A Supply Chain Road Map for Offshore Wind Energy in the United States

Matt Shields,[1] Jeremy Stefek,[1] Frank Oteri,[1] Matilda Kreider,[1] Elizabeth Gill,[1] Sabina Maniak,[1] Ross Gould,[2] Courtney Malvik,[2] Sam Tirone,[2] and Eric Hines[3]

1 National Renewable Energy Laboratory
2 Business Network for Offshore Wind
3 Tufts University

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List of Acronyms

AIMS	adjacent industry manufacturing scale
AMPTC	Advanced Manufacturing Production Credit
BOEM	Bureau of Ocean Energy Management
CapEx	capital expenditures
DOE	U.S. Department of Energy
FTE	full-time equivalent
GBF	gravity-based foundation
GDP	gross domestic product
GW	gigawatt
HLV	heavy-lift vessel
IRA	Inflation Reduction Act
km	kilometer
m	meter
LCOE	levelized cost of energy
MassCEC	Massachusetts Clean Energy Center
MEA	Maryland Energy Administration
MW	megawatt
NOWRDC	National Offshore Wind Research and Development Consortium
NYCEDC	New York City Economic Development Corporation
NJEDA	New Jersey Economic Development Authority
NYSERDA	New York State Energy Research and Development Authority
O&M	operations and maintenance
OEM	original equipment manufacturer
ORBIT	Offshore Renewables Balance-of-system and Installation Tool
RPC	regional purchase coefficient
SBMT	South Brooklyn Marine Terminal
t	metric tonnes
WTIV	wind turbine installation vessel

Executive Summary

The offshore wind energy industry in the United States has been gaining momentum for several years as the project pipeline has expanded, states have established procurement targets, and initial investments have been made in ports and manufacturing facilities. These efforts helped lead to the Biden administration's announcement of a national offshore wind energy target to install 30 gigawatts (GW) by 2030. This announcement not only characterized deployment goals but also identified the need for a domestic supply chain, local workforce, and energy and environmental justice as part of a new offshore wind industry. There is widespread agreement that a domestic supply chain will be critical for the sustainable growth of offshore wind energy in the United States; however, there is a general uncertainty about the scope of such a supply chain, the development time frames needed to build critical resources, the level of investment required, the potential benefits that will be available to local communities and workers, and the significance of gaps in existing manufacturing, port, vessel, or workforce infrastructure on deployment targets.

In this report, the authors describe how a fully domestic offshore wind energy supply chain could develop. We summarize the major barriers that could prevent or delay supply chain expansion and present potential solutions that could help overcome these challenges. We describe the major factors that need to be considered to develop resilient, sustainable, and equitable manufacturing capabilities in the United States. Finally, we present a scenario for a domestic supply chain that estimates the number of required major component manufacturing facilities, ports, and vessels that would need to be developed by 2030 to support an annual deployment of 4–6 GW. This deployment rate would put the nation on a pathway to installing 110 GW by 2050 primarily using domestically produced components. This scenario illustrates the level of investment, development time, and workforce growth that could be required to develop a domestic supply chain. We demonstrate that if individual states leverage their existing manufacturing capabilities to contribute to the offshore wind energy sector, this conceptual supply chain would generate significant workforce and economic benefits throughout the United States, not just in coastal locations with active offshore wind energy programs. The results are intended to provide information to federal and state governments, economic development agencies, organized labor, project developers, manufacturers, and community representatives to facilitate supply chain planning and decision-making. The following sections identify key actions that could help to develop a domestic supply chain and summarize the analysis work detailed in this report (which helps to inform the list of actions).

Pathways To Developing a Domestic Offshore Wind Energy Supply Chain

The following actions, separated into short-, medium-, and long-term time frames, could help the offshore wind sector create a robust, resilient, and sustainable supply chain by overcoming ongoing challenges and barriers. In Section 4, we provide more detailed discussion about each potential action, including the relevant organizations or stakeholders that could be involved and the likely impacts of accomplishing the action.

Table ES1. Summary of Potential Short-, Medium-, and Long-Term Actions To Develop a Domestic Offshore Wind Energy Supply Chain

Action	Outcome
Short-Term Actions: Organizing a Strong Foundation (2023-2024)	
Convene working groups focused on regional and holistic supply chain development	The formation of actively funded groups with decision-making authority, diverse membership, established communication practices, and clear visions for supply chain development
Identify locations to build the next wave of supply chain development equitably and efficiently	Announcements and initial permitting applications for a sufficient number of facilities (e.g., factories, ports, vessels) to meet the demand of the domestic pipeline
Continue to expand the offshore wind energy pipeline	A predictable timeline for lease area sales and state procurement solicitations that extends to (at least) 2035
Assess the need for and impact of incentive mechanisms beyond existing programs	A predictable approach for incentive programs to construct new supply chain assets (e.g., factories, ports, vessels) and produce Tier 1, 2, or 3 components[1] that are not covered through the Inflation Reduction Act or other existing programs
Establish strategies and incentive mechanisms targeted at floating wind infrastructure	A clear and consistent vision that outlines the infrastructure needs to deploy commercial-scale floating wind, including preferred port locations, newly built vessels, and industrialization requirements for floating platforms
Establish curriculum and funding streams for workforce training centers	A standard curriculum for offshore wind energy workers that is acceptable to all major offshore wind manufacturers; committed funds sufficient to open training centers and train an initial cohort
Conduct outreach and education activities with existing suppliers to increase awareness of offshore wind energy opportunities	Increased engagement and contracting between major manufacturers and domestic businesses
Medium-Term Actions: Gaining Critical Momentum (2025–2030)	
Construct the major supply chain facilities needed to meet the demand pipeline	A network of domestic manufacturing facilities that can support the demand from all offshore wind energy projects in the United States; a system of ports and vessels that can support annual deployment without creating significant delays
Continue to expand the offshore wind energy pipeline	A predictable timeline for lease area sales and state procurement solicitations that extends to (at least) 2040 and potentially as far as 2050
Leverage national, regional, and industry working groups to share and develop best practices for supply chain activities	A standardized approach to community engagement, permitting, developing supporting supply chains, and adapting to evolving technologies throughout different states and supply chain sectors

[1] Tier 1, 2, and 3 components refer to finished components, subassemblies, and subcomponents for offshore wind projects as defined in Shields et al. (2022).

Action	Outcome
Incorporate learning from early-stage commercial-scale projects into ongoing operations and decision-making	An evolved supply chain that develops in parallel with technologies and processes that are customized for the social and regulatory considerations within the U.S. market (e.g., foundation technologies to minimize pile-driving noise, refined feeder barge strategies to reduce at-sea risk, improved communication and community outreach)
Train a sufficient manufacturing workforce	Workforce training centers and apprenticeship programs produce a sufficient throughput of trained workers to fill all domestic manufacturing jobs
Evaluate procedural and impact equity metrics for early-stage commercial-scale projects and incorporate best practices into ongoing supply chain development activities	Commonly used best practices that incorporate community feedback throughout the decision-making process for supply chain investment that apply frameworks that have been refined using lessons learned from early-stage projects
Long-Term Actions: Maintaining a Sustainable Industry (Beyond 2030)	
Maintain and upgrade key supply chain infrastructure to adapt to evolving technologies	Existing resources developed in the 2020s (e.g., manufacturing facilities, ports, vessels, workforce training centers) remain active and capable of producing new components (e.g., larger wind turbine components, floating wind components on the East Coast), possibly with the inclusion of new innovations or automation; floating wind infrastructure continues to expand to support increasing levels of deployment
Expand supply chain infrastructure to new regions using lessons learned from early build-out	Offshore wind energy supply chain hubs that are present throughout the United States with capabilities and are customized for the specific technology, regulatory, and community needs of each region
Fill manufacturing gaps in supporting supply chains with domestic production	Critical subcomponents and subassemblies are primarily manufactured in the United States to decrease reliance on global supply chains
Continue to expand the offshore wind energy pipeline	A predictable timeline for lease area sales and state procurement solicitations that extends through 2050

These actions are designed to overcome seven key barriers that we identified through industry outreach and the analysis conducted in this report. They tend to focus on challenges related to effective communication between different stakeholder groups, strategic planning of large investments in an uncertain environment, and understanding the cost/benefit trade-offs between domestically produced and imported components. These barriers include the following (and described in more detail in Section 2.1):

- The Biden administration, the Bureau of Ocean Energy Management, and individual state governments have made substantial progress to create a strong pipeline of planned projects and procurement targets. However, uncertainty surrounding the potential impacts of construction delays, cost overruns, legal complications, or changes in government support for offshore wind energy creates an investment risk that makes it difficult to secure financing for new supply chain facilities (e.g., factories, ports, and vessels).

- Major offshore wind manufacturing facilities can only be built in suitable ports, but construction of these facilities is constrained by limited available port space and uncertain permitting and construction timelines. Wind turbine capacities have been rapidly increasing in recent years (Musial et al. 2022), and if this trend continues, supply chain assets (including ports and vessels) designed around current technology may become obsolete or require additional investment before paying off the upfront investment.
- Existing supplier networks will be stressed to provide the required raw materials and subcomponents needed to fabricate major components.
- Existing port and vessel infrastructure is inadequate to install 30 GW of offshore wind energy by 2030.
- Some offshore wind energy components require a specialized manufacturing workforce that may not be readily available in the United States.
- Recent federal incentives such as clean energy tax credits in the Inflation Reduction Act of 2022 (IRA) will help domestically produced components be cost competitive with imports from established international manufacturing facilities. However, additional incentives may be required to encourage domestic manufacturing of components or supply chain assets that are either not considered in the IRA or receive tax credits that are smaller than the cost premium for domestic manufacturing.
- Incorporating equity and sustainability into supply chain decision-making is resource-intensive and insufficiently incentivized, which may result in unjust outcomes for host communities.

Critical Aspects of a Domestic Offshore Wind Energy Supply Chain

A domestic offshore wind energy supply chain would require significant development of manufacturing facilities, ports, vessels, and a trained workforce to produce, transport, and install the major components required for an offshore wind energy project. Other important infrastructure investments that will likely be necessary to enable major offshore wind development, such as expansion of the transmission grid, are outside the scope of this report. We begin by developing a scenario for a domestic supply chain that could be realized by 2030, and then use this scenario to estimate the potential impacts on the offshore wind sector and related stakeholders.

Supply Chain Scenario

Shields et al. (2022) estimated that deploying 30 GW of offshore wind energy by 2030 will likely require more than 2,100 wind turbines to be installed in U.S. waters. Ambitious global offshore wind energy deployment targets will create substantial demand for the components needed to build these wind turbines and balance-of-system components such as foundations and cables. The limited global manufacturing capacity for these components creates a risk for U.S. projects that choose to import their components from Europe. Therefore, developing a domestic supply chain would reduce reliance on global manufacturers and create jobs and economic benefits in the United States.

In this report, we compare the offshore wind energy pipeline's annual demand for major offshore wind components with the production capacity and development timelines of representative manufacturing facilities to estimate the total number of required facilities and the time frame during which they could be developed. We also provide detailed discussions of the requirements and development challenges that offshore wind manufacturers have identified for each major component in Section 2.4 and Section 2.5. Based on these requirements, we provide a supply chain scenario that includes 34 major component manufacturing facilities (Figure ES1). Most of these facilities would also require significant upgrades at the manufacturing port.

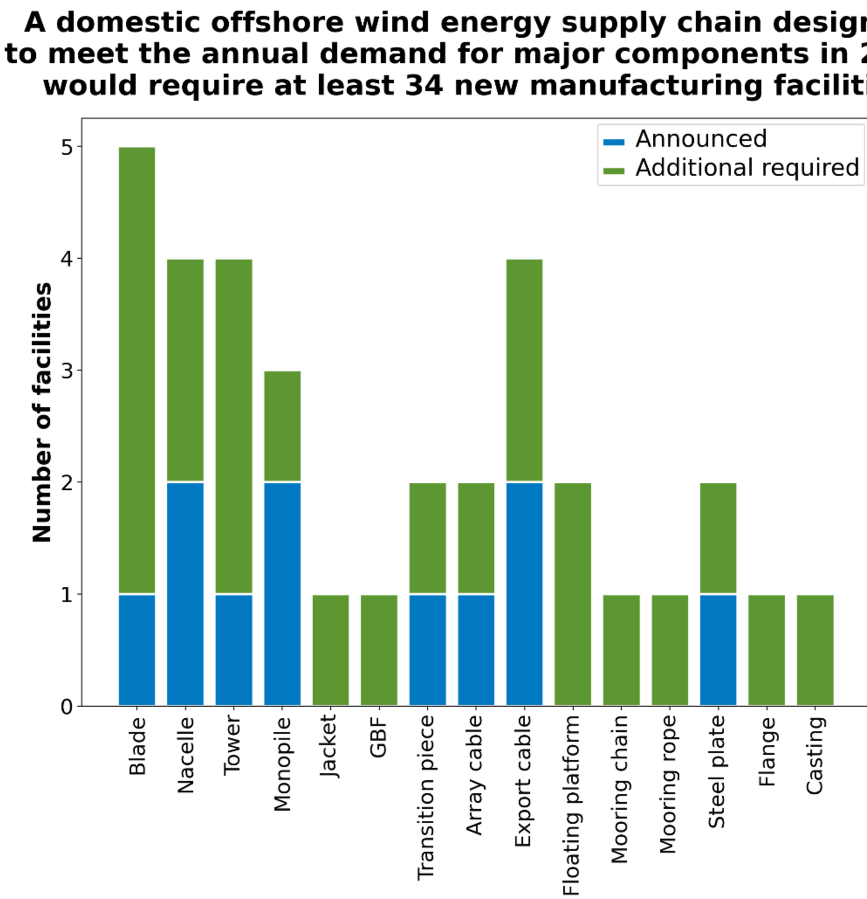

Figure ES1. The number of manufacturing facilities required to develop a domestic offshore wind energy supply chain.

Note: Announced manufacturing facilities include operational, under construction, and announced factories. The number of additional required manufacturing facilities is estimated in this report to meet the average offshore wind energy pipeline demand in 2030. GBF: gravity-based foundation.

This supply chain scenario also includes marshaling ports and large installation vessels (e.g., wind turbine installation vessels, heavy-lift vessels, and specialized feeder barges) that need to be dedicated to the U.S. offshore wind industry. The total investment in these ports and vessels (and including the required upgrades at manufacturing ports) is around $11 billion. The key aspects of the supply chain scenario used in this report are listed in Table ES2. These assets represent a minimum viable supply chain, and additional facilities may be needed to address regional supply chain needs.

Table ES2. A Domestic Supply Chain Scenario for Offshore Wind Energy in the United States in 2030

Parameter	Number
Fixed-bottom wind marshaling ports	8
Floating wind integration ports	2
Dedicated wind turbine installation vessels	4−6
Dedicated heavy-lift vessels	4−6
U.S.-flagged specialized feeder barges	4−8
Manufacturing facilities	34
Development time frame	6–9 years

Finally, we show the investment required for the major manufacturing facilities, ports, and large installation vessels that comprise the domestic supply chain scenario in this report (Figure ES2). The total investment of $22.4 billion does not include support vessels, workforce training programs, expansion of existing businesses in the supporting supply chain, or additional facilities that may be needed for regional demand. As a result, the actual investment this decade could be higher than $22.4 billion. Additional investment would be required beyond 2030 to expand floating offshore wind energy infrastructure.

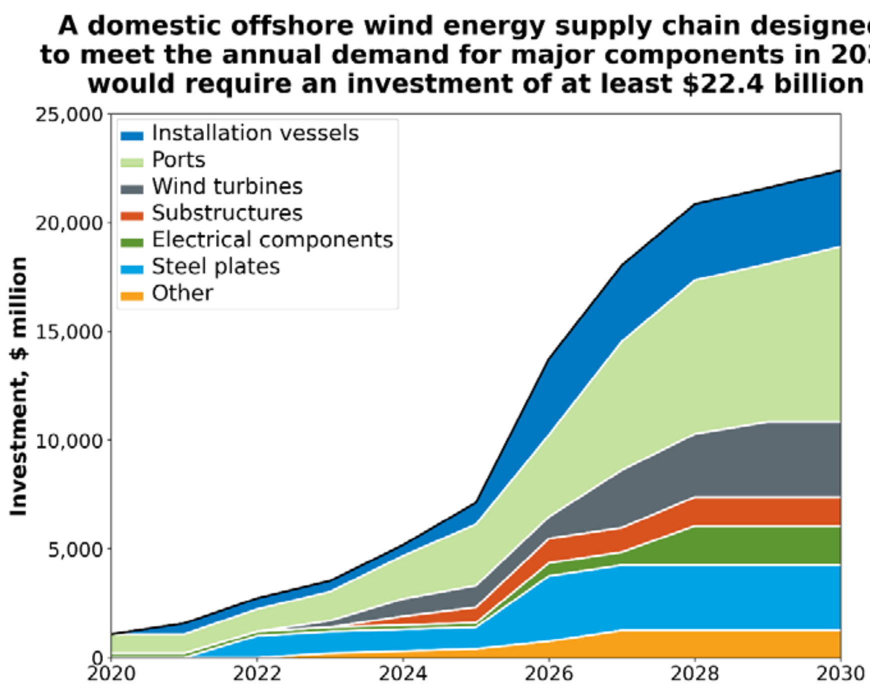

Figure ES2. Cumulative investment over time in the major components of a domestic offshore wind energy supply chain.

Note: Installation vessels include wind turbine installation vessels and heavy-lift vessels, which could be U.S.- or foreign-flagged[2], and specialized feeder barges, which must be U.S.-flagged. Ports include fabrication and marshaling ports.

[2] A U.S.-flagged vessel is registered and operated under U.S. laws, used in a commercial trade within the United States, and owned and operated by U.S. citizens.

Key takeaways include the following:

- A domestic supply chain would require at least 34 new manufacturing facilities for critical offshore wind components to meet demand in 2030.
- The industry will likely need to invest over $11 billion in marshaling ports, fabrication ports, and large installation vessels by 2030 to support the manufacture, transport, and installation of major offshore wind energy components.
- A domestic supply chain will likely require an investment of at least $22.4 billion in manufacturing facilities, ports, and large installation vessels.

Manufacturing of Critical Offshore Wind Energy Components

The dozens of offshore wind component manufacturing facilities that would be needed for a domestic supply chain are all major construction projects that could each cost at least $200–$400 million and take 3–5 years to accommodate stakeholder engagement, financing, permitting, planning, and construction activities. In Section 3.1.2.2, we present accelerated and conservative development scenarios that suggest that it could be possible to develop a full domestic supply chain in 6–9 years. In the accelerated supply chain growth scenario, final decisions and commitments are made to all the required facilities, ports, and vessels by the end of 2023 and permitting and construction activities are streamlined. In the conservative scenario, facility decisions are made by the end of 2024 and permitting and construction activities take longer to complete. Under the accelerated scenario, it is possible to have an operational, fully domestic supply chain by 2030. Even in this ideal case, some offshore wind components will likely need to be imported throughout the 2020s to meet the 30-GW-by-2030 national offshore wind target. In Figure ES3, we show how the offshore wind energy pipeline could be impacted if we assume that projects built after 2025 exclusively use domestically produced components. Under both the accelerated and conservative scenarios, limited manufacturing capacity in the mid-2020s would mean that a domestic supply chain could not meet the full demand for components. Project developers would have to make up this shortage by importing components for about 15–25 GW of projects to achieve the national offshore wind target by 2030. This outcome could still be beneficial because it would enable the offshore wind sector to meet the target while concurrently developing a robust supply chain that would be ready to support sustainable annual deployment throughout the following decades. Further information is provided in Section 3.1.2.

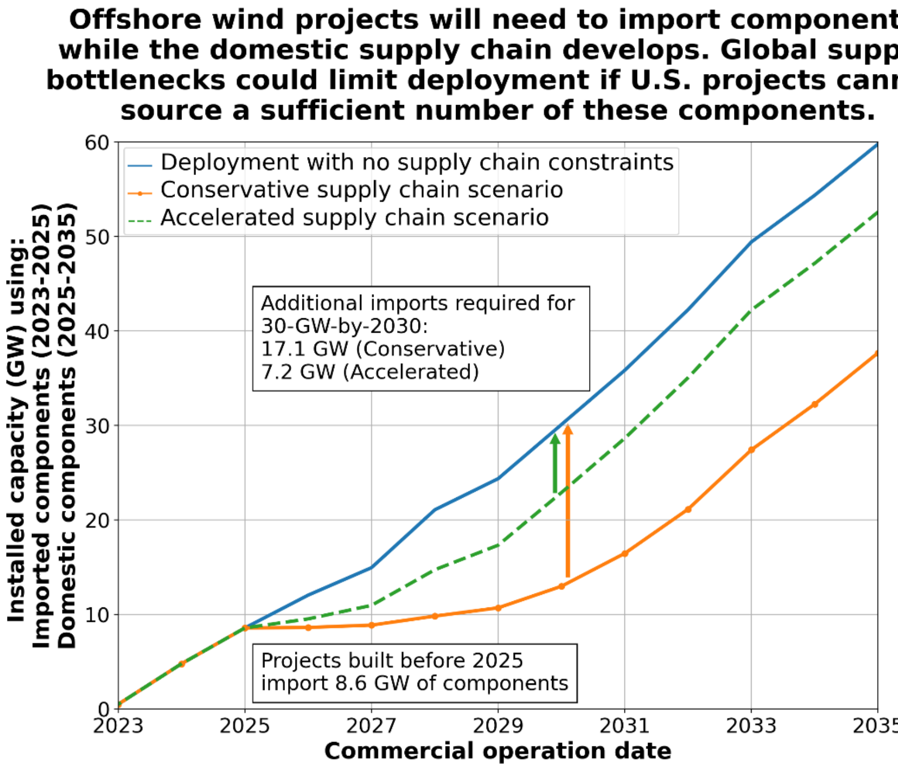

Figure ES3. Manufacturing constraints on offshore wind energy deployment for accelerated and conservative domestic supply chain scenarios.

Note: The time required to plan, permit, and construct offshore wind energy factories results in limited manufacturing capacity in the mid-2020s, which would need to be met by imported components to meet the 30-GW-by-2030 deployment target. All scenarios assume that 8.6 GW of offshore wind energy projects are installed using internationally sourced components by 2025. Including these 8.6 GW, the United States would need to import 15.8 GW of offshore wind components under the accelerated scenario or 25.7 GW of offshore wind components under the conservative scenario to achieve the 2030 deployment target.

Domestically manufactured components have the potential to be cost competitive with imported components because the cost of building new facilities could be effectively offset by reducing transportation costs from Europe, avoiding tariffs on foreign steel, and benefiting from manufacturing incentives from the IRA. However, other local factors could vary significantly between these scenarios and thus impact this margin. Offshore wind manufacturers have identified the differences between European and U.S. labor rates as a potential driver of cost variances that could influence where they decide to site their factories. Furthermore, some major offshore wind components do not qualify for IRA incentives, which could limit their ability to be cost competitive in a global market. We discuss the relative impact of these cost factors in Section 3.2.3. Further study is required to understand the site-specific and component-specific wage differences and how they could drive investment decisions in a domestic supply chain. Regardless of where the components are produced, it is critical that the manufacturers maintain high quality-control standards and support good-paying jobs with robust training programs.

Key takeaways include the following:

- Offshore wind manufacturing facilities could cost at least $200–$400 million and could take 3–5 years to permit and construct.
- As a domestic supply chain ramps up production during the 2020s, the U.S. offshore wind energy sector will likely have to import between 15–25 GW worth of components to meet the 2030 deployment targets.
- Lower transport costs, avoided tariffs, and incentives from the IRA could help domestically produced components be cost competitive with imported ones, although this outcome will likely depend on the difference in labor costs between the locations of U.S. and international facilities.

Port and Vessel Infrastructure

Ports and vessels will be critical to installing offshore wind energy projects in the United States but limited existing resources will create significant bottlenecks in the deployment pipeline. In Section 3.1.1, we model the installation of the fixed-bottom project pipeline using a Baseline scenario where no additional port or vessel infrastructure is developed beyond what has already been announced or started construction. We then use this same model to introduce additional investment scenarios: one scenario (U.S. WTIV) introduces additional U.S.-flagged wind turbine installation vessels (WTIVs) and heavy-lift vessels (HLVs) during the 2020s, and the other (U.S. Feeder) introduces more U.S.-flagged specialized feeder barges in addition to WTIVs and HLVs that could be U.S.- or foreign-flagged. The Baseline scenario shows that over half of the existing pipeline is at risk of not being installed by 2030 because of limited port and vessel availability. The U.S. WTIV and U.S. Feeder scenarios require a greater investment of around $6 billion each but enable the full pipeline of fixed-bottom projects to be installed by 2030. Figure ES4 compares the investment required and installed capacity by the end of 2030 for the three scenarios.

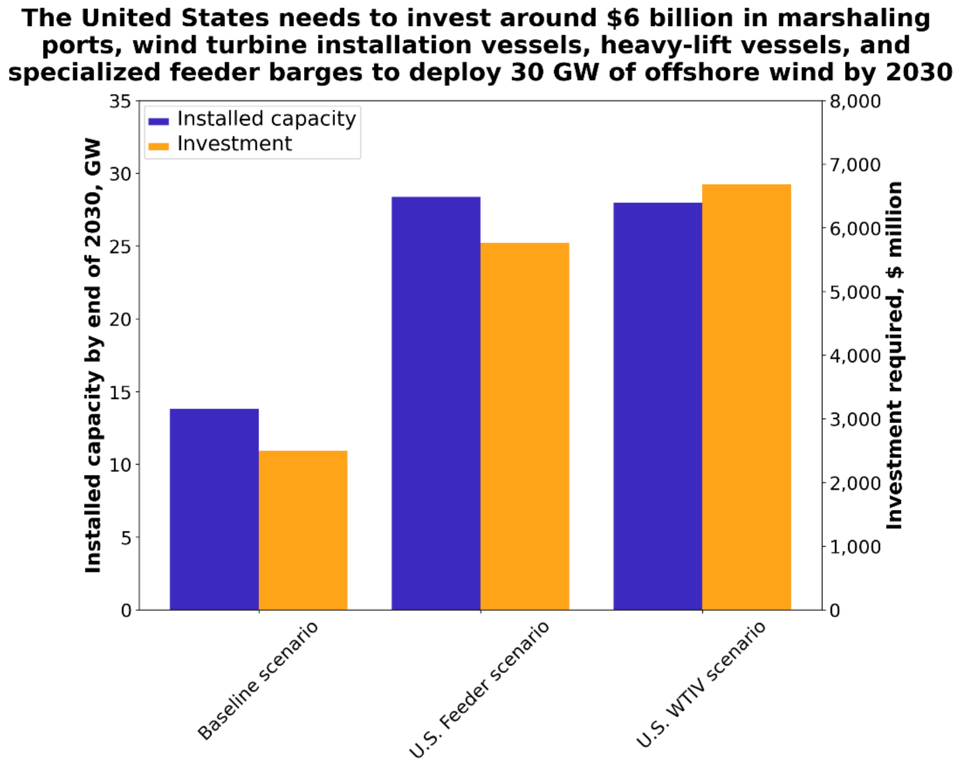

Figure ES4. Installed fixed-bottom offshore wind capacity by 2030 and investment required for different port and vessel scenarios.

Note: Each scenario includes different numbers of marshaling ports, wind turbine installation vessels (WTIVs), heavy-lift vessels (HLVs), and specialized feeder barges. The Baseline scenario includes infrastructure that already exists, is under construction, or has been announced. The U.S. Feeder scenario includes 8 U.S.-flagged feeder barges that are used for all projects, 4 WTIVs, and 4 HLVs. The U.S. WTIV scenario includes 4 U.S.-flagged feeder barges, 6 U.S.-flagged WTIVs, and 6 U.S.-flagged HLVs.

Investment in new marshaling ports and installation vessels is hindered because of uncertainty in the pipeline, which creates risk for investors looking for a return on investment. Building ports is difficult because of the high costs (often involving public financing from state or federal governments) and limited coastal space that is available for building new facilities or expanding existing ones. Investing in new vessels is particularly challenging due to their high capital costs, short construction contracts, and difficulty in creating consistent pipelines of contracts. The Jones Act, which requires vessels transporting merchandise between U.S. ports (including offshore wind turbine locations) to be U.S.-flagged, is a key factor in selecting the vessels that will be used for offshore wind energy projects. The U.S. currently has a shortage of mariners with sufficient offshore wind experience, which could create a short-term installation bottleneck for projects that rely on U.S.-flagged vessels. This risk could diminish over time as more U.S. vessels are built and their crews are appropriated trained.

Furthermore, although domestic shipyards have interest in building new U.S.-flagged vessels, there are a limited number of yards that can construct large, highly specialized installation vessels (such as HLVs and WTIVs), which will constrain the number of these vessels that can reasonably be built in the United States in the 2020s without significant additional investments. Even shipyards with sufficient technical capabilities may have existing commitments throughout the 2020s, which could limit their ability to construct offshore wind vessels. Specialized feeder barges are less expensive to build, have shorter construction time frames, and can be constructed by a greater number of U.S. shipyards, which may cause the nation's industry to favor installation methods that use feeder barges and either U.S.- or foreign-flagged WTIVs and HLVs. Additional investment in marshaling ports for floating projects on the West Coast, Gulf of Mexico, Central Atlantic, and Gulf of Maine will likely be needed for projects installed in the early 2030s. Other types of installation vessels will be required beyond just WTIVs, HLVs, and feeder barges, which will require additional investment in the domestic vessel fleet.

