural gas generation economic retirement	Modeled with assumed cost savings equal to fixed O&M costs	Not modeled
Demand forecast	Based on CEC EPIC PATHWAYS study forecast for a high electrification scenario, optimized for 2050	Based on IEPR 2016/2017 forecast, optimized for 2030
Carbon emissions trajectory	Developed to meet a 2050 target of 80% reduction in the electric sector emissions relative to 1990 levels by 2050;an emissions target of about 8.8 MMT	Developed to meet CARB's Scoping Plan Alternative 1 scenario for 2030
Solar resource potential limitations	Reference case resource potential discounted to 266,932 MW in state to accommodate the higher demand and deeper decarbonizations levels by 2050	Reference case resource potential discount-ed to 122,300 MW in state available in the CPUC adopted 2017 Reference System Plan (RSP)
Wind resource limitations	Limited to 2,594 MW in state and 12,000 MW out of state (WY/NM/PNW).	Limited to 2,335 MW in state and 2,442 MW out of state (WY/NM/PNW) available in the CPUC adopted 2017 RSP

Category	Assumption for This Study	Difference from CPUC IRP 2017-2018 Cycle Assumption
Offshore wind candidate resources	5 offshore wind candidate resources are available for selection in several scenarios	Not modeled
Candidate resource costs	All generation costs updated to be consistent with E3's 2019 review of WECC's Generator Capital Cost Tool	Natural gas candidate resource costs consistent with WECC's 2014 Capital Cost Review of Power Generation Technologies; renewable costs assumed developed by Black & Veatch for RPS Calculator V6.3 Data Updates; battery storage cost assumptions are derived from Lazard Levelized Cost of Storage v2.0 and DNV GL's Battery Energy Storage Study for the 2017 IRP
RPS target	60% by 2030, 100% by 2045 (SB 100 compliant)	50% by 2030 (SB 350 compliant)
EV Loads	By 2030, 100% of EV owners have access to workplace charging	By 2030, 30% of EV owners have access to workplace charging

EXECUTIVE SUMMARY

This report presents research findings on offshore wind development, pursuant to a Proposition 84 Sea Grant from the California Ocean Protection Council to the UC Berkeley Labor Center and Energy & Environmental Economics (E3). Our study addresses two separate but complementary questions for California in the years and decades ahead: 1) what benefits would the emergence of a major offshore wind power sector create for California workers and communities, and what policies might optimize these impacts; and 2) would offshore wind power be a competitive source of renewable energy in comparison to other clean energy sources? These questions are discussed in two sections: Workforce Needs and Policies for Offshore Wind (Chapters 1-6) and Integrating Offshore Wind in California's Grid: An Assessment of Economic Value (Chapters 7-11).

The urgency of these questions derives from the fact that recent studies by the California Energy Commission (CEC) and California Public Utilities Commission (CPUC) indicate that the state will require two to six times more renewables capacity by 2045 than is installed today.[1] However, California's planning processes have only recently begun to consider offshore wind as a component of this future energy supply.

The exponential development of offshore wind power around the world and its projected growth on the East Coast of the United States shows that offshore wind could serve an important role in California's clean energy supply. Globally, offshore wind capacity now tops 22 gigawatts (GW), a tenfold increase over the past decade, with about 20 percent of that installed in 2018 alone.[2] This total is projected to reach between 154 GW and 193 GW by 2030, with at least half expected to be in Europe and much of the rest in China.[3] In the United States, several Northeastern states have made offshore wind a cornerstone of their future clean energy portfolios, with about 22 GW of new capacity mandated by 2035.

California differs from the East Coast and much of Europe in that the state's deep coastal waters will require its wind turbines to be on floating platforms rather than on structures fixed to the seabed. This floating technology has been successfully demonstrated in multiple locations worldwide, with larger-scale commercial projects being planned and contracted for deployment in the near future. While the cost of floating offshore wind today is higher than fixed-bottom offshore wind, the technology is well understood and its cost is expected to decline rapidly with commercialization and greater scale of deployment.

Our chief findings are the following:

Workforce needs and policy

- The results from offshore wind planning and deployment in Europe and the U.S. East Coast show that offshore wind could be a high-road industry that not only helps the state achieve its climate policy goals for emissions reductions, but also spurs broad-based growth, creates quality jobs, and benefits communities. Yet, the benefits could prove less than significant unless the state commits to develop the offshore wind sector with defined goals and sustained support.
- The largest economic benefits from the offshore wind industry would occur if an in-state supply chain were developed for the primary components of wind turbine generators—blades, nacelles (hubs), and towers—as well as the floating platforms, thus creating thousands of manufacturing and construction jobs. But the offshore wind industry is highly globalized, with its supply chain centered in Europe, and by the mid-2020s, China is likely to become a major exporter of wind components. In the absence of trade barriers imposed by the U.S. federal government for national security reasons,[4] California would need to plan strategically to compete for offshore wind supply chain jobs.

- As a first step, state policymakers should set a clear goal for offshore wind as part of the long-term renewable energy planning process (for example, a mandate for at least 8 GW over a decade). If the offshore wind planning process were to evolve in a more piecemeal basis, without strategic direction or fixed targets, wind developers and manufacturers would lack incentive to make major California investments, with the likely result being wind farms built with primarily imported inputs, relatively insignificant economic benefits, and potentially less cost reduction.[5]

- The first major supply chain component to locate in California is likely to be the floating platforms because their bulk makes them hard to transport. But the platform designs expected to dominate the California market in the 2020s could vary significantly in their employment impacts, and the state should carefully analyze these differences. While the U.S. Bureau of Ocean Energy Management (BOEM) selects offshore wind developers via an auction process in which bid price is the chief criterion, the state could leverage its control over permitting, the upgrading of ports, and other regulatory pressure points to influence the developers' selection of platform suppliers.

- The state would benefit from taking a proactive stance in working with industry to identify and develop possible port locations—possibly a multi-site network including Humboldt Bay—and to support development of other infrastructure such as long-distance transmission lines.

- Although the state has a strong workforce training system, including the construction industry's state-certified apprenticeships, skills gaps are likely to be a challenge for offshore wind on the North Coast. The state should consider creating a High-Road Training Partnership (HRTP) for offshore wind to fill these gaps and broaden community access to offshore wind jobs. HRTPs are a new state program of industry-specific training programs that prioritize job quality, equity, and environmental sustainability.[6]

Costs and grid integration

- This study identifies approximately 20 GW of viable offshore wind resources in California with estimated capacity factors ranging from 46 percent to 55 percent. These wind resources comprise five distinct zones: the three proposed BOEM lease areas (Morro Bay, Diablo Canyon, Humboldt Bay) and two additional zones in Northern California (Cape Mendocino and Del Norte). Together, these resource zones represent more than three times California's current onshore wind capacity and, if developed to their maximum potential, could provide approximately 25 percent of the state's future electricity needs.

- Offshore wind may be economically competitive with other resources in California by the late 2020s, once it is commercialized and available at scale. E3's analysis indicates that offshore wind constructed in 2030 would offer approximately $80/MWh in average lifetime avoided costs relative to competing grid resources, which would primarily be a combination of solar photovoltaics (PV), battery storage, and natural gas. For comparison, the latest forecasts from the National Renewable Energy Laboratory (NREL) suggest that the levelized cost of floating offshore wind may fall to $65–$80/MWh by the late 2020s, which would make offshore wind economically competitive compared to the above mentioned alternatives.[7]

- The avoided costs of offshore wind increase over time in every modeled scenario. This cost increase reflects the growing value of offshore wind over time as more and more greenhouse-gas-free energy is required to meet state policy goals and alternative sources become more expensive. For example, the results presented in this study show that if 8 GW of total offshore wind capacity is deployed across the state, annual avoided costs would range from $73/MWh in the early 2030s to almost $88/MWh by 2045. At the same time, the cost of offshore wind is projected to fall dramatically over the next two decades, making offshore wind increasingly cost competitive beyond 2030.

- Offshore wind's value differs slightly among the studied zones, with Humboldt Bay, Cape Mendocino, and Del Norte offering the most valuable wind resources in the longer term. When avoided cost is compared with estimated development costs and transmission availability, Morro Bay appears to be the most economic zone for development. The following table summarizes average avoided grid costs (levelized avoided cost of energy, LACE) and lifetime costs (levelized cost of energy, LCOE) associated with each site, as well as the expected onshore transmission capacity available for offshore wind interconnection in the late 2020s.

Comparison of costs and transmission availability for 2030 by zone

Offshore Wind Resource Zones	Simulated Capacity Factor	Average Avoided Costs 2030-50 LACE, 2 GW scale*	2025-2030 Cost Range LCOE, NREL ATB+E3	Transmission Availability (MW)
Morro Bay	55%	$80/MWh	$62 to $72/MWh	668
Diablo Canyon	46%	$81/MWh	$74 to $88/Gh	3,933
Humboldt Bay	51%	$88/MWh	$66 to $78/MWh	Minimal
Cape Mendocino	53%	$82/MWh	$65 to $76/MWh	Minimal
Del Norte	51%	$83/MWh	$66 to $78/MWh	Minimal

**Each zone contains 1.6 to 6.6 GW of offshore wind potential. Offshore wind zones were modeled at the 2 GW scale to compare economics of a substantial or complete build-out of the resource potential in each zone.*

- Unlike solar PV, which offers more rapidly diminishing value to the grid at larger scales of deployment, offshore wind maintains a similar level of avoided costs at increased scale, providing approximately $80/MWh in lifetime average value for up to 8 GW in total capacity installed in 2030. The average avoided cost of offshore wind may still exceed $70/MWh, even if all the studied resource zones (representing about 20 GW of capacity) were developed.
- Offshore wind would be even more economically competitive if future land use for solar were constrained by environmental protections or if the state aimed to achieve its greenhouse gas (GHG) goals at an accelerated pace. Sensitivity scenarios highlight the value of offshore wind in deep GHG-reduction scenarios in the future, especially when onshore resources are constrained.
- Offshore wind remains cost competitive under our modeling, even if alternative out-of-state wind resources were developed or solar and storage costs fell faster than expected. If 10 GW of out-of-state wind were added or if solar and storage costs fell more rapidly, the average value of offshore wind might fall by 5 percent, suggesting there is limited long-term downside risk to offshore wind development, even if alternative resources were available at low cost.

- Though offshore wind's value appears robust across all scenarios considered, the emergence of new competing technologies in the distant future is a potential downside risk that was not captured in the model. Offshore wind's value is driven primarily by its renewable attributes and a generation profile that coincides well with the grid's evening and winter energy needs, when emissions from remaining gas plants are projected to be highest. Few scalable resources today can offer the same benefits. However, if future technologies and/or resources with similar attributes (e.g., storage, geothermal, modular nuclear, or carbon capture and sequestration) became available at more competitive costs in the future, offshore wind's value to the grid may be reduced.
- This study does not make recommendations regarding the prioritization of offshore wind resource zones for development, which would require more detailed study of resource costs and transmission constraints. For example, limited transmission capacity on the North Coast may cap the amount of offshore wind that can be deployed without significant costs to deliver it onshore. The state would be well advised to carefully examine solutions for resolving this transmission bottleneck.

Part One

Workforce Needs and Policies for Offshore Wind

CHAPTER 1. INTRODUCTION

As California policymakers decide whether and how to support the development of offshore wind power, they need to evaluate the industry's possible workforce needs and economic benefits. As with other clean energy policy options, offshore wind poses a series of economic, environmental, and political trade-offs to be weighed. But offshore wind also appears unique in its potential to be a high-road catalyst of economic activity, one that creates high-quality, high-wage jobs in construction, manufacturing, port operations, marine services, operations, and maintenance. However, as this report discusses, this high-road potential cannot be taken for granted, and a series of careful proactive policies would be needed to encourage development of a local supply chain and broad-based community benefits. Without such policies, the economic benefits of offshore wind could be slim.

There are no easy metrics for analyzing the high-road economic potential of offshore wind. A quantitative modeling of job creation and economic activity is outside the scope of this study, although in this chapter we do review the two sets of quantitative projections that have been published to date. Nor does this report analyze specific skills gaps in the floating offshore wind industry—because floating platform technology is still in its early stages, this task would require close collaboration with developers and manufacturers to assess their hiring and training practices. In particular, this report does not analyze potential workforce implications for the fishing industry because that task would require environmental impact analyses that have not yet been carried out.

Instead, this report conducts a qualitative analysis of workforce impacts and lessons learned in the offshore wind industry elsewhere, and it reviews the potential workforce needs and policy implications of the offshore wind development proposals that are likely to be made in California.

An important caveat in this research is that while it is indeed useful to compare economic projections for offshore wind in California to those of other locations, care must be taken not to compare apples and oranges. A crucial distinction is that California's continental shelf is narrow, and its offshore seafloor slopes steeply downward, while the U.S. East Coast and many European developments to date have been on broad continental shelves that are much shallower far from land. For this reason, California offshore turbines will need to be mounted on floating foundations, while virtually the entire commercially installed offshore wind industry elsewhere in the world is on platforms fixed directly to the ocean floor. For reasons that are analyzed later in this report, many industry leaders caution that the differences between floating and fixed-bottom offshore wind industries cannot be overlooked. For starters, fixed-bottom is already a multibillion-dollar, established industry, with about 22.5 GW installed worldwide and 5.6 GW installed in 2018 alone. Floating wind is in its infancy: the 30 MW Hywind Scotland is the only commercially operating project, while other projects are under construction or nearing commercial operation in France and Japan.

Floating offshore wind has a unique vulnerability that doubles as economic potential: its much greater physical scale and logistical complexity compared to land-based wind farms. By the mid-2020s, floating turbines are expected to average at least 12 MW, with heights exceeding 800 feet.[8] The large offshore blades, which reach up to 300 feet long, cannot be transported on existing highways or rail lines and can only be manufactured quayside or delivered by ship from a manufacturer located at another port. These and other large components either will need to be imported from offshore manufacturers at seaports in Europe or East Asia or must be constructed at California's own ports. The state's challenge will be to stimulate the latter scenario because it would bring well-paid jobs and other local benefits.

As discussed in Chapter 4, California's distance from global wind industry manufacturing centers may give it a limited degree of leeway to develop an in-state supply chain. But competition from abroad still has relevance. The most important factor for developing a local manufacturing supply chain is the volume of the project pipeline ahead—that is, how many gigawatts in offshore wind projects will be guaranteed within a defined time period by federal and state action. If a sufficiently large project pipeline threshold were created—for example at least 8 GW over a decade, as recommended elsewhere in this report—turbine manufacturers and other supply chain firms might be more likely to invest in building new factories in California. If that minimum threshold were not met, however, and if the procurement process evolved more incrementally, wind manufacturers would lack clarity about the future California market for their products. In that case, wind farms likely would be built with primarily imported inputs, and the economic benefits would be markedly less significant.

The main difference between these high-benefit and low-benefit scenarios is the degree of state policy intervention.

For this study, the author interviewed union leaders, offshore wind industry participants, workforce training professionals, and port and transportation specialists to provide firsthand accounts of the impacts of offshore wind elsewhere and the policy implications for California.

Our workforce analysis starts with a review of the existing literature on economic impact projections and an assessment of data and research limitations. In the following chapters, this report analyzes the global track record and lessons learned in fixed-bottom offshore wind in nations where the industry has grown rapidly in recent years. We also review the preparations of U.S. East Coast states as they eagerly anticipate a new boom industry and try to attract supply chain jobs with various policy strategies. Our report then reviews the state's existing toolbox of best-practice policies to encourage high-road labor practices in clean energy and the options for developing offshore wind ports that can serve to cluster manufacturing jobs. Finally, the report looks in depth at the first manufacturing segment that is likely to localize in California—the floating platforms—and shows how the four most likely platform designs could have significantly varying employment impacts.

Projections of California job creation

A 2016 report on California offshore wind by the National Renewable Energy Laboratory (NREL) estimated that a 16 GW build-out by 2050 would create as many as 13,630 construction jobs per year and 4,330 permanent operations and maintenance jobs.[9]

Exhibit 1.1. NREL estimates of average annual jobs in California floating offshore wind

Scenario	Phase	2020-30	2030-40	2040-50
10 GW build-out by 2050	Construction: On-site	100	280	860
	Construction: Manufacturing supply chain	550	1,670	4,940
	Total Construction	**650**	**1,950**	**5,800**
	Operations: On-site	80	270	780
	Operations: Manufacturing supply chain	200	560	1,450
	Total Operations	**280**	**830**	**2,230**
16 GW build-out by 2050	Construction: On-site	260	1,130	2,340
	Construction: Manufacturing supply chain	1,350	5,490	11,280
	Total Construction	**1,610**	**7,750**	**13,620**
	Operations: On-site	130	530	1,270
	Operations: Manufacturing supply chain	370	1,130	3,060
	Total Operations	**500**	**1,660**	**4,330**

Source: Bethany Speer, David Keyser, and Suzanne Tegen, "Floating Offshore Wind in California: Gross Potential for Jobs and Economic Impacts from Two Future Scenarios," National Renewable Energy Laboratory, April 18, 2016.

Note: The construction phase jobs are average per year over each decade, while operations phase jobs are for individual years 2030, 2040, and 2050, not decades, and are ongoing and assumed to last for 25 years. These figures do not include the category of induced employment, which comprises the jobs, mostly in the service sector, that are created by the personal spending by the workers directly employed by wind projects and the wind supply chain.

Projections by BVG Associates for an American Jobs Project report in 2019 used assumptions and modeling methodology different than those used by NREL, so the numbers of the two reports cannot be compared directly.[10] In particular, the BVG numbers include "induced" jobs, which comprise the jobs created (largely in the service sector) by the household spending of those employed in "direct" offshore wind jobs (construction, installation, operations, and maintenance) and "indirect" offshore wind jobs (the manufacturing and fabrication supply chain).

However, a challenge in conducting research for the report has been the industry's standard practice of redacting its contracts for public disclosure, thus resulting in a lack of transparent workforce data for recent and proposed offshore wind projects in California and elsewhere. On the East Coast, for example, each of the public versions of recent project proposals by major wind developers has redacted nearly

Exhibit 1.2. BVG/American Jobs Project estimates of jobs in California offshore wind

	5 GW build-out by 2045*		18 GW build-out by 2045**	
	2035	2045	2035	2045
Direct Jobs	1,880	2,510	5,510	7,930
Indirect	1,035	1,220	2,920	4,595
Induced	1,224	1,567	3,541	5,261
Total	4,139	5,297	11,971	17,786
Construction	3,060	3,202	9,670	12,958
Operation	1,079	2,095	2,300	4,828
Total	4,139	5,297	11,971	17,786
% from construction	74	60	81	73

Sources: American Jobs Project, "The California Offshore Wind Project: A Vision for Industry Growth," February 2019; BVGA/American Jobs Project, "CA Jobs Modeling Methodology," January 10, 2019.

Note: The jobs estimates are per year for the individual years cited. These figures include direct and indirect employment but not the category of induced employment.

Scenario assumes no major state policy support, major restrictions on Central California offshore development by the U.S. military, and the importation of most major manufactured inputs.

**Scenario assumes comprehensive state policies supporting offshore wind, no significant restrictions by the U.S. military, and in-state production of major manufactured inputs.*

all information on economic impact, with dozens of almost entirely blacked out pages, thus making it impossible to verify the companies' claims.[11]

The author also attempted to obtain information via the Memorandum of Understanding for technical cooperation on offshore wind signed by California with Scotland in 2017 and Denmark in 2018.[12] In response to inquiries, the Embassy of Denmark in Washington DC and Danish wind firms MHI Vestas and Orsted responded that they were unable to share detailed information about jobs created or other workforce impacts at existing or proposed wind farms and turbine factories. Jobs data requests to Equinor, whose Hywind Scotland project is the world's only commercial-scale floating wind farm, also were declined. The Scottish government responded to the author's inquiry by stating it had no data on offshore wind employment in Scotland aside from self-reported data by the developer of one wind farm.[13]

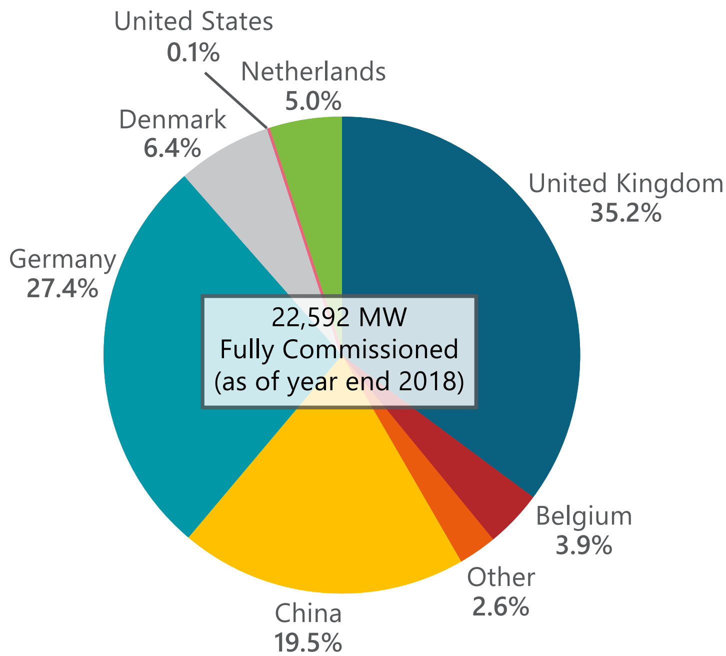
Chapter findings

- Fixed-bottom and floating offshore wind are similar but have major differences. Lessons learned are valuable but should not be conflated entirely.
- Published economic impact projections show that a build-out of 18 GW by 2045 would create as many as 13,620 direct annual jobs in manufacturing, construction, and installation, along a maximum of 4,330 permanent jobs in operations and maintenance.
- However, comparing these estimates to actual employment of existing offshore wind projects is difficult because of the lack of publicly available jobs and workforce data for those projects.

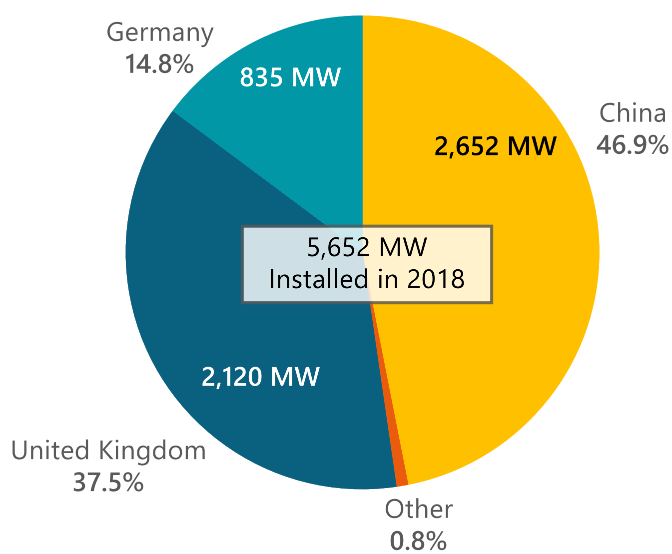
CHAPTER 2. LESSONS FROM ABROAD

While offshore wind is in its infancy in the United States, it is a mature and fast-growing industry in Europe and East Asia, with many useful lessons to be learned. Below is a review of wind energy development in a few key nations.

Exhibit 2.1. The UK is world leader in offshore wind as of 2018...



...but China has a faster growth rate



Source: Walter Musial et al., "2018 Offshore Wind Technologies Market Report," U.S. Department of Energy, August 2019.

United Kingdom

The UK is the world leader in offshore wind power, with plans to more than triple its capacity by 2030. As of mid-2019, the nation had 8 GW of fixed-bottom installed and about 7,200 people employed directly in manufacturing, installation, or operations in the sector.[14] The UK also hosts the world's first operational, commercial-scale floating wind farm, the 30 MW Hywind Scotland project, while a 50 MW floating project, Kincardine, is being installed off the Scottish North Sea coast.[15]

In a heavily publicized industry partnership plan announced in March 2019, the government declared offshore wind to be a strategic economic priority for the next decade. The plan, the Offshore Wind Sector Deal, set a goal of increasing total capacity to 30 GW by 2030, about one-third of the nation's projected total electricity load for that year.[16] The Deal projected that direct employment in offshore wind would rise to 27,000 in 2030, with an increase of domestic manufactured content rising from a reported 50 percent in 2018 to 60 percent by 2030.