Key takeaways include the following:

- Port and vessel infrastructure that either already exists, is under construction, or has been announced could limit offshore wind energy deployment to under 14 GW by 2030 (less than half of the national offshore wind target).
- The United States would likely need to invest around $6 billion in marshaling ports, WTIVs, HLVs, and specialized feeder barges to meet 30 GW of offshore wind deployment by 2030.
- There are a limited number of U.S. shipyards that can construct large installation vessels such as WTIVs and HLVs. This constraint may lead to more projects using installation methods that rely on specialized, U.S.-flagged feeder barges, which would allow WTIVs and HLVs to be either U.S.- or foreign-flagged.
- Additional investment will be required in floating wind marshaling ports after 2030 and other types of installation vessels, but these resources are not considered in this study.

Training a Manufacturing Workforce

An offshore wind energy supply chain in the United States would create a significant number of good-paying domestic jobs. Component manufacturing facilities and their suppliers have the potential to be the largest contributor of employment in the offshore wind industry. To train and certify these workers, developing or expanding robust training programs in the trades that align with component manufacturing and supplier demand could support sustainable workforce growth.[3] The highly specialized components required for offshore wind energy projects demand a workforce with new or expanded skill sets and qualifications. In addition, worker availability will be a challenge because of the time required for training, existing workforce shortages for some trades, worker preferences, and uncertainty about necessary skills needed to manufacture next-generation offshore wind components. As the manufacturing industry ramps up during the 2020s, it will be critical to develop and expand training programs at community colleges, labor unions, and universities so that a domestic workforce will be ready to be hired at new manufacturing facilities. These efforts should prioritize institutions that serve higher proportions of low-income students and students of color, such as historically Black colleges and universities, to create a diverse workforce and an industry with equitable access to opportunities.

[3] This road map focuses on expanding insights into the manufacturing and supply chain workforce. Installation activities will also contribute to the offshore wind energy workforce, including port workers, construction workers at sea, and vessel mariners; the contribution and training requirements for these jobs are highlighted in the "U.S. Offshore Wind Workforce Assessment" (Stefek et al. 2022). Building manufacturing facilities, U.S. vessels, and port upgrades will also require a workforce; however, we have not assessed those impacts.

The domestic supply chain scenario we discuss in this report includes direct jobs within the 34 major manufacturing facilities. We also estimate the opportunity space for direct and indirect supplier jobs producing subassemblies, parts, and materials for the major manufacturing facilities. The number of supplier jobs will depend on the level of domestic content in the supporting supply chain (i.e., how many of these products are made in the United States instead of being imported). In Figure ES4, we show how the major manufacturing jobs and supplier jobs for a range of 25% to 100% domestic content could expand over time. By 2035, an offshore wind supply chain could create around 10,000 major manufacturing jobs and 10,000–45,000 supplier jobs (for 25% and 100% domestic content, respectively). This result indicates that there is a greater job market opportunity in the supporting supply chain than in the major manufacturing facilities. We discuss this result further in Section 3.2.2.2.

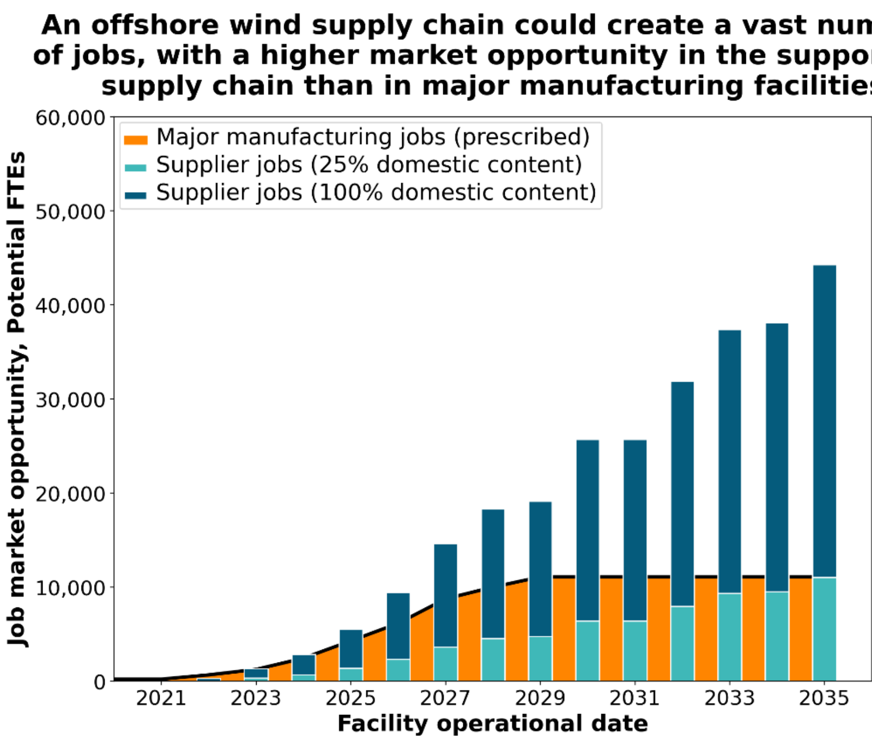

Figure ES5. Major manufacturing jobs and supplier jobs over time assuming a 25% and 100% domestic workforce based on the accelerated supply chain growth scenario.

Note: Major manufacturing jobs are prescribed for each facility in the supply chain scenario and supplier jobs are modeled for varying levels of domestic content. FTEs: full-time equivalents (jobs)

The high proportion of supplier jobs represents a major opportunity for existing businesses with relevant skills and capabilities to manufacture required subassemblies and subcomponents for offshore wind energy. Offshore wind manufacturers and project developers have extensive supplier vetting processes that are time-consuming and potentially confusing for small businesses to navigate. Existing businesses would have to make significant investments in facilities, equipment, certifications, and/or workforce training to qualify as offshore wind energy suppliers. There is a need for increased education and outreach to communicate the role that these businesses can play in the industry, which could help justify the time and financial commitment required to enter the offshore wind supply chain. Furthermore, it will be important to understand the strengths and limitations of existing businesses within individual states and industry sectors so that these supplier jobs can be efficiently distributed throughout the nation by building on existing regional strengths. As a result, we developed a series of metrics to estimate the state-by-state market opportunity for supplier jobs associated with the domestic supply chain scenario presented in this report. These metrics account for states' existing manufacturing capabilities, proximity to the prescribed major manufacturing facilities, and ongoing offshore wind energy planning activities. The total job market opportunity for major manufacturing and supplier jobs is shown in Figure ES6.[4] Improved regional coordination could build on these collective strengths to develop an efficient supply chain that leverages existing capabilities within coastal and noncoastal states. We discuss the potential for a domestic supply chain to create regional benefits in Section 3.2.2.4.

A domestic offshore wind energy supply chain would create a significant job market opportunity throughout the United States. Regional coordination on supply chain activities could build upon the assets of existing industries to create a more efficient supply chain with broadly distributed benefits.

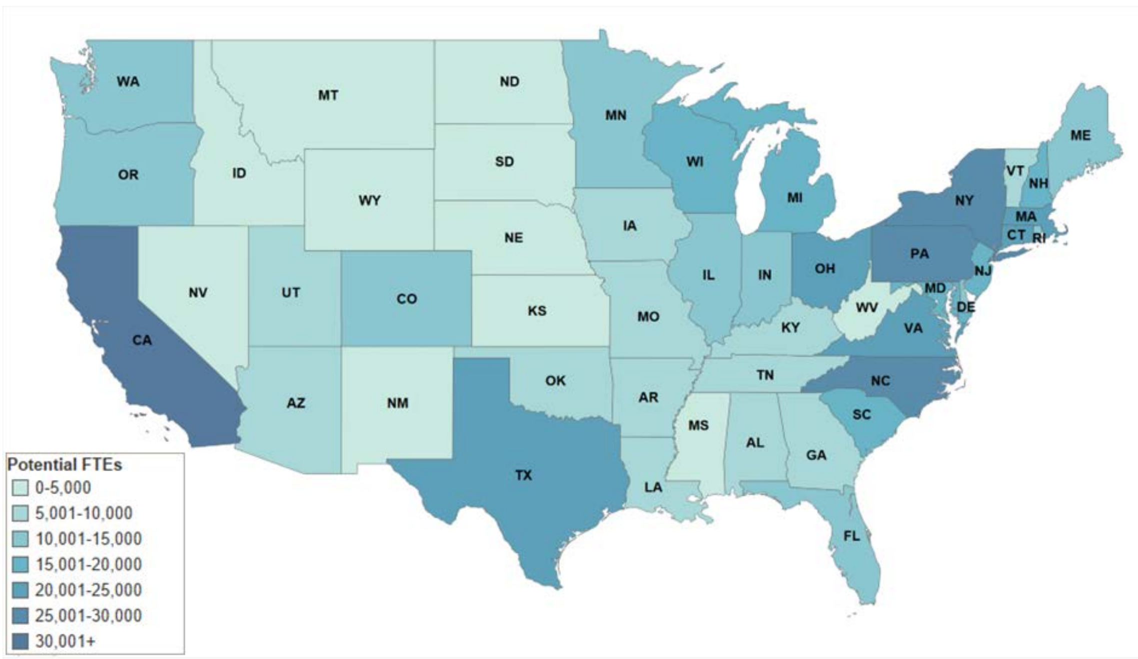

Figure ES6. Total job market opportunity for major manufacturing and supplier jobs by 2035, assuming 100% domestic content.

Note: This figure shows the unique opportunity space to have a share of the jobs for each state but should not be considered as the actual number of jobs. The numbers include major manufacturing and supplier jobs based on scenarios and metrics to estimate the state-by-state market opportunity.

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[4] The job market opportunity represents a relative comparison of the number of national available jobs that could be targeted by each state based on their existing capabilities. It should not be viewed as the actual number of jobs a state will achieve because the job share between states will change as supply chain facilities become operational and hire a workforce from or around a certain state.

Key takeaways include the following:

- The domestic offshore wind supply chain scenario in this report would create around 10,000 full-time equivalent jobs in major manufacturing facilities by 2030.
- For every job created in these major facilities, there is an opportunity space for up to five supplier jobs to produce subassemblies, parts, and materials (depending on how comprehensively the domestic supplier network develops). As a result, there is a greater job market opportunity in the supporting supply chain than in major manufacturing facilities.
- Most states in the United States have existing capabilities that could allow them to participate in the offshore wind supply chain. Improved regional collaboration that engages multiple states could lead to a more resilient supply chain with broadly distributed benefits.

Incorporating Equity and Justice Into Supply Chain Development

Offshore wind supply chain development could create benefits for port communities that have historically hosted disproportionate environmental justice burdens and will be directly affected by new manufacturing facilities (U.S. Environmental Protection Agency 2020a). It will be critical for supply chain decision makers to evaluate the impacts of their activities on these host communities; however, a common framework for assessing these considerations does not currently exist. In Section 2.8, we develop a set of indicators that measure the potential impact of offshore wind supply chain investment on local communities. We then discuss how these indicators could be applied to future supply chain decision-making and summarize ongoing activities being undertaken by state governments, project developers, local governments, community-based organizations, and organized labor to incorporate energy justice principles into planning and development activities.

Key takeaways include the following:

- Meaningfully engaging with trusted local groups and with those most directly impacted by the project is crucial to encourage more just outcomes and community buy-in. If external groups, such as manufacturers or project developers, work directly with community groups to address concerns, it can improve project outcomes and reduce the risk of creating adverse effects for the local community.
- Diverse benefits may be required to address local values and preferences and gain support from various stakeholders. There is typically no one-size-fits-all benefit that supply chain investment could provide to diverse community groups and stakeholders. Understanding the needs of various groups could help identify what benefits are perceived as most valuable to each stakeholder.
- Community context matters. The history, demographics, and existing priorities of port communities can shape their perceptions of a project and how it will impact them. Decision makers that are knowledgeable about and sensitive to local context may be able to avoid conflict and identify solutions that are beneficial to all parties.
- Transparency and accountability in project decision-making are key to building and maintaining trust. Open communication between decision makers and community representatives can help facilitate efficient and mutually beneficial partnerships between industry and community groups.

Summary

It will take time to build a domestic offshore wind supply chain. As a result, there is an urgency to invest in supply chain resources if they are going to contribute to the 30-GW-by-2030 target. Despite this urgency, it will still be critical to meaningfully engage with key stakeholders, including host communities and other groups that will be impacted by new supply chain development. We are faced with a unique opportunity to create a substantial domestic manufacturing industry that can be tailored to support the energy transition, address unique U.S. market conditions, create a stable pipeline of well-paid jobs with robust apprenticeship programs, and maximize benefits to historically disadvantaged communities. Seizing this opportunity will require effective communication and coordination throughout the offshore wind energy sector to make strategic investment decisions in a timely manner while incorporating perspectives from these stakeholders. If we can develop this supply chain in parallel with deploying the first wave of projects in the United States, the domestic industry will be well-positioned to reliably support the expansion of offshore wind energy to help facilitate the transition to a decarbonized economy.

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1 Introduction

The strong pipeline of offshore wind energy projects in the United States represents a significant opportunity to contribute to the nation's decarbonization targets while creating jobs, investing in new infrastructure, and revitalizing underserved communities. A domestic supply chain that comprises major component factories, a robust supporting supply chain, port and vessel resources, a skilled workforce, and an equitable approach to industry growth will form the foundation for achieving these benefits. The importance of forming a domestic supply chain is highlighted in the Biden administration's national offshore wind energy target of 30 gigawatts (GW) by 2030, which emphasizes the need for sustainable local manufacturing and good-paying union jobs (The White House 2021a).

Developing this supply chain is a significant undertaking that requires strategic decision-making from a multitude of stakeholders including federal and state governments, original equipment manufacturers (OEMs), supporting suppliers, host community representatives, project developers, port and vessel operators, workforce educators, organized labor, and the research and development community. Supply chain activity has grown in recent years with around $3 billion of announced investments in manufacturing facilities, ports, and vessels to support offshore wind energy manufacturing and installation (Musial et al. 2022). However, a fully domestic supply chain will require greater investment to create a robust and resilient system that can avoid delays due to global supply chain bottlenecks and realize the potential jobs and economic benefits offered by offshore wind energy. These investments will have the highest impact if they are made strategically to address the areas of highest need, which will require a common vision for a domestic offshore wind supply chain and a universal understanding of the actions required to develop this infrastructure.

This report presents the critical considerations for developing a comprehensive offshore wind supply chain in the United States, including major barriers to investment and potential solutions to overcome these challenges. The findings are based on interviews with dozens of industry professionals, including technology providers and manufacturers, economic development agencies, subcomponent producers, and project developers, combined with newly developed analyses that evaluate the potential impacts of a domestic supply chain on levelized cost of energy (LCOE), deployment bottlenecks, state-by-state job potential, and energy justice impacts on host communities. The primary goals of this report are to present potential scenarios that provide a common understanding of the scope, time frame, and investment required to achieve this future vision, and to highlight critical paths for progressing toward a self-sufficient, sustainable, and just industry.

1.1 The Demand for a Domestic Offshore Wind Energy Supply Chain

Shields et al. (2022) published "The Demand for a Domestic Offshore Wind Energy Supply Chain," which estimated the demand for major components, ports, vessels, and workforce required to support the U.S. offshore wind energy project pipeline. The results were based on a deployment pipeline of awarded, soon-to-be-awarded, and anticipated fixed-bottom and floating lease areas throughout the United States. This pipeline, shown in Figure 1, provides a pathway to meeting the national offshore wind energy target, indicating 30.1 GW of projects that could be installed by 2030. This pipeline has a relatively constant deployment rate of 4-6 GW per year after 2028, which would put the nation on a pathway toward installing a cumulative capacity of nearly 60 GW by 2035 and 110 GW by 2050. Since the publication of Shields et al. (2022), the Biden administration announced expanded plans to grow the floating offshore wind energy industry, including a target to install 15 GW of floating offshore wind by 2035 and a Floating Offshore Wind Shot to reduce the costs of floating offshore wind by 70% over this same time frame (U.S. Department of Energy [DOE] Wind Energy Technologies Office 2022a; The White House 2022b.

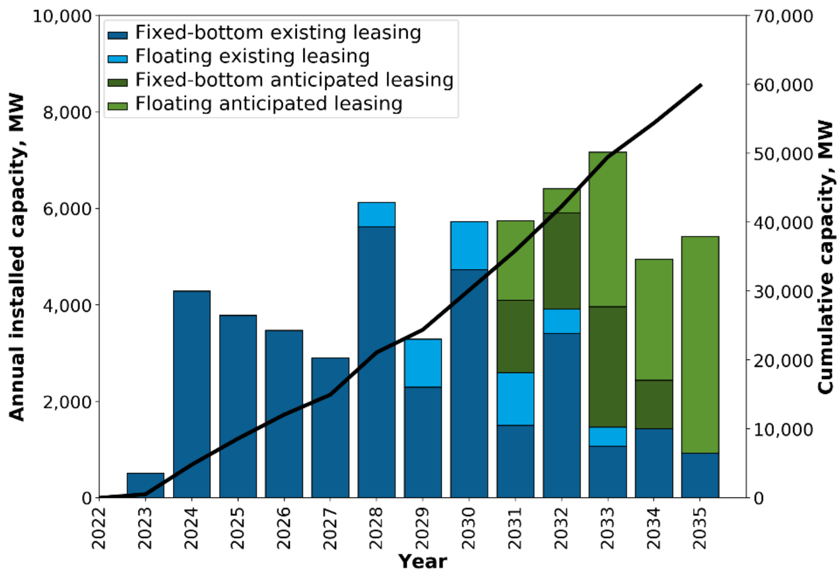

Figure 1. Annual and cumulative installed capacity for existing and anticipated lease areas. *Figure from Shields et al. (2022)*

With no supply chain constraints, 30.1 GW are expected to be installed by the end of 2030. The Bureau of Ocean Energy Management's anticipated leasing of new areas from 2022 to 2025 will be required to maintain a consistent deployment rate after 2030 (MW = megawatts).

Meeting the deployment rates shown in Figure 1 would require a substantial amount of offshore wind energy components and resources, including wind turbines, foundations, cables, and vessels; the demand for these assets is shown in Figure 2. Shields et al. (2022) emphasize that it is not realistic to completely rely on supply chains in Europe or Asia to import all of these components to the United States because global demand for offshore wind deployment is increasing and existing suppliers do not have the production capacity to support the entire industry. For example, Telsnig et al. (2022) estimate that Siemens Gamesa Renewable Energy, General Electric, and Vestas can supply around 6.5–8 GW of nacelle and blade capacity per year. This production capacity would just barely be able to support anticipated European offshore wind deployment of 8–9 GW/year by 2030 (Telsnig et al. 2022). Furthermore, there are a limited number of existing ports and installation vessels in the country that can support commercial-scale offshore wind energy construction, which represents an additional risk to the deployment pipeline. This realization is key in developing a domestic offshore wind supply chain to de-risk the national offshore wind target.

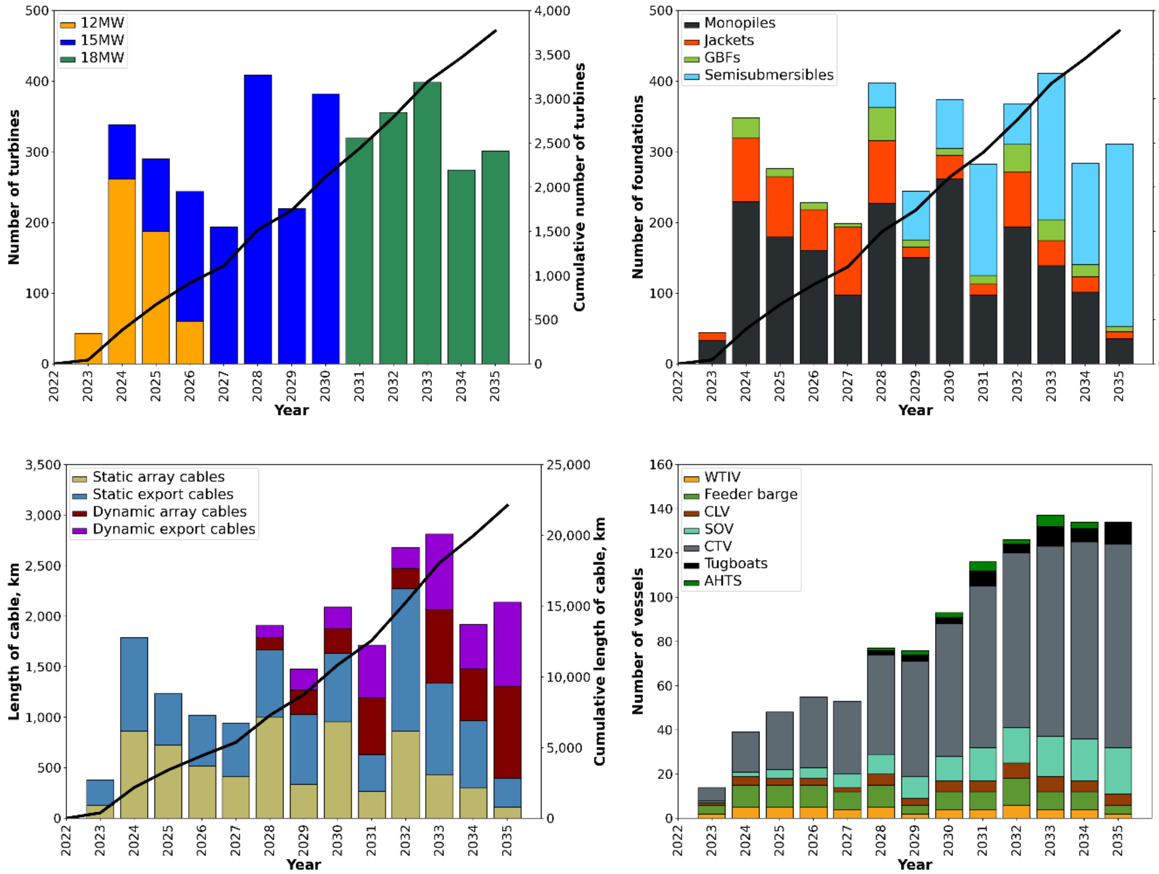

Figure 2. Annual and cumulative component demand for (clockwise from top left) wind turbines, foundations, vessels, and cables. *Figure from Shields et al. (2022)*

GBF = gravity-based foundation; WTIV = wind turbine installation vessel; CLV = cable-lay vessel; SOV = service operation vessel; CTV = crew transfer vessel; AHTS = anchor handling tug supply.

Establishing the manufacturing capabilities to meet the component demand shown in Figure 2 will require a newly trained workforce that can fabricate the specialty components needed for offshore wind energy projects. Shields et al. (2022) estimate that the offshore wind workforce could comprise between 12,300 and 49,000 average annual jobs, depending on prescribed levels of domestic content (i.e., the percentage of the supply chain that is located within the United States); this range of jobs is shown in Figure 3. The job numbers reported in Figure 3 comprise multiple tiers of offshore wind energy components, which are defined as:

- **Tier 1: Finished components**. Finished components are the major products that are purchased by an offshore wind energy project developer, such as the wind turbine, foundation, or cables. Tier 1 suppliers contract directly with the project developer.
- **Tier 2: Subassemblies**. Subassemblies are the systems that have a specific function for a Tier 1 component, which may include subassemblies of numerous smaller parts, such as a pitch system for blades. Tier 2 manufacturers contract with Tier 1 suppliers as a subcontractor or vendor.

- **Tier 3: Subcomponents**. Subcomponents are commonly available items that are combined into Tier 2 subassemblies, such as motors, bolts, and gears. Tier 3 manufacturers are typically vendors that provide components to Tier 2 suppliers.
- **Tier 4: Raw materials**. Raw materials, such as steel, copper, carbon fiber, concrete, or rare-earth metals, are directly processed into Tier 2 or 3 components.

Most of this anticipated workforce is in the indirect supply chain, which produces Tier 2, 3, and 4 components and materials. Many of these roles could be filled by existing domestic suppliers, representing a significant opportunity for local manufacturing and workforce.

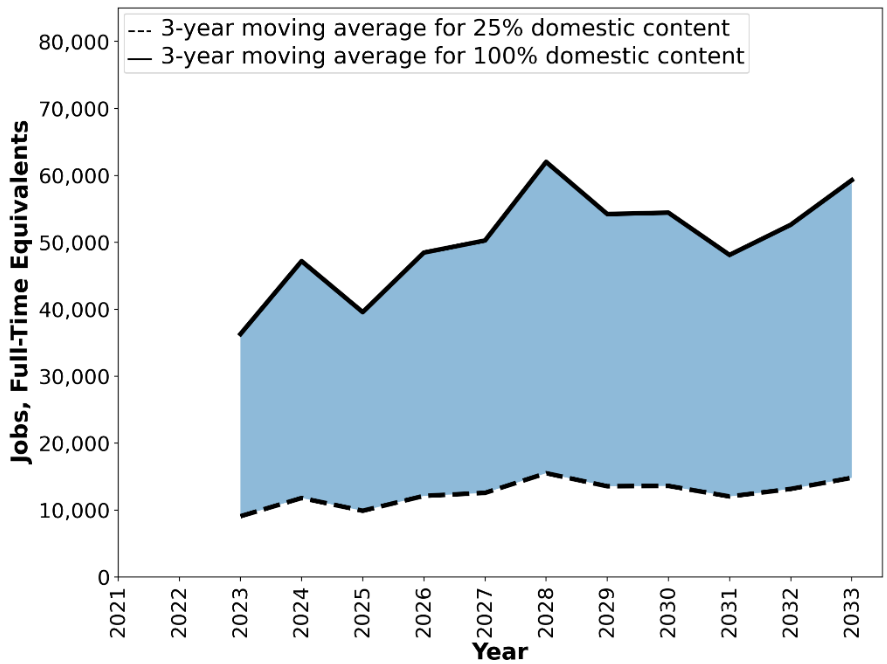

Figure 3. Number of manufacturing jobs for component demand for a range of domestic content in the entire supply chain. *Figure from Shields et al. (2022)*

"The Demand for a Domestic Offshore Wind Energy Supply Chain" concludes that offshore wind has huge potential for creating clean energy and manufacturing jobs, and will require major investment in factories, ports, vessels, and workforce training initiatives. This report builds on the initial findings presented by Shields et al. (2022) to outline pathways to realizing the economic benefits and resilient supply chain to formulate a sustainable, long-term offshore wind energy industry in the United States.

1.2 Report Content

The following sections of this report will present:

- Considerations that decision makers will need to account for when planning or investing in supply chain resources, including major barriers to development, regional supply chain perspectives, requirements for constructing major assets, engaging communities and supporting suppliers, and workforce training (Section 2)

- A scenario-based discussion of what a complete offshore wind energy supply chain could look like, the time frame required to develop supply chain resources, and the level of investment required to develop the supply chain (Section 3.1)

- Analysis of the potential impacts of a domestic supply chain on deployment bottlenecks, job and economic benefit opportunities throughout the United States, the LCOE of offshore wind energy projects, and energy justice impacts on host communities (Section 3.2)

- Potential solutions that could help overcome barriers to supply chain investment and time frames for actionable next steps (Section 4).

An important clarification about the results in this report is that the supply chain scenarios provide examples of possible futures for the U.S. supply chain and are not intended to predict how it will evolve. The authors use these scenarios to demonstrate the potential impacts of the supply chain, which will be based on when and where supply chain resources are developed.

The results of our analysis show that there is a pathway to establishing a robust domestic supply chain by the end of the decade. This report focuses on the supply chain required to deploy 30 GW by 2030, which means that we primarily focus on the infrastructure needed on the East Coast to install the fixed-bottom pipeline. The deployment pipeline from Shields et al. (2022) does assume that 2.5 GW of floating offshore wind energy could be operational on the West Coast by 2030; we therefore include the manufacturing facilities and marshaling ports required to support these projects in the supply chain scenarios presented.

The supply chain scenario includes at least 34 manufacturing facilities for critical components, fabrication ports for most of these facilities, 8 marshaling ports on the East Coast, 2 floating wind integration ports on the West Coast, 4-6 dedicated wind turbine installation vessels (WTIVs), 4-6 dedicated heavy-lift vessels (HLVs), and 4–8 specialized U.S.-flagged[5] feeder barges. These resources will require an investment of at least $22.4 billion in the 2020s. Further analysis will help us better understand how the supply chain will need to expand to support the growth of the floating wind energy industry in the early 2030s. This scenario can be considered an initial investment in the U.S. supply chain to establish a strong manufacturing and workforce foundation that can contribute to the first wave of project installations. We expect that further growth and investment will be needed after 2030.

We will demonstrate that developing a self-sufficient supply chain by 2030 is possible but would require immediate decision-making and investment due to the long permitting and construction timelines required to build manufacturing facilities, ports, and installation vessels. This urgency can potentially conflict with the time required to make strategic decisions that evaluate the impacts of supply chain investment on both the offshore wind energy industry and the host communities that will be impacted by new facilities.

[5] A U.S.-flagged vessel is registered and operated under U.S. laws, used in a commercial trade within the United States, and owned and operated by U.S. citizens.

As a result, it is important to establish sustainable decision-making frameworks that coordinate multiple organizations throughout the industry so that the supply chain can leverage existing strengths and effectively address both short- and long-term needs. We believe that establishing a resilient, sustainable, and just supply chain by 2030 that can support the deployment of 4–6 GW of offshore wind energy per year is equally as important as the actual deployed capacity. Both goals are critical for the long-term success of the offshore wind energy sector. Installing the first 30 GW of projects will help provide valuable insights into the most effective technologies, policies, processes, and skill sets needed to build the offshore wind industry in the United States. Developing a robust and nimble supply chain at the same time will position the industry to apply the experience gained during the installation of the first 30 GW to refine these approaches to best suit the domestic market and expand the role of domestic manufacturing and labor in the long-term growth of the industry.