The vast majority of that growth is expected to be in the fixed-bottom sector, but floating may also see significant expansion from its much lower starting point. An October 2018 study of UK floating wind, commissioned by the Scottish government, estimated that if floating wind were prioritized to meet a target of 20 GW nationwide by 2050 and if the UK government were to markedly increase its support for port development and industrial facilities, the floating sector (not counting fixed-bottom) nationwide would result in a maximum 17,000 annual jobs in construction, manufacturing, and operations and maintenance by 2050, reflecting UK domestic content of 65 percent.[17] Alternately, the study estimated that without government support, the sector would result in a lower build-out of 10 GW by 2050, with only 3,600 annual jobs and local content of 22 percent.[18]

For both fixed-bottom and floating, one advantage for the UK is the nation's existing high levels of workforce skills development. The Offshore Wind Sector Deal anticipates that because of the strong apprenticeship systems in the British construction industry and heavy industry, relatively few training gaps will emerge as the industry grows.[19] A workforce report commissioned in 2018 by the University of Hull noted the comprehensive collaboration between government, academia, private sector, enterprise zones, and unions, especially around Hull, the industry's primary port and turbine manufacturing center.[20] The one area singled out by both reports as needing more government assistance for training was marine services, because of the growing need for operations and maintenance of the thousands of turbines in the ocean.

In what appears to be the first of its kind in the offshore wind industry, the Deal committed to increase the representation of women in the offshore wind workforce to one-third by 2030, doubling female participation from 16 percent in 2018.

Despite this ostensibly positive outlook, offshore wind has been the target of repeated questioning by labor unions and some academic studies. A close look at this criticism is necessary to understand the possible risks as well as benefits for California in projecting supply chain jobs in the sector.

Government data confirm the unions' complaints that most of the existing offshore wind workforce is white collar rather than blue collar. Data for 2017 showed that 4,300 of the 7,200 offshore wind jobs were professional, technical, and administrative positions, with only 1,600 in manufacturing, 700 in operations and maintenance, and 500 in construction.[21]

New turbine blades at the Siemens factory in the British port of Hull. The property, formerly an abandoned railyard and shipyard, was converted in 2017. It employs 1,000 workers and covers about 100 acres—an expanse of land likely not available for long-term lease in any California port except Humboldt Bay.

Photo credit: Siemens Gamesa, https://www.siemens.co.uk/pool/news_press/news_archive/2016/siemens-b75-full.jpg.

The University of Hull study projected that overall employment demand in offshore wind will be strongest for technicians and engineers, with an estimated additional requirement of 10,200 by 2032. This figure represents one-half of the total projected job creation in the sector and reflects the highly skilled, technical nature of many of its tasks, especially in operations and maintenance, as well as the fact that most of the turbine manufacturing jobs are expected to be in Germany, Norway, and Denmark, rather than Britain.

A June 2019 report by the Scottish Trades Union Congress found that the British and Scottish governments' predictions of fast job growth in offshore wind in recent years had turned out to be exaggerated, and it said the governments had failed to adopt policies that would create a local supply chain of turbine manufacturing.[22] The report described a "failure to build a domestic industrial base and an over-reliance on imported goods and services" and criticized "the web of financial interests which leads to overseas state-protected, loss-making industries gaining an uncompetitive advantage."

Business groups see the problem somewhat differently but come to similar conclusions, as expressed by Ross Tyler, vice president of the Business Network for Offshore Wind, a U.S. group:

> The British government made a mistake in its early planning by focusing only on power generation and not ports development. Most UK ports are private, unlike their continental European peers, which were public or received public subsidies, so the UK ports did not make the upgrades needed for offshore wind. As a result, turbine-component factories were built on the other side of the English Channel. Relocating an existing supply chain is costly: the UK government learned this with the hundreds of millions of pounds it used to draw the Siemens Gamesa blade factory to Hull. The UK government now is forced to pay to catch up.[23]

A 2017 report by WindEurope, an industry group, suggested that not just the UK but all Europe was at risk of losing its early dominance over offshore wind manufacturing to East Asia. It concluded:

> International competition in wind energy has intensified in recent years. The growth of wind globally has not translated into more exports for EU manufacturers. The share of EU content in global installed capacity has fallen by 30 percent since 2011. [...] As the wind energy supply chain shifts to markets outside the EU, Europe risks losing the existing jobs and positive trade balance that wind energy has brought.[24]

A January 2019 report for the UK Offshore Wind Industry Council—co-written by some of the same consultants who wrote the 2018 floating wind study—downplayed the significance of blue-collar "traditional manufacturing" in the supply chain and advocated a more hybrid strategy of technology development:

> The development of UK offshore wind capacity has been largely achieved by harnessing the knowledge and expertise that had been developed in countries such as Denmark, Norway, and Germany. [...] Efforts to support and create traditional manufacturing employment [in the UK] will probably not generate export opportunity, and it is important therefore that the sector and UK companies are encouraged to innovate and create valuable intellectual property, which can create enduring economic benefit and export opportunity. Seeking to place traditional manufacturing industry on a level playing field with foreign state-assisted competitors, who are frequently protected within their own markets, is likely to be unsuccessful in the long term.[25]

A February 2019 study of UK offshore wind economic impacts by researchers at Oxford Brookes University found that "there is a major local leakage out of the substantial investments, especially of the main offshore construction works," with 25 percent of the projects' total expenses and employment in the UK and the rest elsewhere in Europe.[26] However, the study suggested that expanded development is likely to produce a greater share of UK jobs as the supply chain localizes.

Leaders of GMB, a large British union, say the UK and Scottish governments have failed to require offshore wind developers to make binding commitments to localize their supply chains. "What is a scandal is that the Scottish government has been consenting projects based on job creation in Scotland, and once the project has been consented, the developers have taken the work abroad," said Gary Smith, the Secretary of GMB Scotland, in an interview. "What's happening is you have a handful of big global players who are set to dominate the market, and those global players invariably have a state backer. [...] Offshore wind has certainly not delivered the economic benefits that were promised. It has not delivered the jobs."[27]

As an example, Smith cited the $2.4 billion Neart na Gaoithe wind farm under development off Scotland by the French firm EDF. Shipyards in Scotland will receive some work to build the fixed-bottom foundations, creating 200 construction jobs, but most of the platform and foundation materials will be manufactured in Indonesia. And while the turbines' source has not yet been announced, they also are expected to be imports.[28]

Unions also complain about Hywind Scotland. Although no final data is available for Equinor's project, a company study before start of construction on the project estimated that it would create 260 short-term jobs in the UK during its installation in 2017 and 33 permanent Scotland-based operations and maintenance jobs—a relatively small local impact because the turbines were entirely manufactured in Norway and then towed across the North Sea to their final destination off the Scottish coast.[29]

Germany

One of the most aggressive players in the offshore wind supply competition is Germany, with generally positive but mixed results. As of mid-2019, the nation had 6.6 GW of fixed-bottom offshore capacity connected to the grid, accounting for 47.6 percent of power generation, and employing 27,100 people in operations or the manufacturing supply chain.[30]

German labor unions have confidently cited offshore wind as a triumph of social-democratic industrial policy, in which government, industry, academia, and unions collaborate to channel resources to emerging industries.[31] In the past year or so, however, the government has reduced its formerly generous feed-in tariff subsidies to the sector, making the sector more sensitive to price competition. Unions have warned that ending the subsidies will put local manufacturers at a competitive disadvantage and will gradually force them to go abroad.

"I fear for the future of wind energy in Germany," said Heiko Messerschmidt, manager for the north German coastal region for the German Metalworkers Union, IG Metall, in an interview. As Messerschmidt explained:

> In recent years, we have lost so many employees and so much supply chain, so much innovation capacity, that we think the wind farms of the future will not be constructed by German companies or German employees. We will only be installing windmills built in cheaper countries—currently that means Portugal, Spain, Poland. Maybe in the future it will be Chinese companies. This is like the solar industry—only a decade ago there was a strong solar manufacturing industry in Germany, but now it's mainly imported from China. This could be the same with the wind industry. That's our fear at the moment.[32]

With 27,000 workers still employed, nearly all of whom have collective bargaining contracts and a standard of living matching the rest of German manufacturing, the industry clearly is not disappearing right away.[33] But the unions' concern is rising because Germany's longtime strategy of strategic support for targeted industries has weakened recently.[34] Since about 2005, Germany's federal government, along with states and cities in the north of the country, have spent billions of euros on port improvements, direct and indirect subsidies for turbine manufacturers, subsidies for transmission interconnections and substations, and worker training.[35] Tightly linked with the Social Democratic Party, the long-time ruling party in Bremen state, IG Metall helped revitalize the port of Bremerhaven after the shipbuilding industry there collapsed in the early 2000s. Working with local officials, the union forged a deal with major wind manufacturers: the port's hundreds of acres of abandoned and semi-abandoned deepwater quayside land would be made available for the manufacturers; in return, the manufacturers agreed to the establishment of "works councils," which are joint labor–management committees with master labor contracts, and accepted the pre-existing prevailing wage scale for shipbuilding, metalworking, and electrical manufacturing.[36]

The Bremerhaven authorities took advantage of the surge in offshore wind power construction in the nearby North Sea in the late 2000s—which was fueled in part by subsidized loans from government-owned development bank KfW—and successfully positioned the port as a regional supply hub. The 2009 founding of a research center, Fraunhofer Institute for Wind Energy Systems, helped push the region to the cutting edge of wind technology. Manufacturers such as Senvion, PowerBlades, WeserWind, and AREVA built factories, and service providers also located there symbiotically, leading to the direct employment of a total of 5,000 workers in Bremerhaven.[37] For several years, the city was the center of the North Sea's booming offshore wind industry, and an apparent success story for offshore wind industrial policy.

But the good times did not last. Bremerhaven's subsequent decline as an offshore wind center shows that a high-road strategy can be undermined by domestic policy shifts and the vicissitudes of market competition. The federal government's generous feed-in tariff subsidies to the sector are set to expire in 2020, which means that all offshore wind power must compete directly on price with other sources of power, including coal.

Since roughly 2015, Bremerhaven has suffered cascading layoffs at all of its wind firms, when they failed to win new supply contracts. Bremerhaven has lost more than 3,000 offshore wind manufacturing jobs in the past two years, and the sole remaining plant—a Senvion blade factory that employs 2,000—is now facing imminent shutdown since the company declared bankruptcy in April 2019.[38]

However, the nearby port of Cuxhaven has placed its bets better than Bremerhaven, investing heavily in port and transportation infrastructure and attracting several successful manufacturers while those in the neighboring port have slumped.

For unions, the lesson is painful but muddled. One thing is crystal clear: sheer luck is an important factor in industrial policy. "We are not certain what the answer should be," Messerschmidt said.[39]

Denmark

Germany's pain has been Denmark's gain. Wind power generation was invented by Danish scientist Poul la Cour in 1891, and windmills have been common throughout the country nearly since then. The world's first offshore wind turbines were installed in Danish waters in 1991, and by 2018, Denmark generated 28 percent of its total electricity supply through onshore wind and 13 percent through offshore wind, both the highest of any nation.[40]

For years, the Danish government subsidized the industry through a generous feed-in tariff. In recent years, however, the subsidies have virtually disappeared.[41] Denmark's competitive auction in 2016 for the 600 MW Kriegers Flak wind farm in the Baltic Sea was won by Vattenfall, a Swedish firm, with Danish-made turbines by Siemens Gamesa, at the equivalent of 5.5 U.S. cents per KWh—the world's lowest price for offshore wind at that time, although that excluded the cost of substation, export cable, and grid interconnection.

Denmark's wind firms have aggressively pursued global markets, becoming the dominant suppliers for the North Sea region and evolving into the offshore wind developer Orsted and turbine manufacturer MHI Vestas, each currently the world's largest in its category.

Although Denmark's own installed offshore wind capacity is only one-fifth of Germany's and one-sixth of Britain's, the country has had proportionally much greater success with wind supply chain manufacturing. The wind sector directly employs about 28,000 people in manufacturing, installation, operations, and maintenance.[42] The Danish government invested heavily in the port of Esbjerg, which became Europe's leading offshore wind supply port and helped replace the nation's shipbuilding industry, which is in gradual decline. Together, these factors have translated into high-quality jobs because Denmark is one of the most unionized nations in the world, and the main union federation, 3F (United Federation of Danish Workers), has strongly supported offshore wind.[43]

In an interview, Jesper Lund-Larsen, political adviser to 3F, said that his union federation had worked in a tripartite alliance with the government and industry since the 1980s to develop the wind industry—first onshore, then later offshore.[44] Even local governments have played a significant role, he said. For example, in manufacturing and port areas, streets are designed to facilitate the passage of turbine blades and other large parts with street poles that fold flat and with traffic circles that have wide, straight shortcuts through the middle.

"We really try to tell the government it should help the offshore wind sector because it produces so many good jobs, and also, it's a way to show other countries we are fulfilling our climate commitments," Lund-Larsen said. "The government took risks and subsidized it for many years, but now it's successful and doesn't need subsidies."[45]

According to a 2017 report by the Danish Energy Agency, another key advantage has been the fact that the agency has been able to centralize decision-making over most aspects of national wind planning. In 1997, the agency created a national master plan for offshore wind growth and has updated it repeatedly since then, allowing the agency to guide permits through local planning agencies, iron out stumbling blocks with environmental review, coordinate payment deals with commercial fishing groups to compensate for loss of fisheries, and ensure grid connections and immediate offtake contracts with local utilities.[46]

China

China is in a class by itself, with a characteristically meteoric growth curve. Although China was a late starter—only putting its first commercial-scale wind farm in the water in 2010 and reaching 1 GW deployed by 2015—it has quickly become the world's major player in the sector, accounting for nearly one-half of newly installed global offshore wind capacity in 2018. The U.S. Energy Department estimates that by 2023, China will have more than 30 GW deployed, comprising about 35 percent of global offshore wind capacity, far outstripping the No. 1 UK.[47, 48] This growth is largely driven by provincial government development plans with aggressive goals, such as Jiangsu's 10 GW and Guangdong's 12 GW, both by end of 2020.[49]

The country's onshore wind manufacturers Goldwind, Envision, and Mingyang are expanding into the offshore market and have become the world's second-, fifth-, and sixth-largest offshore turbine manufacturers, respectively. Their growth is almost entirely based on domestic sales.[50] East Asia industry analysts describe an opaque system of tacit controls that obliges foreign wind developers to create local manufacturing and transfer technology to Chinese firms.[51] In interviews, they also say it's only a matter of time before China becomes a major exporter—perhaps including to California. It is impossible to predict with confidence the evolution of China–U.S. trade relations in the coming years or whether Chinese involvement in California power generation might be viewed as a national security concern, despite both nations' vested interest in clean energy cooperation.[52] Both of these matters are outside the scope of this report, but the prospect of supply chain competition with Chinese-manufactured turbines and other materials seems highly likely to enter the policy calculations of federal and California state decision-makers in the years ahead.

"China is becoming very cost competitive on wind, and in some years from now, it could be able to compete around the Pacific, including on the U.S. West Coast," said Edgare Kerkwijk, a Singapore-based wind investor and a board member of the Asia Wind Energy Association, in an interview.[53]

The Chinese government has not disclosed workforce data for the offshore wind industry. The importance for California of Chinese offshore wind is not necessarily as a model to follow, but as a potential market competitor that could cost the state jobs in the future.

Chapter findings

- Britain's track record in successfully developing offshore wind has not translated into the creation of a large domestic supply chain. The industry is global by nature, and international supply chain competition must be a factor in policymaking.
- Britain also shows that in cases where international competition restricts the potential of job creation in traditional manufacturing, a more realistic strategy to increase local jobs might prioritize white-collar jobs in technology development.
- The case of Denmark shows that sustained government direction and control over many years can steer the success of the offshore wind sector and create a highly competitive industrial cluster.
- As shown by the German example of Bremerhaven, government support for offshore wind port development can play a key role in creating an industrial cluster, but success is not guaranteed to be long lasting, and market fluctuations can be influential—for better or worse.
- Chinese manufacturers do not play a role in offshore wind export markets currently, but in coming years, they are likely to be strong competitors in the California offshore turbine market.

CHAPTER 3.
THE U.S. EXPERIENCE: WHAT STATES CAN DO

In addition to looking abroad, California policymakers can find useful lessons on the U.S. East Coast, where states have committed to 22 GW of offshore wind by 2035, the industry is having a gold rush fever, and many elected officials are enthusiastic boosters of the industry. Best practices (and less-successful practices) can be identified as governments compete against each other for investment and economic benefits, struggle to evaluate the role of offshore wind as a power source in competitive electricity markets, and if warranted, seek to persuade local constituencies and electorates that proactive steps to support the industry are justified.

In these states, governments' priorities are similar to those facing California decision-makers:

- Provide an electricity supply that replaces retiring fossil-fuel generation, meets renewables goals at a competitive price, and serves the grid's needs for stable, reliable power;
- Maximize local jobs and economic development;
- Develop needed workforce skills, using local residents to the extent possible;
- Evaluate the need for and cost of public investment in local infrastructure, including ports and transport facilities; and
- Address public and stakeholder concerns, including environmental impacts.

As each state seeks to develop offshore wind and bring home the benefits for their communities, they need to compete with other regional entities that are seeking the same goals for their jurisdictions, their communities, and their voters. Despite the significant differences between the floating and fixed-bottom offshore technologies, useful information can be gleaned by analyzing workforce impacts of fixed-bottom offshore wind in Rhode Island, New York, Massachusetts, and New Jersey. The key driver—although, as our research found, by no means the only one—is the size of offshore wind deployment. More megawatts in the water means more jobs, but only to a point.[54]

Exhibit 3.1. State policy commitments as of September 2019

State	Capacity Commitment (GW)	Year(s) Enacted	Target Year(s)	Capacity Solicited (GW)
New York	9.0	2018/19	2030/35	0.9
New Jersey	3.5	2018	2030	1.1
Massachusetts	3.2	2016/18	2027/35	1.6
Virginia	2.5	2019	2026	0.1
Connecticut	2.3	2017/19	2020/30	0.3
Maryland	1.2	2013/19	2026/28/30	0.3
Rhode Island	0.4	N/A	N/A	0.4
TOTAL	22.1			4.8

Source: Walter Musial et al., "2018 Offshore Wind Technologies Market Report," U.S. Department of Energy, August 2019.

Rhode Island

The Deepwater Wind Block Island project, which went into operation in late 2016 and remains the nation's only operating offshore wind farm, is viewed by neighboring states as a useful model of regional and political consensus building.[55] Most Northeastern officials agree their workforce needs will be proportionally similar to those of the Block Island project. Despite its small size—six turbines totaling 30 MW—this project involved a comprehensive training program and served as a model of industry–labor cooperation.

The Block Island project provided about 300 annual full-time-equivalent jobs for two years under a Project Labor Agreement (PLA), which is a pre-hire collective bargaining agreement with several labor unions to set terms and conditions of employment for all workers on a specific construction project. The PLA was negotiated by the developer, Deepwater Wind, with the Rhode Island Building and Construction Trades Council. As is common for major construction projects in the Northeast and California, the Block Island PLA required prevailing wage rates, health and pension benefits, and joint employer–labor contributions for apprenticeship programs.[56]

The PLA solidified labor's crucial role as an ally for Deepwater Wind and state officials, a relationship that had been forged when the project was endorsed in 2009 by then-Governor Donald Carcieri. After Carcieri brokered a deal between the company and the unions, labor officials accompanied by crowds of rank-and-file workers appeared at dozens of meetings and hearings of local, state, and federal regulatory bodies, speaking in favor of the project and helping get permits approved.[57]

The Block Island PLA included the following skilled trades, which essentially are the same as those who will work on any offshore wind project, fixed-bottom or floating:

- Piledrivers and Divers (United Brotherhood of Carpenters)—setting the foundation of the platform, driving the foundation into seabed, and cable installation;
- Millwrights (United Brotherhood of Carpenters)—assembly and installation of nacelle, tower, and blades;
- Plumbers and Pipefitters (UA)—assembly and installation of nacelle, tower, and blades;
- Operating Engineers—crane operators and tugboat crews;
- IBEW—electrical;
- Painters—surfacing and painting;
- Elevator Constructors—installation of tower elevators;
- Laborers—multiple tasks; and
- Longshoremen and boat crews—stevedoring and marine services, including during the operations and maintenance phase.

The Deepwater Wind workforce training strategies were built on the extensive existing joint apprenticeship programs in the construction industries of Rhode Island and Massachusetts, which also contributed workers.

"Almost every single worker in Deepwater had gone through a registered apprenticeship program of one kind or another previously," said Andrew Cortes, executive director of Building Futures Rhode Island, an industry–labor training consortium, in an interview.[58] "But what's most important for employers in offshore wind or any other industry is that we have not just specifically trained workers, but an established, adaptable system. We don't just have the exact widget makers you need, but we know how to train your widget makers in any skill as fast as possible."

The Block Island project used turbines and blades imported from France, and the foundations were brought from an oil rig manufacturing firm in Louisiana. The reliance on imports drew criticism from some labor supporters, whose viewpoints were similar to those of the Scottish unions. Michael Williams, interim co-executive director of the BlueGreen Alliance, testified in Congress in June 2019:

> While Block Island's PLA resulted in significant quality job creation through the construction of the project, it largely missed the mark when it comes to the materials that went into the project. The major parts and components of the Block Island farm—with the exception of the foundation—were manufactured outside the United States. As the industry grows, sourcing components domestically represents a significant opportunity to help revitalize American manufacturing.[59]

New York

The most aggressive stance in favor of offshore wind has been in New York State, which has been rapidly ratcheting up its goals amid growing consensus that the industry will be high road, high wage, and labor friendly. By embracing offshore wind so enthusiastically, Governor Andrew Cuomo has attempted to claim national leadership on climate policy, in an implicit challenge to California's hitherto leading role. Understanding how New York adopted such a role provides a useful lesson in offshore wind policymaking.

Central to this development has been the role of the New York State Energy Research and Development Authority (NYSERDA), a state agency that has the combined function of regulating, soliciting, and procuring renewables, including offshore wind power. The unique importance of this combined role in allowing proactive policy support is discussed in Chapter 4 of this report.

New York's commitment to offshore wind has accelerated rapidly in recent years, with Cuomo, labor unions, environmentalists, and state regulators working in sync to develop support for the sector. The state's formal role kick-started in 2016, when the state adopted a Clean Energy Standard that mandated 50-percent renewable power—not including large hydroelectric—by 2030. Labor support was galvanized in 2017 by two influential reports citing the high-road potential of offshore wind: one by the Workforce Development Institute, a labor-supported research organization; and another by NYSERDA.[60] Climate Jobs NY, a labor coalition in coordination with the Cornell University Worker Institute, helped rally labor union support and facilitated union leaders' participation in negotiations with NYSERDA and the governor's office.[61]

"We gradually realized that offshore wind could be a significant producer of good jobs, and so we got pretty involved in the discussions," said Vincent Alvarez, president of the New York City Central Labor Council, in an interview.[62] "I can say we were at the table when decisions were made."

The next year, NYSERDA published the New York State Offshore Wind Master Plan, which noted the state's poor solar and land-based wind resources and cited offshore wind as the state's best alternative for renewable power.[63] The following year brought a commitment by Cuomo to develop 2.4 GW of offshore wind by 2030. But that target was eclipsed by Cuomo's announcement in January 2019 of a "Green New Deal" with a 100-percent clean energy standard by 2040.[64] This requirement accelerated the state's need for offshore wind power, so its target was boosted to 9 GW by 2035.

NYSERDA estimates that the 9 GW build-out would create an annual total of "more than 10,000" total jobs in construction, operations, maintenance, and manufacturing by 2035, not counting imputed employment.[65]

In July 2019, emphasizing his intent to use offshore wind to seek a high national profile as a climate leader, Cuomo signed two large offshore wind contracts as a part of a new law requiring the state to achieve a carbon-free electricity system by 2040 and reduce GHG emissions 85 percent below 1990 levels by 2050. The two wind projects—Empire and Sunrise, headed by Orsted and Equinor, respectively—total 1.7 GW, and a NYSERDA press release said they would create more than 1,600 jobs in New York State annually during construction.[66]

NYSERDA now predicts that the 9 GW build-out will support a maximum annual 10,000 jobs by 2035. But this claim is hard to pin down. A NYSERDA spokeswoman said the 10,000 figure was an extrapolation from an earlier workforce report for the state's previous target of 2.4 GW by 2030. That report estimated a peak annual employment of 3,520 workers by 2028, with 46 percent in manufacturing and 14 percent in installation, and a permanent operations and maintenance employment of 1,090 workers. The NYSERDA spokeswoman said the estimate of 1,600 jobs for the Empire and Sunrise projects was extrapolated from the project proposals by Orsted and Equinor. However, as mentioned in the Introduction, each of the public versions of those project proposals has redacted all information on economic impact, making it impossible to verify the claims.[67]

New York State's deep manufacturing base, major ports, and large construction sector may facilitate the creation of an offshore wind supply chain. A 2017 NYSERDA report about offshore wind workforce needs predicted the state would not strain to provide skilled workers and would successfully train all those needed.[68] Labor union leaders, government officials, and company executives concur, pointing to the robust system of joint union–management training programs such as the Electrical Industry Training Center in New York City.[69]

"There may be some small changes we need to do with our training curriculums, but basically, we've got a good system that is made to be adaptable to the particular needs of any project," said Ellen Redmond, international representative of the IBEW, in an interview. "That's what we always do—it's flexible, and it works."[70]

As discussed later in this chapter, a key difference between New York and Massachusetts is that NYSERDA has mandated PLAs for all offshore wind projects and is using its regulatory power to press wind developers to create a manufacturing supply chain, while Massachusetts has not mandated PLAs and has taken fewer steps to avoid a reliance on imported parts.