A key goal of this report is to identify some of the major barriers that the sector faces and to suggest possible approaches to address these barriers and enable the initial development of the domestic supply chain. Working toward ambitious deployment targets while establishing domestic manufacturing and workforce capabilities will put offshore wind energy in the best position to meaningfully contribute to a decarbonized energy future in the United States.

2 Considerations for Developing Supply Chain Resources

The pathway to developing a domestic supply chain begins with understanding the barriers in place that will affect investment. Through conversations with a wide range of industry experts, we consolidated the major obstacles being faced in the planning and development process into a list of barriers to supply chain development. In this section, we present these barriers and describe why they are significant challenges. We then discuss the major aspects and perspectives of offshore wind supply chain development and review significant factors that must be considered when making decisions about growing the domestic supply chain.

2.1 Barriers to Supply Chain Development

The Biden administration, the Bureau of Ocean Energy Management (BOEM), and individual state governments have made substantial progress to create a strong pipeline of planned projects and procurement targets. However, uncertainty surrounding the potential impacts of construction delays, cost overruns, legal complications, or changes in government support for offshore wind creates an investment risk that makes it difficult to secure financing for new supply chain facilities (factories, ports, and vessels).

The most common perspective that offshore wind energy manufacturers shared with us was that the perceived risks of offshore wind project cost or schedule overruns make it more difficult to secure financing for new facilities that would make up a domestic supply chain. BOEM has made substantial efforts to provide a clear plan for future offshore wind leasing, which is a critical aspect of increasing investor confidence in the pipeline. Still, even with a substantial pipeline of projects in the planning, development, or construction stages, no commercial-scale projects have been commissioned in the United States as of the end of 2022. Major projects have experienced delays due to permitting and legal complications or increased costs relative to initial public filings. Lenders (or manufacturers that finance construction projects from their own balance sheets) typically require a stable 5- to 10-year order book (which could include committed orders, memoranda of understanding, preagreements, or having other types of contractual mechanisms in place) to invest in a new manufacturing factory, port, or vessel.

Conversely, it is difficult for manufacturers to close contracts without having an operational facility. Suppliers prefer a predictable longer-term pipeline to better justify the up-front investment in construction, equipment, training, and certification. They also want to be sure that their facility is in a state that will remain committed to offshore wind energy procurement over its lifetime, which will help guarantee future business with project developers focused on achieving local content requirements for electricity offtake agreements with that state. The uncertainty in the pipeline impacts manufacturers as well as the Tier 2 and Tier 3 suppliers that contribute to the overall supply chain; supporting suppliers are faced with additional uncertainty surrounding the types of certifications required to qualify as offshore wind energy suppliers. Additional sources of deployment uncertainty include the capacity of the electricity grid to handle the injection of significant amounts of offshore wind energy; the ability of the offshore wind industry to coordinate with other ocean users such as fisheries; a lengthy, complex, and sometimes unclear process for environmental and regulatory approval; and the potential for federal or state policies to become less favorable for offshore wind energy in the future.

Major offshore wind manufacturing facilities can only be built in suitable ports, but construction of these facilities is constrained by limited available port space and uncertain permitting and construction timelines. Wind turbine capacities have been rapidly increasing in recent years, and if this trend continues, supply chain assets (including ports and vessels) designed around current technology may become obsolete or require additional investment before paying off the upfront investment.

The size and weight of Tier 1 offshore wind components place strict requirements on the potential locations for new manufacturing facilities. Most importantly, as the finished components are too big to transport via road or railway, factories need to be located at ports or along waterways. The facilities also need sufficient acreage, quayside length, quayside bearing capacity, and navigation channel depth to safely fabricate, maneuver, and load out components. Some offshore wind energy components, such as jackets or transition pieces, are transported vertically, which means that there can be no low bridges along the navigation channel. The rapid growth in wind turbine size creates uncertainty about how offshore wind technology will evolve over the next decade and how manufacturing facilities need to be designed to accommodate larger and larger components.

There is a limited number of existing port facilities in the United States that have sufficient capabilities to meet all of these requirements, and most of the likely locations for new facilities will require significant investment to meet the requirements for component manufacturing facilities. These upgrades will be expensive (potentially hundreds of millions of dollars) and will likely require over a year of site preparation before the manufacturing facility can be constructed. Channel dredging is particularly challenging as it needs to be conducted by the U.S. Army Corps of Engineers, which does not have a fixed timeline for conducting the work. Furthermore, the permitting requirements for building offshore wind energy manufacturing facilities may vary from state to state, which creates additional complexity and uncertainty for manufacturers. Sourcing major components from international supply chains may present a challenge due to competing demand from European or Asian projects. As a result, factories must expand to meet the increasing global demand and uncertain technology evolutions, and manufacturers will choose whether to make their investments in the United States or elsewhere in the world.

Existing supplier networks will be stressed to provide the required raw materials and subcomponents needed to fabricate major components.

Tier 1 offshore wind manufacturing facilities often import underlying components for assembly and finishing operations. Several critical items include steel plates (used in monopiles and towers), rare-earth metals, permanent magnets (used in generators), balsa wood and carbon (used in blades), hub castings, gearboxes, and generators (used in nacelles). European supply chains are expected to be stretched thin to support local offshore wind energy development (Telsnig et al. 2022); although some of these underlying components will likely be provided to the U.S. market, it is unlikely that sufficient production capacity exists to meet the demands of the national offshore wind target. Many of these components could be produced by existing domestic manufacturers that are currently active in sectors such as land-based wind energy, oil and gas, or shipbuilding; however, these companies would have to invest heavily in new certifications, trainings, and equipment to pivot toward offshore wind. Furthermore, many of the European OEMs and project developers have less familiarity with companies in the United

States and would require multiple years to vet suppliers that are new to the offshore wind energy industry. Existing companies in the United States that want to support the industry will require a strong and predictable demand to retool their operations. Finally, recent shocks to global supply chains (primarily the COVID-19 pandemic and the Russia-Ukraine war) have created additional bottlenecks and increased costs for sourcing raw materials and commodities.

Existing port and vessel infrastructure is inadequate to install 30 GW of offshore wind energy by 2030.

Offshore wind energy projects require a marshaling port to stage major components and highly specialized installation vessels to transport and install those components at sea. At least eight ports have been identified as potential marshaling ports and are currently ready, under construction, or planning to develop the capabilities required for offshore wind activities. However, the available acreage at these ports is significantly smaller than corresponding European marshaling ports, which puts the ability of the port to support on-time project installation at risk. As a result, the industry is seeking alternate solutions, such as transporting components directly from fabrication ports to the project installation site; however, this approach requires additional storage capacity at the fabrication ports that may not be available.

A global scarcity of WTIVs and HLVs that can install next-generation wind turbines (15 megawatts [MW] and above) and their corresponding foundations presents a critical challenge. Five European WTIVs exist (or are under construction) that could be used in the United States, but the market will have to compete with European projects for these vessels. The Jones Act ensures that European vessels will not be able to transport merchandise from U.S. ports to the defined project site and will require feeder barges to transport components. One domestic WTIV is currently under construction but will not be enough to service the entire deployment pipeline. Lengthy construction timelines (at least 3-4 years) and a limited number of U.S. shipyards with the capability, availability, and motivation to build WTIVs make it difficult to develop a sufficient number to meet the national offshore wind target.

Finally, investment in new U.S.-flagged vessels has been slowed because of uncertainty surrounding future revisions or reinterpretations of the Jones Act that could limit access to the global installation vessel fleet and adversely impact project development timelines. The United States currently has a shortage of mariners with offshore wind experience, and so any limited access to the global fleet could lead to project delays until a sufficient number of mariners are trained. We do not advocate for limiting or revoking the Jones Act, but we do identify the perceived risk of future changes to the legislation as an obstacle for investing in some U.S.-flagged construction vessels due to the confusion and uncertainty created by this risk.

Some offshore wind components require a specialized manufacturing workforce that may not be readily available in the United States.

A domestic offshore wind energy supply chain could create tens of thousands of jobs, but much of this workforce will require dedicated training beyond what is currently offered. Job roles requiring basic and skilled trades are the most common across industry segments, including construction support roles such as factory-level workers who manufacture offshore wind components, terminal crews who load vessels at ports, and construction crews on vessels. The demand for skilled manufacturing and construction jobs is compounded by high demand in other industries. Therefore, attracting and training workers from these industries will require a transition period and concerted efforts, especially to mitigate potential peaks and troughs of workforce demand.

Marine-grade welding of massive offshore wind energy structures is the primary gap in the expertise of the existing workforce; this particularly applies to monopiles (which are built out of 3- to 5-inch-thick steel plates that could grow to 7 inches in coming years) and WTIVs (which feature jack-up legs that are subjected to frequent load cycles). Other industry sectors anticipate hiring and training local workers (either at U.S. training facilities or at job sites in Europe). For example, a blade production worker that focuses on finishing processes might require training or experience with carpentry or fiberglass repair, which differs from the skills needed in a steel-only component. For workers assembling nacelles, specialties include electrical package installation and mechanical assembly, as well as fabrication skills associated with metal alloys, which are sometimes automated (requiring automated machine operation experience). For cable manufacturing, machine operators must have experience in extruder, drawing, stranding, assembly, screening, jacketing, rewind line, and testing for cables at a low-to-medium voltage or high voltage. The time required for training, existing workforce shortages for some trades, worker preferences, uncertainty about necessary skills needed to manufacture next generation offshore wind turbine components, and lack of transparency into training magnitude and needs for the first phases of offshore wind manufacturing could delay the entire pipeline and create challenges in installing 30 GW by 2030.

Recent federal incentives such as the Inflation Reduction Act of 2022 (IRA) will help domestically produced components be cost competitive with imports from established international manufacturing facilities. However, additional incentives may be required to encourage domestic manufacturing of components or supply chain assets which are either not considered in the IRA or receive credits that are smaller than the cost premium for domestic manufacturing.

Offshore wind energy components produced in new manufacturing facilities in the United States will include cost premiums required to pay off the investment cost of the new facility. Our interviews with Tier 1 and Tier 2 offshore wind manufacturers indicated that, in many cases, the location of next-generation factories will be driven by the ability to produce components that are cost competitive on the global market, built with high quality and safety standards, and contribute prevailing wages and robust training programs to the manufacturing workforce. Most European facilities are already fully depreciated and no longer add these premiums to the components they produce; however, these components incur additional costs for trans-Atlantic transportation and, in some cases, import tariffs. Other key cost categories, such as wages and taxes, depend on the specific component and the location where it is produced. Offshore wind manufacturers indicated that wage differences between the U.S. and Europe are one of the most significant sources of component cost differences, with the U.S. typically being more expensive. Components produced for floating wind energy projects on the West Coast will have to compete with low-cost and relatively mature supply chains in southeast Asia, which are already ramping up production to support projects in South Korea, Japan, and Taiwan (although these components will also incur costs to transport across the Pacific).

More recently, interest rates have begun to climb and subsequently increase the cost of capital required to build new facilities or components. Tax credits, subsidies, and public investment could defray the costs of domestically produced offshore wind components by reducing the upfront capital costs needed for new facilities. The IRA will provide a significant benefit to domestically manufactured wind turbines and foundations, although these incentives do not extend to components such as cables or Tier 2 or 3 parts and will expire in 2032. Furthermore, offshore wind vessels receive a 10% credit off of the sale price, but interviews with vessel operators and shipyards have indicated that building these vessels in the U.S. could be around twice as expensive as foreign shipyards. The uncertainty surrounding the future costs of offshore wind components built in the United States complicates the business model for building new facilities as it is unclear if these components will help developers meet the cost targets they commit to in offtake agreements or allow OEMs to export components to international markets. A domestic offshore wind manufacturing industry will have to mature and innovate to reduce manufacturing costs for long-term cost competitiveness.

Incorporating equity and sustainability into supply chain decision-making is resource-intensive and insufficiently incentivized, which may result in unjust outcomes for host communities.

Due to the availability of current technologies and the size of offshore wind infrastructure components, the offshore wind supply chain must be primarily developed in ports. In the United States, port communities tend to be low-income and mostly nonwhite, with histories of shouldering disproportionately high environmental injustice. Understanding and addressing the impacts that the offshore wind supply chain may have on these communities should be integrated into the planning and development of the domestic offshore wind supply chain. However, because every community is unique in composition, diversity, needs, and historic burdens, there is no one-size-fits-all metric, assessment, or approach for measuring equity or facilitating equitable development and operations.

Economic, social, and environmental metrics can help highlight the unique burdens and needs of a community at a high level, providing a baseline for evaluating both ongoing and anticipated impacts of the port-based industry. Qualitative data should support these quantitative indicators to provide a critical, community-specific context that may otherwise be lacking. Neglecting to understand community context can lead to further problems, such as project delays, harm to community members, and distrust of future development. However, both quantitative and qualitative data can be challenging and resource-intensive to collect, particularly when working with understudied, historically marginalized, or hard-to-reach community members.

Disadvantaged communities tend to have less power over decisions that impact them compared to their more affluent counterparts, and thus may be viewed as the path of least resistance to building new industry. Further, there is the possibility that anticipated positive impacts of supply chain activities will not necessarily benefit the local community. The development of the offshore wind supply chain presents an opportunity to revitalize and uplift port and near-port communities, but attaining this equitably requires intentional planning, long-term investments, and incorporating the concerns and needs of impacted communities. These resource-intensive practices are currently not sufficiently supported by regulations or incentive programs, so it is up to developers to include them in their planning and execution efforts.

2.2 The Inflation Reduction Act of 2022

In August of 2022, the United States passed the IRA, which (in addition to many other goals) took direct action to incentivize domestic manufacturing of offshore wind energy components, good-paying union jobs, and positive impacts on energy communities (H.R. 5376, 117th Congress 2021-2022). The law extends the tax credits for clean energy projects (including the 30% investment tax credit most applicable to offshore wind) and makes their full value contingent on labor practices, including paying prevailing wages and using qualified workers from registered apprenticeship programs. The law also offers bonus credits for projects that meet domestic content thresholds and/or are located in "energy communities" (communities previously dependent on fossil-fuel employment or infrastructure).

Domestic offshore wind manufacturers will likely be most impacted by a new Section 45X Advanced Manufacturing Production Tax Credit (AMPTC), which offers incentives to U.S. manufacturing of certain wind components as listed in Table 1.

Table 1. Advanced Manufacturing Production Tax Credit Provisions in the Inflation Reduction Act of 2022 (H.R. 5376, 117th Congress 2021-2022)

Component	Tax Credit	Tax Credit Value per Component in a 15-MW Wind Turbine System	Approximate Percent of Total Component Value in a 15-MW Wind Turbine System[6]
Blade	$0.02/watt (W)	$300,000	15%
Nacelle	$0.05/W	$750,000	10%
Tower	$0.03/W	$450,000	20%
Fixed-bottom foundation	$0.02/W	$300,000	10%
Floating foundation	$0.04/W	$600,000	5%
Related offshore wind	10% of sales	N/A	N/A

The IRA also expands the Section 48C Advanced Manufacturing Tax Credit to provide $10 billion in tax credits to facilities that produce qualified renewable energy components; the tax credit can be up to 30% of the amount invested in new or upgraded facilities. Components produced in facilities benefiting from the 48C credit cannot also claim the 45X AMPTC. Four billion dollars of these credits are reserved for energy communities. Additional impacts on the offshore wind energy industry include the appropriation of $100 million to study interregional transmission development, the authorization to issue offshore wind leasing off the coasts of North Carolina, South Carolina, Georgia, and Florida, expanding DOE loan programs, and providing funding for green banks to support clean energy investment.

The full impacts of the IRA cannot be fully estimated at this stage due to some remaining uncertainty about how the law will be interpreted and how its implementing guidance will affect domestic manufacturing. New offshore wind manufacturing facilities typically need to operate for at least 10 years to justify the upfront investment; however, the AMPTCs begin to phase out

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[6] We estimated 15-MW component values using the National Renewable Energy Laboratory's Wind-Plant Integrated System Design & Engineering Model (WISDEM®) (https://github.com/WISDEM).

in 2030 and end in 2032. Given the relatively long permitting and construction time it takes to bring new facilities online, the expiration of the AMPTCs limits the ability of manufacturers to take advantage of tax credits during the planned useful life of the factory. The domestic industry could have to make up for the eventual loss of the AMPTCs through innovation, efficiency, and supply chain maturity for domestic components to remain cost competitive with imported components after 2032. Offshore wind energy facilities will have to compete with other manufacturing sectors for a finite (although large) amount of 48C tax credits. Furthermore, the IRA requires future offshore wind leasing to follow the issuance of oil-and-gas leasing; if BOEM does not offer sufficient oil-and-gas opportunities, the offshore wind pipeline may be constrained. Finally, the Internal Revenue Service has not yet issued guidance on details such as how domestic content will be measured or what qualifies as an energy community, which could impact the magnitude of the benefits that specific facilities could obtain (U.S. Department of the Treasury 2022).

Despite this uncertainty, offshore wind energy manufacturers and labor representatives view the IRA as a significant benefit to the industry. Based on our conversations with major manufacturers that are considering building new offshore wind facilities, the incentives in the IRA have the potential to make domestic components cost competitive with imported ones, thereby driving decisions to build new facilities in the United States. The growth of a domestic workforce with good-paying jobs, apprenticeship programs, and directed benefits to energy communities will help to create a sustainable pipeline of workers that can support the industry over the long term. The development of this workforce could engage organized labor to establish positive working conditions that will support the recruitment of a future workforce and will offer these jobs and subsequent benefits to disadvantaged communities (such as port communities) that have a high need for new opportunities and are also most impacted by the growth of the supply chain. Finally, the passage of the IRA demonstrates strong policy support for the offshore wind sector from the federal government and will help to provide transparency and predictability to the cost, policy, workforce, and energy justice considerations that need to be taken into account when investing in new supply chain resources.

2.3 Federal, State, and Regional Supply Chain Perspectives

Section 2.1 discusses the significant challenges associated with developing a domestic offshore wind energy supply chain. Addressing these barriers will require coordination between a range of stakeholders, including federal and state governments, project developers, OEMs, Tier 2 and 3 suppliers, organized labor, and community representatives, each of whom will have a unique role to play in developing the supply chain. At the present time, there is limited engagement between these different groups, which creates uncertainty about the most efficient pathways to strategically develop supply chain resources; for example, many states that are active in offshore wind energy development are focused within their own borders and are not giving detailed consideration to how they can leverage the strengths of their neighbors. This limited communication is not entirely due to competition between states (although some competition exists to claim large supply chain investments) but indicates the lack of an organizational framework with a clear strategic understanding of the most valuable roles each entity can contribute to the growth of the industry.

Realizing that this compartmentalized approach could be hindering the development of a domestic offshore wind workforce and supply chain, the White House and 11 East Coast states announced the Federal-State Offshore Wind Implementation Partnership in July 2022 (The White House 2022a). This agreement between key federal and state decision makers focuses on collaborative efforts to grow the supply chain, develop a skilled workforce, address high-priority gaps, engage with underserved communities, and facilitate effective permitting and environmental reviews.

Following the announcement, the authors collaborated with DOE and the National Offshore Wind Research and Development Consortium to host a 2-day workshop with key representatives from states, the federal government, research agencies, industry, and economic development agencies. The goal of the workshop was to initiate conversations between critical supply chain decision makers to begin developing solutions that meet the objectives of the implementation partnership and to provide these stakeholders an opportunity to voice their perspectives on supply chain development needs and opportunities. These perspectives are incorporated throughout this report.

One focus of the workshop was to explore the opportunity for regional collaboration to better coordinate resources and strategies between states to develop a more effective supply chain. The major findings of the workshop were:

- Regional supply chain clusters provide a high value to the offshore wind energy industry as neighboring states can pool resources and align goals more effectively than the entire spectrum of states involved in offshore wind
- The federal government (or another third-party agency) can play a valuable role in helping individual states form agreements or clusters, as well as coordinating between multiple regional clusters. These types of partnerships or working groups would be more impactful if they are funded or incentivized appropriately.
- Establishing flexible and transparent local content requirements that are consistent throughout the East Coast states would be advantageous and could help to catalyze domestic supply chains. Some proposed examples include:
    - Hierarchical domestic content requirements in offtake agreements in which in-state investments are weighted most highly, followed by regional, domestic, and international investments.
    - A content trading system between states, similar to carbon trading systems.
- Regional agreements help to communicate the opportunity and requirements for getting involved in the supply chain to local companies because there are existing communication pathways and relationships between state governments and local businesses.

A key takeaway from the workshop is that the various entities were uniformly eager to work together to develop effective offshore wind energy supply chain solutions. There are several ongoing efforts in this area, such as the SMART-POWER agreement between Maryland, Virginia, and North Carolina (Maryland Energy Administration 2020) and the Shared Vision between BOEM, New York, and New Jersey (BOEM 2022a). These agreements include pledges from the involved state and federal agencies to streamline regulatory environments, publicize long-term planning efforts to improve certainty in the pipeline, collectively develop supply chain resources, and publish best practices from their collaborations. These regional collaborations are still in the early stages of developing solutions, and their role will gain prominence following the increased incentives for domestic manufacturing within the IRA.

Regional collaborations could potentially grow to include states that do not currently have planned offshore wind procurement targets or active offtake agreements; as we will describe later in this report, many states can play a role in an offshore wind supply chain. Further expanding (and funding) these cooperative groups to develop supply chain solutions that serve the long-term interests of the industry as well as the needs of individual states, communities, and businesses will greatly improve the development of a domestic supply chain.

2.4 Port and Vessel Infrastructure

2.4.1 Ongoing Port and Vessel Development

Building and installing the offshore wind energy pipeline will require a myriad of port and vessel resources, with a particular focus on:

- **Marshaling ports.** A port with sufficient laydown area and quayside loading capabilities to stage major components (e.g., blades, towers, nacelles, foundations) and load them onto installation vessels. The complex logistics of maneuvering and loading these components mean that marshaling ports have the most challenging spatial requirements for offshore wind ports (Parkison and Kempton 2022). Existing and proposed marshaling port locations in the United States are significantly smaller than corresponding facilities in Europe as much of the land area on the East Coast has been developed as residential property or is an environmentally protected area (Parkison and Kempton 2022).

- **Fabrication ports.** Offshore wind component factories need to be located at a fabrication port because the components they manufacture are too large for road or rail transport. These ports require access to a waterway with sufficient navigation channel depth and width for barge access but have fewer air-draft restrictions than marshaling ports as many offshore wind components can be transported horizontally. Individual components and OEMs have their own requirements for fabrication ports and need sufficient space and bearing capacity for local manufacturing operations; however, the demands are less restrictive than those for marshaling ports, and therefore there are a larger number of prospective sites along the East Coast (although all would require significant investment before being serviceable) (Parkison and Kempton 2022).

- **WTIVs**. WTIVs are highly specialized vessels that can transport and assemble offshore wind turbines at sea. Components can be loaded onto the WTIV at the marshaling port, or it can wait at the project site for components to be delivered using feeder barges. The former approach requires the WTIV to be Jones-Act-compliant, meaning that it is built, owned, and crewed by United States shipyards, owners, and sailors. There are only 6−7 WTIVs in the global fleet that can install next-generation wind turbines (Shields et al. 2022; Musial et al. 2022). WTIVs are so specialized that it is unlikely that existing vessels from other industries could be repurposed to install wind turbine components at sea.

- **HLVs.** HLVs are traditionally used in the oil-and-gas industry to transport and install production platforms or install foundations such as monopiles or jackets. As offshore wind turbines continue to grow in size, the industry will likely trend toward using HLVs to install most (or all) foundations and WTIVs to exclusively install wind turbines (Foxwell 2022). Many HLVs are currently occupied in the oil-and-gas market, and new builds may be required to handle next-generation monopiles and/or reduce costs and carbon footprints (Foxwell 2022). HLVs that are active in the oil-and-gas market would likely require significant retrofits to accommodate the different crane, pile-driving, and lift types needed to install offshore wind foundations.

- **Feeder barges.** These U.S.-flagged vessels transport components from ports to offshore wind energy project locations. They could be jack-up vessels, which lift themselves off the seafloor while a WTIV or HLV picks up components from the deck, or they could be floating barges, which need to be stabilized during component transfer (for example, using an external system that would allow the WTIV to lift the barge out of the water (Friede and Goldman 2021). Jack-up barges exist in the United States but are likely too small for next-generation wind turbines, and floating barges are challenging because of the risk of motion during the component transfer (Von Ah et al. 2020). Next-generation specialized feeder vessels are under development, which can fit larger wind turbine components and support other installation activities such as placing rock layers along the seafloor to protect foundations or cables (DEKC Maritime 2021). An offshore wind energy project using a feeder strategy will likely require 2–3 vessels to keep the WTIV or HLV continuously supplied with components (Von Ah et al. 2020).

Other port and vessel resources include operations and maintenance (O&M) ports, fall pipe vessels, anchor handling tug vessels, and semisubmersible barges (Shields et al. 2022); although these assets are critical for the construction and operation of commercial-scale offshore wind energy projects, they do not represent the same deployment risk for the 30-GW-by-2030 target as the five types of resource listed earlier. As a result, this report primarily focuses on marshaling and fabrication ports, WTIVs, HLVs, and feeder barges. It is critical to develop this infrastructure within the United States because there is no realistic scenario in which broad commercial deployment could be achieved without domestic port and vessel resources. A list of announced, planned, and constructed port and vessel assets is provided in Table 2.

We provide further insight into the impact of different port and vessel infrastructure scenarios in Section 3.1.1.

Table 2. Announced, Planned, and Operational Marshaling Ports, Wind Turbine Installation Vessels, and Specialized Feeder Barges for the U.S. Offshore Wind Energy Market

Asset	State	Primary Sponsor(s)	Announced Investment To-Date ($ million)	Status
Marshaling Ports				
New Bedford Marine Commerce Terminal	MA	Massachusetts Clean Energy Center, U.S. Department of Transportation, Vineyard Wind	128	Operational (minor upgrades ongoing)
New London State Pier	CT	Connecticut Port Authority, Ørsted, Eversource	255	Finishing upgrades in 2023
Portsmouth Marine Terminal	VA	Virginia Port Authority, Ørsted	243	Upgrades beginning in 2022, to be completed in 2025
New Jersey Wind Port	NJ	State of New Jersey	540	Phase 1 under construction Phase 2 planned
Tradepoint Atlantic	MD	US Wind, Ørsted	37.2	Not announced
South Brooklyn Marine Terminal	NY	State of New York, Equinor, bp	287	Not announced
Port of Salem	MA	City of Salem, Crowley Maritime Corporation, Avangrid	33.8	Not announced
Arthur Kill Terminal	NY	Not announced	48	Not announced
Port of Humboldt	CA	State of California	11	Planning and design underway
Wind Turbine Installation Vessels				
Charybdis	N/A	Dominion	500	Under construction, to be completed by 2024
Foreign-flagged Maersk WTIV	N/A	Equinor, bp, Maersk Supply Service	Not announced	Expected to be completed by 2025

Asset	State	Primary Sponsor(s)	Announced Investment To-Date ($ million)	Status
Specialized Feeder Barges				
Multipurpose feeder	N/A	Moran Iron Works Shipyard, Green Shipping Line, Keystone Shipping Company, DEKC Maritime	Not announced	Expected mid-2023
Tugs and barges (2)	N/A	Equinor, bp, Maersk Supply Service, Kirby Offshore Wind	Not announced	Expected to be completed by 2025

2.4.2 Barriers To Developing Port and Vessel Infrastructure

The list of port and vessel resources in Table 2 is a good start but will be inadequate to install 30 GW of offshore wind energy by 2030. We provide further analysis of the impact of the bottlenecks created by an insufficient number of ports and vessels in Section 3.1.1; at this point, it is enough to realize that there is a significant demand for further investment in these assets. This bottleneck is sufficiently important that it is listed as its own barrier to developing a domestic supply chain in Section 2.1. Two other barriers have relevant impacts on the ability of the industry to develop further port and vessel infrastructure:

- Uncertainty surrounding the potential impacts of construction delays, cost overruns, legal complications, or changes in government support for offshore wind creates an investment risk that makes it difficult to secure financing for new supply chain facilities
- Building new manufacturing facilities is constrained by limited available space and uncertain permitting and construction timelines.

Although investment in new port or vessel resources is costly—a new marshaling port may cost $300 million-$400 million, and a WTIV built in the United States may cost at least $500 million—the biggest challenge is not the size of the investment but the ongoing uncertainty about when offshore wind energy project construction will begin in earnest in the country. This uncertainty makes it difficult to project revenue streams to justify the upfront investment. Furthermore, installation vessels are contracted to individual offshore wind projects on relatively short-term contracts (about 1 year). Vessel operators need to have multiple confirmed contracts to justify the investment in a large installation vessel, and it is a challenge to sign a contract to install an offshore wind project before the vessel is built. State governments may consider additional metrics when deciding about port investment, such as the number of jobs that they expect to be created. This additional consideration may make it more likely that manufacturing hubs (which create more long-term jobs) will be located near marshaling ports (such as the plans to include manufacturing centers at the New Jersey Wind Port).

Ongoing growth in the global wind energy industry does not provide much additional certainty, as U.S. ports cannot service projects in Europe or Asia and higher vessel construction costs in the

United States will make domestic vessels less competitive in the international market. To help alleviate some of the risk faced by investors, the federal government has taken steps to make loan guarantees and financing available through DOE's Loan Program Office and the U.S. Department of Transportation Maritime Administration (DOE Loan Programs Office 2021; U.S. Department of Transportation Maritime Administration 2022). The Bipartisan Infrastructure Law allocated $17 billion to revitalize ports and waterways, which could be used to benefit offshore wind facilities (The White House 2021b). The IRA provides a 10% production tax credit on the final sale price of an offshore wind vessel available to the shipyard, although this incentive alone is unlikely to make a large construction vessel like a WTIV or HLV cost competitive with a foreign-flagged vessel.

There will always be a demand for U.S.-flagged vessels to support the offshore wind energy industry because of the Jones Act and the high quality of U.S. vessels and sailors. A domestic vessel fleet and workforce can develop to efficiently and safely install offshore wind projects; however, developing these resources will take time and early projects will use a significant number of foreign vessels and labor as the U.S. industry gains experience. When the Don Young Coast Guard Authorization Act of 2022 was proposed (H.R. 6865, 117th Congress 2021-2022), industry stakeholders were strongly opposed because it would vastly reduce the number of available installation vessels and would lead to significant project delays during this early phase of offshore wind energy development. The potential for future legislation that revises the Jones Act and impacts project design choices has created additional uncertainty and hesitation for investors considering building U.S.-flagged installation vessels.

Even with sufficient financing, constrained space and availability in existing shipyards will present a bottleneck to building a fleet of offshore wind vessels. Although the shipbuilding industry is eager to support the construction of new vessels, existing shipyards typically have navigation channels or berths that are too small to allow passage of a built WTIV, insufficient workforce with the experience for building these specialized vessels or are already committed to other projects (often with military contracts) throughout the decade. As it can take 3-4 years to build a WTIV, this limited number of facilities presents a challenge for building the 5-6 WTIVs that would be required if primarily Jones-Act-compliant WTIVs are used to construct the 30-GW pipeline (Shields et al. 2022). There are more facilities that can build smaller vessels such as feeder barges. This availability may push the U.S. market toward using more feeder barge solutions than the European market (with foreign-flagged WTIVs remaining at the project site), although this approach introduces additional risks and significant safety concerns of at-sea transfers of massive components.

Space constraints are also relevant for identifying the next marshaling ports that need to be developed on the East and West Coasts. On the East Coast, there is little room to expand existing ports or build ones, which will result in relatively small facilities. Although project developers and manufacturers could feasibly manage operations under this constraint, it will increase the risk of project delays as there will be a smaller buffer of project components stored on-site.

On the West Coast, there is currently no facility that is ready to stage a commercial-scale floating wind energy project (Porter and Philipps 2016). Ports designed for floating wind operations will have different requirements than those built for fixed-bottom projects, such as the need for on-site manufacturing of floating platforms, quayside capabilities for wind turbine integration, and navigation channels that are sufficiently wide to tow out a fully assembled floating wind turbine. The vast distances between existing West Coast ports and planned BOEM lease areas suggest that there will be a need for multiple ports to reduce transport time, cost, and emissions.

Developing port and vessel infrastructure is not primarily constrained by the capital cost, as the U.S. offshore wind energy pipeline should be sufficient to recoup these investments as well as create local jobs and economic benefits at ports and shipyards. The challenge is in strategically planning the number, location, and capabilities of the ports and vessels that are required for the domestic market in an uncertain environment that makes it difficult to find investors. Increased planning and coordination between states with existing ports or shipyards and offshore wind energy project developers and OEMs can help overcome these challenges, along with continued support by the federal government in the form of loan guarantees and port improvement grants. This coordination will have to take place quickly to meet the national offshore wind target but must also prioritize meaningful stakeholder engagement related to the construction of major infrastructure projects.

2.5 Manufacturing of Critical Offshore Wind Energy Components

2.5.1 Manufacturing Facility Requirements

During the development of this report, we identified 12 major components component categories (e.g., cables, mooring ropes and chains, large castings, and forgings) or materials (e.g., steel plates) that are essential to developing a domestic offshore wind energy supply chain (see Table 3). Manufacturers have announced their intent to construct some of these facilities in the United States (see Figure 47), although many more facilities will be required to meet the demand pipeline. To better understand the specific needs of each component manufacturer and the barriers to constructing and operating U.S. offshore wind energy component manufacturing facilities, the team conducted detailed interviews with nearly 20 component manufacturers. These interviews were used to create a detailed summary of factory specifications and barriers to domestic supply chain development (see Appendix A).

[7] Further description of these facilities is provided in Shields et al. (2022) and Musial et al. (2022).

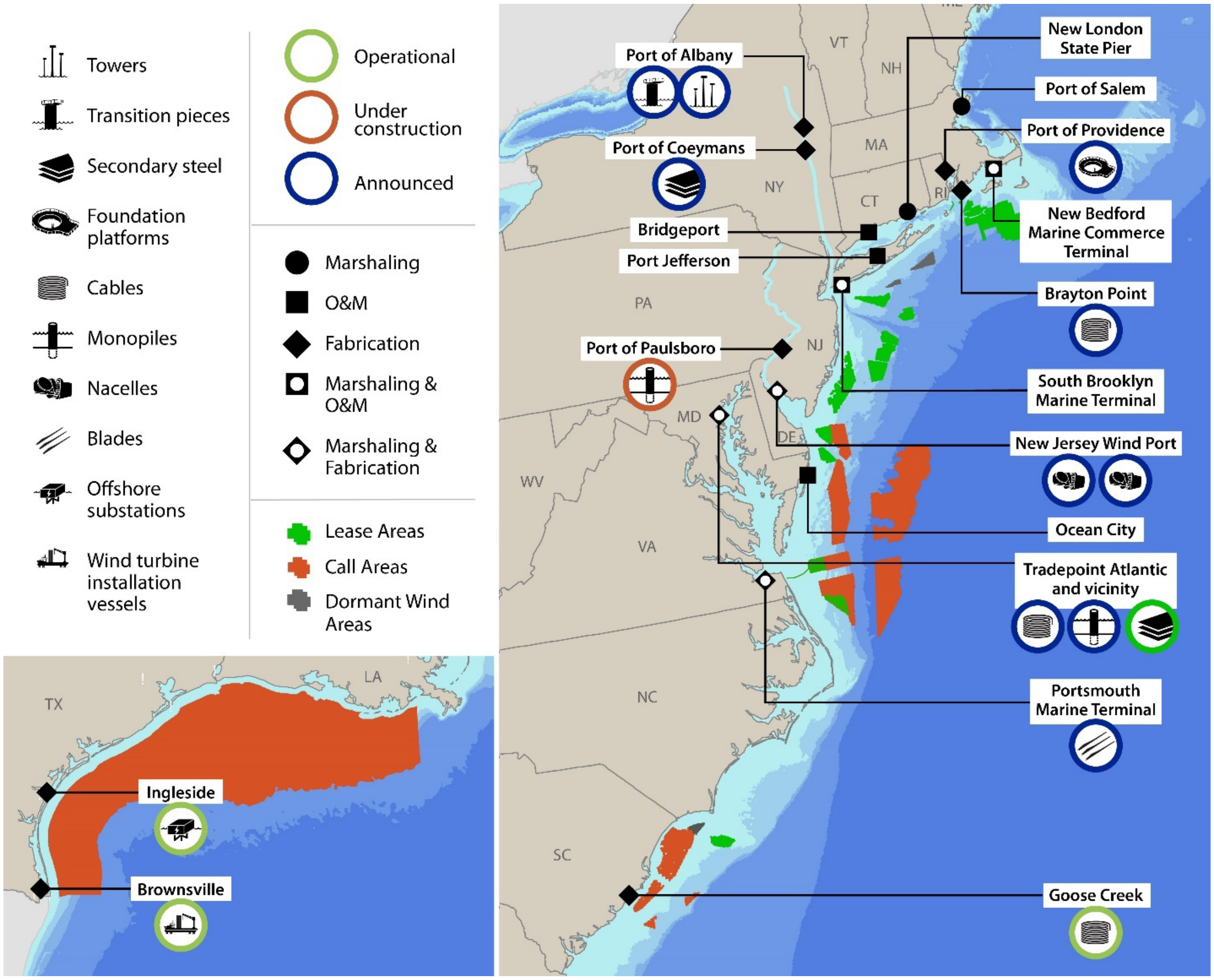


Figure 4. Announced manufacturing facilities for critical offshore wind energy components in the United States. *Figure from Musial et al. (2022)*

We also identified a variety of common themes for factory specifications during the interview process (Table 3). For instance, most major component manufacturing facilities require coastal sites with a laydown area (storage and facility footprint) of over 40 acres and quayside infrastructure for loading and unloading of finished components and materials. A select few of those components (e.g., blades, jackets, monopiles) require up to 100 acres to accommodate facilities, component transportation during manufacturing activities, and storage. An additional theme that we identified during the interview process involves the facility costs (e.g., buildings, equipment, and land) for components. Blades, nacelles, towers, monopiles, transition pieces, cables, and steel plates all require facility investments of more than $200 million.

Table 3. Generic Factory Specifications for Critical Offshore Wind Components

Component	Throughput	Investment cost ($ million)	Permitting and construction time (years)	Laydown area (acres)	Navigation channel depth (meters)	Direct jobs (full-time equivalent jobs)
Blade	225/year (yr)	300	3–5	80	7	500
Nacelle	100/yr	250	3–5	40	10	230
Tower	100/yr	250	3–5	45	10	290
Monopile	100/yr	400	2	80–100	8	550
Jacket	50/yr	10	N/A	80–100	8	550
Gravity-based Foundation (GBF)[8]	50–60 GBF/yr	50	1–2	50–60	12	300
Transition piece	100	200	2–3	45	10	300
Floating platforms	50/yr	100	1	Varies depending on design	12	240
Cable	550 kilometers (km)/yr (array) 250 km/yr (Export[9])	350	5–6	45	6 (array) 10 (export)	230
Mooring rope and chain	2,000 km/yr (rope) 2,000 km/yr (chain)	50 (rope) 500 (chain)	4–5	50 (chain)	~10	110
Steel plate	1,000,000 metric tonnes/yr	2,000	5	300	10	460

[8] We provide job estimates for a GBF facility that can produce 3–4 units per month using 2–3 production lines. An alternate GBF facility concept in which dozens of structures are built in parallel has been used for European projects and could potentially create thousands of direct jobs to build all foundations for an offshore wind energy project concurrently (Durakovic 2022; Fried et al. 2022). More research is required to understand how to design a commercial GBF facility and what the spatial requirements would be for such a facility.

[9] These specifications assume a high-voltage alternating current export cable. High-voltage direct current export cables can have higher throughput as the cable only has one extruded copper core, which reduces manufacturing time.

Component	Throughput	Investment cost ($ million)	Permitting and construction time (years)	Laydown area (acres)	Navigation channel depth (meters)	Direct jobs (full-time equivalent jobs)
Large castings and forgings	Varies depending on component	110	2−4	10	N/A	240

2.5.2 Barriers To Developing New Manufacturing Facilities

We evaluated the barriers to supply chain development from Section 2.1 for each of the major component facilities. As shown in Table 4 (with more detailed provided in Appendix A), two barriers were considered universal to all components: pipeline uncertainty and limited port and vessel infrastructure. Uncertainty in construction time frames and the growth of the pipeline beyond 2030 creates an investment risk that was identified by most manufacturers that could impact the decision to construct domestic manufacturing facilities. Limited port and vessel infrastructure is a dual issue that impacts each component either through the development of individual fabrication ports for each facility, or the transportation and installation components once they are manufactured. Incorporating energy justice into supply chain decision-making is an industrywide challenge that impacts the construction of any new or expanded manufacturing facility. We therefore list energy justice to be a relevant barrier for all components and highlight additional components with specific manufacturing-related environmental impacts.

Additional barriers were identified as having the ability to potentially affect decisions related to the construction of manufacturing facilities to support domestic production of offshore wind components: limited space and permitting uncertainty and lack of a specialized workforce. Most offshore wind component manufacturing facilities can take up to 5 years for permitting and construction, which could impact a facility's ability to contribute to 2030 goals. Workforce issues extend beyond training concerns to include the identification, recruitment, and retention of workers.

Table 4. Summary of High-Level Barriers' Impact on Individual Supply Chain Components

The blue shaded boxes indicate manufacturing-specific barriers, whereas the orange shaded boxes indicate barriers that extend beyond manufacturing and into the larger offshore wind industry.

	Barrier to Domestic Supply Chain Development						
Component	*Construction and pipeline uncertainty*	*Limited space and permitting uncertainty*	*Constrained supply networks*	*Limited port and vessel infrastruc-ture*	*Lack of specialized workforce*	*Cost compet-itiveness*	*Incorpor-ating energy justice*
Blade[10]	Orange	Blue		Orange	Blue		Orange
Nacelle	Orange	Blue	Blue	Orange	Blue		Orange
Tower	Orange	Blue	Blue	Orange	Blue		Orange
Monopile	Orange	Blue	Blue	Orange	Blue		Orange
Jacket	Orange		Blue	Orange	Blue		Orange
GBF	Orange			Orange			Orange
Transition piece	Orange	Blue	Blue	Orange	Blue		Orange
Floating platforms	Orange	Blue		Orange		Blue	Orange
Cable	Orange	Blue	Blue	Orange	Blue	Blue	Orange
Mooring rope and chain	Orange	Blue	Blue	Orange	Blue	Blue	Orange
Steel plate	Orange	Blue	Blue	Orange	Blue	Blue	Orange
Large casting and forging	Orange	Blue		Orange	Blue	Blue	Blue
Offshore substation	Orange			Orange	Blue	Blue	Orange
Bearing	Orange	Blue		Orange		Blue	Orange
Anchor	Orange			Orange			Orange

[10] Initial interviews that we conducted with wind turbine manufacturers indicated that cost competitiveness is a potential barrier for domestic manufacturing of blades, nacelles, and towers; however, the incentives in the IRA will likely help to mitigate this barrier and so we do not highlight it in this table.

2.5.3 Geopolitical and Environmental Risks From Global Supply Chains

Domestic manufacturing of offshore wind components presents an opportunity to reduce some dependencies on foreign supply chains. DOE assessments have shown that several clean energy technologies rely on insecure supply chains with geopolitical risks such as social instability, unfair trade practices, or human rights issues, such as child labor or forced labor (DOE 2022). Furthermore, outsourcing the production of offshore wind components or materials to foreign countries with lower environmental standards than the United States could result in products that have significant adverse impacts on local resources or communities (DOE 2022). One example that encompasses both risks is the wind energy industry's reliance on rare-earth materials used in direct-drive generators that are mined and refined in China (DOE 2022). Finally, supply chain shocks such as the COVID-19 pandemic and the Russia-Ukraine war can create global bottlenecks in materials and components that could delay the construction of the U.S. pipeline or increase project cost as demand outpaces supply.

The global nature of the offshore wind industry likely means that there will always be some level of dependence on imported materials or components; however, offshore wind energy stakeholders—such as manufacturers, government agencies, and organized labor—have an opportunity to proactively identify components that pose a significant environmental or geopolitical risk and to consider shifting their production to the United States. This process could also involve identifying new technology solutions to mitigate the need for critical elements, such as continued research and development into superconducting generators that require less rare-earth content than conventional designs (DOE 2021). A domestic supply chain could help make the offshore wind industry more resilient to shifts in the global market in addition to creating jobs and economic benefits within the nation.

2.6 Engaging Tier 2 and Tier 3 Suppliers

2.6.1 Opportunities for Existing Domestic Manufacturers in the Offshore Wind Energy Supply Chain

The dozens of subcomponents and subassemblies that are required to build an offshore wind energy project allow domestic manufacturers to leverage their existing strengths and support the growth of the new industry. There are a number of challenges that must be addressed to jump-start the efforts to prepare existing manufacturers for the offshore wind energy supply chain. We find that there are many U.S. manufacturers with an interest in offshore wind, but many will need to obtain certifications, take steps to qualify as a supplier with a Tier 1 manufacturer, invest in education to understand their role in the supply chain, and participate in workforce training programs. In addition, further outreach is needed to engage a broader spectrum of existing manufacturers to increase awareness of the offshore wind opportunity on the horizon.

Tier 2 and Tier 3 suppliers refer to the manufacturers of subassemblies and subcomponents that are integrated into major Tier 1 components (Shields et al. 2022). While Tier 1 components are unique because of their extreme size and specialization, many Tier 2 and 3 components are similar to components produced in other industries (such as land-based wind energy or oil and gas). The diverse supply chain network of supporting components could enable noncoastal states to participate in the offshore wind industry and realize some of the potential benefits. Existing businesses could consider developing partnerships with international companies that have existing expertise and global connections. Shields et al. (2022) report that there is a higher potential for jobs and economic benefits in the indirect supply chain (which encompasses Tier 2 and 3 suppliers) than in the direct supply chain (the Tier 1 manufacturing facilities), and many of these components can be manufactured by these noncoastal states or states without announced offshore wind energy targets. This geographic diversity is not realistic for the massive Tier 1 components that need to be produced at port facilities. Developing a diverse, nimble, and resilient supply chain for supporting components in the United States would help create a self-reliant offshore wind industry. As a result, the industry would be less susceptible to shocks in the global supply chain and could activate a greater percentage of the available jobs and economic benefits associated with the manufacturing of offshore wind components.

2.6.2 Barriers for Existing Domestic Manufacturers To Transition to Offshore Wind Energy Activities

2.6.2.1 Awareness of the Offshore Wind Opportunity

Despite the magnitude of the opportunity that is available to existing Tier 2 and 3 suppliers in the United States, each individual business faces significant obstacles to qualify as a supplier to OEMs. The first challenge is an issue of communication and awareness. Despite ongoing efforts from state economic development agencies, developers, and OEMs, many existing businesses in relevant industry sectors are simply unaware of the presence of offshore wind activities and the manufacturing needs for major components. There is a need for increased education and outreach to communicate the potential role that these suppliers can play in the growing industry. Some states have hosted "supply chain 101" events to present the offshore wind opportunity to local businesses, which is one way to engage local industries (MassMEP 2021; Maryland Energy Administration undated).

2.6.2.2 Retooling Existing Operations

Even if existing Tier 2 and 3 suppliers are aware of the potential of offshore wind energy, they are faced with challenges to retool their operations to meet the qualification standards to manufacture offshore wind components. Although some skill sets and equipment are transferable from existing industries, such as aerospace, oil and gas, heavy industrial, construction, steel fabrication, ship building, and land-based wind, offshore wind OEMs have lofty requirements for their supporting suppliers. These requirements are necessary to lower risk of expensive repairs in the harsh ocean environment, maintain safety standards during installation, and reduce the likelihood of project delays if a supplier cannot deliver products on schedule due to quality or financial instability issues. Most existing Tier 2 and 3 suppliers will have to invest in new equipment, training, and/or certifications to qualify as an offshore wind supplier. This level of investment can be daunting, especially given the uncertainty surrounding the offshore wind energy pipeline. From an OEM's perspective, selecting these new suppliers with no experience in offshore wind introduces risk to their project budget and schedule. OEMs have existing relationships with suppliers in Europe and will need to be confident in new suppliers to contract with them.

2.6.2.3 Obtaining Certifications

Conversations with OEMs, Tier 1 suppliers, developers, and other stakeholders who currently work in offshore wind energy make it clear that certifications are required for existing domestic manufacturers to become a supplier of a Tier 1 manufacturer. However, there is a lack of understanding of the different offshore wind certifications, what it takes to qualify, and which certifications apply to different scopes of work. Currently, there is no consistent certification standard across the entire supply chain; rather, required certifications are often on a case-by-case basis, depending on a company's specifications to be a preferred supplier.

Certifications can also apply to various aspects of an organization. For example, the end product may have to comply with specific quality standards, and the employee fabricating the subcomponent may have to complete a particular workforce certification, while the company itself may have to adhere to a certain set of procedures—all to be a supplier for an OEM or Tier 1 supplier. Moreover, the organization may have to follow a certain set of procedures to qualify for another certification. It is unclear to domestic manufacturers when they are required to have a specific certification and various Tier 1 manufacturers may require different certifications for the same subassembly or subcomponent. All in all, certifications are complex, not standardized, situational, and can vary across products and companies.

Adding to the confusion surrounding certifications is that industry efforts to develop a certification for wind industry manufacturing, specifically APQP4Wind, have not been universally accepted. This certification was designed by international wind turbine manufacturers and suppliers to standardize, simplify, and strengthen the quality planning and product approval process in the industry. However, it has not been universally adopted and some international manufacturers and suppliers recognize other certifications.

In total, we identified more than 35 certifications that are relevant to offshore wind energy component manufacturing; a list and description of these certifications is provided in Appendix C. Some certifications are only relevant to specific components, whereas others are more commonly used throughout the industry (e.g., the ISO 9001:205, EN 1090, ISO 384, and various American Welding Society certifications). This list reflects an evolving understanding of the type of certifications that are needed by Tier 2 and Tier 3 suppliers and is not comprehensive.

2.6.2.4 Engaging With Diverse Business Enterprises

The growing offshore wind energy supply chain could involve various business enterprises that have been left out in the past by other industries (such as small businesses, minority-owned business enterprises, women-owned business enterprises, disability-owned business enterprises, and veteran-owned business enterprises, known collectively as XBEs). Several states, such as Massachusetts, Maryland, and New York include XBE criteria in their state procurement systems.[11] Maryland, New Jersey, and Virginia have also offered offshore wind supply chain training courses to businesses in their states and prioritized marketing targeted at XBE. In addition, project developer and Tier 1 suppliers are developing programs to target XBEs.

In addition to the typical challenges faced by existing domestic manufacturers seeking entry into the offshore wind energy supply chain, XBEs have unique barriers and work must be done to

[11] The term XBE was established to inclusively encompass the full range of disadvantaged business enterprises. XBE includes, but is not limited to, a wide range of disadvantaged businesses, including minority-owned businesses, women-owned businesses, veteran-owned businesses, service-disabled-owned businesses, disabled-owned businesses, and lesbian, gay, bisexual, transgender, queer (LGBTQ) businesses.

ensure opportunities are extended to these enterprises. Many small- or medium-sized businesses learn about contract opportunities through informal networks that are less common for XBEs, resulting in fewer opportunities in public contracting (Minority Business Development Agency 2016). The offshore wind energy industry similarly relies on informal networks and preexisting relationships to de-risk investments without including XBEs in these networks. As a result, the offshore wind industry could perpetuate previous shortcomings and create additional obstacles for these companies. XBEs typically face more barriers in obtaining capital, which could limit their ability to invest in the training, equipment, facilities, or certifications needed for offshore wind energy activities (Watson et al. 2022; Bates et al. 2018; Minority Business Development Agency 2017; Burdock et al. 2022). Finally, as these are businesses that have been left out of the traditional model, additional work must be done to ensure outreach and engagement of XBEs.

2.6.3 Evaluating the Relevance of Existing Businesses

Establishing the relevance of existing manufacturers and understanding the investment and education required to prepare them for offshore wind energy is a critical step for the industry to take. In this study, we identified readily available high-level metrics that are about existing U.S. businesses that can be used to evaluate how effectively an existing industry sector can support the expansion of domestic Tier 1 manufacturing. The following metrics are typically available in state or national supply chain registries, such as the Business Network for Offshore Wind's Supply Chain Connect database (Business Network for Offshore Wind undated), or commonly used economic impact tools:

- Type of products being manufactured
- Location(s) and number of facilities, including proximity to planned Tier 1 suppliers
- Size of workforce
- Relevant or transferable experience from similar industries
- Certifications
- State-level Regional Purchase Coefficients, which measure a region's ability to meet the demand for a specific type of component.

Other metrics, such as the likelihood of a business to deliver products on time or the quality of the business's products, are important factors in selecting specific suppliers but are difficult to quantify when considering an industry sector. In Section 3.2.2, we demonstrate a methodology for aggregating these metrics to determine state-level adjacent industry manufacturing scale (AIMS) for each component.

2.7 Training a Manufacturing Workforce

2.7.1 Types of Offshore Wind Manufacturing Roles

Manufacturing jobs could be the largest contributor of domestic employment in the offshore wind energy industry.[12] Because of the large number of workers, especially in the trades, the United States will need to modify and expand existing training programs while collaboratively creating new programs, where warranted. Close cooperation among manufacturers, labor unions, and community colleges will help prepare skilled trade workers to perform job functions unique to each manufacturing facility or supplier as well as facilitate workforce development.

Figure 5 shows the breakdown of the types of workers that support component assembly and fabrication at offshore wind energy manufacturing facilities. This percentage breakdown is an average across all components. The largest part of a manufacturing facility's workforce is factory-level workers. Factory-level workers perform specialized tasks such as welding, assembling, electrical cutting, trimming, polishing, painting and finishing, plasma cutting, blasting, heavy lifting, and crane operating on the production floor.

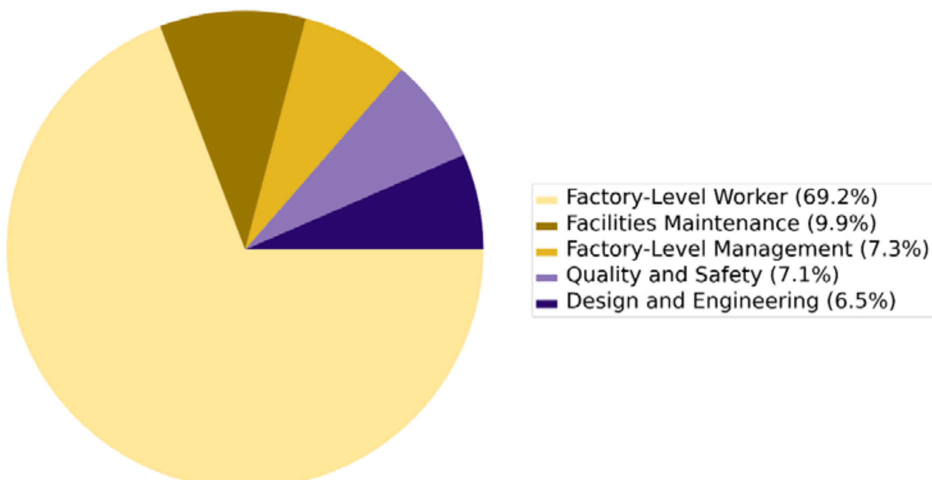


Figure 5. A breakdown of the types of workers in a component manufacturing facility

Manufacturing and supply chain jobs can be categorized into five main types:

- **Regional professional** roles, which represent those working at the corporate level as part of operations
- **Factory-level management** roles, which are responsible for the management and oversight of the factory and involved in plantwide processes, such as operations, management, or production

[12] Additional jobs will be needed to load vessels at U.S. ports, construct offshore wind energy projects, and operate vessels at sea. The "U.S. Offshore Wind Workforce Assessment" (Stefek 2022) highlights the contribution of port and maritime construction workers, such as skilled trade workers and mariners, and their training requirements. Building manufacturing facilities, U.S. vessels, and port upgrades will also require a workforce; however, we have not assessed the impacts of those activities.

- **Design and engineering** roles, which are responsible for designing and testing components
- **Quality and safety** roles, which are responsible for the quality of produced materials and products, as well as the safety and health of the workers
- **Factory-level workers**, or those doing the physical processes involved in production
- **Facilities maintenance** roles, which may include repairs or ensuring cleanliness and hygiene of the facility.

Table 5 summarize these manufacturing and supply chain job roles that are highlighted in the "U.S. Offshore Wind Workforce Assessment," which provides role descriptions, education, and experience requirements (Stefek et al. 2022).

Table 5. Types of Manufacturing and Supply Chain Workers and Their Respective Roles (Stefek et al. 2022)

Worker Type	Job Roles
Regional professional	• Regional corporate executive* • Administrator • Sales and marketing manager and team • Business development manager and team**, research and development manager and team,** manufacturing and sourcing manager and team** • Human resources manager and team • Counsel**
Factory-level management	• Production engineer** • Manufacturing engineer** • Plant manager** • Operations manager**
Design and engineering	• Design engineer** • Testing engineer** • Supply chain analyst**
Quality and safety	• Quality assurance/quality control officer/specialist** • Quality assurance inspector* • Quality control engineer* • Safety officer/advisor • Purchasing manager/assistant** • Logistics manager • Nondestructive test and inspection technician*
Factory-level worker	• Materials handler • Production supervisor* • Manufacturing associate/operator – welder, machine setter, assembler • Electrical technician**
Facilities maintenance	• Maintenance supervisor • Maintenance technician/engineer • Cleaning staff
***Knowledge or training specific to offshore wind energy technology or industry recommended** *****Knowledge or training specific to offshore wind energy technology or industry required**	

Qualifications for training, education, and experience vary across these roles. In general, roles such as regional professional, factory-level management, design and engineering, and quality and safety require higher levels of education or experience. Universities can create specialized curricula and experiences to provide the offshore-wind-technology-specific knowledge and training required to support these roles. While many skills are transferrable, knowledge or training specific to offshore wind technology is preferred for many of these positions, which can likely be obtained through specialized or company training. Many factory-level workers are highly skilled trade workers, such as electricians. These roles may require a specific training, vocational training, an associate degree, or certifications. However, some factory-level workers, such as assemblers, may only need to possess on-the-job training and a high school diploma or General Educational Development (GED) test.

2.7.2 Expanding and Developing Training Opportunities

Labor unions, community colleges, and universities will all play a critical role in providing the training and skills needed for the manufacturing and supply chain workforce. Partnering with manufacturing facilities and suppliers can help these workforce stakeholders develop programs that align with industry training requirements and scales to meet (but not exceed) the number of workers needed for different roles. Collaboration with federal, state, and local government and organizations can also help standardize training and certification requirements, secure funding for training programs, establish training facilities, and encourage networking opportunities.