NYSERDA is taking several steps to work with developers to advance workforce development, creating the following programs exclusively for the offshore wind workforce:[71]

- Advisory Council on Offshore Wind Economic and Workforce Development;
- Offshore Wind Training Institute, with a $20 million budget for training;
- Community and Workforce Benefits Fund: $3 million to establish the institutional infrastructure for training and pre-apprenticeships, especially in underserved communities; and
- Jobs and Supply Chain Technical Working Group to coordinate $10 million in state grants from 2018-25 for job training and port development.

Unlike some other states, New York's offshore wind planning process has incorporated labor union leaders in state planning, with the express goal of ensuring that the industry adopts high-road workforce solutions. "We are working directly with NYSERDA and the governor's office to get out in front of offshore wind labor needs, create good jobs, and make sure that the training infrastructure we already have will be strengthened any way that's needed," said Vincent Alvarez of the New York City Central Labor Council.[72] "We want to make this industry a success."

Massachusetts

The state has set a goal of 3.2 GW of fixed-bottom offshore wind by 2035, and its initial major project, the 800 MW Vineyard Wind, is expected to be the first major project on the East Coast. As of the writing of this report, that project was unexpectedly delayed, subject to a potentially wide-ranging cumulative environmental impacts review by BOEM. The review is expected to be finished in late 2019 or early 2020.[73] The regulatory issues behind the BOEM review are outside the scope of this report, although the review's parameters and findings could influence the paths forward for other projects on the East Coast and possibly California.

A 2018 report by the Massachusetts Clean Energy Center, a state agency, estimated that by 2030, an initial build-out of 1.6 GW by 2030 would create a range of 6,878 to 9,852 construction job-years and 964 to 1,748 permanent operations and maintenance jobs, all including the category of induced jobs—which comprises the additional jobs, mostly in the service sector, that would be created as a result of the personal spending by the households that earn income directly from wind projects and the wind supply chain.[74]

Unlike New York, where NYSERDA requires that wind developers sign PLAs with unions and pay prevailing wage, Massachusetts is legally unable to do so—as discussed later in this chapter.

Also unlike New York's prediction of no labor shortages for offshore wind, the Massachusetts report predicted that workforce skills gaps would indeed appear. The state made this projection despite the likelihood that Massachusetts' initial wind farms will use mainly imported components and foreign "jack-up vessels" for installation.[75] The 2018 report envisioned shortages in several categories of workers, which would need to be recruited from out of state, unless developers and the state could train them:

- Maritime workers such as tug pilots and crews, "who would need to be incentivized to leave established industries such as commercial fishing to work in offshore wind";
- Longshore workers and machinists;
- Stevedoring and machinery services in the ports used by developers;
- Construction crews, including iron and steel workers and welders; and
- Operations and maintenance teams.

The workforce reports for both New York and Massachusetts noted that while developers and turbine manufacturers typically provide technology-specific training, they require their new installation, operations, and maintenance workers to have already completed the technical or health and safety training programs of the Global Wind Organization (GWO). Under federal law, all offshore workers also require certification under the Standards of Training, Certification, and Watchkeeping for Seafarers.[76] In May 2019, the state awarded $721,500 in grants to five academic institutions and the Pile Drivers and Divers union to establish offshore wind training programs.[77]

New Jersey

Only days after Governor Phil Murphy took office in January 2018, he set a statewide 3.5 GW goal for offshore wind by 2030, as part of a new target of 100-percent clean energy by 2050. He envisioned offshore wind as a vertically integrated industry with an in-state manufacturing supply chain. Working with the Business Network for Offshore Wind, the state created a New Jersey Offshore Wind Supply Chain Registry as a means of helping companies create manufacturing synergies.[78]

In June 2019, the state Board of Public Utilities awarded a contract to Orsted for its 1.1 GW Ocean Wind project. According to a governor's office press release about the award, the project will create "an estimated 15,000 jobs over the project life." [79] The statement also said Orsted won the deal over competing bids from EDF/Shell and Equinor because Orsted offered greater economic benefits, including development of an in-state supply chain. As part of its application, Orsted signed a Memorandum of Understanding (MOU) with the South Jersey Building and Construction Trades Council, calling for a PLA for offshore wind construction jobs that pay prevailing wage. It also signed MOUs with three local universities—Rowan, Stockton, and Rutgers—to create wind apprenticeship programs and professional/technical development programs with Stockton and Rutgers Universities.[80]

Less than two weeks after that award, Orsted and German manufacturer EEW announced an MOU to build an offshore wind foundation factory in Paulsboro at the site of a former oil refinery.[81] As with other states, however, the jobs claims by the state government and Orsted project are difficult for independent analysts to evaluate fully because the published version of its project proposal is heavily redacted. Most details of Orsted's plans for job creation, skills training, technology, and infrastructure in the proposal are not available to the public. [82]

Workforce and supply chain policy tools for states

This section compares the applicability of policy tools used in other states to California.

In most countries with offshore wind industries, the national government signs a power purchase agreement (PPA) directly with the wind farm developer and the local utility in a package deal that often involves rights to the seabed and transmission links to the electric grid. In the United States, BOEM competitively awards rights for development in a given area, with price the only criterion evaluated. Companies then must arrange for their own transmission links and negotiate with the state government or utilities to sell them the power. This process means state government agencies, rather than the federal government, may have potentially significant negotiating power—but only if their implementing legislation allows them to use it.

Under the Commerce Clause of the U.S. Constitution, states and local jurisdictions can impose labor and local content requirements on state and local government procurement contracts and subsidy programs but cannot impose such requirements on private, third-party contracts, unless a state agency is directly a party to those contracts.

There is a crucial difference between California and many East Coast states. In California, the Public Utilities Commission (CPUC) does not directly control power procurement and thus cannot impose labor standards or local content requirements, except where explicitly authorized by legislation, for example, SB 350 (De León 2017), which increased the Renewables Portfolio Standard (RPS), requires all transmission line work to be done under the prevailing wage. In contrast, many East Coast states' energy regulatory authorities can impose labor standards and other contract conditions on offshore wind developers because they were explicitly given that authority legislatively. Of the East Coast states that have taken the lead on offshore wind, most—including New York, New Jersey, and Connecticut—have created bidding preferences related to labor standards and local content requirements. Massachusetts and Rhode Island have not done so, although their elected leaders and labor unions have worked together toward some of the same results.

Local content requirements

Another important policy tool is local content legislation or regulation, which requires developers to source a determined share of their inputs from in-state suppliers. However, in a region of relatively small states, the logic of each state demanding that wind companies use local ports and set up in-state manufacturing plants is questionable. Many Northeastern state government officials admit that rather than each state competing directly with its neighbors, a more logical strategy would be regional cooperation, with each major wind factory and port serving a multi-state area. They admit, however, that cooperation will likely be limited.

"Is each of our states big enough, or with a big enough wind commitment, to support at least one full offshore wind port, plus turbine factories and major service installations, or would it make more sense to have a regional approach?" asked Bruce Carlisle, director of the Massachusetts Clean Energy Center offshore wind program, in an interview.[83] "It's probably the latter, but our jobs are to work for our states and bring home the benefits, and it's difficult to break out of those silos."

The following table, adapted from unpublished research by the U.S. Department of Energy, shows that Eastern states have explicitly chosen to try to maximize economic benefits from offshore wind. The details vary, but the common denominator is that the states' legislatures have given detailed instructions to state regulatory agencies to require that wind developers meet targets for job creation, training, and high job quality.

Exhibit 3.2. Eastern states' legal tools to impose labor standards and local content requirements on power contracts

CONNECTICUT	
Labor Standards in Statute	Mandatory
Local Content Preference in Statute	Preference
Statute	"The commissioner shall include requirements for contract commitments in selected bids that require payment of not less than the prevailing wage [...] and require selected bidders to engage in a good faith negotiation of a project labor agreement [...] shall specify the minimum terms that such project labor agreements shall address. [...] shall consider factors including [...] any positive impacts on the state's economic development."
Authority	Department of Energy and Environmental Protection, Public Utilities Regulatory Authority, and Office of Consumer Counsel
RFP Text	"The commissioner must include requirements for selected bids that: (A) require payment of not less than the prevailing wage [...] (B) require selected bidders to engage in a good faith negotiation of a project labor agreement [...] shall consider factors, including, but not limited to [...] any positive impacts on the state's economic development."
Other Components of Project Agreements	Revolution Wind (300 MW) • PPA requirements redacted • Invest $57.5 million in port of New London and sign 10-year lease

MARYLAND		
Labor Standards in Statute	Mandatory	
Local Content Preference in Statute	Mandatory	
Statute	"The Commission shall use the following criteria to evaluate and compare proposed offshore wind projects: [...] the extent to which an applicant's plan provides for the use of skilled labor, particularly with regard to the construction and manufacturing components of the project, through outreach, hiring, or referral systems that are affiliated with registered apprenticeship programs [...] provides for compensation to its employees and subcontractors consistent with wages outlined under §§ 17–201 through 17–228 of the state finance and procurement article."	
Authority	MD Public Service Commission	
RFP Text	"Evaluate several aspects of how each proposed OSW project would affect employment, labor, and small businesses in the State [...] provide for the use of skilled labor and appropriate agreements to promote the prompt, efficient, and safe completion of the project; and, provide for compensation to employees and subcontractors consistent with the wages outlined in §§ 17-201 through 17-228 of the State Finance and Procurement Article."	
Other Components of Project Agreements	Skipjack (120 MW) • 34% of total Capex ($204.8 million) spent in state • Use Baltimore as installation port • Use Ocean City as O&M port • Invest $25 million in steel fab plant	US Wind (248 MW) • 19% of total Capex ($291.6 million) spent in-state • Use Baltimore as installation port and Ocean City as O&M port • Invest $51 million in steel fab plant • Invest $26 million in Tradepoint Atlantic shipyard

NEW JERSEY

Labor Standards in Statute	Mandatory
Local Content Preference in Statute	Mandatory
Statute	"A cost-benefit analysis for the project including at a minimum: (a) a detailed input-output analysis of the impact of the project on income, employment, wages, indirect business taxes, and output in the state with particular emphasis on in-state manufacturing employment; (b) an explanation of the location, type, and salary of employment opportunities to be created by the project."
Authority	NJ Board of Public Utilities
RFP Text	"In-state impacts or benefits that need to be included in the cost-benefit analysis include, but are not limited to: 1. Employment; 2. Wages; 3. Indirect business taxes; and 4. Output, with a "particular emphasis" on manufacturing employment."
Other Components of Project Agreements	Ocean Wind (1,100 MW) • $15 million in grants for local infrastructure • O&M base in Atlantic City • Workforce development for students in Atlantic City • MOU with South Jersey Building and Construction Trades Council for a PLA • Invest with EEW to build foundations factory in Paulsboro

NEW YORK

Labor Standards in Statute	Mandatory
Local Content Preference in Statute	Mandatory
Statute	NYSERDA may consider prevailing wage and PLAs as contract requirements, taking into account potential costs and benefits in the context of offshore wind construction and operation […] NYSERDA is expected to include a local content provision in the evaluation criteria."
Authority	NYSERDA & NY PSC
RFP Text	"Prevailing Wage Requirement […]. and Project Labor Agreement. […] includes those net expenditures by developers and their supply chains in New York State, including in-state purchases, employment, and payments/benefits to New York State government or other entities. The Proposal will also describe the degree to which the development and construction of the Offshore Wind Generation Facility will directly create short- and long-term jobs in New York State."
Other Components of Project Agreements	Empire Wind (816 MW) & Sunrise Wind (880 MW) • $287 million for long-term port infrastructure investments • $20 million for offshore wind training institute

MASSACHUSETTS	
Labor Standards in Statute	Voluntary
Local Content Preference in Statute	Voluntary
Statute	"Where feasible, create and foster employment and economic development in the Commonwealth."
Authority	MA Department of Energy Resources and Department of Public Utilities
RFP Text	"Where feasible, a proposed project demonstrate that it creates additional employment and economic development in the Commonwealth [...] and direct employment benefits"
Other Components of Project Agreements	**Vineyard Wind (800 MW)** • $2 million offshore wind workforce development • Martha Vineyard O&M facility • Port of New Bedford staging area

RHODE ISLAND	
Labor Standards in Statute	No
Local Content Preference in Statute	No
Statute	N/A
Authority	N/A
RFP Text	N/A
Other Components of Project Agreements	**Revolution Wind (400 MW)** • PPA requirements redacted • Invest $40 million in local port infrastructure

Source: Adapted from Paul Spitsen, "OSW Labor Table," U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, August 16, 2019.

Tools that can be used in California climate policy

In California, in contrast, state agencies such as the CPUC and other local government entities have a less direct but more extensive range of policy tools to improve labor standards and encourage local manufacturing content. State and local governments will have many opportunities to use these tools because offshore wind developers will need government assistance and approval at many levels: regulatory permitting; direct subsidies for port and infrastructure upgrades; interconnections to the grid; and long-distance transmission planning. Community choice electricity providers (CCAs), which are fast absorbing the major utilities' market share and are expected to be the principal offtakers for offshore wind, could provide another point of leverage. Some CCAs,[84] but not all, have partial requirements that their PPAs include prevailing wage and PLAs and provide other local economic benefits, and these requirements could be expanded on a comprehensive basis.

The following summary of best practices in California labor policies for the clean energy sector is adapted for offshore wind from "Putting California on the High Road: A Jobs and Climate Action Plan For 2030," a forthcoming report by the UC Berkeley Labor Center for the state Workforce Development Board.[85]

- **Community Workforce Agreements (CWAs) and Community Benefits Agreements (CBAs).** These are often used in climate investments involving large-scale construction projects, such as those funded by the state Greenhouse Gas Reduction Fund. For offshore wind, they could be used by developers and in infrastructure projects such as port improvements. Although terminology varies, CWAs are PLAs that also include goals for hiring from local communities and/or targeted disadvantaged groups,[86] while CBAs are legally enforceable agreements negotiated between community groups and a developer and require similar local benefits.[87] However, not all CBAs meet a commonly accepted standard, as described in the Case Study below.

- **Responsible procurement policies.** These policies allow state and local government agencies to include requirements such as a floor on wages, skill standards, and other workforce standards in bidding evaluation for contracts for large capital equipment and public services and in grant programs. A key example is the U.S. Employment Plan as created by Jobs to Move America.[88]

- **Skill standards**. Because of the worker safety risks inherent in offshore wind farms, the state could create standards to ensure safety and high performance in their manufacture, installation, operations, and maintenance.[89] One relevant precedent is the California state law (SB 54, 2012) mandating a "skilled and trained workforce" in private sector construction or maintenance work in refineries—meaning that a specified share of workers must be either enrolled in or have graduated from a specified list of state-certified apprenticeship programs.[90] However, California's offshore wind farms are slated to be in federal waters, outside the state's limit of control three miles from the coast, so these skills certifications would need to focus on activities within state jurisdiction. As mentioned above, wind farm insurance companies also are likely to insist on Global Wind Organization safety standards for offshore operations, including in federal waters.[91]

- **High-road industry training partnership.** The state Workforce Board's new initiative for a High-Road Training Partnership (HRTP) program[92] could be adapted for offshore wind. An HRTP for the sector would create a collaborative partnership with the offshore wind industry to support added modules to existing apprenticeship programs and enhancements of labor–management partnerships, and other employer-led training initiatives in non-unionized parts of the offshore wind supply chain. This initiative could partner with community colleges and other training organizations to deliver workforce skills—especially in areas such as the North Coast, where skills gaps may exist.

- **Workforce analysis.** Agencies that are tasked with promoting the accelerated market adoption of clean energy technologies such as offshore wind could require a workforce analysis be conducted by all companies, local government agencies, and other entities that bid for or receive state support. They could be asked to identify: 1) the occupations that are critical to the planning, installation, maintenance, and operations; 2) any performance problems that are related to skills gaps; and 3) the relevant training and skill requirements that the business uses to engage qualified workers.

- **Just Transition**. This term refers to support for displaced workers and communities when government climate policy results in significant job loss in fossil fuel-related businesses.[93] An example could be municipal programs to transition the workers at municipal gas-fired utility power plants into new offshore wind projects, providing similar terms and conditions of employment and other protections.[94]

CASE STUDY

SCRUTINY FOR MORRO BAY COMMUNITY BENEFITS AGREEMENT

Not all so-called community benefits agreements follow a commonly accepted standard, as proved in November 2018 when the wind developer Castle Wind signed a deal with the City of Morro Bay related to a 1 GW offshore wind farm that the company had proposed nearby.[95] The deal, which both sides termed a "Community Benefits Agreement," gave the company exclusive use of the 668 MW in excess transmission infrastructure from the city's Dynegy power plant, mothballed in 2014. In exchange, the company gave a $250,000 cash payment to the city and made a number of non-specific, non-binding promises for local economic benefits.

The deal was atypical of most CBAs. It did not include mention of prevailing wage or joint apprenticeship programs, make any binding commitments to hire local residents or members of disadvantaged communities, or did it incorporate any other commonly accepted elements of a CBA. A subsequent Memorandum of Understanding between Castle Wind and with Monterey Bay Community Power (MBCP) to provide up to 1 GW of power— in other words, almost the entire output of the wind farm— did not mention a binding commitment to labor standards or community hiring, although recent MBCP power purchase agreements have included a prevailing wage requirement.[96]

In an interview, Castle Wind's CEO, Alla Weinstein, suggested that her offshore wind farm project might be mostly non-union.[97] "I don't think so, I'm not sure about that," she responded to a question about whether she was expecting to sign a Project Labor Agreement. "Not necessarily. Maybe just the electricians would need to be union. That's really premature to discuss at this moment. We'll see later on."

Labor unions say the Castle Wind agreements did not meet an adequate standard. "This was mere public relations spin and was not a real community benefits agreement, that's all I can say," said Cesar Diaz, legislative and political director of the State Building Trades and Construction Council, in an interview.[98] "It will not hold up over time."

Chapter findings

- The regulatory agencies of East Coast states have greater legal authority than those in California to directly impose labor standards and local content requirements on offshore wind developers.
- Nevertheless, California has a wide variety of policy tools to optimize workforce outcomes in the offshore wind industry, and these tools deserve close consideration by state policymakers. State and local governments can use their regulatory leverage over project permitting, direct subsidies for port and infrastructure upgrades, offshore transmission interties, and long-distance transmission planning, among others. CCAs could also adopt and expand requirements that their PPAs include prevailing wage and PLAs and provide other local economic benefits.
- Developer commitments such as Community Benefits Agreements should be encouraged, but they also deserve close scrutiny and should meet the standards of robust CBAs rather than just using the CBA label.
- The state's new High-Road Training Partnership initiative could be a model for the offshore wind industry.

CHAPTER 4. CALIFORNIA'S GORDIAN KNOT: PORTS AND SUPPLY CHAIN

As discussed previously, offshore wind's economic benefits would be greater if the supply chain were localized. This chapter examines some of the conditions that are needed to make California's supply chain become local.

Chapter 1 outlined the results of the two principal jobs forecasting studies to date, which found that by the 2040s, offshore wind would create a maximum of 13,620 direct jobs in manufacturing and construction and 4,330 jobs in operations and maintenance.[99] More important than these actual numbers, however, are the underlying assumptions about the share of local content. For the state's first wind farms, it is likely that most components will be imported. In later phases, turbine manufacturers might set up factories in California. Just how fast the supply chain is localized depends on many factors, with state policies playing an influential role.

Exhibit 4.1. California supply chain: Modeling assumptions for 2036-45, in percent of total supply chain

Study	Goal by 2045	Nacelle	Blades	Tower	Platform	Installation	O&M	Marine Services
NREL	10 GW	25%	50%	100%	30%	30%	50-100%	50%
	16 GW	50%	100%	100%	65%	65%	75-100%	75%
BVG/ AJP	5 GW	Imported	Imported	Imported	California	Mixed	Mixed	California
	18 GW	Imported	California	California	California	Mixed	Mixed	California

Sources: Bethany Speer, David Keyser, and Suzanne Tegen, "Floating Offshore Wind in California: Gross Potential for Jobs and Economic Impacts from Two Future Scenarios," National Renewable Energy Laboratory, April 18, 2016; American Jobs Project, "The California Offshore Wind Project: A Vision for Industry Growth," February 2019.

As also mentioned in Chapter 1, California is far from major wind industry manufacturing centers in Europe, Asia, or the central and eastern United States. For that reason, California may have extra leeway to develop a local supply chain for offshore wind—although it must start from near zero.

California's current lack of a supply chain

California is the nation's fourth-largest wind power generator, but its wind supply chain is negligible. The state has no factories manufacturing large-size blades, nacelles, or towers, and it makes only a small share of other wind components. In recent years, manufacturers have had little reason to set up operations in California because the installed capacity of land-based wind grew a total of only 6 percent from 2013-2018, and industry groups say few potential sites are available for future growth.[100] The few new turbines that are being installed (mostly as "repowering" or replacements for older, smaller turbines) are sufficiently modest in size to be imported by rail or truck from other states.

For a variety of economic, logistical, and political reasons, wind turbines deployed offshore will be considerably larger than those placed on land. Currently, the largest fixed-bottom turbines being installed are 10 GW, twice as large as the biggest land-based turbine and reaching 750 feet high, while industry projections are for turbines averaging 12-15 GW by the mid 2020s, with heights exceeding 800 feet.[101] So while the components for land-based wind farms can be delivered by rail and truck, the large offshore blades, which reach up to 300 feet long, cannot be transported on existing highways or rail lines and can only be delivered by ship from a manufacturer located at quayside.