Labor unions are a major stakeholder in vocational training across many different industries, providing many different types of workers with opportunities to gain knowledge and skills. Unions are playing an active role in developing the offshore wind energy workforce as the industry grows, both in supplying a domestic workforce and ensuring jobs in the industry offer competitive salary and benefits. Labor unions, such as American Federation of Labor and Congress of Industrial Organizations, North America’s Building Trades Unions, and Massachusetts Building Trades Council have been successful in negotiating project labor agreements and memoranda of understanding with developers such as Ørsted and Vineyard Wind to hire a construction workforce to support the offshore wind industry. These agreements are expected to fund preapprenticeship and recruitment programs, encourage collaboration to identify necessary skills for training programs, and provide job opportunities for a domestic workforce (Effross 2022). Success in expanding and developing training for construction workers could be replicated for manufacturing workers; these trained construction skilled trade workers could also support manufacturing activities. Some examples of the ways in which existing labor unions programs could support the manufacturing workforce include:

- **Developing curriculum.** In order to ensure a qualified workforce is available, labor unions are focused on integrating offshore-wind-energy-specific skills into their existing network of training and apprenticeship programs as well as developing training programs focused on offshore wind requirements. The International Brotherhood of Electrical Workers and the National Electrical Contractors Association have developed curriculum and “boot camps” for wind turbines and other renewable energy technologies for apprentices and skilled journeymen to develop their skills (International Brotherhood of Electrical Workers undated).

- **Offering apprenticeships.** Apprenticeship programs help people gain the necessary skills and experience for trade careers. Apprenticeship programs can impart fundamental knowledge and skills on new workers while specialized or customized courses and on-the-job training for journey-level workers can help improve the skills of the incumbent workforce. Labor union apprenticeships are practically free for those who are working in addition to taking courses (hence the motto, "earn-while-you-learn"). Preapprenticeship, or apprenticeship readiness programs, have been established to build a committed and diverse pool of candidates who are prepared for the rigors of registered apprenticeship. Unions have indicated that preapprenticeship programs are key mechanisms that they use to attract and train underserved populations to enter the union workforce. Joint labor-management programs, which are partnerships between employers and a labor union in the manufacturing sector, share many of these characteristics.[13] Expanding existing union-led training programs, such as apprenticeships, could help meet the workforce need for factory-level workers in manufacturing. It is worth noting that there are far fewer registered apprenticeship programs in manufacturing than in construction (U.S. Department of Labor 2021). Employer-only sponsored apprenticeship programs may be more commonplace in manufacturing than in construction, which may mean a greater level of effort is required to develop quality labor union training programs to support the manufacturing and supply chain segment of the offshore wind energy industry.[14]

In addition to labor unions, community colleges can offer associate degrees and training programs to support facility-level management, quality and safety, and factory-level workers. To ensure a well-trained workforce is available for manufacturers and suppliers, existing programs can be leveraged and new programs developed in parallel with planned manufacturing facilities. The following examples of community college programs aim to support the offshore wind energy manufacturing and supply chain:

- **Certificates and associate degrees.** Hudson Valley Community College in Troy, New York, offers several certificates and associate degrees to support manufacturing in the offshore wind energy industry, especially in welding and fabrication to support the tower manufacturing facility at the Port of Albany and the foundation component manufacturing facility at the Port of Coeymans. The college is partnering with the manufacturers who will produce the components to provide a skilled workforce pipeline of welders and fabricators. In addition, it is focusing student recruitment efforts on priority populations in urban and rural disadvantaged communities, providing full or partial scholarships to participants (New York State Energy Research and Development Authority [NYSERDA] 2022). NYSERDA issued a competitive award to Hudson Valley Community College through New York Offshore Wind Training Institute funds for training and skills development.
- **Partnerships.** Gloucester County Institute of Technology (GCIT) is a 4-year vocational-technical public high school located in Deptford Township, New Jersey, that is collaborating with EEW American Offshore Structures to expand and tailor its welding and painting

[13] Examples of joint labor-management partnerships include the United Auto Workers alliances with Ford and General Motors and Kaiser Permanente's labor management partnership for managers and physicians (AFL-CIO 2022).
[14] The U.S. Department of Labor defines employer-only apprenticeship programs as wholly administered by the employer, whereas joint labor-management apprenticeship programs are between an employer and a labor union.

programs to support the monopile manufacturing facility at the Paulsboro Marine Terminal in Gloucester County. Through a memorandum of understanding, the New Jersey Economic Development Authority (NJEDA) will provide up to $75,000 for programs that prepare students and workers for jobs in heavy-steel offshore wind component manufacturing, funded by the New Jersey Board of Public Utilities. EEW and GCIT have also secured donated welding equipment from welding manufacturer Lincoln Electric that will be used in production to support training on the specialized machines and welding consumables used in the monopile fabrication facilities. Lincoln Electric will also be conducting a train-the-trainer program for GCIT and other regional vocational school welding instructors focused on the primary welding processes and materials used in production. (Gloucester County Institute of Technology 2021). Partnerships like this often build the strongest workforce development programs.

Universities are predominantly focused on creating a workforce on the professional level, providing the education required for engineers, professional support roles, and scientists and researchers, among others to support manufacturing facilities. The United States has a robust network of university programs to educate students in regional professional, design and engineering, and quality and safety roles. The skills for these types of roles are generally transferable among industries, so the development and expansion of new degree programs is not as critical as skilled trade roles. However, research has shown that industry organizations often prefer direct experience in wind energy (Stefek et al. 2022), so additional offshore-wind-specific coursework could be created to supplement existing degree programs to help meet this need.

Collaboration among governments, industry, academic institutions, labor unions, and community-based organizations is key to addressing offshore wind workforce needs efficiently, effectively, and equitably by preparing a workforce that meets the technical, geographic, and timeline needs for anticipated wind energy projects. To train the large number of potential manufacturing workers, partnerships between labor unions and community colleges are key, and may lead to greater efficiencies in workforce development. Labor unions could bring people into apprenticeship training programs and sponsor them for training opportunities at community colleges. Community colleges could provide curriculum, facilities, and credits for apprentices. State governments and organizations can help provide funding opportunities for initiatives to support collaboration and training development.

The following may also be helpful to provide workers for manufacturing and suppliers:

- The skilled workforce that supports oil-and-gas manufacturing facilities in the Gulf of Mexico could transition to support offshore wind component manufacturing. Fabricators in the Gulf of Mexico manufactured the jackets for the Block Island Wind Farm. This experienced workforce could be utilized in the offshore wind energy industry (Musial et al. 2020). Many oil-and-gas workers have transferable skills and could transition to roles like project managers, safety supervisors, or electricians. Trade workers in roles such as welding, electrical, nondestructive testing, and coating could also transition to support facilities. The offshore wind industry could represent a new opportunity for oil-and-gas workers as the country looks to meet more of the energy and transportation needs with renewable energy, which may impact job availability in the fossil-fuel industry.

- Veterans can leverage their technical skills developed in military service and work in the increasing professional and trade opportunities within the manufacturing sector. The manufacturing sector could consider expanding a program like Helmets to Hardhats to support offshore wind component manufacturing. This program is a prime example of a partnership between labor unions and construction industry contractor associations aimed at helping veterans, transitioning active-duty military service members, and helping National Guard and Reservists secure a quality career in the construction industry via a registered apprenticeship. In 2007, the initiative expanded with the creation of the Wounded Warrior program that focuses on serving disabled veterans by connecting them to careers or supportive roles in the construction industry.[15]
- All stakeholders involved in offshore wind energy workforce development have expressed interest in and are committed to encouraging participation of underrepresented and underserved populations and practicing environmental justice in the U.S. offshore wind energy industry. Many stakeholders see the development of offshore wind energy as an opportunity to improve diversity and inclusion in the workforce in traditional economic sectors (i.e., construction and manufacturing) while addressing the racial wealth gaps in the communities that will be impacted by offshore wind projects and associated infrastructure. For instance, the American Federation of Labor and Congress of Industrial Organizations has initiatives to support increased diversity in their member unions as well as requirements to audit diversity throughout its ranks.

2.7.3 Training Barriers for the Offshore Wind Workforce

Although there are many ways to grow the offshore wind energy workforce, there are still barriers in training the potential large number of workers needed, including:

- **Standardization of specialized training requirements.** Companies requesting different skills, certifications, and experience requirements can cause confusion for labor unions and community colleges who want to properly train workers. In the manufacturing space, there are many types of roles (e.g., welders, electricians, metal fabricators, painters, assemblers); therefore, different training programs are needed to provide the necessary skill sets. Key requirements, especially for a workforce needing specific credentials, should be standardized and communicated by industry facilities to training organizations. Having standardized role definitions, requirements, or credentials would ensure appropriate programs are developed that meet industry requirements.
- **Alignment of training timing.** Aligning the facility operational date with training program development and using these programs to train workers is an important near-term priority to ensure facilities can meet their production requirements with a domestic workforce. Collaboratively planning the development of manufacturing facilities and workforce development could ensure that a cohort of trained workers are ready as employers begin the hiring process at new factories. Accelerating the timing of training programs or increasing on-the-job training can help align domestic workers with these roles and bridge the most critical gaps, especially as plans to build, expand, or transition facilities are solidified. Industry should increase the transparency and visibility into their plans to develop

[15] For more information, visit: https://helmetstohardhats.org/about-us/.

manufacturing facilities so that labor union and community colleges can expand their recruitment and training programs and facilities strategically to match the needs of facilities. It is important to develop training programs in partnership with planned facilities to ensure that an adequately trained, local workforce is available when and where needed.

- **Competition for workforce between industries.** Many skilled tradespeople are expected to be in high demand in the manufacturing sector. There are already workforce shortages for some trades; for example, offshore wind energy projects are expected to have a large demand for iron and steel workers and construction welders. Massachusetts Clean Energy Center conducted a study (Frongillo and Jordan 2021) indicating there is already a low supply of workers in these occupations. Understanding the workforce needs of related industries will enable stakeholders to plan for potential gaps and leverage related training and education programs and initiatives. Expanding or developing additional community college and union-led training programs, such as apprenticeships, may be needed to ensure sufficient factory-level workers for manufacturing, especially in a job market that is competitive for skilled trades.
- **General lack of awareness of opportunities.** Creating awareness around the diversity of manufacturing roles will help attract labor unions and education institutions to expand and develop training programs. It will also help attract workers to fill these roles. It is important to have a pipeline of interested students for training programs who can be hired by these manufacturing facilities. Engaging students in renewable energy from an early age and including offshore wind, particularly in coastal communities, will be important in developing a trained workforce. Skilled tradespeople with existing skill sets can be leveraged in the offshore wind energy industry but also need to be made aware of the opportunities. In addition, expanding preapprenticeship and other training programs can help attract and train underserved populations to enter the workforce, promoting a more equitable and diverse workforce.

2.8 Incorporating Equity and Justice Into Supply Chain Development

2.8.1 The Need for Equity in Supply Chain Decision-Making

Offshore wind energy and a supporting domestic supply chain have the potential to play a large role in decarbonizing the American energy system. Concurrently, this work has the potential to address environmental and energy justice aims targeted by the Biden administration, such as reducing localized air and water pollution in communities hosting fossil-fuel infrastructure and other polluting facilities. As described in Section 3.2.2, a domestic supply chain for offshore wind energy also has strong potential to bolster port communities by bringing in local jobs, revitalizing industry and infrastructure, and benefitting local economies far beyond manufacturing and assembly facilities alone. This work is especially critical and potentially beneficial for U.S. port communities, which are often home to low income and/or nonwhite populations, often experience negative impacts from port activities, and may be considered environmental justice communities (U.S. Environmental Protection Agency [EPA] 2020a). However, in the pursuit of these economic and social benefits through the build out of an offshore wind energy supply chain, there is a risk that members of port communities may become disproportionately burdened by supply chain activities, as has often occurred with other industries operating at ports (EPA 2020a).

Historically, port communities have faced disproportionately high exposures to pollutants and toxins as a result of port activities like movement of goods and freight (EPA 2020b). Such cumulative environmental exposures have led to disproportionate health burdens and associated healthcare costs for residents of port communities (EPA 2020b). Emissions from diesel engines are of particularly high concern, with links to significant health issues like premature mortality, heart and lung disease, and respiratory symptoms (EPA 2020b). Other environment and health concerns include noise and light pollution, water quality and pollution issues, ecological impacts, and reduced access to natural spaces (EPA 2020c). In recent years, many port communities have also begun to experience the impacts of climate change, with sea level rise, flooding, and extreme weather presenting significant risks (EPA 2020c).

Meaningful and equitable community engagement and consideration in the development process are critical for developing a successful offshore wind energy supply chain. Due to histories of noninclusive decision-making in environmental justice communities, which include port communities, there is often a higher baseline of community distrust of those with decision-making and development authority (University of Michigan School for Environment and Sustainability 2022). Engaging communities in supply chain decision-making can help build trust and create more positive long-term relationships between communities and the industry. Additionally, engaging communities in early project planning stages can help avoid project slowdowns, relocations, or cancellations that can stem from community pushback.

Through the Biden administration's Justice40 initiative, the federal government aims to direct 40% of applicable federal investment to disadvantaged communities (DOE Office of Economic Impact and Diversity 2022). DOE's Office of Economic Impact and Diversity developed eight policy priorities and 36 burden indicators to define disadvantaged communities broadly (DOE Office of Economic Impact and Diversity 2022). Similarly, this report provides complementary indicators that can be used to measure the potential and realized impacts of offshore wind energy supply chain investment.

In Sections 2.8.2–2.8.4, we will discuss potential challenges to incorporating justice concepts at scale across the industry, provide a set of metrics that can be used to evaluate project impacts, and outline some of the current work on equity in the offshore wind energy supply chain.

2.8.2 Barriers To Incorporating Equity and Justice in Supply Chain Decision-Making

2.8.2.1 The Need to Simultaneously Address Community and Climate Concerns

Communities facing environmental injustice may distrust external stakeholders in positions of power, especially if community members were not included in previous decision-making processes (University of Michigan School for Environment and Sustainability 2022). Community residents are also those best suited to make decisions to support their communities in the long term, and therefore should be meaningfully included in, or given power to drive, decision-making surrounding new development (University of Michigan School for Environment and Sustainability 2022). Incorporating just and equitable best practices when developing industry in and around historically burdened communities can be time- and resource-intensive. Conversely, there is a need to reduce carbon emissions as rapidly as possible to minimize the worst impacts of climate change, which will disproportionately burden low-income and historically marginalized communities first.

Together, these two facts may seem contradictory; one requires slow and methodical development processes while the other asks that we radically change our energy systems as quickly as possible. However, it is also important to recognize that exchanging one type of injustice for another does not result in an equitable solution, as there is potential for the energy transition to facilitate "the (re)use of development methods that led to disproportionate negative impacts on communities of color and low-income communities" (Baker 2019). Thus, it is important to tread a careful line between moving quickly to change our energy systems and meaningfully considering the communities impacted by energy infrastructure.

2.8.2.2 Challenges in Sharing Best Practices Throughout the Supply Chain

A universal framework for equitable and just best practices for offshore wind energy supply chain development does not currently exist. Therefore, manufacturers and developers will be largely responsible for incorporating these considerations into projects in collaboration with local governments, community-based organizations, and other interested stakeholder groups. Each potential community that could host supply chain facilities is different, and as such the most equitable development path will look different from place to place. Section 2.8.4.1 outlines indicators that could provide critical community context for developers, manufacturers, and governments making siting and implementation decisions.

2.8.2.3 Social Barriers to Equitable Engagement

In some communities that have historically seen insufficient representation in decision-making, residents may be less likely to engage in decision-making processes when given the opportunity, due to lack of faith that their input will ultimately be incorporated. Additionally, people living in historically burdened communities may be less likely to have spare time, energy, or mobility to engage meaningfully in these processes. Community-based organizations that are interested in engaging may similarly lack the capacity to do so, especially in communities that host more serious or immediately threatening environmental justice concerns. Together, these factors can lead to a project incorrectly presenting as being generally accepted by the community.

2.8.3 Current Work in Environmental and Energy Justice in the Offshore Wind Energy Supply Chain

Most published research related to energy justice and equity in the offshore wind energy supply chain focuses on Europe and other countries with more established offshore wind industries. However, there is growing experience in the United States that provides useful lessons for equity in U.S. contexts, as several offshore wind supply chain projects have now been completed and many more have begun preliminary phases. In accordance with federal policies and the growing environmental justice movement, many states, developers, and local and regional organizations have begun to incorporate equity and energy justice into their offshore wind energy planning, solicitations, and other actions.

An important distinction is that not all offshore wind equity actions are connected to the more specific issue of equity in the offshore wind energy supply chain. For example, states might emphasize the link between offshore wind energy development and reducing environmental justice burdens—often through policies that use funds from clean energy development to provide benefits for disadvantaged communities—but this is not necessarily relevant for the offshore wind supply chain. This section focuses primarily on examples of actions and policies pursued by different actors that specifically address energy justice and equity in the offshore wind supply chain.

2.8.3.1 State Governments

New Jersey is constructing the New Jersey Wind Port with equity principles in mind, including using union labor, requiring developers and contractors to pay a prevailing wage, and setting standards for the inclusion of diverse workers and businesses. NJEDA requires that at least 15% of businesses working on constructing the port are woman-, minority-, or veteran-owned, and have set worker diversity goals of 18% people of color and 6.9% women (State of New Jersey 2022). Many of the NJEDA Wind Institute's workforce programs emphasize equity and inclusion; for example, the Offshore Wind Workforce and Skills Development Grant Challenge will give priority "to applicants that propose initiatives supporting training and job access for residents of Overburdened Communities" (NJEDA 2022). NJEDA also created the New Jersey Wind Port Diversity and Local Engagement Advisory Committee, which brings together local community stakeholders, community-based organizations, and state agencies to work on equity (BOEM 2022a).

The Massachusetts Clean Energy Center (MassCEC), a state economic development agency, is working to support lower-income and minority workers entering the offshore wind energy industry. In 2021, MassCEC distributed $1.6 million in grants to offshore wind education and training programs that aim to overcome specific barriers faced by minority and low-income workers, such as lack of transportation needed to access training sites (Shemkus 2021). In a 2021 offshore wind workforce report, MassCEC identified a list of 284 "priority communities" in the state based on metrics of unemployment, income, demographics, education, and language (Frongillo and Jordan 2021). A key finding was that the state should help members of priority communities prepare to join the offshore wind industry by providing basic services and low-cost, pretraining programs (Frongillo and Jordan 2021).

NYSERDA and the State University of New York launched the Offshore Wind Training Institute in 2021 to train workers to join the industry. As part of its first solicitation through the institute, New York made $3 million available to "support educational and training organizations focusing on early training and skills development, including preapprenticeship training, for disadvantaged communities" (NYSERDA 2021).

The Maryland Energy Administration has also launched several programs that are directing funds and resources to disadvantaged communities including requiring investment and capital expenditure in Maryland. A certain amount of those funds is required to be contracted for small-, minority-, woman-, and veteran-owned businesses (Maryland Energy Administration 2022). The administration also offers the Maryland Offshore Wind Workforce Training Grant Program, which requires outreach and communication plans to historically underserved communities. It specified that grant funds may be applied toward wrap-around services like childcare and transportation to facilitate participation and engagement from underserved and disadvantaged communities (Maryland Energy Administration 2022). Finally, the state instituted an ambassadorship program to minority-owned businesses to ensure they are aware of upcoming opportunities and have the tools to benefit from the offshore wind supply chain as it expands (Maryland Energy Administration 2022).

2.8.3.2 Project Developers

As part of their Ocean Wind offshore project, which is being developed off the coast of New Jersey, Ørsted and PSEG established the $15-million Pro-NJ Grantor trust to support small, woman- and minority-owned businesses as they prepare to participate in the offshore wind energy industry (Ocean Wind 2021). The first round of funding was distributed in November 2021, with six minority- and woman-owned businesses receiving $450,000; several of these businesses plan to use the funds for supply-chain and workforce-related projects (Ocean Wind 2021).

Vineyard Wind, a project off the coast of Massachusetts that started construction in 2022, has committed to "Look Local First" to help Massachusetts' businesses and workers access opportunities in offshore wind energy (Vineyard Wind undated). In accordance with this policy, Vineyard Wind and the New Bedford Ocean Cluster, Inc. launched the Act Local program to connect New Bedford area businesses with opportunities in the offshore wind supply chain (Froias 2021); New Bedford is the site of the state's first offshore wind port. Vineyard Wind also hired a former New Bedford City Councilor, Dana Rebeiro, as a community liaison to help "ensure that local communities receive the greatest possible benefit when it comes to jobs and other opportunities and are well informed as the project moves forward" (Vineyard Wind 2020).

2.8.3.3 Local Governments

The New London State Pier project is a major port improvement project currently underway in the city of New London, Connecticut, involving a partnership between the Connecticut Port Authority, investor-owned utility Eversource, and offshore wind developer Ørsted. Though generally enthusiastic about hosting an offshore wind hub, New London city leaders have at times been vocal critics of the project, arguing that the city has been excluded from decision-making and from receiving fair compensation for hosting the port (Smith 2021a). In the city's view, the massive benefits expected to be brought to the state and region from offshore wind development, facilitated by State Pier, should entitle the city to an equitable share of benefits for hosting the port (Smith 2021a). A point of contention during the early years of the State Pier project was the lack of a host community agreement, or a contract through which a developer agrees to provide the community hosting a development with specified benefits and, if applicable, to mitigate negative impacts of the project.

Following the city's public advocacy for an equitable agreement, Ørsted, Eversource, and New London Mayor Michael Passero signed a host community agreement that secured at least $750,000 per year for the city over a 7-year period if the project proceeds as planned (Smith 2021b). Annual payments can increase up to $1.5 million if the state procures more offshore wind energy, with a cap of $9 million (Smith 2021b). Passero stated that he was "thrilled that we can get on board now because with the agreement signed today, the residents of New London are being treated fairly" (Smith 2021b). Additionally, the city will have greater involvement in decision-making at State Pier in the future, as a state law passed in 2021 gives New London city leadership a seat on the Connecticut Port Authority's board of directors (An Act Concerning Oversight and Transparency at the Connecticut Port Authority 2021).

2.8.3.4 Community-Based Organizations

The Sunset Park Task Force and UPROSE are two community-based organizations in Brooklyn, New York, that have been behind the effort to transform South Brooklyn Marine Terminal (SBMT) into an offshore wind turbine assembly facility. The task force collaborated with Equinor, New York City Economic Development Corporation, and NYSERDA to develop plans for the SBMT revitalization project that would prioritize the community's vision for a sustainable, equitable use of the facility (Esema 2022). UPROSE, an environmental justice nonprofit organization in Brooklyn, has also been involved in advocating for offshore wind energy supply chain activities at SBMT. The organization's executive director wrote that "offshore wind energy can address the neighborhood's vulnerabilities by saving maritime industrial sites, displacing dirty fossil-fuel plants that disproportionately affect people of color, and creating thousands of local jobs" (Yeampierre and Adrar 2018).

The final project agreement includes various direct benefits for the Sunset Park community and the broader New York City population. First, Equinor committed $5 million to increase local workforce capacity through training programs and other initiatives (Simko 2022; Esema 2022). Beyond the monetary commitment to workforce training, Equinor also committed to prioritizing local hiring and growing the capacity of local businesses to support the growing offshore wind energy industry with a specific focus on minority-owned businesses. The hiring provision did not include a local hiring quota, but the job marketing will target the local community. Finally, through negotiations with the community, Equinor established Waterfront Pathways, a program that will help local companies navigate the contract bidding process through education and direct support (Esema 2022). Other unique community benefits include commitments to making SBMT a low-emissions facility and investment in an offshore wind learning center (New York City Economic Development Corporation 2022).

2.8.3.5 Organized Labor

Labor unions have been significantly involved in developing the offshore wind energy supply chain thus far and will continue to help ensure equitable community impacts like the creation of high-quality jobs. It is worth noting that many unions "have historically been predominantly white male workers, and many minority- and women-owned businesses do not currently employ union labor" (Stefek et al. 2022). To address the historic lack of diversity in their membership, some unions are taking steps such as auditing diversity within their ranks or offering preapprenticeship programs that help underrepresented individuals prepare for entry into more rigorous apprenticeships (Stefek et al. 2022). Using both union labor and diverse hiring practices, as is being done with the New Jersey Wind Port project, can help ensure minority workers living in proximity to the offshore wind supply chain have access to high-quality jobs in the industry.

2.8.3.6 Key Takeaways from Existing Supply Chain Equity Efforts

The ongoing efforts to make the offshore wind energy supply chain more equitable can provide important lessons for future supply chain activities. The following four key takeaways, accompanied by examples from Sections 2.8.3.1–2.8.3.5, summarize some of the lessons learned thus far:

- Meaningfully engaging with trusted local groups and with those most directly impacted by the project is crucial to encourage more just outcomes and community buy-in. If external groups (such as manufacturers or project developers) work directly with community groups to address concerns, it can improve project outcomes and reduce the risk of creating adverse effects for the local community. In the case of the SBMT project, engaging with trusted community organizations like the Sunset Park Task Force and UPROSE allowed project developers to understand the local context and make decisions that earned support from the community.

- Diverse benefits may be required to address local values and preferences and gain support from various stakeholders. There is not likely to be a one-size-fits-all benefit that supply chain investment could provide to diverse community groups and stakeholders. Understanding the needs of various groups could help to identify what benefits are seen as most valuable to each stakeholder. For example, community benefits provided for supply chain facilities have thus far included funding for workforce and business development, support for minority- and women-owned businesses, prioritization of local workers and businesses in hiring and contracting, diverse hiring standards, a commitment to create a low-emissions facility, direct compensation through a host community agreement, and the creation of an offshore wind education center.
- Community context matters. The history, demographics, and existing priorities of port communities can shape their perceptions of a project and how it will impact them. Decision makers that are knowledgeable about and sensitive to local context may be able to avoid conflict and identify solutions that are beneficial to all parties. For example, local priorities were an important consideration in the development of SBMT, as the community had long advocated for the port to have a sustainable use with local benefits. In another example, MassCEC identified priority communities in the state based on demographics and created recommendations to help those communities access offshore wind industry opportunities.
- Transparency and accountability in project decision-making are key to building and maintaining trust. Open communication between decision makers and community representatives can help facilitate efficient and mutually beneficial partnerships between industry and community groups. In the case of Connecticut's New London State Pier project, breakdowns in communication between project developers and the local government were a source of conflict, causing the city of New London to lose trust in the project's ability to provide local benefits. The project developers, the state of Connecticut, and the city of New London were able to address this concern by creating a host community agreement and integrating the local government into the decision-making process for the port.

2.8.4 Evaluating Equity Within Supply Chain Communities

In this section, we present indicators and metrics that can be used to understand community contexts, procedural equity, and impacts from supply chain development. We define indicators and metrics for the purpose of equity assessments as follows:

- **Indicators**: High-level categories that collectively reflect the energy justice status of a community
- **Metrics:** Specific statistics or data that can be collected to evaluate each indicator.

We compiled these indicators and metrics based on resources such as EPA's "Environmental Justice Primer for Ports" (2020) and the White House's materials on Justice40 (DOE Office of Economic Impact and Diversity 2022), supplemented by conversations with organizations developing and implementing equity best practices within the offshore wind industry.

Many of these data are readily available through tools such as EPA's EJScreen tool or the U.S. Census and are therefore relatively affordable to acquire and assess. We have selected metrics that are easily accessible through these national-level tools; more granular data on a state or local level may allow for expanding or refining the individual metrics that are ultimately utilized, and data availability may differ for each community. These indicators and metrics form a framework that could help the offshore wind sector incorporate equity more systematically into supply chain decision-making.

2.8.4.1 Contextual Indicators and Metrics

As a preliminary step that may help guide equitable development processes, project decision makers and developers may use contextual indicators and related metrics, such as those provided in Table 6, to determine base-level community contexts prior to project development. The goal of using these contextual indicators would be to understand the baseline state of a community prior to it being affected by supply chain development; this can help project developers understand potential vulnerabilities and make it easier to evaluate a project's impacts in the future.

Contextual information about a community is often best understood through qualitative data, as there may be a lack of quantitative data available and/or more complex community dynamics and history that would not be captured through quantitative data. Section 2.8.4.4 discusses the utility of qualitative data.

Table 6. Contextual Indicators and Example Metrics

Indicator	Example Metric
Social Vulnerability	Social Vulnerability Index percentile
Racial or Ethnic Composition of Community Members	Demographic data (e.g., race, ethnicity, immigration status, tribal affiliation)
Impoverished Community Members	Poverty rate
	Median household income or per capita income
	Energy burden (% of household income used for energy costs)
	Rent burden (% of household income used for housing costs)
Community Members With Educational Barriers	High school or college graduation rates
	Linguistic isolation rate (percentage of households where all individuals over age 14 speak English less than very well)
	Percentage of households with internet access
Unemployed Community Members	Unemployment rate
	Underemployment rate
Community Members With Barriers to Employment	Incarceration rate or percentage who were formerly incarcerated
	Transportation access rates (e.g., percentage of individuals lacking access to personal or public transportation)
	Percentage of individuals not authorized to work due to immigration status
Health of Community Members	Cancer rates
	Asthma rates
	Percentage of individuals living with disabilities
	Percentage of individuals with health insurance
	Healthcare cost burden rates
Environmental Health	Air-quality statistics (e.g., levels of particulate matter or volatile organic compounds)
	Proximity to EPA-designated contaminated sites and other environmental hazards

2.8.4.2 Procedural Indicators and Metrics

Once a site has been vetted and development seems like a feasible and beneficial option for the community, it would be important to track procedural equity and justice throughout the decision-making process. Consideration of procedural equity should begin before the decision is made to host a project and should continue to be updated during decisions about siting, construction, job creation, and other aspects of the project that will impact community members. While many elements of procedural justice are best captured through qualitative data, such as trust and relationship-building with community members, there are some quantitative indicators (Table 7) that may be used to monitor baselines and ensure that efforts to engage stakeholders are meaningful, equitable, and effective.