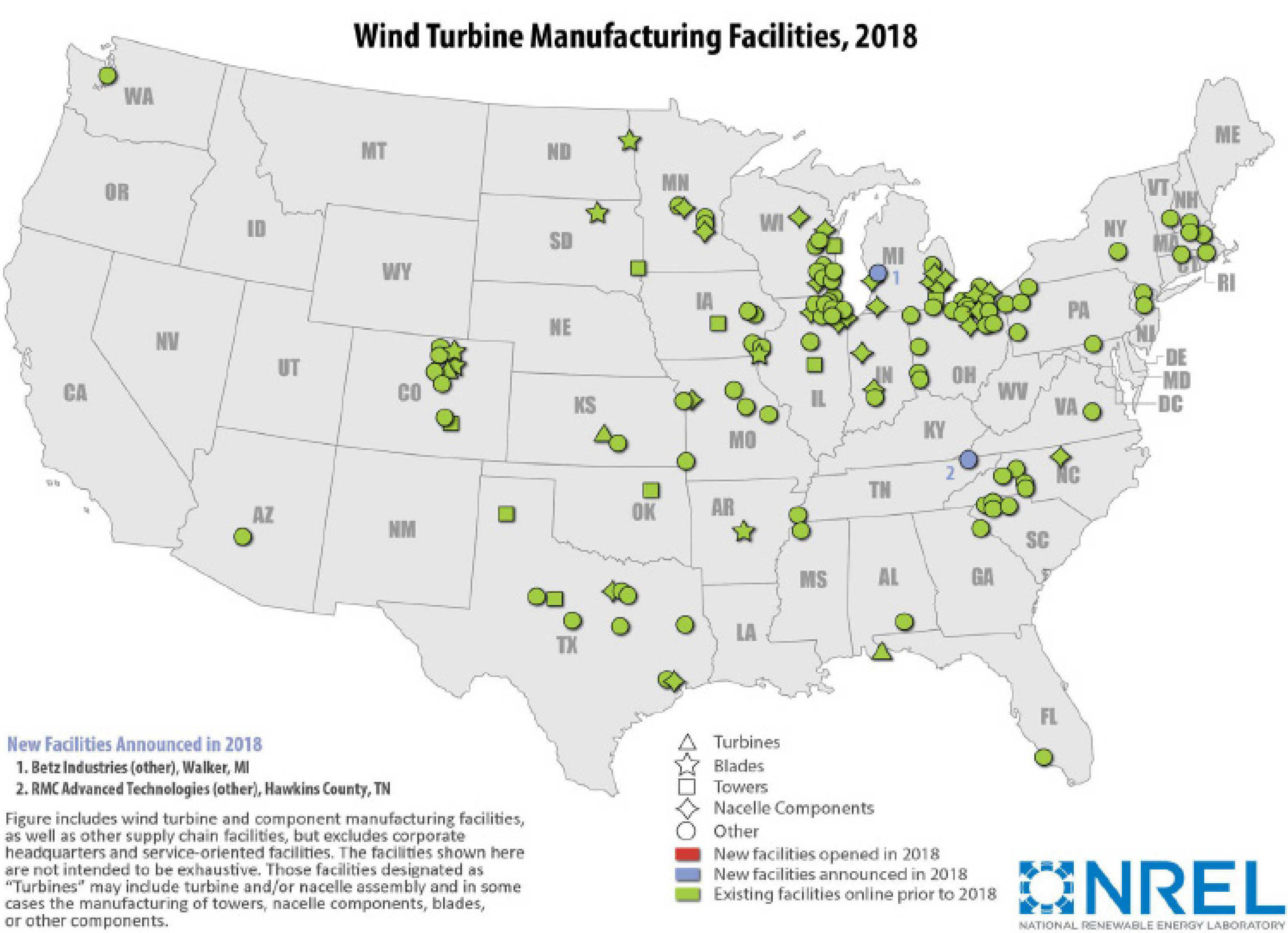
For California offshore wind, turbine factories in Iowa or Colorado won't suffice. Either these huge, complex components will need to be imported across the ocean from offshore manufacturers at seaports in Europe or East Asia, or factories must be constructed at California's own ports. The latter would be preferable from an economic development perspective because they would bring well-paid jobs and other local benefits, but like any major manufacturing facility, they would require significant investment—a decision driven by investors' perceptions that sufficient demand for their products could be predicted with confidence.

Exhibit 4.2. California's meager wind supply chain: No major components included

Firm	Product Classification	Facility Location
AOC LLC	Materials, polyester resin	Perris
Atmospheric Systems	Sensors	Valencia
Bal Seal Engineering	Generator components	Foothill Ranch
Barksdale Control Products	Hydraulics and controls	Vernon
DEX	Electronic components	Camarillo
DMC Power	Cables and transmission	Carson
Gradient Lens	Borescopes	Phelan
GS Manufacturing	Resins and adhesives	Costa Mesa
Halus Power Systems	Small wind turbines	San Leandro
Interplastic	Resins and polymers	Hawthorne
Lift-It	Rigging hardware	Los Angeles
RLH Industries	Fiber optics	Orange

Source: "Email from Danielle Mills, Director of American Wind Energy Association California," June 25, 2019.

Exhibit 4.3. California's existing sources of wind turbines and components



Source: Walter Musial et al., "2018 Offshore Wind Technologies Market Report," U.S. Department of Energy, August 2019.

Does California's geographic isolation create competitive advantage?

California faces somewhat less of the local-versus-regional competitive dilemma than other regions. Several factors account for this difference.

California is much larger than East Coast states and most European nations and also more geographically isolated. Although California's economy is slightly smaller than Germany's, for example, the state is being prioritized by BOEM planners as the first offshore wind development area on the West Coast, ahead of Hawaii and Oregon in the planning queue, while Germany is part of a highly integrated European offshore wind industry. The U.S. East Coast is much closer than California to Europe's well-established offshore wind manufacturing centers. For example, New Bedford, Massachusetts, is 3,397 nautical miles from Esbjerg, Denmark, while Humboldt Bay is 8,461 miles from Esbjerg and 5,218 miles from Shanghai.[102]

Yet, some wind developers don't see distance as a determining factor. Shipping costs of the blades and nacelles may be less important than their manufacturing costs, and foreign-sourced items may be competitive against any California-sourced inputs, they say. A California supply chain would need to leverage its other, proximity-based advantages, including synergy with smaller inputs of the supply chain and with assembly, installation, and operations and maintenance locations.

"The impact of ocean transport costs in foreign sources versus local manufacturing is smaller than you might think," said Dominique Roddier in an interview.[103] Roddier is Chief Technology Officer of Emeryville-based Principle Power, a partner firm in Redwood Coast Energy Authority's proposed project off Humboldt. Principle Power is planning to source its Humboldt turbines and platforms in Asia, with South Korea and China as possible sources, depending on market developments in the 2020s, Roddier said.

Investment threshold: State commitment for at least 8 GW

With the cost of a major turbine factory typically running to several hundred million dollars, companies will need confidence in the market, which in this case means a sufficiently large and certain pipeline of projects that BOEM will auction and whose power will be purchased by California offtakers. Among turbine manufacturers and government officials, a rule of thumb is that firms will only invest the hundreds of millions of dollars to build high-tech factories for blades, nacelles, and towers once there is a strong likelihood that at least 8 GW in offshore capacity will be auctioned off over the next decade.[104] For a large turbine manufacturer like Siemens, MHI Vestas, or GE, such an auction pipeline would mean that no matter which project developers win the auctions, they will be shopping for turbines and other inputs, and some factors—but not all—may contribute to a decision to establish production locally.

Massachusetts, New York, Virginia, Connecticut, New Jersey, Maryland, and Rhode Island have made offshore wind commitments totaling 20 GW by 2030, so the manufacturers' threshold has been met with room to spare for the East Coast. Each of those states is now vying to be the first to attract a turbine manufacturing plant, wooing companies with elaborate promotion roll-outs and tax breaks.

"We think that volume is sufficient now, and we're planning to invest here on the East Coast in the near-term future," said Jason Folsom, U.S. Sales Director for MHI Vestas, a Danish–Japanese turbine manufacturer.[105] "We do not want to run our new market business from Europe. We're here to build stuff, and we're here for the long haul."

For this reason, West Coast shipyard unions such as Boilermakers and Machinists, which have lost thousands of jobs in recent decades but maintain a slim foothold in San Diego, Alameda, and elsewhere,[106, 107] might gain significant employment if certain types floating foundation manufacturing took off in California, as described in Chapter 5.

Turbine manufacturers say that a key factor in driving down the cost of floating turbines is cutting costs in manufacturing the hulls. "Floating is a different industry than fixed-bottom," said Folsom.[108] "It's all about the foundation. The challenge is how do you construct these? They're going to be really, really big.

That's where the cost differential is going to be, that's where you have to cut costs. Depending on the technology and the conditions, having local manufacturing of them in California could be an important part of cost reductions."

The problem of finding suitable ports

However, there are few ports in California that could serve as manufacturing or assembly hubs. One key limitation is bridge clearance. As mentioned above, offshore wind-farm turbines of the 2020s are expected to be as tall as 750 feet, which means their pieces must be transported by ship because they would not fit on rail or truck. At that height, no port with a bridge to seaward would be able to serve as a final assembly port, which eliminates all ports in the Bay Area and Delta and large areas of the ports of Los Angeles, Long Beach, and San Diego.

For the same reasons, floating offshore turbines must be fully assembled at a port and towed directly out to the final destination. In contrast, land-based turbines are assembled on site by heavy construction equipment, and fixed-bottom offshore turbines are assembled at their final ocean destination by "jack-up" vessels that erect themselves over the sea floor on stilts and serve as a fixed construction platform, with materials (and often workforce) delivered directly to the wind farm from multiple locations, often abroad.

Offshore wind developers say logistics are tricky for floating projects. "For floating, the supply chain is more difficult to understand," said Edgare Kerkwijk, an offshore wind financier in East Asia, in an interview.[109] "You need a big port area with lots of space, like for laying down 100-meter [330-feet] blades, and towers at least that big, with no bridge clearance restrictions because the turbines are towed out fully erect from the quay. You will need to upgrade ports, but most available ports have scarce land area available. The economic benefits will be huge, but it's a hard nut to crack."

A 2016 report of California port needs for BOEM found that the state has no port with these requisite features:

- High-quality, existing deepwater port facilities and infrastructure;
- At least 100-200 acres of nearby land suitable for assembly and manufacturing and likely to be available for lease; and
- Absence of air draft restrictions (i.e., no bridge to seaward).[110]

In general, the report found that the most-promising California ports are too busy to be able to make space for offshore wind. For example, San Diego's shipyard at General Dynamics–NASSCO has great capacity for manufacturing floating platforms but is very busy with federal defense contracts. It is also on the landward side of the Coronado Bridge, which means that turbines on platforms could not pass. Los Angeles and Long Beach also have high capacity, as well as some areas without air draft restrictions, but both ports are extremely busy and congested. Port Hueneme is busy with auto and banana importing and would be unlikely to have extensive land available.

The BOEM report also found that some Bay Area ports with air draft restrictions (because of the Golden Gate Bridge), such as Vallejo, Stockton, and West Sacramento, have available land and could serve as sites for some manufacturing platform and turbine components, which could then be shipped disassembled to the final assembly location.

According to the BOEM report and many industry experts, California's most viable site for final assembly of offshore turbines is the Port of Humboldt Bay. This port has deepwater access with no bridge restrictions and hundreds of acres of empty, available quayside land at the site of pulp and lumber mills that were abandoned when the region's forest industry collapsed in the 1990s. However, the port itself would need extensive rebuilding and upgrading, as well as dredging of shipping lanes to allow heavy cranes to assemble the floating platforms. The area has no railroad and poor highway connections to the outside, with only one container-capable highway, SR 299, that conforms to federal interstate truck length guidelines.[111]

The area also faces severe workforce challenges, with a relatively small construction industry and few workers with industrial skills or marine qualifications. The Humboldt County's 2018 Workforce Development Report found near full employment in all sectors and widespread difficulty in hiring and retaining workers.[112] Existing apprenticeship programs for the construction trades and for Merchant Mariner/Seaman could be expanded to address the offshore wind industry's needs on the North Coast, perhaps in collaboration with the College of the Redwoods, CSU Maritime Academy, and the region's tribal governments, all in the context of a High-Road Training Partnership, as described in Chapter 3.

In interviews, Jeff Hunerlach, head of the Humboldt–Del Norte Building Trades Council, and Marina Secchitano, president of the Inlandboatmen's Union of the Pacific, said that the unions would help adapt the existing joint union–employer programs. "We're used to doing this, and we would be glad to work with the state and employers, and anyone else, to ensure the trained crews you're going to need for offshore wind anywhere on the West Coast," said Secchitano.[113]

"Our apprenticeship programs will give you what you need for offshore wind, whether it's platform assembly or the port or transmission lines," said Hunerlach.[114] "Just give us enough advance notice, and we will ramp up."

In a sign of local optimism, the Humboldt Bay Harbor District is actively pitching itself as an offshore wind manufacturing location. In August 2019, it issued a Request for Proposals for companies to develop a 100-acre area as an offshore wind terminal and manufacturing facility.[115] Proposals were due November 1, 2019, but potential port developers faced several challenges: the federal BOEM leasing process still had not started definitively; the state had not yet provided any aid to develop the port; the area still lacked a major transmission line to export offshore wind power to the state grid; and highway transportation links are poor, as mentioned above.

In interviews, many industry stakeholders said the state would likely need to step in with economic development funds to help develop a network of offshore wind ports and enable the construction of one or more high-capacity transmission lines to connect the North Coast with the state grid. "There are different ways of constructing the ports and manufacturing infrastructure that will be needed for California offshore wind," said Liz Burdock, CEO and president of the Business Network for Offshore Wind, in an interview.[116] "But as we have seen in the East, state governments need to be proactive and work directly with industry in identifying needs, finding suitable facilities, moving obstacles aside, and providing funding."

Chapter findings

- California lacks an existing supply chain for major wind components, but if the state created one, it could serve as the main supplier for offshore wind along the West Coast and in Hawaii.
- Manufacturers would be more likely to build a California supply chain if the state and federal governments set a firm target at least 8 GW in offshore capacity per decade, scheduled to start in the mid-2020s.
- East Coast states are subsidizing new offshore wind port facilities, vying to be manufacturing hubs.
- California lacks suitable port and manufacturing locations. The state would benefit from taking a proactive stance in working with industry to identify and develop possible locations—possibly a multi-site network of ports, including Humboldt Bay. In addition, the state would need to address the North Coast’s lack of transmission interconnection to the state grid.
- A High-Road Training Partnership could be created for offshore wind to resolve skills gaps that might emerge, especially on the North Coast.

Could the abandoned pulp and lumber mills at the Port of Humboldt Bay be converted into a manufacturing hub for offshore wind, like Esbjerg, Denmark?

Humboldt Bay

Hundreds of acres of industrial ruin

Photo credit: U.S. EPA

Esbjerg, Denmark

Major hub for North Sea offshore wind

Photo credit: Port of Esbjerg

CHAPTER 5. FLOATING PLATFORMS

One of the state's first major points of leverage over supply chain decisions is likely to be for the floating platforms that support the turbines. This chapter examines the differences between the principal platform designs and their implications for workforce impacts.

The various plans for offshore wind blades, nacelles, and towers have similar designs and technology, so their manufacturing processes are likely to have similar workforce impacts.[117] The main variable is where their factories will be located—abroad or in California. As discussed earlier, production may be more likely to be located in California only once a sufficiently large pipeline of large projects has been guaranteed, probably at least 8 GW over a decade.

The first offshore wind manufacturing facilities to set up in California are likely to be for floating platforms, because of their large bulk, extra cost in transport, and some inventors' attempts to design for local manufacture, as described later in this chapter. For the same reasons, the first offshore wind manufacturing facility announced on the East Coast was a fixed-bottom foundation factory in Paulsboro, New Jersey, in a joint investment by the German–Chinese pipe manufacturer EEW and wind developer Orsted.[118]

In an interview, Walt Musial, manager of offshore wind research at NREL, said that California's offshore wind developers will likely wind up choosing among four floating platform technologies or related variants—Ideol's FloatGen, Principle Power's WindFloat, the Maine Aqua Ventus, and Stiesdal Offshore Technologies' TetraSpar—each of which could have markedly different workforce impacts and therefore deserve comparative analysis.[119] The developers will choose any version that best fits their project needs and bottom line, which could in turn be influenced by priorities set by the state. Although BOEM will choose the developers via the auction process, California will have considerable influence over which platform technologies are chosen by the winning bidders. In particular, state and local governments can use their leverage over whether to provide subsidies and permits for port improvements and manufacturing siting, local transportation upgrades, and offshore transmission interties, among others. A 2018 NREL report estimated that platforms would comprise 29.5 percent of the total capital cost for floating wind farms, so the differences in employment impact between competing designs could be significant.[120] Of course, these jobs differences would need to be balanced against the eventual difference in the designs' costs, which are unknown at this point.

In a sign of the unpredictable nature of technology development, the floating sector's first platform design ever deployed commercially is now out of contention for California. Equinor's unique, single-spar technology for its Hywind Scotland wind farm requires 250 feet of draft at the final assembly location, making it too deep for any California harbor.

The following analysis was carried out in consultation with Bob Jennings, Northern California director for the State Building and Construction Trades Council, who reviewed the four companies' publicly available materials on their design and construction methods.[121] Jennings emphasized that his analysis was preliminary and incomplete and said he would need more detailed information and actual project proposals to make a more informed judgment. But he noted there were clear differences among the platform technologies related to the amount of work and the skills that would be needed by each one and the type and acreage of port facilities that would be required.

HOW FLOATING WIND PLATFORMS ARE MADE

All companies have attempted to create platform designs that allow for serial production, streamlined logistics, and low costs.[122]

For concrete platforms, local suppliers of reinforced concrete will be required, and the platform will usually be constructed through a slipform process, in which concrete is poured into a continuously moving form to create a single structure with no joints. The process typically requires a large dock area and a hardened quay with sufficient load bearing to cope with the weight of the structures being transferred at water's edge. Ironworkers and plasterers are typically used here, along with carpenters, operating engineers, and laborers.[123]

For steel platforms, construction will consist of plate bending, cutting, welding, rolling, and coating. Component assembly will take place first—for steel semi-submersible designs, this category could include water entrapment plates, column shells, and steel joints—before the full structure is welded together. Pipefitters, plumbers, boilermakers, and other skilled workers may be needed in addition to the above-mentioned trades.

Many designs have adopted modular methods of fabricating and assembling the hull sections.

Then, a series of protective coatings will be applied to protect the surface against corrosion from seawater and air. Once assembled, the structure is lifted into the water by a gantry crane or slid into a dry dock for turbine assembly. While a dry dock is preferable for most designs, a slipway is also suitable. Developers prefer to avoid the lifting of the full platform structure because it can weigh up to 1,500 tons and require the use of heavy lift cranes, which are in short supply and thus expensive.

Parts of these structures could also be constructed on an installation barge, lessening the need for dock acreage, which often is used intensively by other port clients.

As the four developers' materials make clear, none of the floating designs is final although some early models have been fully tested in sea trials. To varying degrees, each is still undergoing a significant process of development and modification. Still, the fundamental manufacturing process and needs of each one is apparent, as well as the type and acreage of port facilities that would be required. These variables could have significant impact on California job creation—and thus the policy tools discussed in Chapter 3 may be worth considering. Although the exact difference in jobs impact cannot be quantified with available information, this report attempts a brief, qualitative analysis of each design. As mentioned above, this analysis does not consider the potential cost differences, which cannot be calculated with publicly available information.

Ideol: FloatGen

The website of Ideol, a French firm, emphasizes its focus on low-cost, standardized manufacturing and low infrastructure needs.[124] FloatGen is primarily made of molded concrete, with relatively small amounts of steel. "In comparison to other steel floating foundations, which are imported from abroad, the use of concrete for Ideol's floating foundation allows the construction to be located as close as possible to the deployment site," the company website states.

The Ideol website contains videos and other materials detailing the manufacturing process. They explain that they are planning on the use of alternate construction methods involving both pre-assembly and slipforming. Both, however, are highly automated. An example of slipforming can be seen in the screen grab from an Ideol video. It shows pieces of the floating platform being loaded onto a barge, where they will be connected and then submerged to allow assembly of the superstructure, tower, and turbine on top.[125]

Ideol's modular construction method

Photo credit: Screen grab from Ideol concept animation video.[126]

In an interview, the company's Chief Sales and Marketing Officer, Bruno Geschier, touted his design as being the most practical option for California given the state's limited port availability.[127] "Some [floating platform] technologies are extra infrastructure hungry, but ours is designed to have very light needs. We do not need a major port, which in California's case means we don't need a multi-hundred-million-dollar rebuild for Humboldt Bay. We can even use floating barges." The platform's draft at dockside is only 25 feet, said Geschier, who also is chair of the floating wind task force of WindEurope, the European wind industry chamber. That level is not a stretch for most small ports—for example, Humboldt Bay channels are already dredged to 38 feet, and depths at most larger ports are at least 50 feet.[128]

His company currently has a 2 MW floating prototype installed off the coast of western France, in a project financially supported by the European Union. Geschier said the majority of the prototype's supply chain was locally manufactured, including the mooring system and other components. After reviewing the company's materials, Jennings said the claims seemed credible, although more detailed information would be needed.

Ideol construction of a 2 MW floating platform

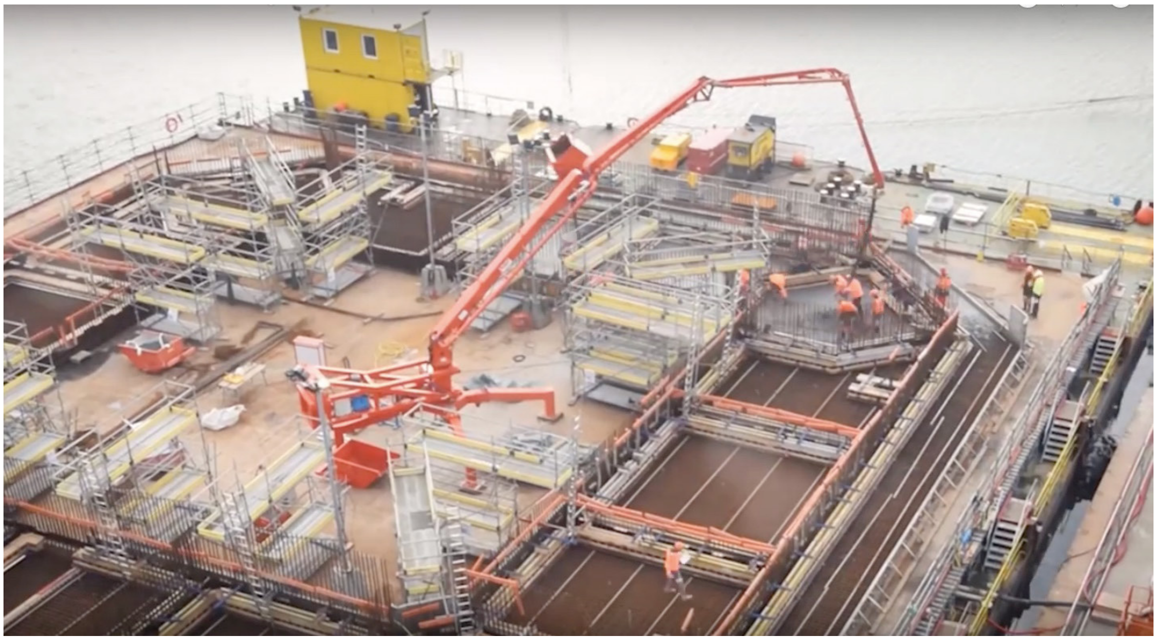


Photo credit: Screen grab from Ideol video.[129]

Summary of Ideol workforce impacts and port infrastructure requirements

- More quickly adaptable and thus could bring more jobs to California at the start.
- Needs standard port gantries and hardened quayside, but no dry dock or specialized facilities. Less infrastructure investment for state and wind developers.
- Modular construction method is heavily automated, thus perhaps less labor intensive.
- May have less jobs growth potential in the long term.

Principle Power: WindFloat

Principle Power, a Portuguese/Spanish firm that is headquartered in Emeryville, has reached an MOU with Redwood Coast Energy Authority to supply an undetermined share of the power from its proposed 150 MW floating wind farm off Humboldt County. The company's platform design, WindFloat, is all steel, and relies on a complex internal system of hydraulics to give it superior stability and reduced risk. However, Principle Power admits that the major platform components for its initial projects in California will be manufactured in East Asia—probably either South Korea or China—and shipped across the Pacific. Final assembly will be in a California port, with welding and other skilled metal work.

In an interview, Dominique Roddier, Chief Technology Officer of Principle Power, said the company is currently revising its design to try to reduce its ports and infrastructure needs.[130]

Principle Power platform assembly concept

Photo credit: Screen grab from Principle Power final assembly concept video.[131]

Summary of Principle Power workforce impacts and port infrastructure requirements

- Initial products will be manufactured in East Asia, thus few California supply chain jobs.
- Needs many large port gantries. Significant infrastructure investment required from state and wind developers. These factors could create relatively larger construction employment than other options, yet also cause added cost and difficulty in finding suitable port facilities because of the existing congestion of California ports.
- Final assembly would have metalworking jobs.
- Could have greater jobs growth potential in the long term than other options if manufacturing were localized in California. Possible need for shipyard trades such as Boilermakers and Machinists.

Maine: Aqua Ventus

This project has been helmed for the past decade by a University of Maine-led consortium funded primarily with $40 million in grants from the U.S. Department of Energy.[132] After a 2013 prototype, the consortium is now planning to put two 6 MW floating turbines in state waters in the Atlantic. The project was stalled for years under previous Governor Paul Page, a vocal opponent of wind power. But it was finally greenlighted in June 2019, when Governor Janet Mills signed legislation requiring the state's Public Utilities Commission to buy the project's power.[133] The project leaders have announced they hope to arrange final financing in late 2019, begin construction in 2021, and start commercial operation in 2022.[134] At that time, the project would become the first commercial-scale floating wind project in the Americas.

The Aqua Ventus platform design uses a mostly concrete hull. The project's director, Habib Dagher, Executive Director of the Advanced Structures and Composites Center at the University of Maine, said in an interview that the platform design is intended to be low cost and easily manufactured.[135] "Any bridge construction company could build it," he said. "It doesn't need a dry dock or any specialized techniques. For a California project, there are many construction companies in the state that could do it."