As in the previous section, the following indicators and metrics could guide decision-making and community engagement processes but are not in themselves sufficient for creating an equitable supply chain. Flexibility in engagement efforts, such as changing methods or locations of engagement, may be necessary to ensure procedural equity. For example, if the community members engaging in decision-making processes are not from the area or neighborhood most directly impacted by supply chain development, then some adjustments to engagement strategies and accessibility may be warranted to ensure that the most impacted community members are reached. Unlike the previous section, many of these metrics are not readily available through public databases due to their uniqueness to each project. Therefore, data collection would be needed to gather and assess data on a project-by-project basis.

Table 7. Procedural Equity Indicators and Example Metrics

Indicator	Example Metric
Community Group Engagement	Number of local* community groups interacting with the project development process
	Change in number of local* community groups engaged over time
	Diversity of membership in engaged local* community groups relative to area demographics
Community Member Participation	Number of local* residents interacting with the project development process
	Change in engagement of local* individuals over time
	Diversity of engaged residents relative to local* area demographics
	Proportion of local* population engaging in process
Accessibility of Information and Engagement Processes	Is information about a project made available to the public through a variety of modes (e.g., online, distributed via mail)?
	Are translated written materials or translators made available during engagement opportunities (if needed)?
	Are engagement opportunities occurring at times of the day and year that are accessible to a wide variety of community members?
	Are engagement opportunities located in places that are easily accessed by a wide variety of community members?
Agency and Decision-Making Power	Proportion of decision-making bodies consisting of local* community members
	Diversity in decision-making bodies relative to local* area demographics
	Number of project decisions and/or changes to project plans made as a direct result of community input
Trust and Relationship-Building	Ratings or other quantitative evaluations of trust, respect, relationships, and fairness provided by community members

* "Local" can have many definitions, including "within a 10-mile radius" or "from a low-income zip code in the surrounding city," and should ultimately be decided through collaboration with community members and decision makers familiar with the area. Importantly, this definition must only include people who were already residents prior to project development, and who did not relocate solely for the purpose of the development; the definition must also remain consistent throughout the term of assessing a project for its use to be effective.

2.8.4.3 Impact Indicators and Metrics

Once a project is in its construction or operation phases, most remaining equity questions would be raised around the impacts on individuals, businesses, and the community as a whole. To address these questions, we broke down the types of impacts into indicators and metrics in two categories: socioeconomic and health/safety. Some of these indicators would require specific or targeted research, whereas others could emerge from routine data collection like an existing census or poll. Accordingly, data availability and approaches to data collection would need to be determined before implementing the metrics. Coordination between stakeholders to collect and share data on impact metrics may be useful; for example, a developer could share data on local workforce impacts with local and state governments. Impact indicators may take a longer time to emerge relative to the indicators in previous phases, so it would be important to monitor trends over time and adjust any activities accordingly.

Table 8. Socioeconomic Impact Equity Indicators and Metrics

Indicator	Example Metric
Local Workforce	Number of local* workers trained throughout project development process
	Percent of project workers that are local
	Percent of work hours performed, or percent of wages earned, by local employees
	Percent of jobs created for locals that are long term, high quality, and pay a prevailing wage
	Representativeness of workforce demographics to larger community demographics
Local Businesses	Number of local small businesses served through project outcomes
	Percent of local small businesses served through project outcomes that are minority- or women-owned
	Net change in local business quantity/revenues
Local Homes/Families	Change in poverty rates
	Change in property values
	Displacement rates (and potential causes, including gentrification, environmental safety, eminent domain, etc.)
	Population growth and community revitalization
Community Support	Change in tax revenue and subsequent community services

* “Local” can have many definitions, including "within a 10-mile radius" or “from a low-income zip code in the surrounding city,” and should ultimately be decided through collaboration with community members and decision makers familiar with the area. Importantly, this definition must only include people who were already residents prior to project development, and who did not relocate solely for the purpose of the development; the definition must also remain consistent throughout the term of assessing a project for its use to be effective.

Table 9. Health, Safety, and Environmental Indicators and Metrics

Indicator	Example Metric
Monitoring	Is funding for monitoring contaminants, pollutants, toxins, and particulates present and used for appropriate monitoring activities?
	Are monitoring results shared with the public and used to implement actionable changes if needed?
Workforce Safety	Percentage of workers with health conditions caused by the workplace
	Percentage of workers with injuries or accidents caused by insufficient workplace safety
	Are injuries or health conditions occurring disproportionately across different groups (e.g., race, class, gender)?
Community Safety	Change in rates of household health and safety issues
	Communitywide air-quality and water-quality impacts (e.g., particulate matter, volatile organic compounds, heat, pollutants)

2.8.4.4 Applying and Implementing Quantitative Metrics

Each set of quantitative indicators provides a framework to evaluate the impacts of offshore wind energy supply chain development on local communities. Manufacturers, project developers, government agencies, and communities can use the metrics to ensure development maximizes benefits to communities while minimizing negative impacts. The indicators provided in this road map are not an exhaustive list of all potential indicators and metrics, but they provide a means of applying various types of indicators to different stages of the development process. Depending on local context, adjustments may need to be made to the context, procedural, and impact metrics; engaging with community members, community-based organizations, and local governments may help determine which metrics are most salient.

Applying energy justice metrics across the development process is important to understanding the scope of impacts from a project. Indicators would likely be collected by the organization leading the development of the supply chain asset, such as a Tier 1 manufacturer planning a new component factory or a port authority or state government considering the construction or expansion of a port. At a minimum, the lead developer should provide continuity across the project phases and track indicators across the three categories. Figure 6 shows a conceptual framework for how these energy justice considerations could be implemented throughout the project lifecycle.

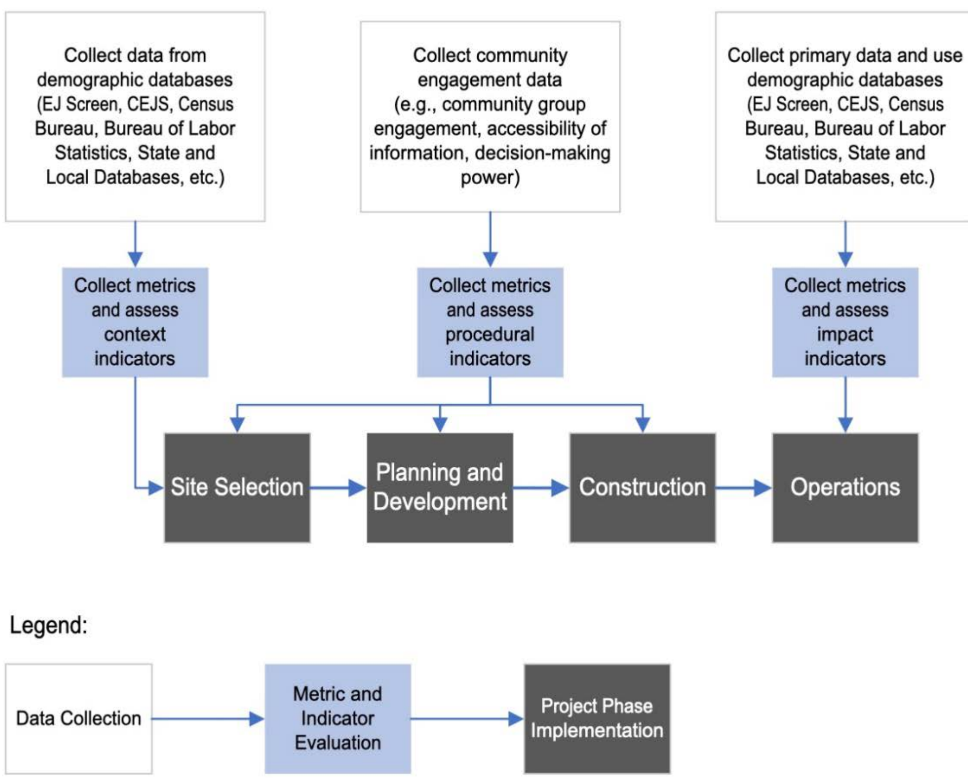


Figure 6. Conceptual framework for applying energy justice metrics in the development of a new supply chain asset such as a port or manufacturing facility

For the lead developers of a supply chain project, indicators could initially be used to understand potential community vulnerabilities as well as opportunities to provide economic development or other benefits that fit the community's needs. Beyond the lead developers of the project, we encourage stakeholders to utilize the full breadth of metrics that are most relevant to their offshore wind energy supply chain footprint. For example, an economic development organization working to promote offshore wind jobs could use the procedural metrics to measure the effectiveness of their community engagement activities, whereas a component manufacturer might be more interested in utilizing impact metrics to understand the community health and safety impacts of their operations.

2.8.4.5 Beyond Quantitative Data

Notably, the previously mentioned indicators and metrics are only the beginning of understanding community contexts, needs, and preferences and evaluating equity in the offshore wind energy supply chain. These indicators and metrics can serve as a guide for designing equitable supply chain actions, determining the types of community engagement and benefits that are appropriate, and deciding whether and how to pursue supply chain development in a given community. However, quantitative data have limitations, as there may be aspects of community contexts and impacts that are best captured through qualitative data produced through interviews, surveys, and other methods.

For example, qualitative research can play a critical role in learning local history and understanding the dynamics that have shaped a community, such as significant land uses or industries, important organizations or individuals in the community, shared values and priorities, community conflicts, and existing social or environmental injustices. This information can help supply chain decision makers identify significant stakeholders, anticipate local needs and preferences, and understand how certain decisions may be perceived by members of the community.

Qualitative data can be useful for understanding how to involve and consider indigenous communities when developing the offshore wind supply chain. Several offshore wind energy projects that are proposed or currently being developed are in close proximity to coastal Indigenous communities, and the same is likely to be true of supply chain facilities. Thus, the industry should be aware of the need to engage in tribal consultation processes and consider how supply chain activities may impact Indigenous communities. Exploring Indigenous sustainability and sovereignty concepts through qualitative frameworks may be useful, and one starting point could be considering questions such as the following, which have been adapted from the Energy Equity Project Framework (University of Michigan School for Environment and Sustainability 2022):

- How can the offshore wind industry promote visibility, healing, and a different relationship with energy for Indigenous communities?
- How can the offshore wind industry respect and honor Indigenous sovereignty and traditional knowledge?
- How do we measure/evaluate progress toward Indigenous sovereignty in the realm of offshore wind energy?

3 The Impacts of a Domestic Offshore Wind Energy Supply Chain

The considerations outlined in Section 2 indicate that several barriers and challenges exist to establishing a domestic offshore wind energy supply chain. Developing this supply chain in time to meaningfully support the installation of 30 GW by 2030 presents an additional challenge due to the long timelines required to finance, permit, and construct ports, vessels, and manufacturing facilities. Understanding what this supply chain requires to meet the national offshore wind energy target and deployment beyond 2030 can help federal, state, and industry stakeholders strategically plan how to invest in local resources to both de-risk the 2030 deployment targets, establish a sustainable and self-sufficient industry, and realize the significant benefits that can be achieved through an offshore wind industry in the United States.

In this section, we aggregate the individual facility considerations presented in Section 2 and Appendix A with a broad screening of available state port and workforce resources to define a viable supply chain scenario that could meet the manufacturing requirements of the U.S. pipeline by 2030. It is important to clarify that the supply chain defined here is not a prediction of where offshore wind manufacturing facilities will actually be built; instead, it is intended to demonstrate one possible scenario under which the supply chain could evolve, and to use this scenario to estimate the impacts on offshore wind energy project deployment, distribution of job potential between states, and energy justice impacts within host communities. We explore several sensitivities around the prescribed scenario, including the time frames in which facilities need to be announced and constructed to achieve a domestic supply chain by 2030. The major goal of this section is to demonstrate the critical investments that are needed to establish a domestic supply chain, assess when these investments need to be made to build the supply chain by 2030, and characterize key impacts of the domestic supply chain.

3.1 A Conceptual Domestic Offshore Wind Supply Chain

In Section 2.5, we described the manufacturing facilities required to meet the average demand from the United States offshore wind pipeline along with the investment required to permit and construct each facility. We focus on the critical components identified in Section 2.5 to define this supply chain, although we also assess the potential role of existing suppliers of supporting components. Nearly every one of these major manufacturing facilities would require a port or waterfront location to be developed to support the construction and loadout of massive offshore wind components.

In addition to fabrication port requirements, we discussed the need for marshaling ports and installation vessels (specifically, wind turbine installation vessels, heavy-lift vessels, and feeder barges) to stage and install offshore wind energy projects. In this section, we define the manufacturing facility, port, and vessel requirements needed to establish a domestic supply chain. We include time frames for developing these assets and consider conservative and accelerated scenarios to understand how construction time frames affect the readiness level of the domestic supply chain.

The results we present define a conceptual domestic supply chain that could meet manufacturing and installation requirements by 2030. This scenario is only one out of limitless possibilities and is not intended to predict how the supply chain will evolve in the United States.

3.1.1 Marshalling Ports and Installation Vessels

We begin by considering the port and vessel requirements that would be needed to meet the installation requirements of the 30-GW pipeline. This analysis focuses on the East Coast (fixed-bottom) pipeline, as the large number of projects could be subjected to delays as they compete for a finite set of port and vessel resources in the 2020s. The goal of the analysis is to understand the constraint on deployment that existing port and vessel resources pose to the national offshore wind target, and to estimate the level of investment required to alleviate this bottleneck.

3.1.1.1 Modeling Approach

Some of the required ports and vessels for offshore wind energy project installation either already exist, are under construction, or have been announced and will begin construction soon; however, it is unclear how effectively these resources meet the demand of the U.S. pipeline. We define a Baseline scenario that includes these existing, in-progress, and announced assets, but does not include any additional infrastructure expansion. The Baseline scenario effectively sets a minimum bound on the offshore wind deployment that can be accomplished with known port and vessel resources. We will show that these resources are inadequate to install sufficient projects on the East Coast to reach the 30-GW-by-2030 target.

Achieving the 30-GW target will require further investment in ports and vessels; however, the focus of this investment (particularly on the type of vessels required) is unclear. Project installation in the United States could rely on domestically built WTIVs and HLVs using methods that are common in Europe or could rely more heavily on feeder barges that transport components to U.S.- or foreign-flagged WTIVs and HLVs. Both scenarios would require constructing more Jones-Act-compliant vessels, which should focus on either WTIVs and HLVs (in the first case) or feeder barges (in the second case) because these vessels will likely create the most restrictive barriers to constructing projects on time (Shields et al. 2022). We define scenarios that identify the number of these vessels that need to be available to the U.S. market throughout the 2020s to reach the 30-GW-by-2030 target.

We define two options in which either all projects (except those marshaling out of ports with size constraints) use a WTIV or HLV to both transport and install components, or all projects in the pipeline use feeder barges to transfer components. This framework effectively means that one scenario requires significant U.S.-built WTIVs and HLVs, and the other requires significant U.S.-built feeder barges. In the second scenario, the required WTIVs and HLVs could be sourced from the global market at the risk of competing with international demand or built domestically if sufficient shipyard capacity can be realized. We use these two scenarios to frame the range of vessels that could be needed to install foundations and wind turbines.

The available port and vessel resources in each scenario are:

- **The Baseline scenario** (existing, under construction, and announced assets) includes:
  - Marshaling ports: New Bedford Marine Commerce Terminal, New London State Pier, Portsmouth Marine Terminal, Phase 1 of the New Jersey Wind Port, Tradepoint Atlantic, and the South Brooklyn Marine Terminal
  - WTIVs: One foreign-flagged vessel assumed to be contracted from the European market, a second foreign-flagged vessel that is available in 2023, the first Jones-Act-compliant vessel, which is currently under construction (Charybdis), and the unnamed Equinor/bp/Maersk WTIV
  - HLVs: Two foreign-flagged HLVs
  - Feeder barges: Four U.S.-flagged feeder barges
- **The U.S. WTIV scenario** (targeted investment in U.S.-built WTIVs and HLVs) can use all the assets from the Baseline scenario for project installation, as well as:
  - Marshaling ports: Salem, Phase 2 of the New Jersey Wind Port, and Arthur Kill Terminal
  - WTIVs: Three new U.S.-flagged WTIVs
  - HLVs: Three new U.S.-flagged HLVs.
- **The U.S. Feeder scenario** (targeted investment in U.S.-built feeder barges) can use all the assets from the Baseline scenario for project installation, as well as:
  - Marshaling ports: Salem, Phase 2 of the New Jersey Wind Port, and Arthur Kill Terminal
  - WTIVs: Three WTIVs (U.S.- or foreign-flagged)
  - HLVs: Three HLVs (U.S.- or foreign-flagged)
  - Feeder barges: Four new U.S.-flagged specialized feeder barges.

We also define the dates when these resources become available to the offshore wind energy market in each scenario, as shown in Figures 7 and 8. These dates are based on public announcements of development timelines, estimates from similar offshore wind supply chain projects, and input from industry experts. The U.S. WTIV scenario prescribes operational dates for WTIVs and HLVs that would be difficult to achieve without compelling domestic shipyards to immediately pivot to offshore wind vessel construction. This scenario is intended to provide a reference for the number of domestic WTIVs and HLVs that would be required to meet the 30-GW build-out requirements, not to suggest a likely development pathway for domestic vessel production.

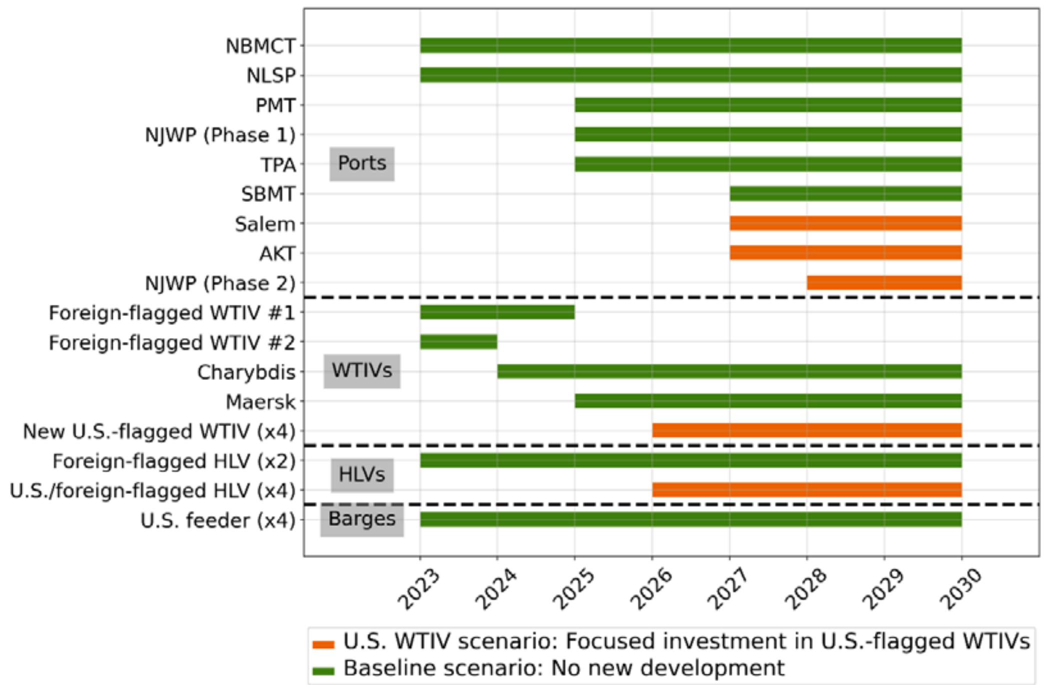


Figure 7. Availability of marshaling ports, WTIVs, HLVs, and feeder barges in the U.S. WTIV scenario (with the Baseline scenario shown as a reference).

NBMCT = New Bedford Marine Commerce Terminal, NLSP = New London State Pier, PMT = Portsmouth Marine Terminal, NJWP (1) = New Jersey Wind Port (Phase 1), TPA = Tradepoint Atlantic, SBMT = South Brooklyn Marine Terminal, NJWP (2) = New Jersey Wind Port (Phase 2), AKT = Arthur Kill Terminal

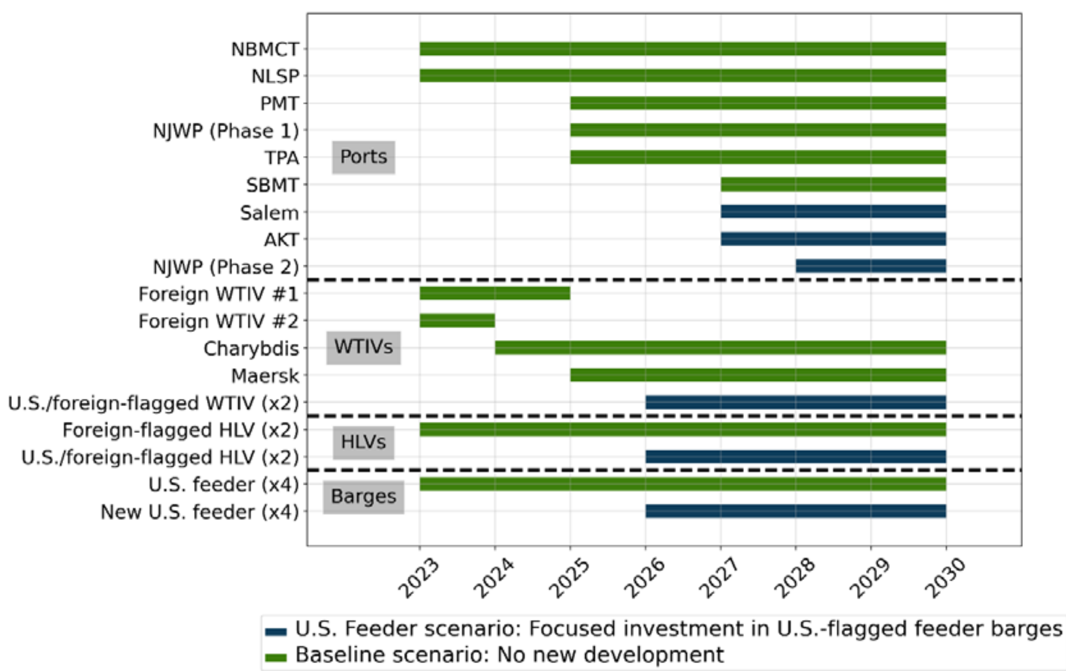


Figure 8. Availability of marshaling ports, WTIVs, HLVs, and feeder barges in the U.S. Feeder scenario (with the Baseline scenario shown as a reference).

NBMCT = New Bedford Marine Commerce Terminal, NLSP = New London State Pier, PMT = Portsmouth Marine Terminal, NJWP (1) = New Jersey Wind Port (Phase 1), TPA = Tradepoint Atlantic, SBMT = South Brooklyn Marine Terminal, NJWP (2) = New Jersey Wind Port (Phase 2), AKT = Arthur Kill Terminal

We developed a dynamic model to evaluate the installation times and bottlenecks for each scenario. The model, based on the National Renewable Energy Laboratory's Offshore Renewables Balance-of-system and Installation Tool (ORBIT) offshore wind cost and logistics model (Nunemaker et al. 2020), simulates the installation of each project in the East Coast pipeline. These projects comprise the baseline deployment scenario from Shields et al. (2022). The capacities of individual projects were slightly adjusted from Shields et al. (2022) to match the estimates provided by Musial et al. (2022).

In this modeling approach, each project is assigned to a likely marshaling port based on the project developer and/or location. A pool of WTIVs, HLVs, and feeder barges is available to all projects for foundation and wind turbine installation. These port and vessel resources become available at the scheduled times shown in Figure 7 or 8. In reality, other vessels, such as service operation vessels, crew transfer vessels, fall pipe vessels, and guard/survey vessels, will be required for project installation; however, in this analysis, we focus on the vessels likely to create the most significant bottlenecks.

At each time step in the simulation when an individual project is scheduled to begin installation, the model checks if the appropriate port and installation vessels are available; if either are committed to a different project, delays begin to accrue and the new project cannot begin installation until all required resources are available. In this way, we can estimate the risk of delay for each project and aggregate this over the entire pipeline to determine how limited port and vessel resources may constrain the capacity of offshore wind that can be installed by the end of 2030. A more detailed explanation of the modeling methodology is provided in Appendix B.

Shields et al. (2022) suggest that 2.5 GW of floating offshore wind energy could be developed on the West Coast by 2030. There is currently too much uncertainty about the West Coast port infrastructure that will support this deployment to include floating wind within the model. Further analysis will be required to evaluate floating wind port and vessel scenarios to understand potential constraints that could develop beyond 2030. In this analysis, we are more concerned with understanding how the stack-up of many fixed-bottom projects creates bottlenecks in port and vessel resources; therefore, we assume that 2.5 GW of floating wind capacity can be installed by 2030 and use the dynamic modeling approach to estimate the fixed-bottom port and vessel resources required to construct the remaining 27.5 GW required to achieve the 30-GW-by-2030 goal.

3.1.1.1.1 Offshore wind deployment by the end of 2030 for each scenario

Figures 9–11 show the modeled deployment timelines between 2023 and 2036 for the Baseline, U.S. WTIV, and U.S. Feeder scenarios; the hatched bars for each project show the time that each project is delayed relative to its planned installation start date due to a lack of available port or vessel resources. Each bar represents a specific project in the U.S. pipeline, although we label them by state instead of by name to focus on the impact of port and vessel constraints on the overall pipeline instead of individual projects.

Under the Baseline scenario, about half of the 30-GW pipeline is delayed beyond 2030. Simulated projects commonly experience multiple-year delays as they wait for an inadequate number of resources to come online. This bottleneck becomes particularly challenging in 2025–2027 as we estimate that 13 projects intend to begin construction during this time frame with a set of port and vessel capabilities that can only support 2−3 projects at a time. Even this limited scenario would require over $2 billion of investment to complete the planned construction of marshaling ports and installation vessels; if this funding is delayed or does not materialize, the installed capacity could be even lower than 13 GW.

The U.S. WTIV and U.S. Feeder scenarios in Figures 10 and 11 show how increased investment in port and vessel infrastructure can effectively unlock the deployment pipeline and more than double the fixed-bottom capacity that can be installed by 2030 to at least 28.0 GW. Including the 2.5 GW of West Coast floating wind projects available to the U.S. pipeline would then make it possible to achieve the national offshore wind target (Shields et al. 2022). Unsurprisingly, these scenarios would require a significantly larger investment of almost $6 billion (an additional $4 billion over the Baseline scenario). A key difference between these scenarios is the number of WTIVs and HLVs that are needed to meet the deployment demand. The U.S. WTIV scenario, in which U.S.-flagged WTIVs and HLVs are used for most projects (except for projects that stage out of New Bedford Marine Commerce Terminal and South Brooklyn Marine Terminal, which require feeder barges due to spatial constraints), requires a total of six of each type of vessel. The U.S. Feeder scenario, which requires all projects to use feeder barges, requires four WTIVs and four HLVs (but a greater number of feeder barges). The U.S. Feeder scenario allows projects to be installed more quickly because the WTIV and HLV do not spend time transiting to port, which reduces the overall demand for these vessels; however, it does create additional risk and challenges from at-sea component transfers. Given the anticipated global shortage of WTIVs and HLVs (Shields et al. 2022), the reduced demand for these vessels in the U.S. Feeder scenario may lead to more project developers choosing this option.

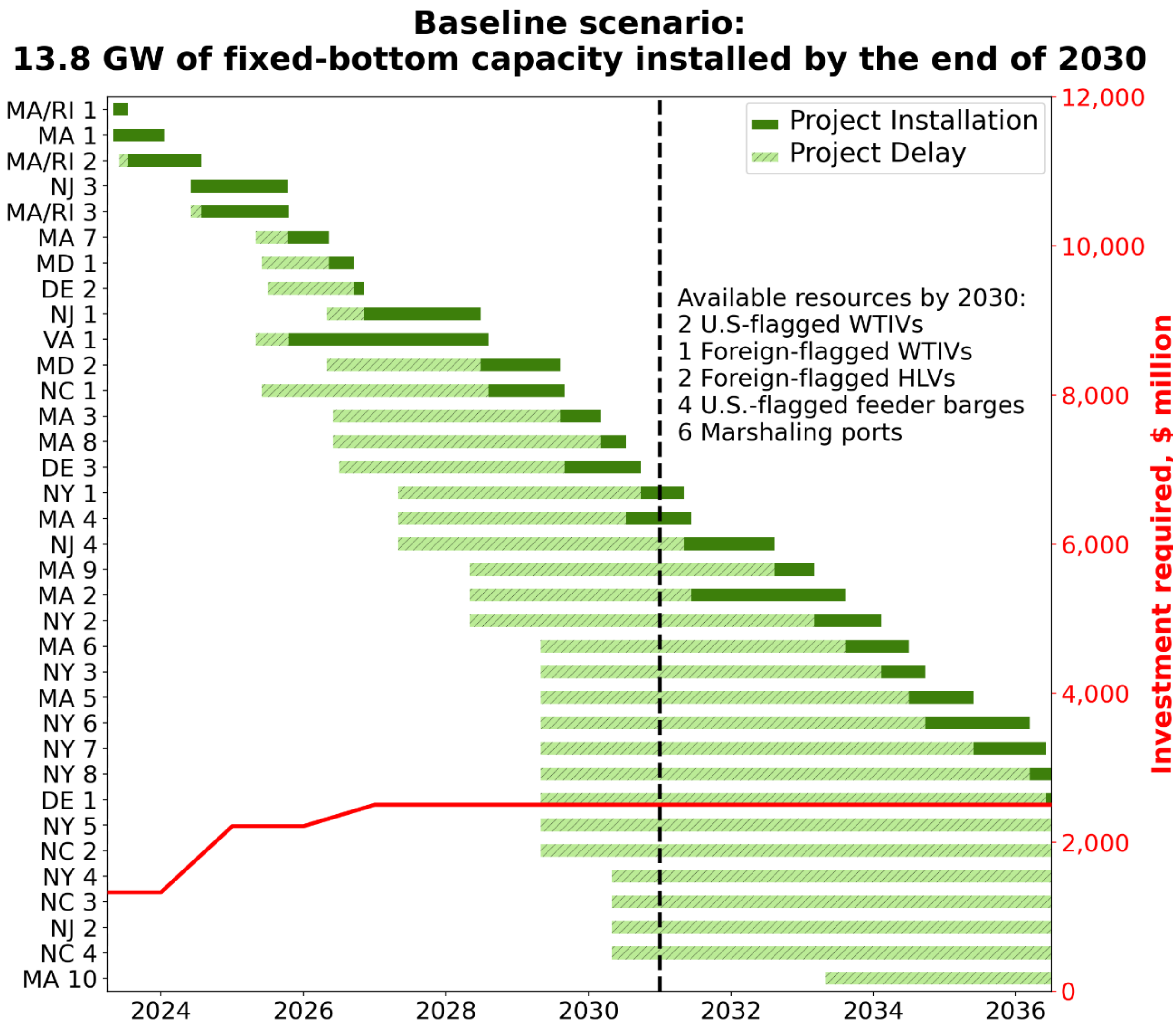


Figure 9. Deployed fixed-bottom capacity and project delays for the Baseline scenario. Total investment in marshaling ports, WTIVs, and HLVs are also shown.

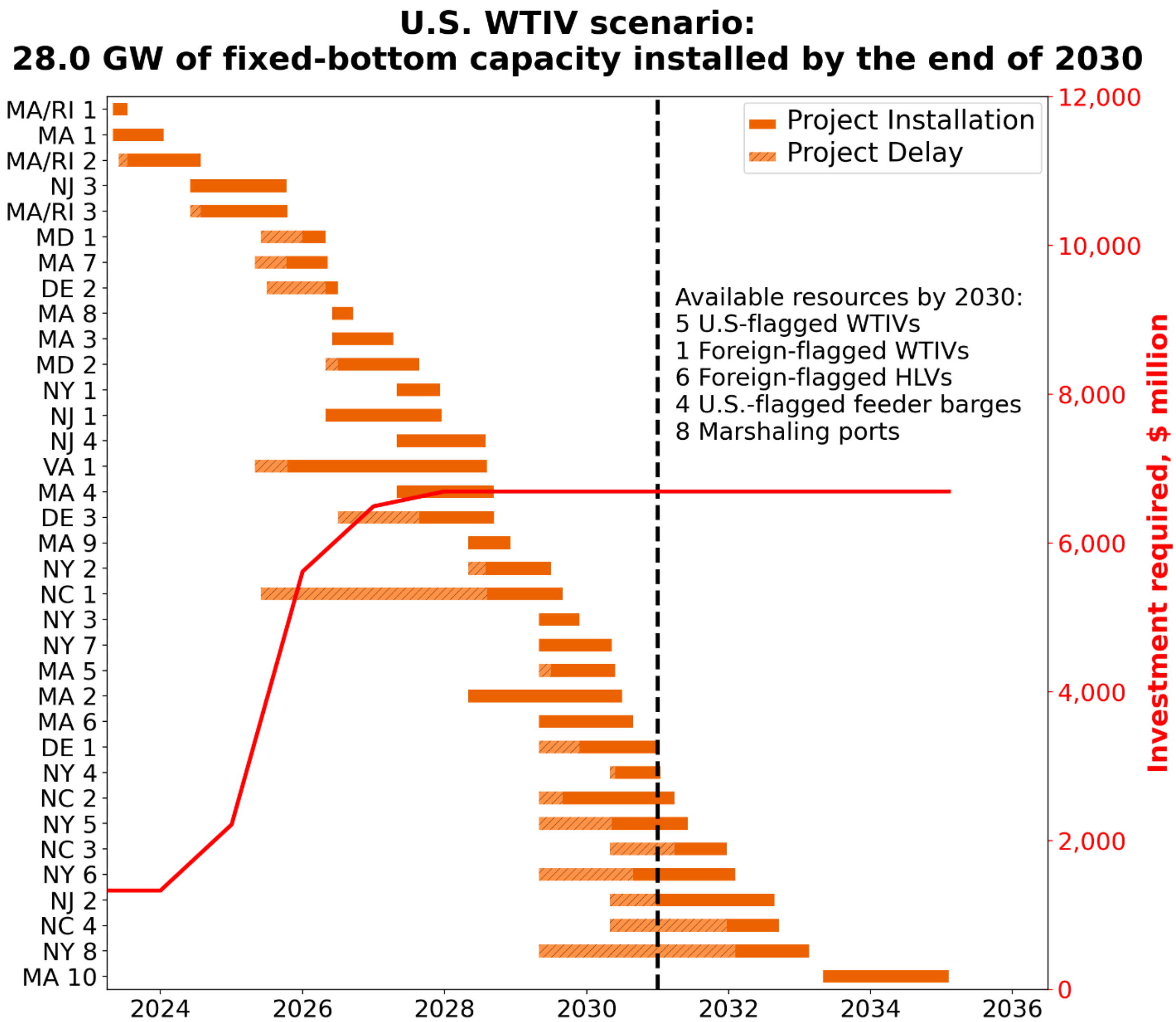


Figure 10. Deployed fixed-bottom capacity and project delays for the U.S. WTIV scenario. Total investment in marshaling ports, WTIVs, and HLVs are also shown.

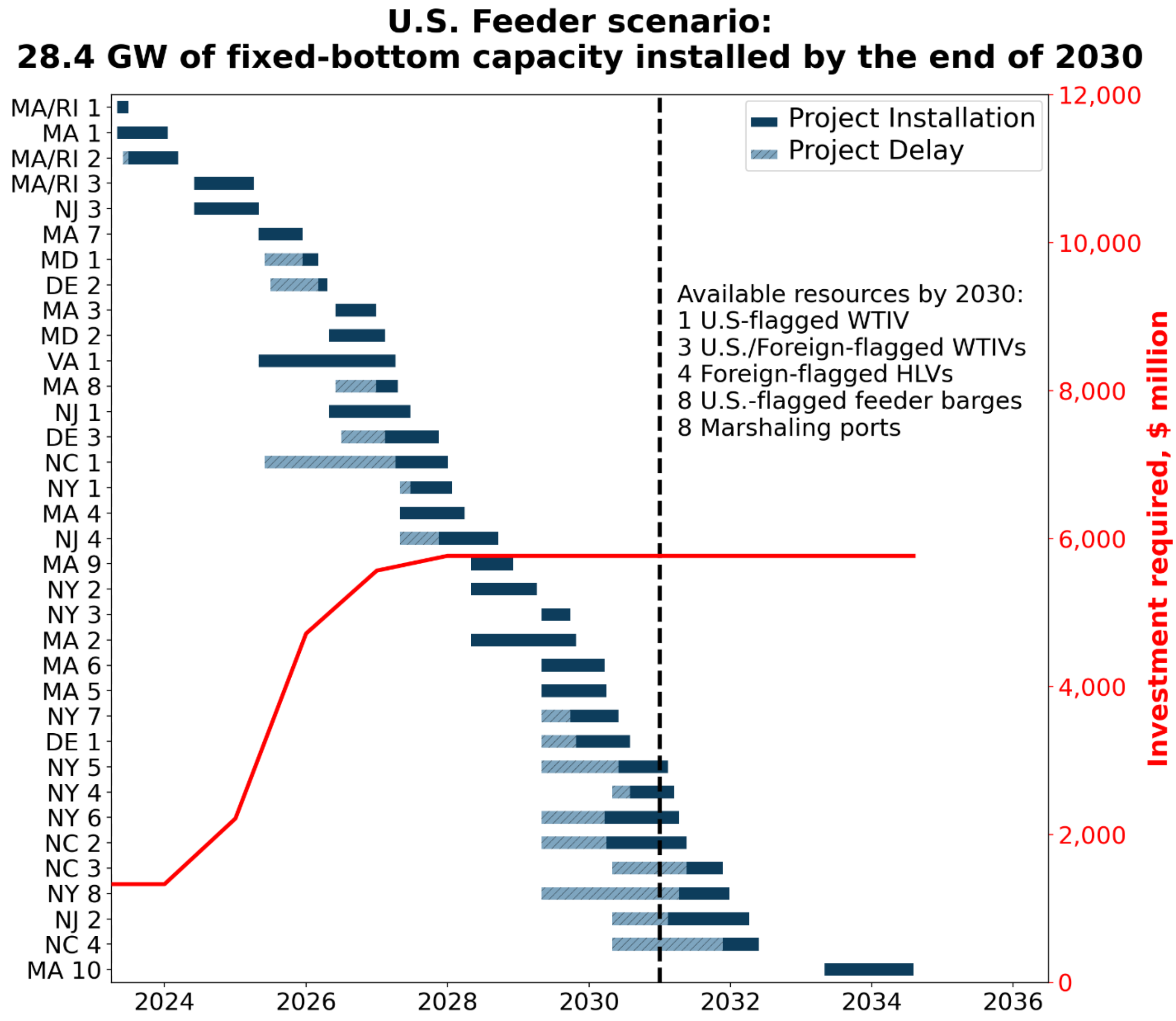


Figure 11. Deployed fixed-bottom capacity and project delays for the U.S. Feeder scenario. Total investment in marshaling ports, WTIVs, and HLVs are also shown.

Most offshore wind energy developers with projects in the U.S. pipeline have experience in the European market and have primarily relied on the WTIV strategy with no feeder barges. Developers have expressed a preference for using this strategy because of its familiarity; however, as the challenges in building a fleet of domestic WTIVs have become more apparent, developers have started to view feeder strategies as more realistic for the U.S. market despite risks associated with the need for additional vessel contracts, transferring large components at sea, and the global shortage of WTIVs (Von Ah et al. 2020). It is revealing that, despite the clear need for WTIVs that we have demonstrated in these results, there have not been further announcements for U.S.-flagged WTIVs in the 2 years since Dominion Energy announced the investment in Charybdis (Dominion Energy 2020). Instead, we have seen an announcement for a foreign-built WTIV that will be committed to the U.S. market with an accompanying set of U.S.-flagged feeder barges (Maersk Supply Service 2022). This approach could produce lower-cost WTIVs while energizing the U.S. shipbuilding industry to produce specialized and highly capable feeder vessels. It is likely that the eventual state of the U.S. vessel fleet will be in between the U.S. WTIV and U.S. Feeder scenarios, with some domestically produced vessels and some reliance on feeder barges and foreign-flagged WTIVs and HLVs.

Figure 12 summarizes the deployment and installed capacity results from Figure 8–10 for the modeled scenarios. The United States would have to invest at least $6 billion in marshaling ports, WTIVs, and HLVs to provide sufficient resources that can mitigate project delays and help achieve the national offshore wind energy target. These investments need to be planned early to obtain construction permitting and shipyard positions. Without planned and committed investment in marshaling ports and installation vessels, the United States may miss the boat on the opportunity to install 30 GW of offshore wind energy by 2030.

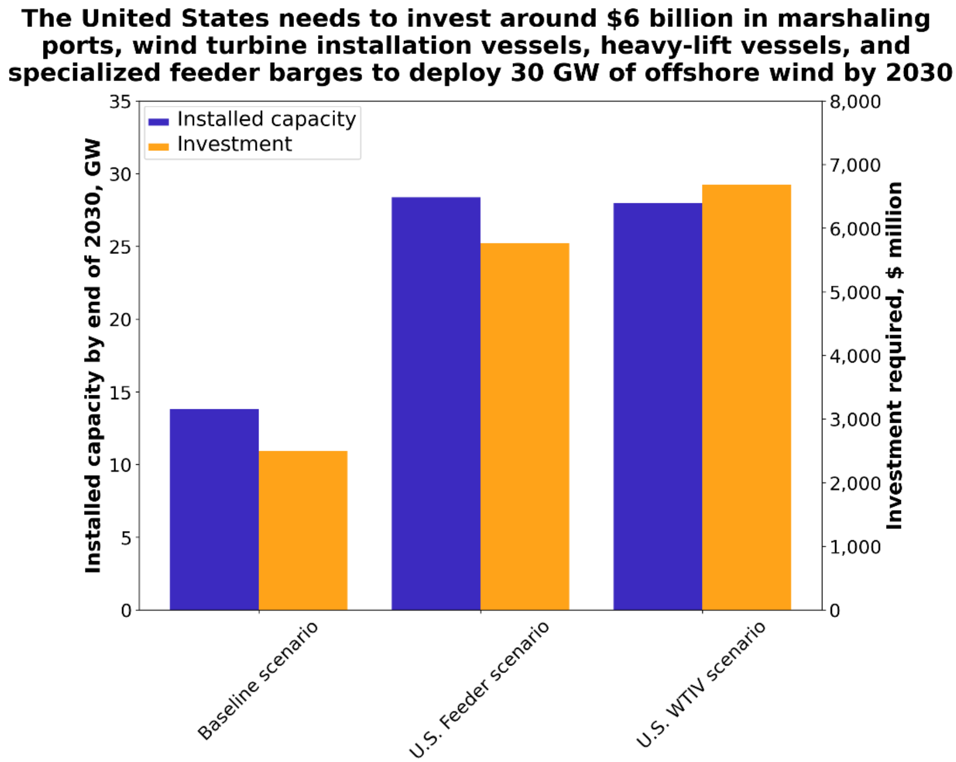


Figure 12. Summary of installed capacity and capital investment required for the Baseline, U.S. WTIV, and U.S. Feeder port and vessel scenarios

3.1.1.2 Additional Port and Vessel Considerations for a Domestic Supply Chain

This analysis only considers the East Coast (fixed-bottom) pipeline with a focus on deployment levels by 2030. As deployment expands to the West Coast in the late 2020s, the floating wind energy industry is likely to experience similar bottlenecks. As described in Section 2.4, West Coast ports that can marshal floating wind projects are effectively nonexistent and there is likely to be a shortage of anchor handling tug vessels and semisubmersible barges used for platform construction, mooring line prelay, and some tow-out operations. As the planning stages for floating wind leasing and development ramp up, it will be critical for industry and West Coast states to collaboratively identify the riskiest types of infrastructure that will require targeted investment. It is possible that the floating wind industry could require 2-3 integration ports on the

West Coast, one in the Gulf of Mexico, one in the Central Atlantic, and one in the Gulf of Maine to service the range of floating projects expected to begin construction by the early 2030s, with a net investment of approximately $2 billion. Further work must be done to understand the number of floating wind ports needed and the associated cost and development requirements.

In addition to the floating wind port and vessel requirements, the offshore wind energy industry will require a significant number of vessels beyond the WTIVs, HLVs, and feeder barges described in this section. We focus on the foundation and wind turbine installation processes to highlight a critical gap in the exiting vessel fleet; however, additional vessels such as crew transfer vessels, service operation vessels, cable-lay vessels, fall pipe or other scour protection vessels, and a myriad of survey and support vessels will be required throughout the full installation process. Most of these vessels will be U.S.-flagged, and construction of over a dozen of these vessels is either underway or planned (Musial et al. 2022; American Clean Power 2022).

Some existing vessels could potentially be repurposed from their current industries to support offshore wind energy activities. Estimating the full investment in the U.S. vessel fleet is beyond the scope of this study and would require additional hundreds of millions of dollars to be spent at domestic shipyards to build the capabilities needed to install and maintain the U.S. pipeline.

3.1.2 Manufacturing Facilities

In Section 2.5 we described the capabilities of each type of major manufacturing facility that we specify to be part of the domestic supply chain. By comparing the throughput of these facilities with the annual demand for components specified by Shields et al. (2022), we estimate the number of facilities that would be required (these details are specified for each component in Appendix A). In Figure 13, we aggregate the number of facilities required for each component to give an estimate of the size of the offshore wind energy supply chain. The scenario we present has a total of 34 Tier 1, 2, and 3 manufacturing facilities that would be required to manufacture the critical components for the supply chain. Eleven of these facilities have already been announced, although only one is operational and one more is actively under construction. Additional investments in supporting supply chain facilities, such as secondary steel facilities, have also been announced but are not a focus of this report (Shields et al. 2022; Musial et al. 2022).

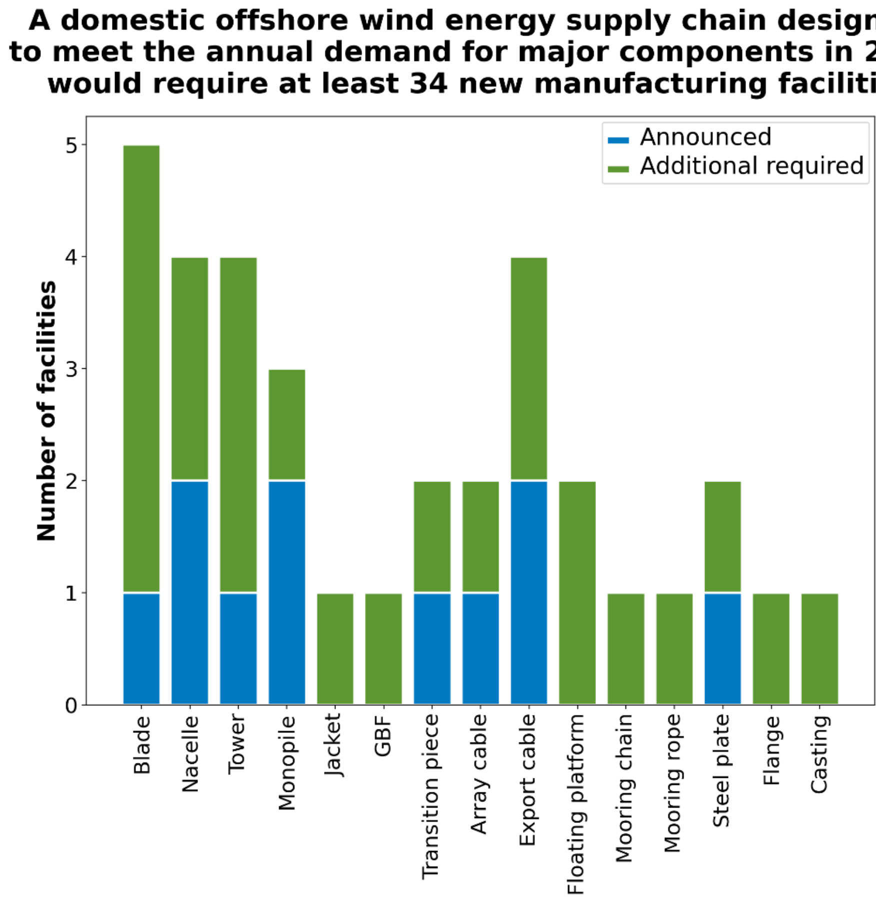


Figure 13. Total number of major component manufacturing facilities required for a domestic offshore wind energy supply chain. Some facilities have already been announced by manufacturers and additional facilities would be required to meet the anticipated pipeline demand.

The supply chain defined by the facilities listed in Figure 13 represents an initial phase of development to support the build-out of the existing project pipeline. Additional facilities (and continued maintenance investment in the listed facilities) would be required as the pipeline and deployment expands into new regions and technologies. It is possible that, during the 2020s, additional manufacturing capabilities may be developed to address regional supply chain needs and introduce further market competition. These considerations are beyond the scope of this study; instead, we identify the minimum viable supply chain that is needed to support the average demand for components by 2030.

We envision a supply chain that would develop in such a way to allow competition between different technologies in the 2020s. The number of wind turbine facilities (e.g., manufacturing blades, nacelles, and towers) is sufficient for the three major OEMs to each potentially have a footprint in the United States (although we do not specify which facility corresponds to each OEM in this study). The wind turbine facility scenario includes a blade, nacelle, and tower facility on the West Coast that would service the growing floating wind energy market.

We also include manufacturing capabilities for multiple types of fixed-bottom substructures, with three monopile facilities, one jacket facility, and one gravity-based foundation (GBF) facility. The construction and operation plans filed by early phase project developers have indicated a preference for monopiles and jackets, which comprise around 75% of operating global projects (Musial et al. 2022). We expect that most U.S. projects built in the 2020s will use monopiles, with some opportunity for jackets and possibly GBFs. GBFs face some additional obstacles beyond supply chain constraints because they can have restrictive soil condition requirements and have historically been perceived as more expensive than monopiles; however, they do not require pile-driving into the seabed which reduces the noise impact on marine mammals, and can be installed without the use of a WTIV as the wind turbine and substructure can be assembled at port and floated to the project site. These advantages have led to some interest and funding dedicated to considering GBFs for the U.S. market (National Offshore Wind Research and Development Consortium 2021). As a result, we include a jacket facility and a GBF facility in the supply chain scenario to indicate the potential role for these components in the future of the U.S. offshore wind market by 2030, although their contribution to the overall supply chain investment is relatively small because they can be developed at ports or shipyards with relatively minor upgrades to their existing infrastructure (such as extending or strengthening bulkheads, investing in new cranes or welding equipment, or setting up a mobile concrete batch plant). We still expect that monopiles will control the market share throughout the 2020s, although this may change beyond 2030 as the industry continues to learn and evolve. Further study is required to better understand the cost-benefit trade-offs of GBFs for domestic offshore wind energy projects.

Finally, we do not specify the type of floating platform that will be used for early floating wind projects in the 2030 time frame. Most projects have announced a substructure type plan on using semisubmersibles, although dozens of other concepts exist that could be the right technology for the U.S. West Coast (Musial et al. 2022; ABS Group 2021). We assume that the floating platform facilities defined in Figure 13 would be built as an integral part of floating wind integration ports and that the space, equipment, workforce, and storage requirements would be relatively similar between viable platforms for the West Coast. This assumption means that the supply chain demands are relatively independent of the technology type. These manufacturing facilities would have to be sufficiently nimble to adapt to evolving floating platform designs as the wide range of current options converges toward market leaders and these concepts progress from prototypes to mass production.

3.1.2.1 Fabrication Port Resources

The majority of the 34 facilities highlighted in Figure 13 would need to be located at a port as the components they produce are too large to transport via road or rail. As part of the domestic supply chain scenario, we have screened over 100 U.S. ports to identify a permissible (existing) port for each new manufacturing facility based on physical site constraints, potential regional advantages such as labor rates or proximity to offshore wind energy projects, and the nature of the offshore wind business environment established by state governments. We have selected a port for each new factory, but we do not report them here to avoid endorsing a particular site. The important takeaway is that sites exist for manufacturing facilities; however, they would all require significant investment and development time to be ready for offshore wind energy activities. The fabrication port scenario is summarized in Table 10, and a full description of the methodology used to assign a fabrication port to a planned manufacturing facility is provided in Appendix B2.

Table 10. Fabrication Port Locations for Each Manufacturing Facility in the Domestic Supply Chain Scenario.

Facilities that have already been announced are highlighted in blue, and additional required facilities are highlighted in green. The port facilities for announced facilities are also provided.

Component	Factory Name	Type	State
Blade	SGRE	Announced	Portsmouth Marine Terminal, Virginia
	Blade 1	Additional	North Carolina
	Blade 2	Additional	Massachusetts
	Blade 3	Additional	New Jersey
	Blade 4	Additional	Oregon
Nacelle	General Electric	Announced	New Jersey Wind Port, New Jersey
	Vestas	Announced	New Jersey Wind Port, New Jersey
	Nacelle 1	Additional	Rhode Island
	Nacelle 2	Additional	California
Tower	Marmen Welcon	Announced	Port of Albany, New York
	Tower 1	Additional	Maryland
	Tower 2	Additional	Maine
	Tower 3	Additional	California
Monopile	EEW	Announced	Port of Paulsboro, New Jersey
	US Wind	Announced	Tradepoint Atlantic, Maryland
	Monopile 1	Scenario	Virginia
Jacket	Jacket 1	Additional	Louisiana
GBF	GBF 1	Additional	North Carolina
Transition piece	Smulders	Announced	Port of Albany, New York
	Transition piece 1	Additional	New York
Array cable	Hellenic	Announced	Tradepoint Atlantic, Maryland
	Array cable 1	Additional	New York
Export cable	Nexans	Announced	South Carolina
	Prysmian	Announced	Massachusetts
	Export cable 1	Additional	Rhode Island
	Export cable 2	Additional	South Carolina
Steel plate	Nucor	Announced	Brandenburg, Kentucky
	Steel plate 1	Additional	Georgia
Casting	Casting 1	Additional	Pennsylvania
Flange	Flange 1	Additional	New Hampshire
Floating platform	Floating platform 1	Additional	California
	Floating platform 2	Additional	California
Mooring chain	Mooring chain 1	Additional	Texas
Mooring rope	Mooring rope 1	Additional	Maine

A summary of the number of manufacturing facilities allocated to each state in this scenario is provided in Figure 14. As described in Appendix B2, one of the goals of the assignment methodology was to develop a reasonably evenly distributed network of supply chain facilities because the offshore wind industry is expanding throughout all regions of the United States. There are several states that have proactively developed supply chain resources and have remaining capacity for new facilities, such as New York and New Jersey, which have a higher number of assigned facilities; however, the major component supply chain in this scenario has a presence in 17 East Coast, West Coast, and Gulf of Mexico states.

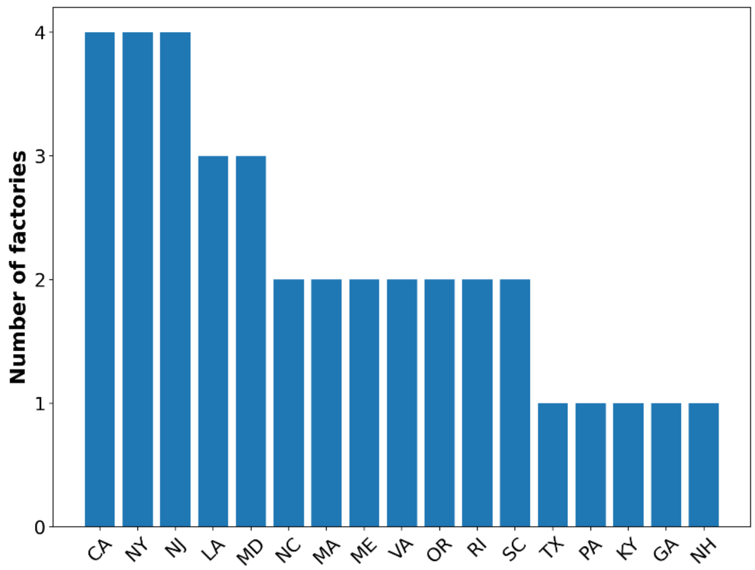


Figure 14. Distribution of manufacturing facilities by state in the domestic supply chain scenario

3.1.2.2 Development Time Frames and Manufacturing Capacity

The facilities required for a domestic supply chain are all construction projects that require significant permitting and construction time frames. These multiyear timelines are also exposed to risk of delays attributed to uncertainty around when the facilities will be announced, how long it will take to upgrade the port (which will vary from site to site), and how long the permitting and construction processes will take. We therefore define two scenarios for the facility construction time frame: an accelerated scenario with short construction timelines and early commitments to supply chain investment, and a conservative scenario with longer timelines and later commitment dates. The accelerated and conservative timelines are based on discussions with industry experts. The assumptions for each scenario are described in Table 11.

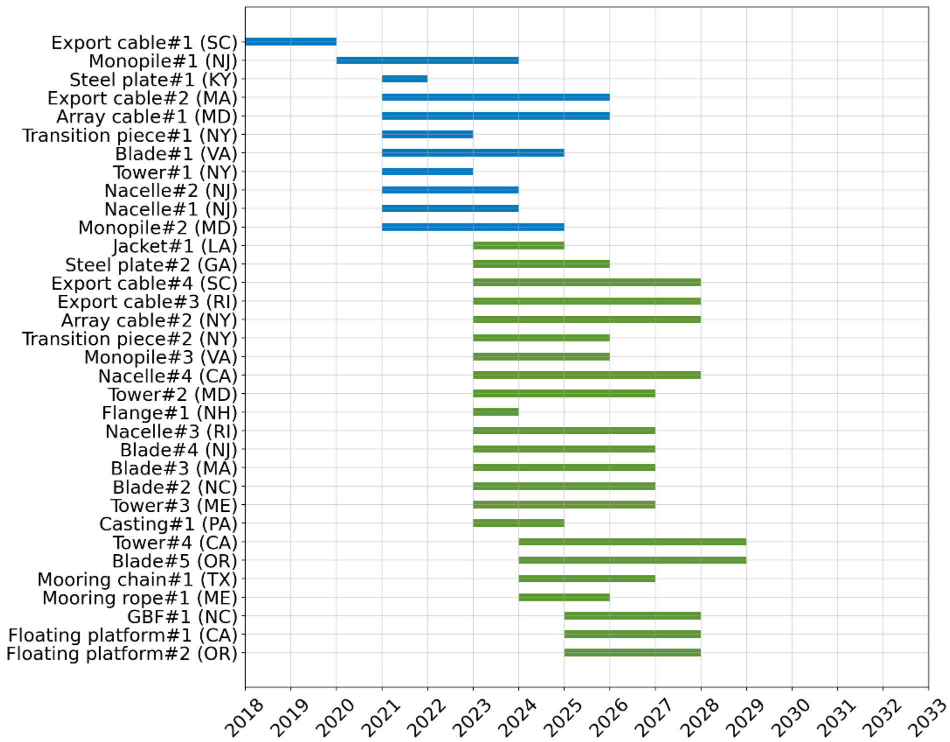
Table 11. Definitions of Accelerated and Conservative Supply Chain Development Scenarios

	Scenario	
Parameter	*Accelerated*	*Conservative*
Announcement date	2023	2024
Fixed-bottom port upgrade duration (years)	2	4
Floating port construction duration (years)	3	5
Facility construction duration per component (years)	Minimum value from Table 3	Maximum value from Table 3

Using these time frames, we develop charts for the accelerated and conservative scenarios (Figure 15). We then determine the percentage of the overall pipeline demand that the domestic supply chain can support over time by first calculating the fraction of each supply chain component that can be manufactured by the new domestic facilities in a given year and then averaging over the number of component types that need to be fabricated in that year. We define this metric as the manufacturing capacity of the domestic supply chain and use the following equation, where n is the types of components (e.g., blades, monopiles, cables) that need to be fabricated in a given year and x_i is the fraction of each component that can be produced by domestic supply chain facilities in that year.

$$Manufacturing\ capacity = \frac{\sum_i^n x_i}{n}$$

It is important to note that the demand percentage plots reflect the manufacturing date for components, not the date that these components are installed at the offshore wind energy plant. We assume a 2-year lead time from the beginning of manufacturing to installation, meaning that components manufactured in 2028 would then be installed in 2030; therefore, the manufacturing capacity in 2028 drives the ability of the offshore wind industry to domestically produce the components needed by the end of the decade. The accelerated scenario has most facilities available by 2028, whereas many facilities in the conservative scenario are delayed until the early 2030s.