However, further information about Aqua Ventus construction techniques was not available, making a detailed assessment difficult. Videos on the project website showing the 2013 construction of a one-eighth-scale, 65-foot-tall prototype design showed the use of standard construction techniques and did not indicate modular methods.**[136]** The result could be additional job creation but also might raise costs and could raise the amount of port land needed.

Maine Aqua Ventus project: 2013 construction

Photo credit: Screen grab from Aqua Ventus video.[137]

Summary of Aqua Ventus workforce impacts and port infrastructure requirements

- Design requires simple construction methods and thus could bring more jobs to California at the start, with flexible locations.
- Many construction firms would be able to do the work.
- Aqua Ventus would need extensive construction and assembly work by construction trades including operating engineers, pipefitters, laborers, and electricians.
- Port infrastructure needs are likely moderate.

Stiesdal Technologies: TetraSpar

TetraSpar is the product of Henrik Stiesdal, a Danish wind technology inventor. It is the most bare bones of the four designs analyzed here, intended for low cost as a top priority. The floating platform is all steel, comprised of tubes that the company says could be manufactured by any wind tower factory elsewhere in the United States and transported by train or truck to California. According to the company, the tubes would require machine welding but little human welding upon arrival in the assembly port.

For these reasons, TetraSpar would require relatively little California manufacturing labor. TetraSpar has not yet been water tested at scale, but Stiesdal's reputation as the former Chief Technology Officer at Siemens and as a successful, serial inventor has made many industry observers take his design seriously.[138]

Further details of TetraSpar needs were given in an email interview by Jim Lanard, CEO of Magellan Wind, which has submitted wind farm proposals to BOEM for Humboldt and the Central Coast and is expecting to use Stiesdal's technology.[139]

Lanard described a deliberately spare assembly process invented by Stiesdal, saying his company's use of the TetraSpar design would require the use of a small fraction of the dock space needed by its competitors. He said TetraSpar assembly would only need a space of 100 meters by 100 meters, or three acres—far less than the dozens of acres needed by other companies—if a nearby offsite storage and/or a quayside supply barge also were available. If this reduced space estimate were accurate, it would greatly facilitate California's Gordian Knot of identifying and obtaining access to port space and thus jump-start the offshore wind industry.

Tubular assembly of TetraSpar

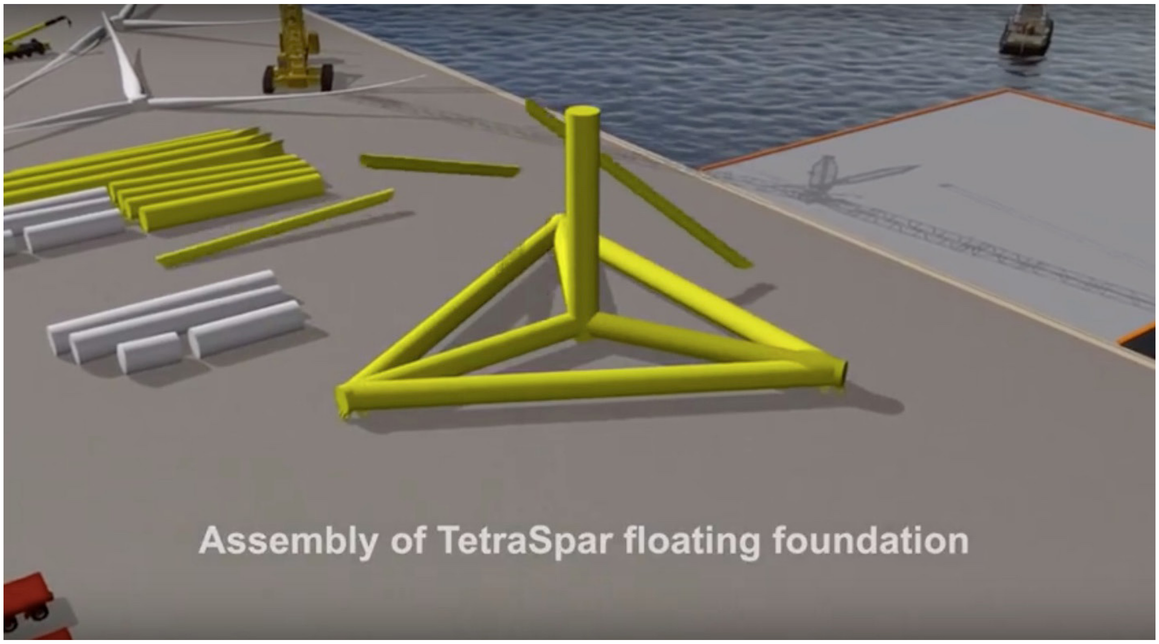


Photo credit: Screen grab from Stiesdal assembly concept video.[140]

Summary of Stiesdal workforce impacts and port infrastructure requirements

- Very little California labor in manufacturing or assembly.
- Requires little port space and only basic cranes and gantries, thus making it relatively easy to find port facilities.
- Lower cost to state government because of lower infrastructure needs.

Exhibit 5.1. Impacts of the leading platform design alternatives

Platform	Materials	Job Skills & Trades	Local Content & Jobs	Likely Locations	Dry dock Needed	Dock Acreage
Ideol	Concrete	All building trades for platform assembly	High	California	No	Medium
Principle Power	Steel	All building trades for ports	Very low at start except high port construction; possibly high in later manufacturing	East Asia	No	Large
Aqua Ventus	Concrete	All building trades?	Unclear, possibly high	California	No	Medium
Stiesdal	Steel	Minor	Low	Other U.S.	No	Small

Chapter findings

- Of the four platform designs analyzed, Ideol and Aqua Ventus appear to have the highest immediate need for skilled, in-state labor.
- Principle Power would produce relatively few jobs initially in manufacturing and assembly, although its apparent requirement for extensive port facilities would require considerable construction work as well as the ports' willingness to provide significant acreage for long-term lease. Eventually, Principle could provide more jobs than the other designs, if its manufacturing were relocated to California from East Asia.
- Stiesdal's platform appears to be designed expressly for minimum labor needs and streamlined California operations, thus producing at low cost but with fewer jobs in manufacturing and assembly.
- The project developers that win the BOEM auctions can choose any platform design they wish, and cost will surely be a key determinant. But the state and local governments could influence these choices and thus seek to maximize positive workforce results through its leverage over permitting, siting, and infrastructure upgrades, as well as the policy levers described in Chapter 3.

CHAPTER 6. CONCLUSION

The results from offshore wind planning and deployment in Europe and the U.S. East Coast show that floating offshore wind could provide significant high-road employment and economic development for California. But it will not do so without studying and heeding the lessons learned elsewhere. Offshore wind has a fully globalized supply chain, and California's distance from other regions that have developed a robust wind energy industry gives the state a slight advantage but no free pass from economic competition that could cost jobs and income.

California can learn from foreign nations and East Coast states that concerted government direction and control in the offshore wind sector can create successful outcomes for workers and communities. Like the UK, California will need to realistically assess the potential of job creation in traditional manufacturing alongside the potential for harnessing technological research and innovation to create professional and white-collar jobs in the sector.

California can also learn from its own experience in state climate policy, using its well-stocked toolbox of best practices to produce successful workforce outcomes. While the federal government chooses the winners of the BOEM auction process solely on price criteria, the state and local governments could adopt policies and practices that might optimize high-road economic impacts. In particular, the state it could utilize its existing toolbox of climate workforce policies as levers over permitting, port siting and reconstruction, and transmission planning. Such actions could maximize the resulting jobs and local benefits, including Community Workforce Agreements, prevailing wage requirements, job training, and access for disadvantaged communities.

California lacks a supply chain for its existing land-based wind power sector, so the task of creating one for offshore wind will not be easy. The size of the project pipeline ahead is crucial, and state policymakers should endeavor to set clear goals for offshore wind as part of the state's long-term renewable energy planning. If a sufficiently large project pipeline threshold is created—for example, a state mandate for at least 8 GW over a decade starting roughly in the mid-2020s—turbine manufacturers and other supply chain firms might be more likely to invest in building new factories in California. This scenario coincides with the findings of the grid integration analysis in Chapters 7-11 of this report, which conclude that if 8 GW of total offshore wind capacity were deployed across the state, its direct costs would drop significantly and its avoided costs would rise, thus potentially making offshore wind economically competitive in relation to other grid resources such as PV, battery storage, and natural gas.

But if the planning process were to evolve in a more piecemeal basis, with only a few projects here and there, without strategic direction or fixed targets, the result would likely be offshore wind farms built with primarily imported inputs and with relatively insignificant economic benefits.

Similarly, the state would be well advised to take a proactive stance in working with industry to identify and develop possible locations—possibly a multi-site network of ports including Humboldt Bay—and to support critical infrastructure such as long-distance transmission lines. As California advances toward the ambitious goal of a carbon-free economy, offshore wind poses an unusual challenge of industrial policy, one that urges state policymakers to plan strategically to maximize benefits over the long term.

Additional research would be valuable to fill in the information gaps identified in this report. In particular, this research could benefit from more effective utilization of the state's existing agreements for data sharing and technical cooperation with Denmark and Scotland and through industry cooperation in the context of a High-Road Training Partnership for offshore wind.

Part Two
Integrating Offshore Wind in California's Grid: An Assessment of Economic Value

CHAPTER 7. INTRODUCTION

In the past decade, offshore wind has emerged as a clean, scalable source of energy that is increasingly cost competitive with onshore grid power and renewables. A majority of offshore wind deployment to date has occurred in Northern Europe, where installed capacity grew from less than 2 GW in 2008 to more than 18 GW in 2018.[141] This growth has been fueled in part by improvements in turbine scale and the resulting reductions in project costs. For example, power output from a modern offshore wind turbine has increased from around 2 MW each a decade ago to 9+ MW for newer, more powerful turbines installed today. As a result, project costs per MW have fallen by 45 percent in the past five years and will continue to drop as the industry moves to even larger 10-12 MW turbines currently under development by leading manufacturers.[142]

As discussed earlier in this report, the U.S. market for offshore wind development is on the cusp of fast development. While only 30 GW of offshore wind generating capacity is in the water off Rhode Island, East Coast states are planning about 22 GW by 2035. California, in contrast, has yet to study offshore wind or consider this resource in its long-term planning efforts. For this reason, limited data exists regarding the performance, cost, and overall economics of future offshore development in California.

This study provides an initial assessment of California's offshore wind resource potential and performance characteristics, as well as offshore wind's value to the grid and economic feasibility for large-scale deployment to meet California's long-term climate policies.

Study approach

As a first step in characterizing California's offshore wind resources, E3 collaborated with the California Energy Commission (CEC) to identify zones for potential future offshore wind development. E3 then curated hourly wind speed data and simulated the hourly power generation from future wind turbines sited in each zone. Next, E3 performed a high-level transmission screening to quantify the amount of offshore wind capacity from each zone that could be interconnected with the grid without triggering the need for costly onshore transmission upgrades. Taken together, this data will provide a useful initial characterization of California's offshore wind resources for modeling in the state's resource planning efforts.

The second step of this study focused on modeling the cost competitiveness of the newly defined offshore wind resources to the California grid. E3's analysis framed the value of offshore wind in two ways, using an avoided cost framework:

1. **Resource Savings**—How would offshore wind help the state achieve its energy goals by reducing reliance on other resources, which may be finite in potential? Specifically, how much new onshore wind, solar, and battery storage capacity could be avoided if offshore wind were built instead? How much additional gas capacity could be retired?
2. **Cost Savings**—What economic value does offshore wind provide the grid in terms of avoided costs? For every megawatt-hour of offshore wind, what is the associated dollar savings from reduced reliance on onshore wind, solar, battery storage, and existing gas plants and the fuel they burn?

COST SAVINGS: ENERGY VALUE AND CAPACITY VALUE

Offshore wind offers multiple sources of avoided costs to the grid. Two of the biggest categories are energy value and capacity value. **Energy value** represents the total energy cost savings from offshore wind. For example, if energy market prices are $60/MWh in a given hour, receiving a MWh of offshore wind would save a utility $60 in avoided market purchases in that hour. Therefore, the energy value of offshore wind would be $60 and, if it could be produced at less than $60, offshore wind would be cost competitive.

Capacity value represents the price for generation capacity (MW) needed during peak hours of the year to ensure that power supply can reliably meet demand. Capacity value in California is generally compensated through Resource Adequacy (RA) contracts, which are signed to keep plants online during peak hours. Offshore wind's capacity value, as determined by the power it could reliably be expected to generate during peak hours, would offset the need for RA contracts with gas plants or other peak capacity costs.

This analysis was performed using a proprietary version of E3's RESOLVE capacity expansion model, which has been used to analyze renewable integration economics and support integrated resource planning efforts in leading jurisdictions across North America.

After characterizing the state's offshore wind resources and estimating the avoided costs offered by these resources, E3 has provided a high-level summary of how these avoided costs compare to the estimated cost of offshore wind development on the California coast and the likely scales and dates at which offshore wind may be economic.

Summary of results

Through this study, E3 identified five different offshore wind resource zones with a total potential generation capacity of approximately 21 GW. Each zone provides at least 1.6 GW of capacity, and the simulated capacity factors for the zones range from 46 percent to 55 percent.[143] Together, these resource zones represent more than three times California's current onshore wind capacity and, if developed to their maximum potential, could provide approximately 25 percent of the state's future energy needs.

E3's economic analysis found that **offshore wind likely offers $70-$80/MWh in average avoided costs to the grid in the 2030 timeframe**, primarily by significantly reducing the state's need for new solar and battery storage investments and facilitating the retirement of additional existing gas plants. **This level of avoided costs would make offshore wind economically competitive by the late 2020s, given forecasted cost declines for floating offshore wind technology.** E3's analysis of a recent NREL cost data yields illustrative levelized costs of $65-$80/MWh for California offshore wind by 2025-2030. In addition, E3's scenario modeling suggested that the avoided costs offered by offshore wind are robust across several future sensitivities:

- The **avoided costs from offshore wind are expected to increase over time** as the state's GHG reduction goals become more stringent, ranging from approximately $70-$75/MWh in 2030 to $85-$90/MWh in value by 2045.
- **Offshore wind's avoided costs would not significantly diminish at increased scale**, offering approximately $80/MWh in levelized avoided cost at up to 8,000 MW in total capacity. The average grid value of offshore wind may still exceed $70/MWh, even if all of the studied resource zones representing 21,000 MW of capacity were developed.
- **Offshore wind's value would differ slightly among the studied zones**, with Humboldt Bay, Del Norte, and Cape Mendocino offering the largest avoided costs on a $/MWh basis. When avoided cost is compared with estimated levelized cost and transmission availability, **Morro Bay appears to be the most economic zone for future development**.
- **Offshore wind would offer additional economic upside if future land use for solar were constrained by environmental protections or if the state aimed to achieve its GHG goals at an accelerated pace**. Sensitivity scenarios highlighted higher avoided costs from offshore wind in deep GHG-reduction scenarios, especially when onshore resources are constrained.
- **Offshore wind would retain significant value, even if alternative out-of-state wind resources were developed or solar and storage costs fell faster than expected.** The average avoided costs of offshore wind might fall by 5 percent if 10 GW of out-of-state wind were added or if solar and storage costs fell more rapidly, suggesting there are limited long-term downside risks to offshore wind development even if alternative resources were available at low cost.

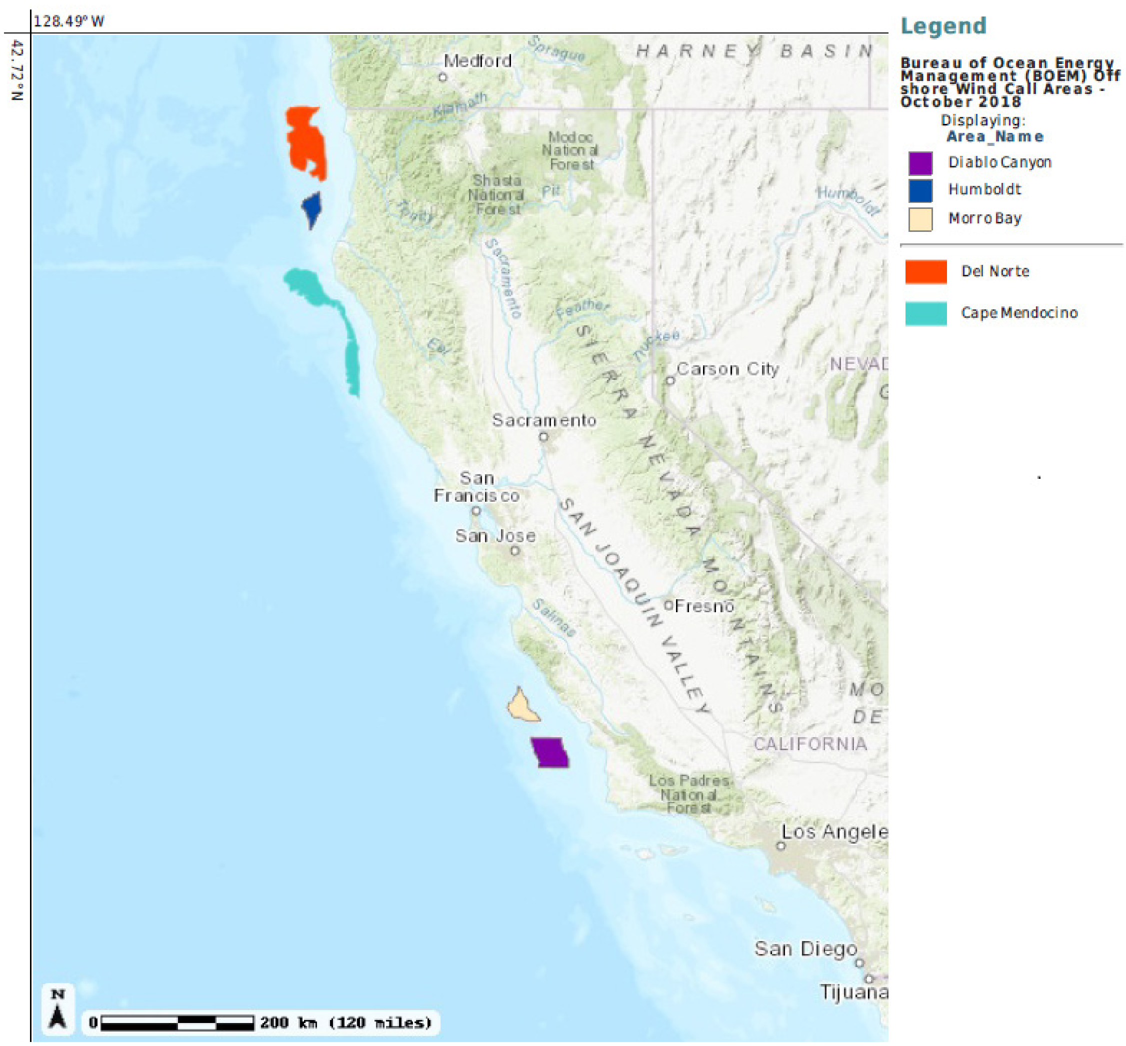
The remainder of this report describes the details of E3's research, analysis, and findings.

CHAPTER 8. CHARACTERIZATION OF CALIFORNIA'S OFFSHORE WIND RESOURCES

Offshore wind zones and potential

In order to have a robust representation of the offshore wind potential for the State of California, this study considered data from several publicly available sources. Offshore wind resource zones were identified based on existing BOEM call areas for California, as well as potential future development sites identified in studies by BOEM and NREL. The selected zones were Morro Bay, Diablo Canyon, Humboldt Bay, Cape Mendocino, and Del Norte. E3 included this wide set of sites to evaluate all areas that might be considered for commercial development and estimated the value they might have in a future with high renewable energy demand.

Exhibit 8.1. Selected offshore wind resource zones



Source: California Offshore Wind Energy, Bureau of Ocean Energy Management.

The Morro Bay, Diablo Canyon, and Humboldt Bay resource zones represent the existing offshore wind call areas established by BOEM.[144] The Cape Mendocino and Del Norte resource zones are areas identified as having potential for future commercial development based on NREL and BOEM studies.[145] When defining the Cape Mendocino and Del Norte zones, E3 removed any areas that fell within Navy exclusion areas and state or federal environmental protections, such as marine sanctuaries. Finally, resource zones were bounded by a minimum distance to shore of approximately 20 miles. The sites considered provide a total resource potential of around 21 GW, based on NREL's assumed offshore wind farm power density of 3 MW per square kilometer.

E3's assumptions regarding the offshore wind resource potential in each zone are shown in Exhibit 8.2.

Exhibit 8.2. Offshore wind resource potential assumptions

Offshore Wind Resource Zone	Resource Potential Area (Sq. km)	Resource Potential (MW)
Del Norte	2,201	6,604
Cape Mendocino	2,072	6,216
Diablo Canyon	1,441	4,324
Morro Bay	806	2,419
Humboldt Bay	536	1,607
Total	**7,051**	**21,171**

Offshore wind zone generation profiles

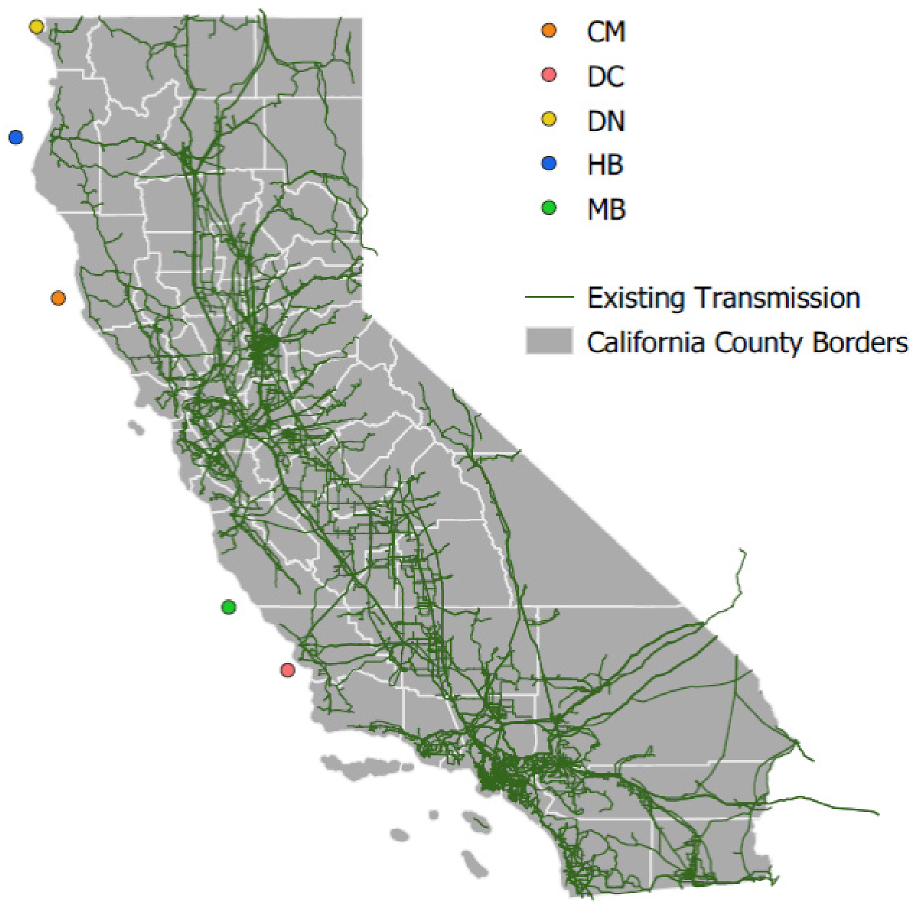
To represent the offshore wind resources within E3's RESOLVE model, historical hourly energy generation profiles for each zone had to be simulated. E3 performed this simulation using wind generation data from NREL's Wind Prospector toolkit[146] and assumed a next-generation 12-MW turbine with a hub height of 150 meters (nearly 500 feet) and a power curve similar to the GE Haliade-X turbine. Due to a paucity of generation data for sites within the boundaries of the selected resource zones, this study uses single representative sites from NREL's Wind Toolkit database for each of the five resource zones. As a result, the simulated power output for each zone may not reflect the full range of local wind conditions in the areas surrounding each site.

Exhibit 8.3 shows the assumed average capacity factor (estimated annual energy output as a share of maximum potential output) over the three historical years of wind speed data for each of the resource zones.[147]

Exhibit 8.3. Capacity factor assumptions for selected resource zones

Offshore Wind Resource Zones	Average Capacity Factor (percent)	Representative Site Latitude	Representative Site Longitude
Morro Bay	55%	35.788760	-121.807210
Diablo Canyon	46%	35.093899	-121.012955
Humboldt Bay	51%	40.776300	-124.683100
Cape Mendocino	53%	39.108059	-124.106138
Del Norte	51%	41.901344	-124.402435

Exhibit 8.4. Representative sites for offshore wind generation profile



CHAPTER 9. MODELING OF OFFSHORE WIND AVOIDED COSTS IN RESOLVE

To estimate the avoided costs provided by offshore wind to the California grid, this study relied on E3's RESOLVE model developed to identify the least-cost future generation portfolios for meeting California's clean energy goals. RESOLVE is a capacity expansion model that uses linear programming to identify optimal long-term generation and transmission investments in an electric system, subject to reliability, technical, and policy constraints. Designed specifically to address the capacity expansion questions for systems seeking to integrate large quantities of variable resources, RESOLVE layers capacity expansion logic on top of a reduced-form production cost model to determine the least-cost investment plan, accounting for both the up-front capital costs of new resources and the variable costs to operate the grid reliably over time. In an environment in which most new investments in the electric system have fixed costs significantly greater than their variable operating costs, this type of model provides a strong foundation to identify potential investment benefits associated with alternative planning scenarios.

LEVELIZED AVOIDED COST OF ENERGY (LACE)

LACE represents the average value of a generator to the grid over its expected lifetime, as measured by the avoided costs that would otherwise be incurred if the generator did not exist. These avoided costs are an indicator of the revenues that may be available to a new wind farm: if grid energy during the hours of offshore wind production would normally cost $60/MWh at the beginning of a wind farm's life, increasing to $80/MWh near the end of the project's life, a buyer should be willing to pay approximately $70/MWh to the wind farm in a fixed-price long-term contract over the wind farm's life. If the cost to buy a project's energy were less than the average avoided cost of grid energy, or LACE, it would be economic.

As stated by the U.S. Energy Information Administration, "Power plants are considered economically attractive when their projected LACE (value) exceeds their projected LCOE (cost)… The relative difference between LCOE and LACE is a better indicator of economic competitiveness than either metric alone."[148]

Using this model, E3 employed a levelized avoided cost of energy (LACE) method to estimate the break-even levelized cost at which offshore wind resources would be economically competitive—in other words, the value of offshore wind to the grid (see text box). To identify the avoided cost of offshore wind resources in California, the RESOLVE model was run under two cases: 1) without any offshore wind build-out ('Reference Case'); and 2) with specified quantities of offshore wind added to the system ('Offshore Wind Case'). In the offshore wind cases, the offshore wind resource was added to the system at zero cost (along with zero transmission cost). The avoided cost of the offshore wind resource was then calculated as the total cost savings (i.e., "avoided cost") for a given Offshore Wind Case relative to the Reference Case without offshore wind.

Levelizing the annual avoided costs over the amount of offshore wind energy production in each year gives the levelized avoided cost of energy (LACE) on a dollar-per-MWh ($/MWh) basis for a project's life. In order for a wind resource to be economically competitive with the grid, its LACE must exceed its levelized cost of energy (LCOE), including cost of transmission.

The avoided costs from offshore wind calculated by E3 reflect its contributions in energy, capacity, and GHG reductions to the grid. The energy value of offshore wind includes diversity benefits from production during low- or zero-solar generation hours, when prices are highest. The capacity value of offshore wind reflects the savings from reduced investments in energy storage to meet peak load and the ability to retire additional gas plants that would otherwise be kept online for reliability needs. Offshore wind has the additional value of providing GHG-free renewable energy during evening hours, when grid emissions and reliance on gas plants are highest. This value is captured via carbon prices, which are modeled in RESOLVE to ensure compliance with the state's GHG-reduction policies. There are also other benefits of offshore wind not reflected by LACE, such increasing the diversity of technologies used to meet the state's clean energy needs (effectively a technological hedge), as well as macroeconomic benefits that are outside the scope of RESOLVE.

Study scenarios and sensitivities

This study examines a suite of scenarios to estimate the avoided costs from offshore wind relative to a Reference Case where offshore wind is not available as a resource. E3 has focused on two categories of scenarios in particular:

- A set of **Offshore Wind Scale Scenarios** with varying levels of offshore wind penetration from 1 GW to 20 GW to test how offshore wind's avoided costs might evolve with greater deployment; and
- A set of **Offshore Wind Zone Scenarios** with the same level of offshore wind resource penetration (2 GW) in each of the five resource zones to test how the zones rank in relative value.

All of these core scenarios assume a future in which California's clean energy needs are met primarily with in-state resources. These cases do not consider the possibility of out-of-state resources connected via new transmission and delivered into California, which is instead considered in a separate sensitivity scenario described below.

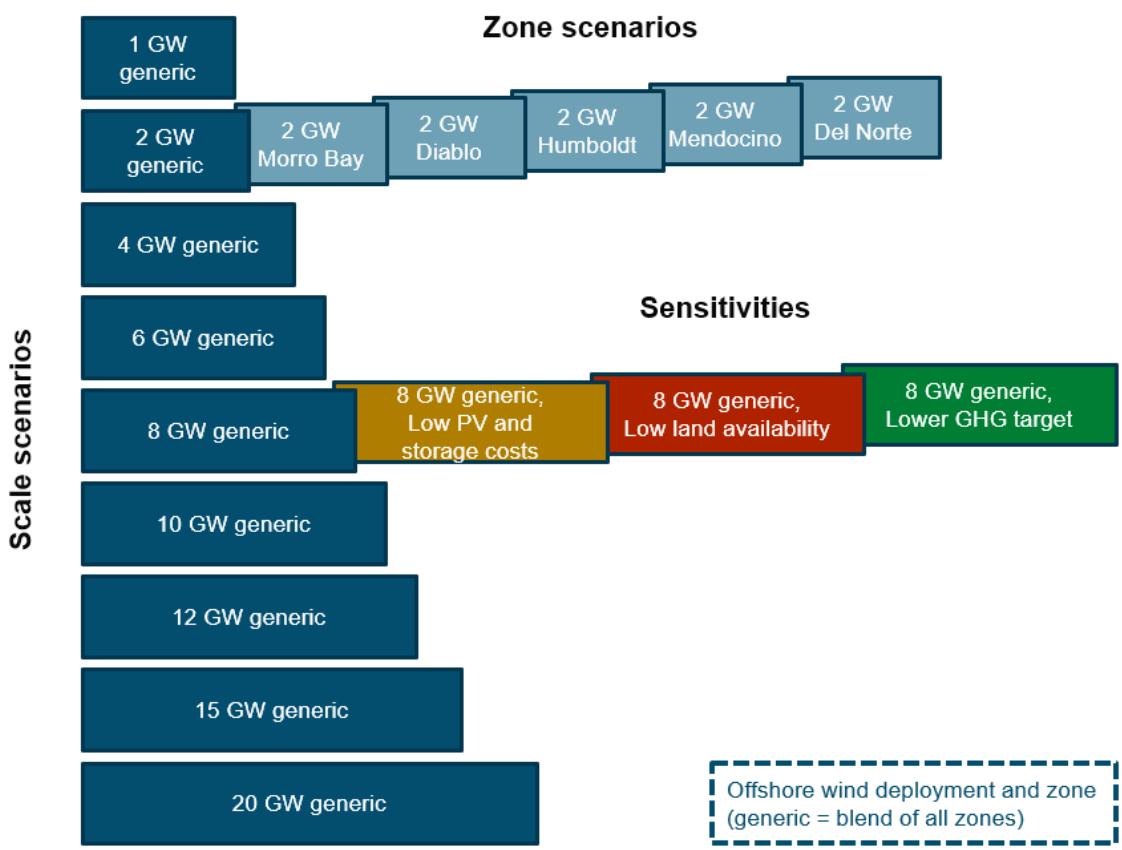
The long-term scenario analysis conducted in this type of study relies on projections of future conditions that are inherently uncertain. With the transition of the industry towards resources that consume less fuel but are more capital intensive, new sources of uncertainty become important considerations for resource planners—for instance, future anticipated cost reductions for resources like solar and battery storage. This study conducts sensitivity analyses on a number of such uncertainties to evaluate the robustness of the conclusions reached in this analysis. The list of sensitivities explored within this analysis is shown in Exhibit 9.1. This set of sensitivities is in no way exhaustive, but includes a number of key factors that should be considered in long-term resource planning and decision-making. Finally, sensitivities are not tested against all scenarios, but against a central scenario selected for more detailed examination through the sensitivities.

Exhibit 9.1. Inventory of sensitivities explored in the analysis

Sensitivity	Description
Out-of-State Wind	Allowing 5 GW of onshore wind resource from Wyoming and New Mexico to be selected by the optimization
Low Technology Costs	Alternate price projections for solar and storage technologies that evaluate the impact of a lower technology cost trajectory on the cost of decarbonization
Low Land	Assumes that due to land use constraints for areas with high conservation value, resource potential for the RESOLVE resource zones for solar, onshore wind, and geothermal are reduced

All scenarios and sensitivities meet a California state-wide target of at least 80-percent GHG reductions by 2050 relative to 1990 levels, as well as 100 percent of electric retail sales from zero-carbon source to be in alignment with California SB100. A summary of the modeled scenarios and sensitivities is shown in Exhibit 9.2.

Exhibit 9.2. Offshore wind capacity in each model scenario and sensitivity



CHAPTER 10. STUDY RESULTS

This chapter presents a summary of E3's findings related to the avoided cost of offshore wind in California across all forecast scenarios. While there is still significant uncertainty around the future cost of developing floating offshore wind, which may range from $60 to $125/MWh in 2030, the results presented below suggest that offshore wind would offer a levelized system value of approximately $80/MWh in 2030.

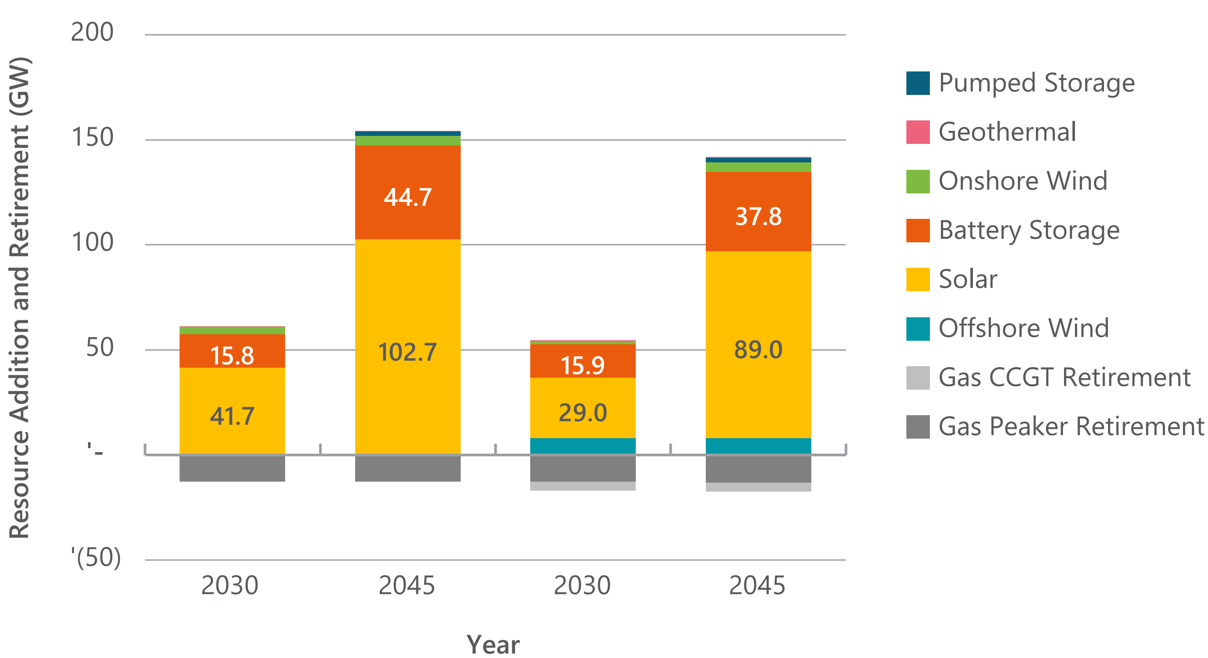
These results capture the value of offshore wind power due to its renewable attributes and the coincidence of its energy generation with the times of day and seasons of the year when solar generation is low. The need for extra renewable power during fall/winter and evenings will become more pronounced in coming years because existing state policies to encourage buildings electrification are expected to significantly increase grid loads.[149]

The implications of these results for offshore wind economics are discussed at greater length in Chapter 11.

Avoided cost of floating offshore wind in California

Across all model scenarios and sensitivities, the avoided cost from offshore wind is driven by its ability to offset the cost of new renewables and battery storage and accelerate the retirement of gas generation. For example, the addition of 8 GW of offshore wind would offset the need for approximately 7 GW of battery storage and 14 GW of solar PV in 2045, while allowing for the retirement of an additional 5 GW of combine cycle and gas peaker plants, as shown in Exhibit 10.1.

Exhibit 10.1. Resource additions and retirements with and without 8 GW of offshore wind



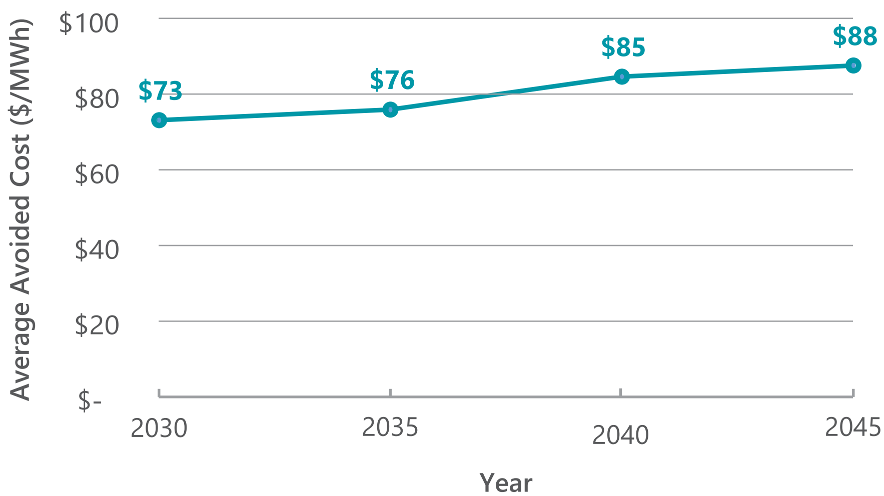
Offshore wind most consistently offsets the demand for solar and for energy storage, which is needed to shift excess solar generation into evening hours, when it is needed most. As the grid becomes increasingly solar saturated in future years, the amount of storage needed to shift solar to evening hours increases. Hence, 8 GW of offshore wind offsets 7 GW of storage by 2045. This savings from avoided investment in storage is one reason that offshore wind increases in projected value over time in every scenario. Another reason is carbon value: offshore wind generates during the non-solar evening hours when most remaining carbon emissions occur, which becomes increasingly valuable in a context where state GHG policies call for increasingly steep future GHG reductions.

The following sections summarize the annual avoided costs of offshore wind (i.e., average value) and how it evolves over time, as well as the 20-year levelized avoided cost as an indicator of the value for new offshore wind projects beginning in the 2030 timeframe. This 20-year LACE is representative of the price that a developer might expect in a PPA with a buyer of an offshore wind project's output.

Avoided cost of offshore wind over time

Offshore wind offers increasing avoided costs over time in every scenario, reflecting its growing value in a GHG-constrained grid. Exhibit 10.2 shows the average value of offshore wind from 2030 to 2045 at five-year model increments, if 8 GW total were deployed across the state. In this scenario, offshore wind's average avoided costs increase from $73/MWh in early 2030s to almost $88/MWh by 2045, an increase of 20 percent over this 15-year horizon.

Exhibit 10.2. Avoided cost of offshore wind energy over time

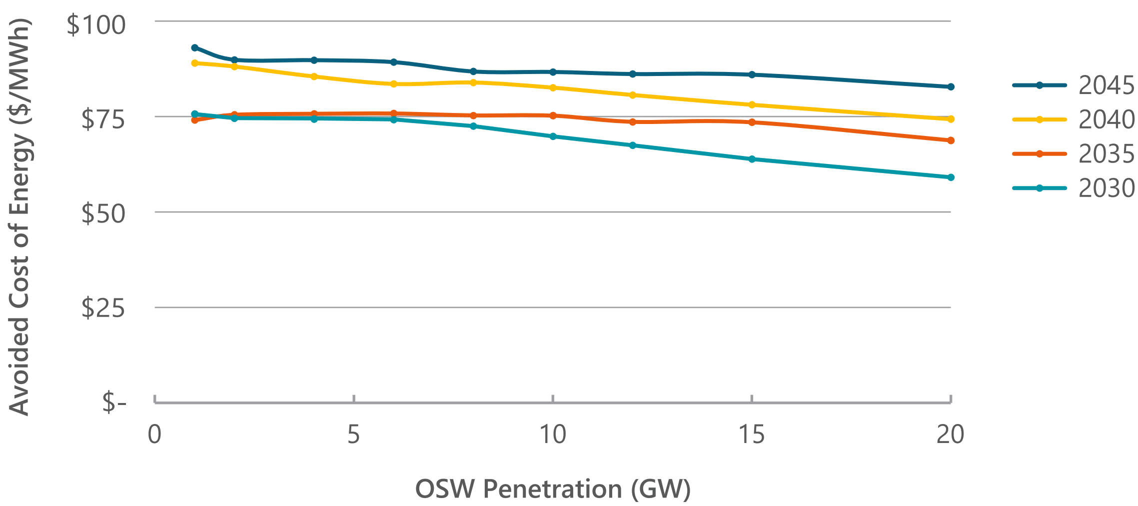


Avoided cost of offshore wind at different penetrations

While the avoided costs from offshore wind increase over time, they are also subject to saturation effects as more offshore wind capacity is added to the grid. The first megawatt of offshore wind is the most valuable, as it replaces the most expensive alternative resource (the marginal resource) when it generates energy. The second megawatt of offshore wind offsets the second-most expensive alternative resource. As more offshore wind is added in the model, the average value provided by offshore wind declines as offshore wind offsets alternative energy sources that are increasingly lower on the supply curve (i.e., less costly energy sources). This trend is similar to the value deterioration experienced by solar, though less dramatic because offshore wind generation is more evenly spread throughout the day than solar, which generates in a narrower window determined by the sun.

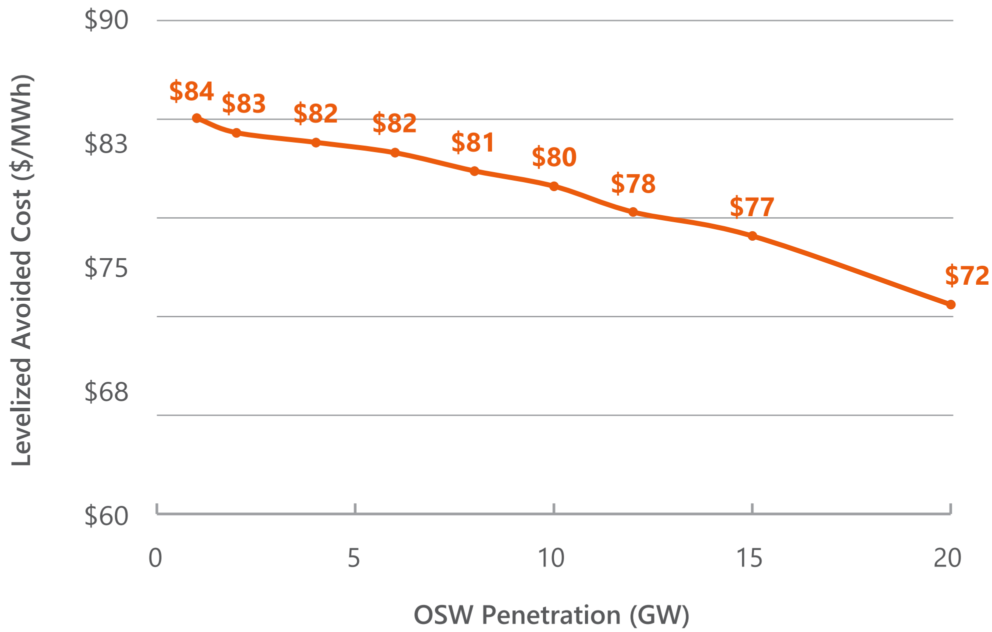
While offshore wind's value does begin to decline at deeper penetrations, its value is relatively stable at deployments up to 6-8 GW before saturation effects begin to appear. Beyond 8 GW, every additional gigawatt of offshore wind decreases the average avoided costs of all offshore wind by 1-2 percent. This saturation effect becomes less significant over time as offshore wind demand grows firmer at larger scales.

Exhibit 10.3. Avoided cost of offshore wind at different levels of penetration



Averaged over time, the annual avoided costs in Exhibit 10.3 yield the 20-year LACE metric in Exhibit 10.4. Here, the declining trend in value with offshore wind saturation becomes notable beyond 8 GW in scale. Note that while 1 GW of offshore wind appears to be the most valuable scale on a $/MWh basis, offshore wind would likely face supply chain economies of scale that drive costs significantly lower at larger penetrations. For example, a West Coast market size of 10 GW might incentivize investment in local manufacturing that drives costs down by $10/MWh. The optimal deployment of offshore wind will depend on how these LACE values intersect with levelized costs to deploy offshore wind, which will reflect overarching market-level trade-offs between cost, value, and scale.

Exhibit 10.4. Levelized avoided cost of offshore wind energy with different levels of penetration



Avoided cost of offshore wind by zone

In addition to generic estimates of offshore wind's avoided cost by year and level of penetration, E3 has investigated the relative value of offshore wind by resource zone. The approach compares avoided cost of energy in all five candidate zones from 2030 to 2045. All zones have same order of magnitude avoided cost, but certain zones appear more valuable by around 15 percent in the long run. The most valuable wind profiles in the near term are Humboldt Bay, Diablo Canyon, and Morro Bay, which rank highly in the 2030s. In the longer term, the Northern California wind sites of Humboldt Bay, Del Norte, and Cape Mendocino increase significantly in avoided costs due to a changing grid portfolio.

Exhibit 10.6 ranks all five candidate zones by LACE over a 20-year project lifetime. Similar to the findings from Exhibit 10.5, the LACE of all zones exhibits the same order of magnitude rankings. Humboldt Bay is the most valuable site with a levelized 20-year avoided cost of $88/MWh, which is 10-percent higher than the least valuable zone, Morro Bay.

Note that these LACE metrics are not indicative of relative merit of offshore wind at each site, as they do not account for differences in the average cost of offshore wind production at each site. The LCOE at each site depends directly on the *quantity* of wind produced (i.e., high-capacity factor sites that generate more wind power are cheaper per unit of energy produced), whereas the avoided costs per MWh in Exhibit 10.5 describe the average *quality* of the wind power produced (i.e., the grid value, with generation during evening, peak-demand hours worth more than generation during low-value, midday hours). For example, the Morro Bay site might produce 11 MWh for every 10 MWh produced at Humboldt Bay, but each MWh would be worth less on average. The relative benefit-to-cost considerations for each site are evaluated in more depth in Chapter 11.

Exhibit 10.5. Avoided cost of offshore wind energy by zone

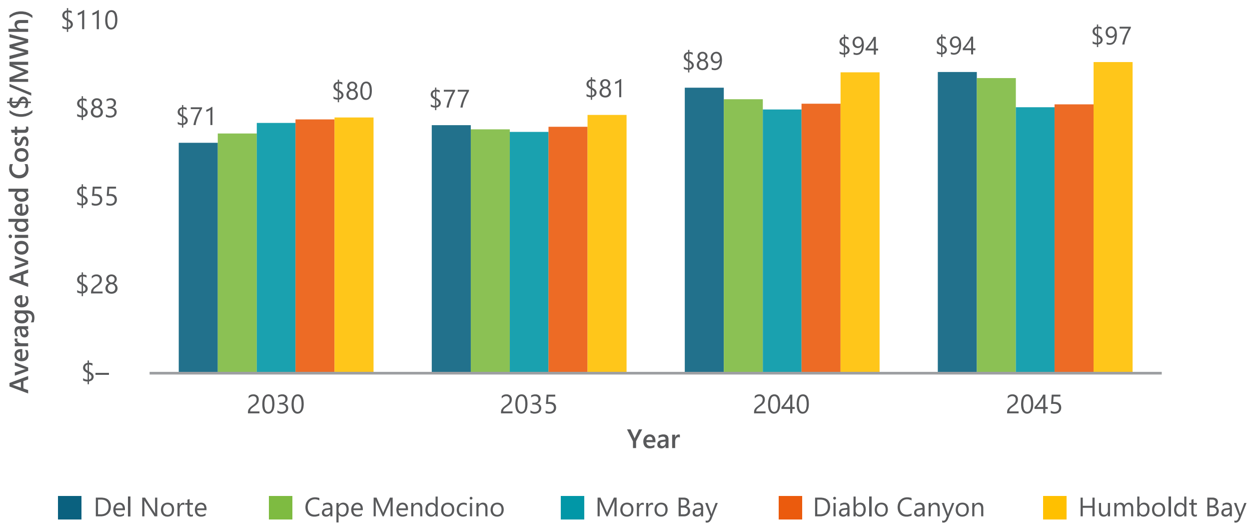
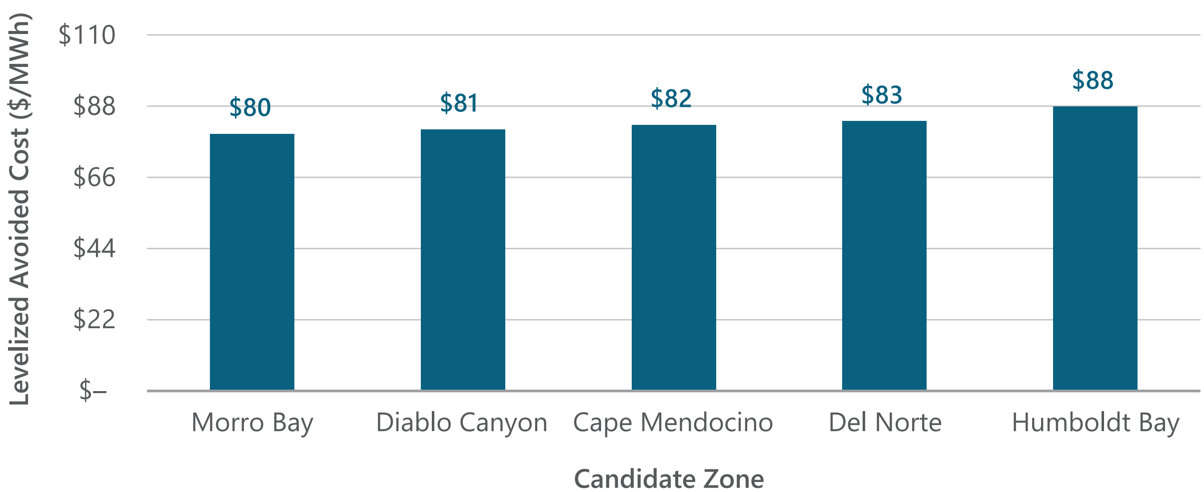


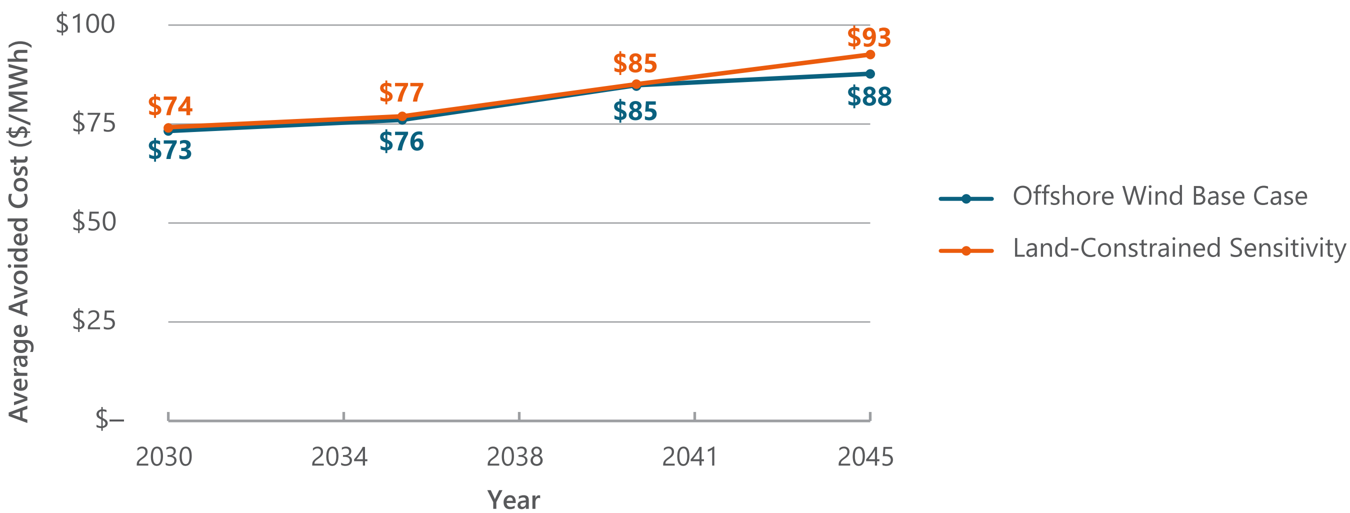
Exhibit 10.6. Levelized avoided cost of offshore wind energy by zone, 2030-2050



Avoided cost of offshore wind in land-constrained scenario

Though technically feasible to develop, many land areas are not available for onshore energy development due to their preservation for cultural or environmental reasons. Thus, a limited-resource potential scenario was studied to address the potential for more-constrained land use requirements in the future. Exhibit 10.7 illustrates the effects of a land-constrained sensitivity scenario where on average only 28 percent of the baseline renewable potential is available for resource development (primarily impacting the potential for new solar capacity). The applied reduction in potential varies resource by resource. Some resources' potentials are not reduced, while others are completely eliminated. The land-constrained case has negligible impact in the near term. However, by 2040, the avoided cost of energy starts to deviate. By 2045, the avoided costs from offshore wind in the land-constrained sensitivity is around 5-percent higher than the base case. The higher avoided costs from offshore wind in the land-constrained case reflects the fact that the cheapest onshore renewable resources will run out more quickly, leaving only inferior, more costly areas for development. Depending on the restrictiveness of future land-use rules, offshore wind may become increasingly valuable in the future as the best onshore resources are developed and fewer alternatives remain.

Exhibit 10.7. Avoided cost of offshore wind energy in land-constrained scenario



Another alternative resource sensitivity was run to identify the impact of lower solar and storage costs on the value of offshore wind. Because offshore wind primarily displaces solar and storage, if these resources were cheaper in the future then offshore wind would offer less value in avoided costs. Exhibit 10.8 indicates that a reduction in solar and storage costs has a consistent impact on the value of offshore wind energy over all model years.

One final sensitivity related to alternative resources is the potential impact of out-of-state wind. In general, offshore wind and out-of-state wind are substitutes that reduce each other's value. In the base case, no new out-of-state wind is allowed. In the sensitivity scenarios, 5 GW of Wyoming wind and 5 GW of New Mexico wind are available for the model to select. Because out-of-state wind has a high capacity factor and does not emit GHGs, it is a competitor with offshore wind, decreasing the avoided cost from offshore wind by $7/MWh (~10 percent) in the early 2030s and by $4/MWh (~5 percent) in 2045. While there is a temporary inversion in this trend in 2035,[150] the average avoided cost from offshore wind is lower across the modeled years when out-of-state wind is introduced as an option.

Exhibit 10.8. Avoided cost of offshore wind energy in low solar and storage cost scenario

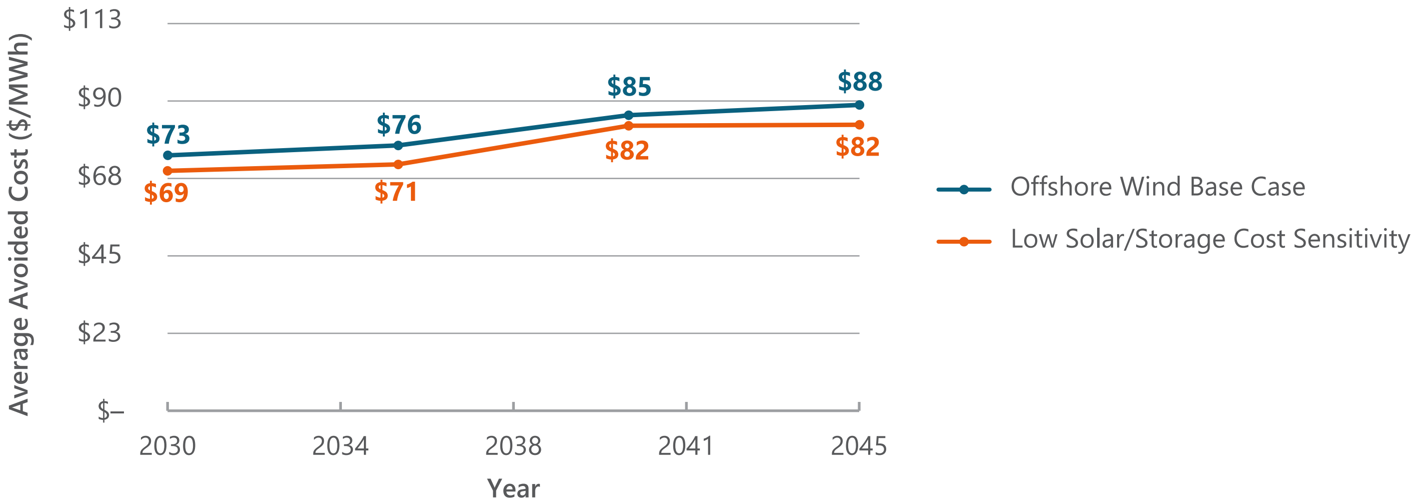
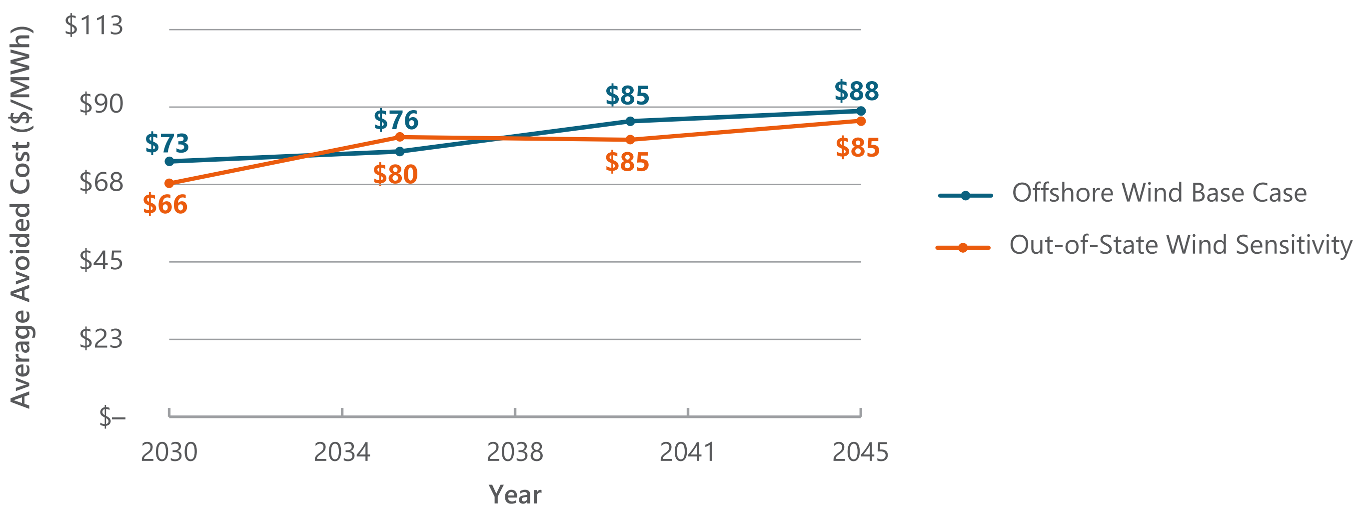


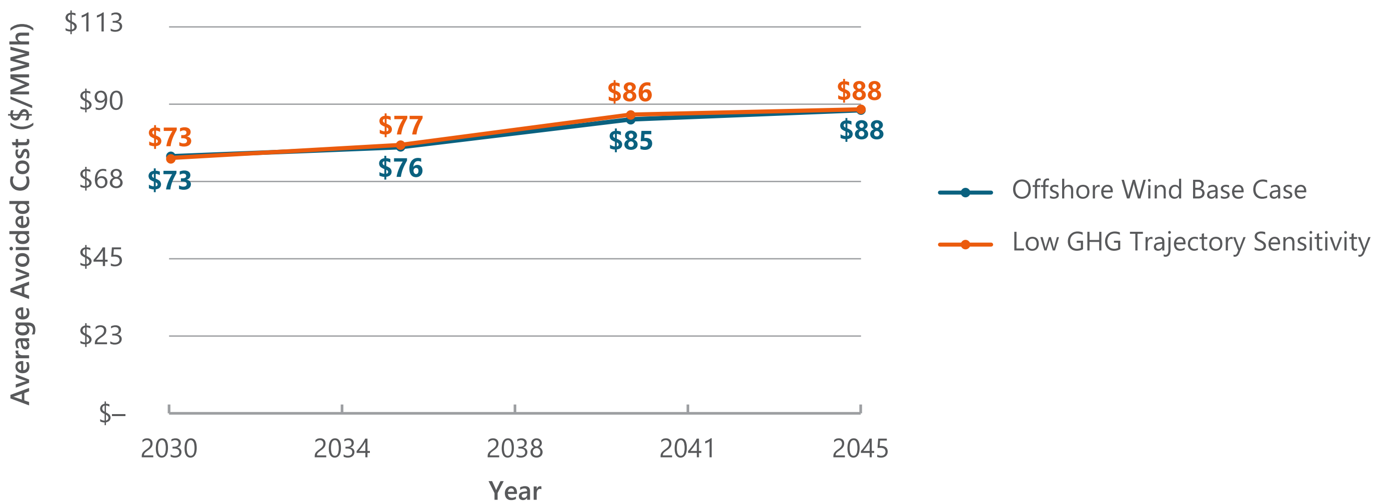
Exhibit 10.9. Avoided cost of offshore wind energy in out-of-state wind import scenario



Avoided cost of offshore wind under alternative policy scenario

In order to explore how sensitive the avoided cost of offshore wind is to more ambitious GHG policies, a lower GHG target sensitivity was studied. In the base case, California is required to comply with a 70-percent GHG reduction by 2030 and 88 percent by 2045. In the sensitivity, California is assumed to target an early achievement of the current 2045 goal by 2040. In this case, the GHG target between 2030 and 2040 is linearly interpolated. Exhibit 10.10 demonstrates that a tighter GHG policy (e.g., early achievement by 2040) might increase the value of offshore wind by a small amount in years where the GHG target is more stringent. In this case, a tighter GHG policy in 2040 increases the avoided costs from offshore wind by $1/MWh, or around 1 percent.

Exhibit 10.10. Avoided cost of offshore wind energy in low greenhouse gas emission trajectory scenario



Projected costs of floating offshore wind in California

In order to evaluate the economics of offshore wind given the estimated avoided costs described above, E3 examined recent literature on the forecasted levelized cost of floating offshore wind.

At the time of this study, limited data existed regarding the potential future cost of floating offshore wind. This technology is in the early stages of commercialization and has not yet seen the level of deployment of fixed-bottom offshore wind, which is the dominant technology employed in Europe and planned for the Northeastern United States. However, floating offshore wind technology has been successfully demonstrated with full-scale turbines, and larger 200-MW-scale projects are due to come online globally over the coming years.[151] As global deployment grows and floating base technology matures, offshore wind in California is likely to decline in cost. Ultimately, the economic viability of offshore wind in California will depend on just how far costs decline.

Recent studies have given varying projections. For example, NREL's 2017 Assessment of the Economic Potential of Offshore Wind estimated that for the Pacific Coast, "in 2027, nearly 3 GW of capacity was calculated to be available below $100/MWh, with 70 GW below $125/MWh."[152] But more recent studies have painted a more optimistic picture. NREL's 2019 Annual Technology Baseline predicted rapidly falling costs for floating offshore wind globally that would yield levelized costs of approximately $70-85/MWh in 2025 and potentially as low as $60-75/MWh by 2030.[153] Similarly, WindEurope has forecasted floating offshore wind costs reaching €40-60 /MWh [$45-$67/MWh] by 2030, given a clearly defined path for project volumes and industrialization.[154] However, it is unclear whether these more optimistic projections fully account for the cost of necessary transmission upgrades, which may vary from site to site.

The potential cost range of $60-$125/MWh for floating offshore wind is indicative of a new technology on the edge of commercialization. Due to poor economies of scale and risk premiums required to finance early projects, the first floating offshore wind projects will likely arrive at higher costs, closer to $100/MWh than $70/MWh. However, with continued commercialization and worldwide experience, floating offshore wind will likely benefit from similar cost declines to those experienced by solar PV and onshore wind over the past decade.

CHAPTER 11. CONCLUSION

Based on the levelized avoided cost estimates in this study and the projected costs from the latest NREL Annual Technology Baseline (ATB), offshore wind may be competitive by the late 2020s in California, once commercialized and available at scale. However, limited transmission capacity may cap the amount of offshore wind that could be deployed without significant costs to deliver it onshore. This key uncertainty may limit the future development of offshore resources.

Economic viability of offshore wind

If floating offshore wind costs fell to just $70 to $80/MWh, the avoided costs from offshore wind might exceed the cost of offshore wind in several California resource zones within the next decade. In this circumstance, offshore wind may be valuable to deploy at a larger scale until either: a) diminishing grid value drives the avoided costs of offshore wind below project costs; or b) the cost of necessary transmission upgrades makes additional offshore wind deployment cost prohibitive.

Though offshore wind's value appears robust across all scenarios considered, the emergence of new competing technologies in the distant future is a potential downside risk that was not captured in the model. Offshore wind's avoided cost value is driven primarily by its renewable attributes and generation profile that coincides well with the grid's evening and winter energy needs, when emissions from remaining gas plants are projected to be highest.[155] Few scalable resources today can offer the same benefits. However, in the long run, new technologies may provide competition. The biggest risk to offshore wind's value is the emergence of dispatchable clean energy technologies such as small modular nuclear reactors, carbon capture and sequestration, or biofuels. If any of these technologies became commercialized in the future and available at competitive cost and scale, then the estimated avoided costs of offshore wind in this study might decline.

On the whole, offshore wind has substantial upside value over the next two decades, including: a) increasing avoided costs over time as the state's GHG goals become more constraining; b) declining costs over time with greater deployment and investment in the global supply chain; and c) potential increases in avoided costs if the state's onshore resources were to become more constrained by environmental protections that stymy development.

Development opportunities and challenges in California

Comparison and prioritization of zones

This study does not make any recommendations regarding the prioritization of offshore wind resource zones for development. However, a high-level look at the generation profile data, the results presented in Chapter 10, and preliminary analysis of the available transmission in the defined resource zones provides a foundation for which further study can be done.

By evaluating offshore wind zone benefits (LACE) relative to costs (LCOE), each zone can be evaluated in terms of relative economics, which will vary based on wind generation profiles and capacity factors in this model. As is shown in Chapter 10, the avoided cost of the resource in each zone is not solely dependent on the average capacity factor of the generation profile, but the capacity factor assumed for each resource zone will have a direct impact on LCOE.

Finally, the existing onshore transmission headroom and the proximity of the resource zones to load pockets will also play a significant role in determining which resource zones are developed first.

Exhibit 11.1 shows a summary of the relative LACE (avoided cost), LCOE (cost) based on NREL's 2019 ATB Techno-Resource Group 9 and E3 analysis, and the available transmission headroom for each zone by 2030.[156] Taken together, these metrics illustrate the potential economic case for offshore wind in each zone.

Exhibit 11.1. Comparison of 2030 LACE, LCOE, and transmission headroom by zone

Offshore Wind Resource Zones	Simulated Capacity Factor	*Zone Average Avoided Cost* 2030-50 LACE, 2 GW scale*	*2025-2030 Cost Range* LCOE, NREL ATB+E3	Transmission Headroom (MW)
Morro Bay	55%	$80/MWh	$62 to $72/MWh	668
Diablo Canyon	46%	$81/MWh	$74 to $88/MWh	3,933
Humboldt Bay	51%	$88/MWh	$66 to $78/MWh	Minimal
Cape Mendocino	53%	$82/MWh	$65 to $76/MWh	Minimal
Del Norte	51%	$83/MWh	$66 to $78/MWh	Minimal

**Each zone contains 1.6 to 6.6 GW of offshore wind potential. Offshore wind zones were modeled at the 2 GW scale to compare economics of a substantial or complete build-out of the resource potential in each zone.*

Future transmission needs

Beyond the existing transmission capacity at the Morro Bay and Diablo Canyon zones, there is a need for new transmission to deliver offshore wind generation to load pockets. Two possible solutions exist for solving this issue:

- **Onshore transmission expansion**, building on existing land based transmission infrastructure and connecting landfall substations to load pockets.
- **Undersea cables directly to load pockets**, which will involve using high-voltage DC (HVDC) cables to transmit the generation output from the offshore wind farms directly to the load pockets.

There was insufficient publicly available cost data to enable the modeling of either of these transmission solutions accurately in this study. However, if offshore wind development were to become economic in the future, there might be a significant need for new transmission to unlock offshore wind capacity at a broader scale.

Areas for further research

This study shows that offshore wind may be economic as a resource to help California meet its long-term GHG and zero-carbon electricity generation targets. While this analysis presents insightful results, there are opportunities for deeper research and more robust results if the challenges identified below are investigated in more detail:

- More data on wind speed and generation profiles for offshore wind must be compiled to improve modeling of the potential performance of offshore wind resources;
- More detailed cost data on offshore wind technology, especially floating offshore wind, must be produced to assess the economic viability of offshore wind and sensitivity of costs to varying conditions such as ocean depth, location, wind speeds, transmission distance, etc.; and
- More data on the cost of new transmission development, especially from Northern California to load pockets in the Bay Area and Southern California, must be analyzed versus the cost of onshore transmission upgrades necessary to deliver new onshore resources such as solar PV and out-of-state wind.

APPENDIX A: CALIFORNIA POLICY BACKGROUND

Current climate policy and long-term energy goals in California

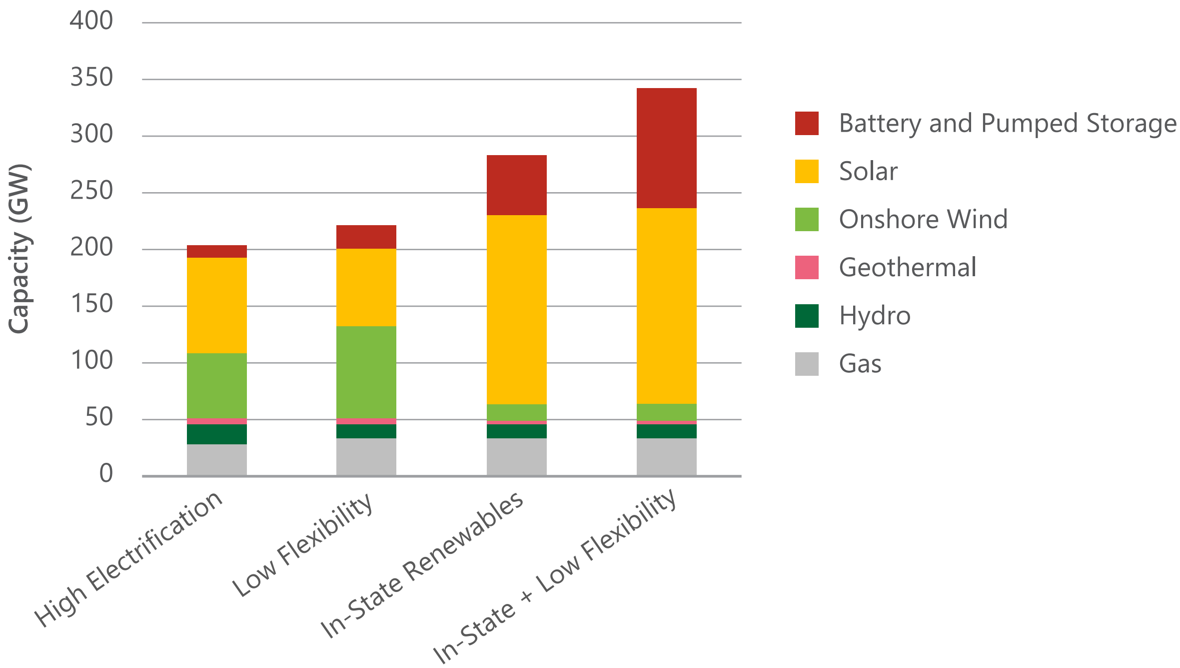
California's two environmental policies that most directly impact power markets and demand for renewable energy are the Renewables Portfolio Standard (RPS) mandate and the pricing of carbon emissions. California's RPS policies date back to 2002 and have since been revised several times to incorporate increasingly stringent targets for renewable energy supply. An important consequence of California's RPS program is that its market support for new technologies helped drive down early-stage costs to enable much cheaper, fully commercialized deployment. For example, solar power purchase agreements (PPAs) signed before 2010 were priced as high as $200 per megawatt-hour (MWh), whereas the Los Angeles Department of Water and Power (LADWP) recently signed a solar PPA at $19.97/MWh, marking a 90-percent cost reduction for the same resource in the same state just a decade later.[157] Onshore wind PPAs have followed a similar trajectory, declining in cost from more than $100/MWh to less than $40/MWh today.[158] SB100, passed in 2018, increased California's targets to 60-percent renewable energy supply by 2030 and 100-percent GHG-free power supply by 2045.[159] Compliance with SB100 alone will require the state to approximately double its existing renewable energy capacity by 2030, adding at least another 20 GW.

California's GHG policies offer an even more comprehensive mandate for combatting climate change. Under AB32 and Executive Order S-03-05, the state has committed to reduce its GHG emissions to 40 percent and 80 percent below 1990 levels by 2030 and 2050, respectively. These goals require a much broader reimagining of California's energy economy, including significant reductions of emissions from the transportation and building sectors in addition to the electric grid. According to E3's 2018 report for the California Energy Commission, the **total new renewable capacity needed to meet California's 2050 GHG goals could range from 100 to 150 GW.**[160] The amount of renewable capacity needed will depend on the type of resources used to reduce GHG emissions in the power sector (e.g., solar versus wind power) and the amount of emissions reductions attributable to the power sector versus mitigation efforts in other parts of the economy (e.g., switching to electric vehicles for transportation).

As shown in Exhibit A.1, California's current resource options for reducing GHG emissions by 2050 lean heavily on just three types of resources: solar PV, onshore wind, and energy storage. This finding is consistent with the California Public Utility Commission (CPUC) Integrated Resource Planning (IRP) process, which earlier in 2019 recommended four different 2030 resource portfolios to inform the California Independent System Operator's (CAISO) Transmission Planning Process (TPP).[161] All portfolios focused primarily on identifying the best mix of solar, wind, and battery storage to meet the state's long-term GHG and RPS goals in four plausible future scenarios related to GHG policy targets and the ability to rely on out-of-state resources.

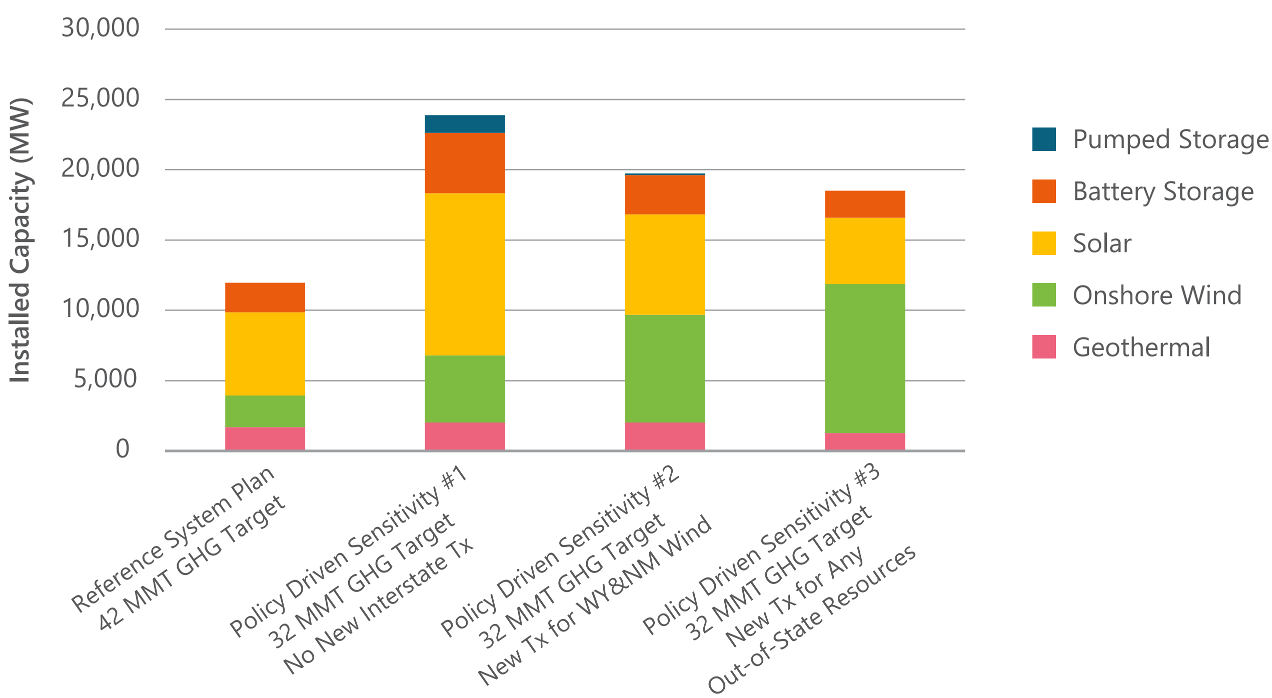
These long-term planning studies, which inform the state's energy procurement, transmission investment, and associated policy decisions, have yet to formally model offshore wind as a future supply option for GHG-free energy. The present study seeks to close a longstanding information gap by investigating the potential role of offshore wind to help meet California's long-term policy goals.

Exhibit A.1. California 2050 generation portfolios under differing GHG-reduction compliance pathways



Source: Energy and Environmental Economics, "Deep Decarbonization in a High Renewables Future," California Energy Commission, June 2018.

Exhibit A.2. Proposed 2030 generation portfolios from CPUC IRP 2017-18 planning cycle



Source: *CPUC, "Proposed IRP Portfolios for the 2019-20 CAISO Transmission Planning Process," January 11, 2019.*

Compliance programs to implement California's policy goals

RPS: Renewable energy certificates (RECs)

The RPS program incentivizes new renewable energy development by putting a market premium on energy generated from renewable resources. Effectively, renewable energy generators are granted certificates (RECs) for every unit of energy produced. Electricity suppliers, such as investor-owned utilities (IOUs) and community choice aggregators (CCAs), are required to obtain an increasing number of RECs over time, which creates a market for RECs and a price signal for project developers.

E3 models California's RPS program as a constraint within RESOLVE that ensures that future resource portfolios comply each year with SB100 requirements (i.e., 60-percent renewable energy by 2030 and 100-percent carbon-free energy by 2045). RESOLVE effectively identifies the REC price needed to incent development of new renewable generation until the target number of RECs are generated. If renewable energy is cost competitive in a given year without any REC market support (i.e., the state exceeds its RPS targets without needing a subsidy for renewables), then the REC "shadow price" in the model is zero.

GHG pricing: Cap-and-trade program

The most comprehensive climate policy in California is the cap-and-trade program instituted under AB32, which is used to price carbon emissions in the state. The cap-and-trade program is an economy-wide mechanism for implementing the state's goal to reduce GHGs emissions 40 percent by 2030 and 80 percent by 2050 (relative to 1990 levels). These goals are enforced through the program's cap on emissions, which declines by a fixed percentage each year. Emitting sources covered by the program include large power plants, industrial sources, and fossil fuel distributors; entities must acquire allowances for their emissions, with the sum of allowances in any year equaling the program cap for that year. Carbon pricing is also applied to electricity imports from outside of California to account for out-of-state emissions and create a level playing field in wholesale power markets.

Recent California carbon prices have been in the range of $15/metric ton CO2e.[162] For a typical combined cycle gas plant, carbon pricing at this level increases marginal costs of generation by approximately $5/MWh. Carbon costs at all fossil-fueled generators thus appear in wholesale market bids and the resulting power market prices experienced in CAISO.

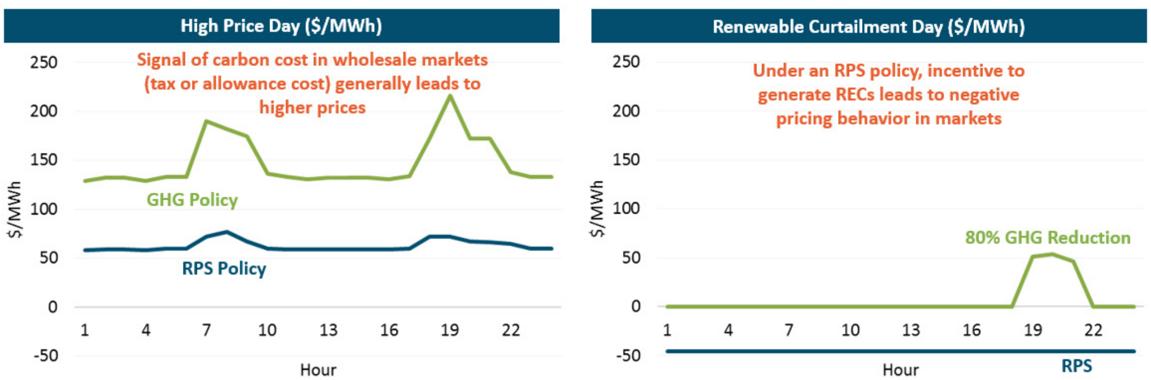
Based on E3's modeling, **California's carbon-reduction goals appear to supersede the renewable energy goals under SB100 by 2030.** In other words, to meet the state's long-term GHG-reduction goals, by 2030 the power sector will need to exceed the pace of clean energy adoption mandated under SB100.

This policy dynamic will be translated to power markets through an **increasing carbon price and deteriorating REC price**. Under a carbon cap that becomes more stringent over time, carbon prices will generally increase to reflect the increasing marginal cost of carbon reductions. For the power sector, carbon prices will rise to the level needed to incentivize switching to less-carbon-intensive power; for example, higher carbon prices will make wind power more competitive relative to gas-fired power, which will incentivize investment in new wind projects. At the same time, renewable energy procurement to meet carbon policy requirements may exceed the amount needed for SB100 compliance, which will reduce the marginal cost of RECs.

The shift from California's historical, RPS-focused market regime to a future, more GHG-focused market regime will have significant implications for energy market prices and investment decisions. Unlike the RECs used to track RPS compliance, carbon prices provide a more granular time-varying market signal throughout each day because the cost of carbon is passed through to energy prices on a real-time basis that directly correlates with carbon intensity. In the evening hours, when peak electricity demand occurs, the CAISO must fire up its most costly and least-efficient generators to supply the grid. The marginal "peaker" plants in these hours emit significantly more carbon per MWh of electricity generated, meaning they must pay a higher carbon price that gets passed through to energy markets. Looked at another way, the value per MWh of replacing fossil generation with clean generation is highest in these peak hours, which generally occur in the evening.

The difference between energy prices in an RPS-driven regime and carbon-price-driven regime is illustrated in Exhibit A.3.

Exhibit A.3. Differing impact of RPS and carbon pricing policies on energy markets



Carbon-driven market trends are particularly relevant for valuing investments in future renewable resources, such as offshore wind, because they capture the time-dependent carbon-reduction value of intermittent resources and their associated generation profiles (e.g., solar generation that peaks at midday versus wind generation that correlates with evening hours). The RESOLVE model used in this study dynamically models carbon prices and their impact on hourly emissions and energy value. The optimal least-cost resource mix for meeting annual carbon caps and the associated shadow price for carbon are two of the model's primary outputs.

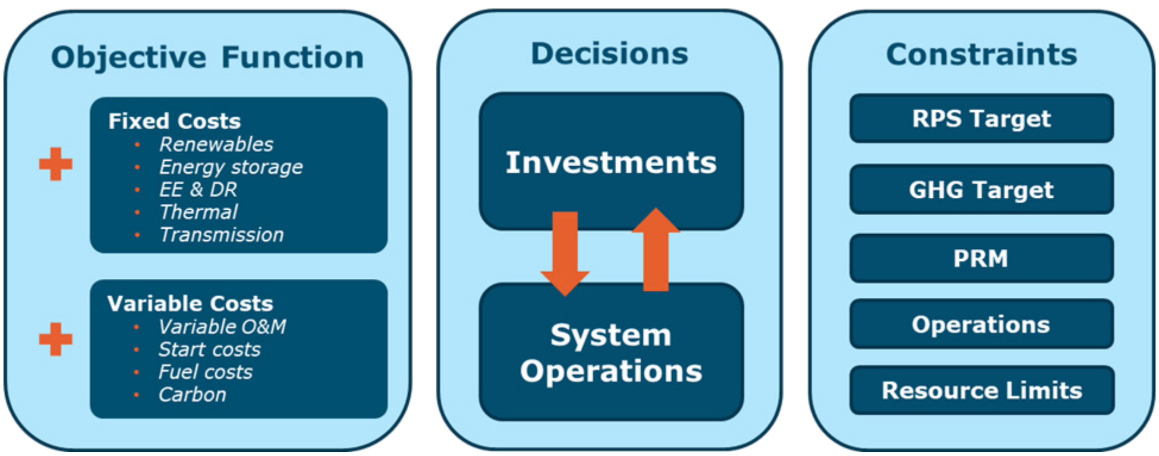
APPENDIX B: RESOLVE MODEL BACKGROUND AND DETAILED MODEL ASSUMPTIONS

This appendix contains a detailed summary of key inputs and assumptions in the RESOLVE model used in this study.

RESOLVE model overview and current uses

RESOLVE is a capacity expansion model that uses linear programming to identify optimal long-term generation and transmission investments in an electric system, subject to reliability, technical, and policy constraints. Designed specifically to address capacity expansion questions for systems seeking to integrate large quantities of variable resources, RESOLVE layers a capacity expansion logic on top of a reduced-form production cost model to determine the least-cost investment plan, accounting for both the up-front capital costs of new resources and the variable costs to operate the grid reliably over time. In an environment where most new investments in the electric system have fixed costs significantly larger than their variable operating costs, this type of model provides a strong foundation to identify potential investment benefits associated with alternative scenarios.

Exhibit B.1. RESOLVE modeling methodology



RESOLVE's optimization capabilities allow it to select from among a wide range of potential new resources. The full range of resource options considered by RESOLVE in this study is shown in Exhibit B.2.

Exhibit B.2. Resource options considered in RESOLVE

Resource Option	Examples of Available Options	Capabilities
Natural Gas Generation	• Simple cycle gas turbines • Combined cycle gas turbines • Reciprocating engines • Repowered CCGTs	• Dispatches economically based on heat rate, subject to operational constraints • Contributes to ramping and reserve needs • Provides large capacity value
Renewables Generation	• Geothermal • Hydro upgrades • Solar PV • Onshore wind • Offshore wind	• Curtailable when needed to balance load • Provides partial capacity value based on ELCC
Energy Storage	• Batteries (>1 hr) • Pumped storage (>12 hr)	• Balances variability of renewable generation by storing excess for later use • Contributes to ramping needs
Energy Efficiency	• HVAC • Lighting • Dryer, refrigeration, etc.	• Reduces load, retail sales, planning reserve margin need
Demand Response	• Interruptible tariff (ag) • DLC: Space and water heating (res)	• Contributes to planning reserve margin needs

To identify optimal investments in the electric sector, maintaining a robust representation of prospective resources' impact on system operations is fundamental to ensuring that the value each resource provides to the system is captured accurately. At the same time, adding investment decisions across multiple periods to a traditional unit commitment problem significantly increases its computational complexity. RESOLVE's simulation of operations has therefore been carefully designed to simplify a traditional unit commitment problem where possible while maintaining a level of detail sufficient to provide a reasonable valuation of potential new resources. The key attributes of RESOLVE's operational simulation are listed below:

- **Hourly chronological simulation of operations:** RESOLVE's representation of system operations uses an hourly resolution to capture the intraday variability of load and renewable generation.

This level of resolution is necessary in a planning-level study to capture the intermittency of potential new wind and solar resources, which are not available at all times of day to meet demand and must be supplemented with other resources.

- **Planning reserve margin requirement:** When making investment decisions, RESOLVE requires the portfolio to include enough firm capacity to meet coincident system peak plus an additional 15 percent of planning reserve margin (PRM) requirement. The contribution of each resource type towards this requirement depends on its attributes and varies by type; for instance, variable renewables are discounted compared to thermal generators because of limitations on their availability to produce energy during peak hours.
- **GHG cap:** RESOLVE also allows users to specify and enforce a GHG constraint on the resource portfolio for a region. As the name suggests, the emissions cap requires that annual emissions generated in the entire system to be less than or equal to the designed maximum emissions cap. As it designs future portfolios, RESOLVE chooses both: 1) how to dispatch new and existing resources to meet the goal (e.g., displacing output from existing coal plants with increased natural gas generation); and 2) what additional investments are needed to further reduce carbon in the system.

Model mechanics: Inputs and outputs

RESOLVE relies on a wide range of inputs and assumptions to carry out analyses. The key categories of these inputs and assumptions are summarized in Exhibit B.3.

Exhibit B.3. Summary of core inputs and assumptions for RESOLVE

Input Category	Description
Policy Constraints	Annual percentage of renewable energy credits (RECs) required and cap on GHG emissions
Demand Forecast	Annual demand and peak forecast for the CAISO system
Existing Resources	Capacity, commission dates, retirement dates, and operating characteristics for all existing and planned resources within the CAISO system
New Resources	Costs and performance for candidate resources considered in the portfolio optimization
Hourly Profiles	Hourly profiles for all the components of demand; hourly generation profiles for solar and wind resources; hourly profiles for all other chronological hourly dispatch resources like EE
Fuel Price Forecasts	Fuel price forecast data for all thermal resources
NW and SW Market Representation	Load and resource assumptions for external zones connected to CAISO service territory

RESOLVE produces a wide range of useful output data for resource planning purposes. A few of the key results metrics include:

- **Resource additions in each investment period (MW).** The cumulative total capacity of new resources added throughout the modeled period by RESOLVE as a result of its optimization.
- **Annual generation by resource (GWh).** The generation by all the resources in the portfolio (existing and additional) in each of the modeled years.
- **Annual renewable curtailment (percent).** The level of curtailment experienced in each modeled year due to the imbalance between variable resource availability and hourly demand.
- **Annual RPS level reached (percent).** The level of renewable penetration achieved in each scenario expressed as a percentage of annual retail sales.
- **Ongoing fixed operations and maintenance costs ($MM).** The ongoing cost for operating and maintaining existing resources.
- **All-in fixed costs ($MM).** The costs associated with all the additional new resources in the portfolio.
- **Variable and fuel costs ($MM).** The cost of generation for all resources.
- **Net cost (or revenue) ($MM)**. Associated with purchases (or sales) from external zones.

APPENDIX C: OFFSHORE WIND RESOURCE LOCATION DEFINITIONS

Data regarding boundaries and resource potential for the Humboldt Bay, Morro Bay, and Diablo Canyon zones were based on BOEM data for the proposed California call areas. For the Cape Mendocino and Del Norte resource zones, boundaries and resource potentials were based on a combination of data from BOEM, NREL, and CEC studies. Exhibit C.1 shows a 50-square-mile grid surface overlay on the existing BOEM map of the California offshore wind resource up to 1,100 meters (3,600 feet) water depth, while Exhibit C.2 shows the selected grid cells and the centroid longitudes and latitudes for each cell used to compose the Cape Mendocino and Del Norte zones. Each grid cell is 50 square miles and has a resource potential of 388 MW.

Exhibit C.1. Map of Cape Mendocino and Del Norte offshore wind resource zones

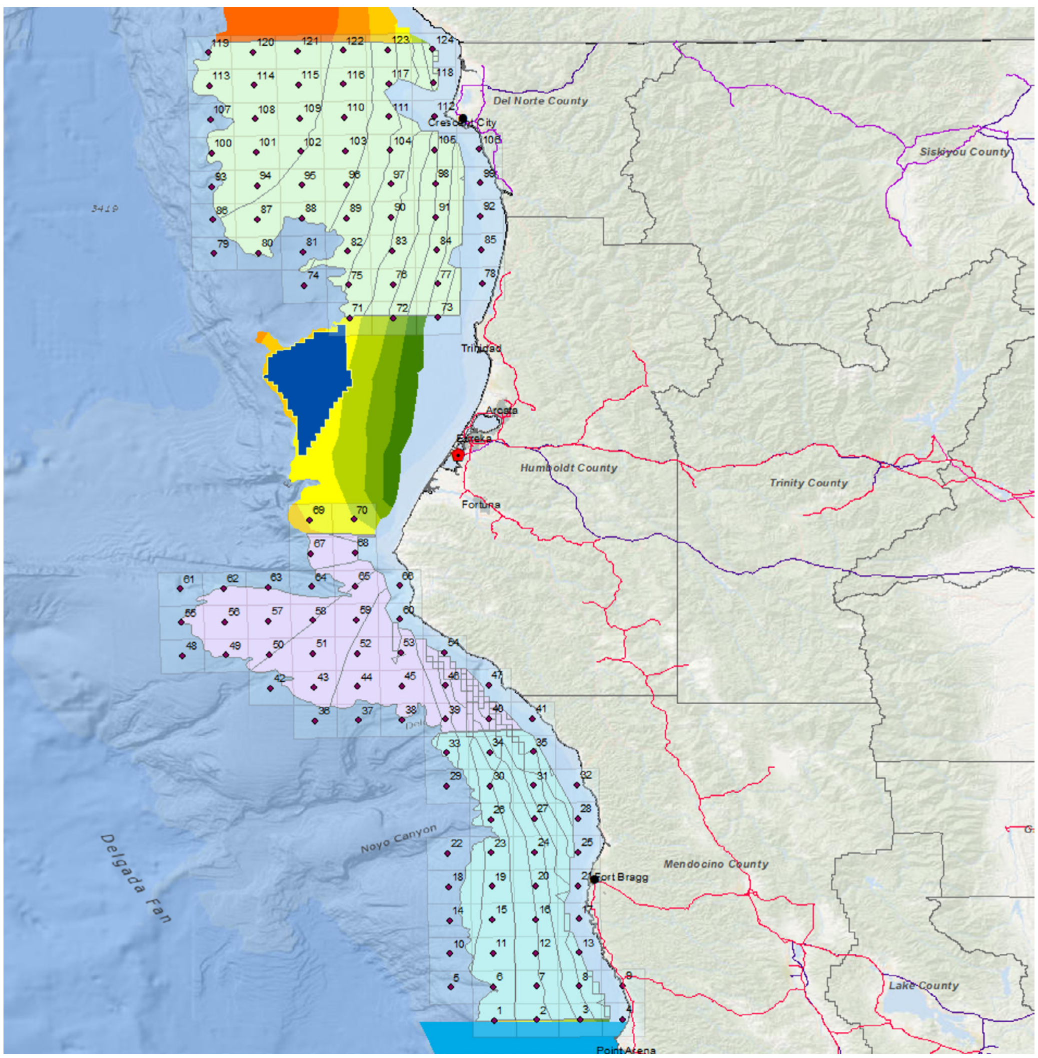


Exhibit C.2. Grid-level location data for Cape Mendocino and Del Norte resource zones

Cape Mendocino			Del Norte		
Grid Index	Latitude	Longitude	Grid Index	Latitude	Longitude
6	39.108059	-124.106138	75	41.255934	-124.549084
11	39.210584	-124.107745	82	41.358403	-124.551511
15	39.313108	-124.109360	87	41.456867	-124.826352
19	39.415629	-124.110983	88	41.458949	-124.690159
23	39.518149	-124.112615	89	41.460870	-124.553952
26	39.620667	-124.114255	94	41.559317	-124.829234
30	39.723183	-124.115903	95	41.561407	-124.692826
43	40.024332	-124.654219	96	41.563335	-124.556405
44	40.026159	-124.520905	100	41.659506	-124.968740
49	40.122689	-124.923688	101	41.661765	-124.832132
50	40.124830	-124.790202	102	41.663863	-124.695508
51	40.126817	-124.656701	103	41.665798	-124.558870
56	40.225157	-124.926585	108	41.764212	-124.835044
			113	41.864381	-124.975015

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