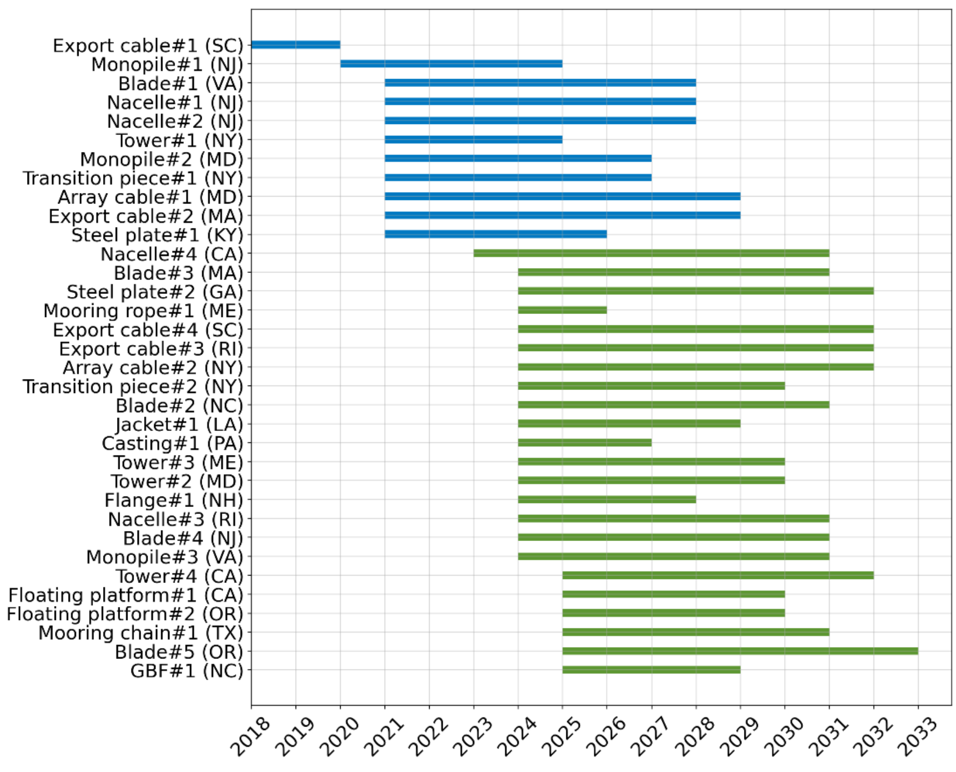


Figure 15. Facility construction schedules for the accelerated (top) and conservative (bottom) supply chain scenarios

The effects of the different supply chain growth scenarios on the industry's manufacturing capacity are shown in Figure 16. A small nonlinearity occurs in 2026, as the demand for floating components comes online. Under the accelerated scenario, most components can be manufactured domestically by 2028 and a full supply chain is realized by 2030. The conservative scenario cannot achieve a fully domestic supply chain until 2033. We will discuss the implications of the manufacturing capacity of the industry for project deployment in Section 3.2.1.

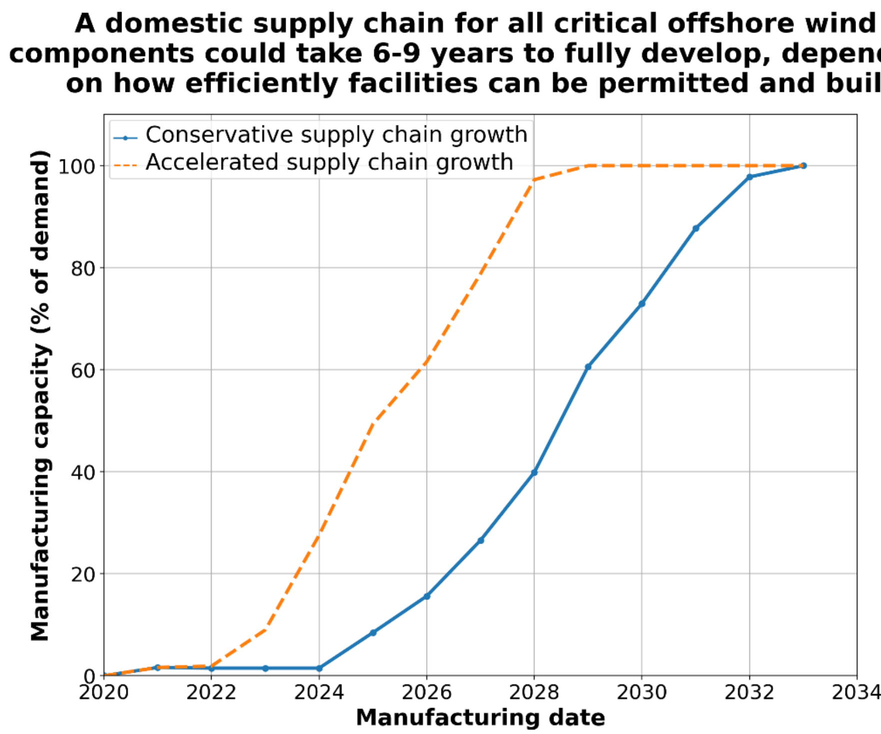


Figure 16. Growth in manufacturing capacity of the domestic supply chain over time for the accelerated and conservative development scenarios

3.1.3 Required Supply Chain Investment

We combine the investments in the marshaling ports (fixed bottom and floating), fabrication ports, WTIVs, HLVs, feeder barges, and manufacturing facilities described in the previous sections to estimate the total investment required to develop a domestic offshore wind supply chain. We assign the costs per asset to the operational date of the facility to demonstrate how this investment would grow over time; this is a simplified depiction of the investment schedule, which will typically be committed in multiple stages over the planning and development processes of a new facility. The results are shown in Figure 17.

We use the U.S. Feeder scenario from Section 3.1.1 to estimate the total investment because this approach is gaining traction with project developers due to the long time frames associated with building U.S.-flagged WTIVs and HLVs. Because this scenario allows WTIVs and HLVs to be U.S.- or foreign-flagged, we still include the investment cost for these vessels in the cumulative investment in the supply chain to convey the need for the U.S. industry to invest in new vessels to achieve ambitious deployment targets. The difference in vessel costs between the U.S. WTIV and U.S. Feeder scenarios is relatively small ($3.55 billion and $3.30 billion, respectively), and so does not greatly impact the overall investment required in the supply chain.

Building a supply chain by 2030 that can support the near-term deployment demand of the U.S. offshore wind pipeline would require an investment of at least $22.4 billion in major manufacturing facilities, ports, and large installation vessels to be made this decade. The largest investments go to ports, vessels, and steel manufacturing. The actual offshore wind supply chain would require additional investment in Tier 2 and 3 preparation, O&M ports, additional vessels (such as fall pipe vessels, crew transfer vessels, and floating wind installation vessels), and workforce training. This profile represents the first phase of required investment in the offshore wind energy supply chain. Additional resources would be required in the early 2030s to expand floating wind manufacturing and installation capabilities and to maintain and upgrade existing facilities to adapt to new technologies.

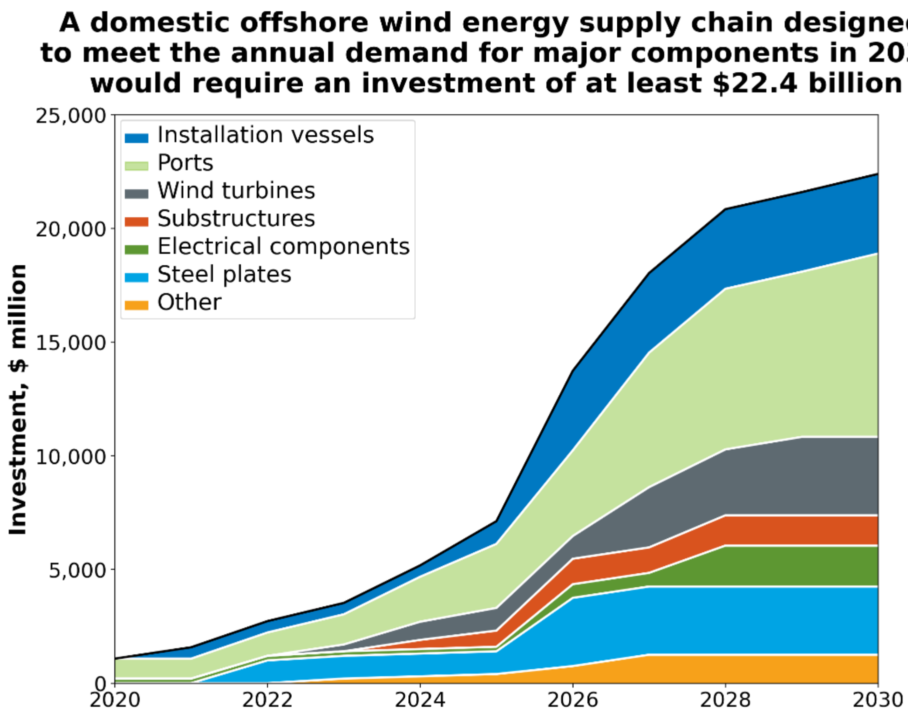


Figure 17. Cumulative investment over time in the major components of a domestic offshore wind supply chain.

Note: Installation vessel investment is based on the U.S. Feeder scenario and includes WTIVs and HLVs, which could be U.S.- or foreign-flagged, and specialized feeder barges, which must be U.S.-flagged. Ports include fabrication and marshaling ports.

3.1.4 Summary of the Domestic Supply Chain Scenario

Based on the findings in the previous sections, we specify a domestic supply chain scenario that can be fully realized by 2030 to minimize bottlenecks in installation and manufacturing. We report the range of vessels from the U.S. WTIV and U.S. Feeder scenarios and refer to the WTIVs and HLVs as "dedicated" vessels to indicate that they could be U.S.- or foreign-flagged depending on vessel availability and design choices for individual projects, but need to be consistently available in the United States throughout the 2020s to alleviate installation bottlenecks. The development time frame is the total time required to permit and construct all required manufacturing facilities after a hypothetical date when all these facilities are announced. The time frame range corresponds to the accelerated and conservative manufacturing scenarios. This supply chain scenario, summarized in Table 12, is the basis for the impact analysis conducted in Section 3.2. This scenario represents an initial investment in the supply chain to support the initial build-out of the pipeline. Additional resources must be developed by the early 2030s to support expanded floating offshore wind energy deployment.

Table 12. A Domestic Supply Chain Scenario for Offshore Wind Energy in the United States in 2030

Parameter	Number
Fixed-bottom wind marshaling ports	8
Floating wind integration ports[16]	2
Dedicated wind turbine installation vessels	4−6
Dedicated heavy-lift vessels	4−6
U.S.-flagged specialized feeder barges	4−8
Manufacturing facilities	34
Development time frame	6–9 years
Total investment	$22.4 billion

3.2 Impacts of a Domestic Supply Chain

In the following sections, we evaluate the impact of developing a domestic supply chain on project deployment, cost of energy, workforce, and energy justice.

3.2.1 Capability To Supply 30 GW Of Components By 2030

Shields et al. (2022) defined a baseline deployment projection based on existing and anticipated lease areas that can potentially yield an installed capacity of 30.1 GW by the end of 2030 and 59.8 GW by the end of 2035. This pipeline assumes no supply chain constraints and does not specify where the components are sourced from; however, Shields et al. (2022) also describe how global supply chains will already be stretched to meet commitments to European and Asian countries that are actively deploying offshore wind energy. The risk associated with relying on international components is one of the primary value propositions for developing a domestic offshore wind supply chain; however, the time required to develop this supply chain presents a challenge to meeting the national offshore wind target.

[16] As we describe in Appendix A, floating wind integration ports are also used as floating platform assembly facilities so there is some overlap between the number of manufacturing facilities and floating wind integration ports.

We can use the growth of the U.S. supply chain manufacturing capacity developed in Section 3.1.2 to estimate the impact that these development timelines could have on the national offshore wind target and the extent to which this target would rely on international supply chains. This evaluation assumes that there is sufficient port and vessel infrastructure to install projects on time and no exogenous delays (such as offshore wind project permitting or raw material shortages) impact project timelines. We assume two phases in the pipeline:

- **Commercial operation dates between 2023 and 2025**. Projects exclusively source components from European suppliers. We assume that most major components need to be manufactured 2 years prior to the commercial operation date,[17] meaning that these components need to be begin construction by the end of 2023. As most offshore wind manufacturing facilities will not be operational by this time, we assume that early-stage project developers plan on importing most of their components. We assume that there are no constraints on sourcing components during this phase (in other words, the supply meets the demand).
- **Commercial operation dates after 2025**. Projects exclusively source components from the growing domestic supply chain. During this time frame, deployment rates in Europe and Asia are expected to increase (Musial et al. 2022; Telsnig et al. 2022) and it will become increasingly difficult for projects in the United States to procure components from these markets. This time frame coincides with an increasing number of domestic projects that plan to be operational by the late 2020s. Therefore, we consider the mid-2020s to be a critical time for the domestic supply chain to meet pipeline demand. We scale the unconstrained annual deployment from Shields et al. (2022) by the manufacturing capacity defined in Section 3.1.2 to estimate the percentage of the pipeline that can be built domestically in each year under both the accelerated and conservative supply chain scenarios defined in Section 3.1.2.2. This simple approach does not consider which components (e.g., wind turbines, foundations, cables) are available to U.S. projects in a given year; however, as a project cannot be commissioned until all components are installed, we use this approach to convey the capabilities of the overall supply chain.

The cumulative capacity installed under unconstrained, accelerated (domestic), and conservative (domestic) supply chain scenarios is plotted in Figure 18. These trajectories are identical until 2025 and begin to diverge as we consider that projects pivot to only domestically sourced components. Because the domestic supply chain cannot yet meet the full component demand, these scenarios fall below the unconstrained deployment projections. The combination of an incomplete domestic supply chain and the increasing number of projects after 2025 creates a gap between the unconstrained deployment needed to reach 30 GW by 2030 and the manufacturing capabilities in the United States. This diverging deployment corrects itself as the supply chain matures (the slope of the accelerated and conservative scenarios match the unconstrained scenario by 2029 and 2033, respectively); however, the delays in the mid-2020s pose a significant setback to the 2030 deployment target, with the accelerated and conservative scenarios reaching installed capacities of 22.7 GW and 12.0 GW by the end of 2030.

[17] This assumption is consistent with the methodology from Shields et al. (2022). It typically takes about 1 year to manufacture a full order of components for one offshore wind energy project. The components can then be staged for up to a year so that project developers can trust they are readily available for project installation and will not cause delays (even if this results in additional storage costs during this time).

The results in Figure 18 are not a forecast of installed capacity but indicate a bound on how supply chain constraints can impact deployed capacity in 2030. It is possible (even likely) that the United States will continue to source some components from international suppliers in the late 2020s. The results in Figure 18 suggest that the United States would need to import components for around 15 GW–25 GW of projects to meet the national offshore wind target, even if a full capacity domestic supply chain is operational by 2030. This procurement strategy would create additional challenges as the global supply chains are stressed to meet demand from other countries and may not have the available throughput to provide this magnitude of components for U.S. projects.

It is important to understand how reliant the United States could be on imported components to reach the 30-GW target, and this estimate suggests that, even in the accelerated supply chain scenario, the majority of components would have to be sourced internationally to meet this target. However, it is more important to recognize that the offshore wind energy industry will continue to expand beyond 2030 (both domestically and globally) and that establishing a robust supply chain in the 2020s to support the long-term expansion of the industry will provide a strong foundation for sustained deployment and local economic benefits.

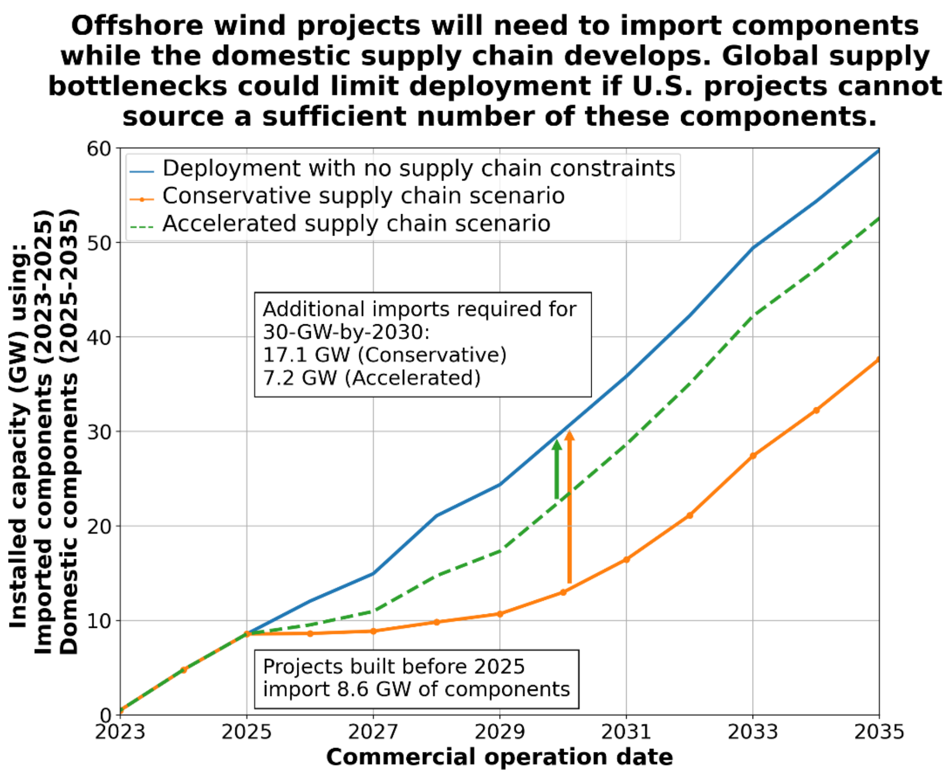


Figure 18. The time required to plan, permit, and construct offshore wind factories results in limited manufacturing capacity in the mid-2020s, which would need to be met by imported components to meet the 30-GW-by-2030 deployment target.

Note: All scenarios assume that 8.6 GW of offshore wind projects are installed using internationally-sourced components by 2025. Including these 8.6 GW, the U.S. would need to import about 15 GW of offshore wind components under the accelerated scenario or about 25 GW of offshore wind components under the conservative scenario to achieve the 2030 deployment target.

3.2.2 Distribution of Jobs and Economic Benefits

Section 2.6 describes how there is a significant opportunity for existing Tier 2 and 3 manufacturers in the United States to support the build-out of the offshore wind energy industry if these suppliers can expand their facilities, capabilities, or workforce to qualify as offshore wind suppliers. The potential diversity of the supporting supply chain encourages the entire country to become engaged in offshore wind, not just coastal states that are actively pursuing offshore wind construction and operations.

In this section, we characterize how the supply chain scenario presented in Section 3.1 creates an opportunity space for the entire supply chain ecosystem in the United States to support offshore wind energy and discuss how jobs and economic benefits could be distributed throughout a network of participating states. This analysis requires two building blocks: an assessment of existing suppliers to manufacture components throughout the supply chain, and an approach to assigning jobs to major manufacturing facilities and suppliers in individual states based on the adjacent industry manufacturing scale. Although the results are specific to the scenario defined in this paper, the methodology and insights demonstrate how a domestic supply chain can create regional-level benefits and collaboration opportunities between states.

3.2.2.1 Manufacturing and Supply Chain Job Market Opportunity

Component manufacturing using a domestic supply chain represents the largest jobs potential for the U.S. offshore wind energy industry. Average annual employment levels (full-time equivalent [FTE]/year) from 2024 to 2030 are estimated at 12,300 and 49,000, depending on the annual deployment rate and a 25% and 100% domestic content, respectively (Shields et al. 2022).[18] This figure includes both direct component manufacturing (which fabricates or assembles final components at a manufacturing plant) and indirect supplier jobs (which produces parts or materials for a major component). Although Shields et al. (2022) reported these job estimates, they did not provide any discussion about how the jobs could be distributed between different states, a hiring timeline, or how this could drive collaboration or regional planning activities.

The timing and geography of major manufacturing facilities and those facilities leveraging a U.S. supply chain to source subassemblies, parts, and materials have a significant impact on the development of a U.S. manufacturing workforce. To understand the full employment potential of the manufacturing and supply chain offshore wind energy sector, we assume major manufacturing facilities use a totally domestic workforce and the entire supply chain is based in the United States using U.S. workers (e.g., 100% domestic content). [19] The job estimates used in Sections 3.2.2.1 and 3.2.2.2 are based on "The Demand for a Domestic Offshore Wind Energy

[18] In all likelihood, the actual number of jobs would fall within this range as the domestic supply chain grows to support the offshore wind energy project pipeline. The lower end of this range represents if 25% of components are produced in the United States, the upper end of the range represents if 100% of components are produced domestically.

[19] The 100% domestic content is an assumption. Domestically manufacturing, producing or assembling all components, sub-components, parts, and materials is highly unlikely. We use the 100% domestic content scenario as an indication of the highest workforce level that the United States may need to hire. In all likelihood, the actual number of jobs would fall within a range as the domestic supply chain, growing in parallel with the offshore wind energy pipeline and at a rate dependent on using domestic content.

Supply Chain" (Shields et al. 2022) and "U.S. Offshore Wind Workforce Assessment" (Stefek et al. 2022) reports.[20]

To better understand the timing and geographic considerations of U.S. manufacturing and supply chain development, we take the job estimates for the different types of components from (Shields et al. 2022) and (Stefek et al. 2022) and apply them to the following three categories:

- **Major manufacturing jobs (prescribed).** This category is based on the number, location, and operational dates of major manufacturing facilities in Section 3.1.2. In the previous reports, we estimated the direct jobs associated with the major manufacturing facilities for different components. The potential direct job contributions associated with the major manufacturing facilities is approximately 10,000 jobs out of the 49,000 jobs (20% of total job opportunity) assuming 100% domestic content. Because major manufacturing jobs are based on building U.S. facility locations, most jobs would be domestic; but if a facility location changes, the state-level job impact would change.
- **Supplier jobs.** This category represents the opportunity space for direct and indirect jobs associated with producing subassemblies, parts, and materials for major manufacturing facilities. In Shields et al. (2022), we estimated the potential direct and indirect job contributions associated with producing subassemblies, parts, and materials for each major component. This estimate is approximately 39,000 jobs out of the 49,000 jobs (80% total job opportunity) assuming 100% domestic content. Achieving this opportunity would require all manufacturing facilities contracting with U.S.-based suppliers for all subassemblies, parts, and materials within components. The number of jobs in each state would change based on the level of domestic content the U.S. supply chain achieves.
- **Job market opportunity.** This category represents the sum of the job impacts from the major manufacturing and supplier jobs categories. This total represents the full opportunity space for the offshore wind energy industry assuming fully domestic content, all components, subassemblies, parts, and materials are sourced and produced by a U.S. workforce. The job market opportunity shows how the average annual employment could be distributed across states and based on a timeline of facility operations. This category is different from the average annual employment of 12,300 and 49,000 jobs from Shields et al. (2022) because it shows the unique opportunity space for each state to have a share of the potential total employment. Because some states may have overlapping opportunity spaces based on similar manufacturing capabilities, the total job market opportunity we discuss in Section 3.2.2.4 has a greater number of potential jobs than estimated in Shields et al. (2022).

We provide additional timing and geographic jobs charts along with additional context, methodology, and approach for these categories in Appendix B.

[20] The same methodology was used to estimate the number of jobs in the "U.S. Offshore Wind Workforce Assessment" (Stefek et al. 2022) and "The Demand for a Domestic Offshore Wind Energy Supply Chain" (Shields et al. 2022).

3.2.2.2 Timing of Job Impacts Based on Scenarios

Analyzing the timing for the supply chain workforce provides a potential scenario to help inform education and training development and ensure a workforce is adequately trained and ready to hire as U.S. manufacturing begins production. The operational date of manufacturing facilities determines when workers can start producing components and when those plants would contract suppliers. It is also important to understand how the risk of delays due to announcement, permitting, and construction time frames impact the timing to train and hire a workforce to support these facilities. The timing of the job market opportunity for the accelerated and conservative supply chain scenarios from Section 3.1.2.2 is shown in Figure 19. Supplier jobs are shown across a range of domestic content (e.g., 25% to 100% domestic content), as there is more uncertainty about how many sub-components, parts, and materials may be sourced domestically to support the major component facilities, which under the scenarios are assumed to be developed in the United States to meet the pipeline demand.

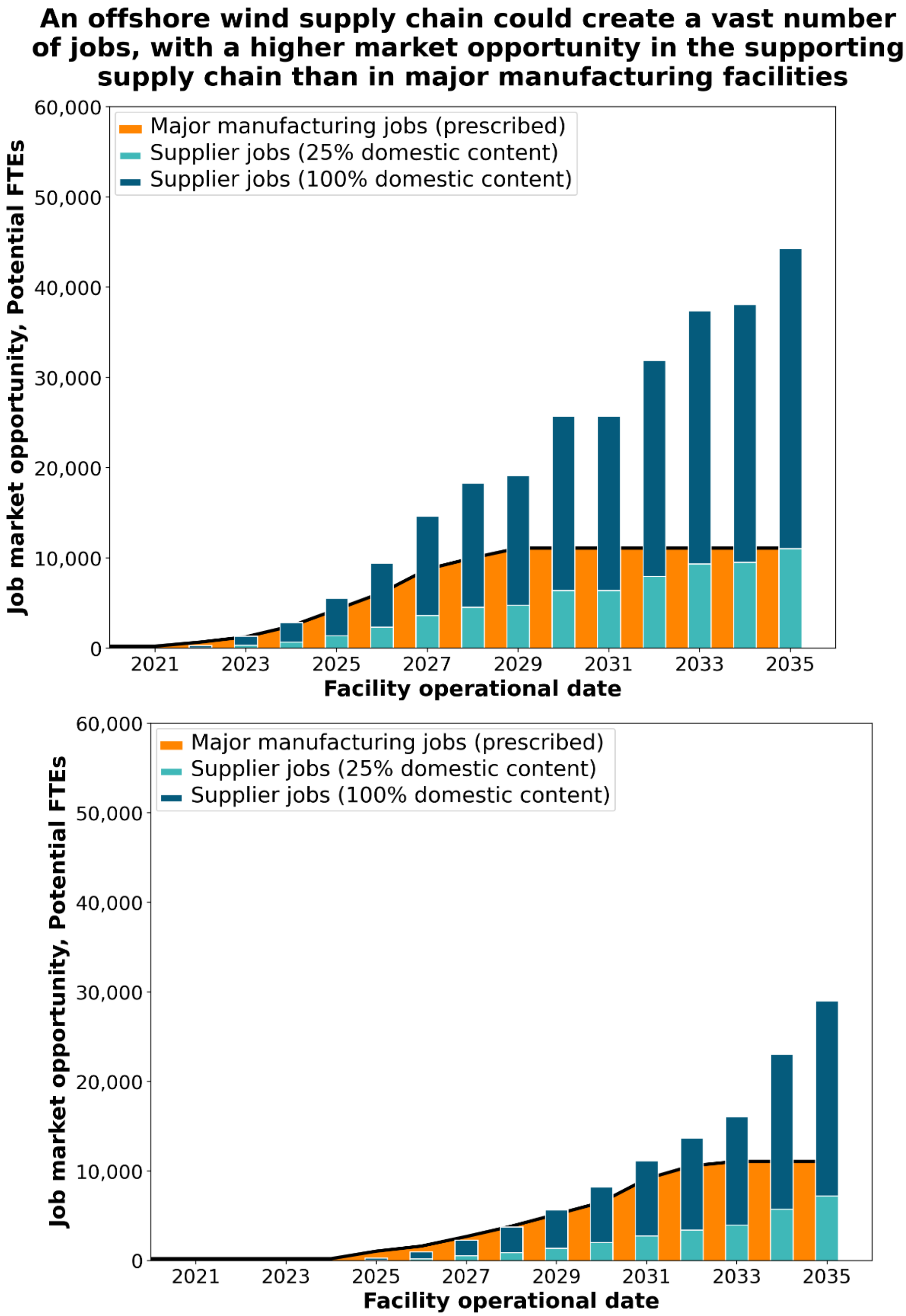


Figure 19. Major manufacturing jobs (prescribed) over time and supplier jobs assuming a 25% and 100% domestic workforce based on the accelerated (top) and conservative (bottom) scenarios

Under an accelerated scenario, the modeled job market opportunity for major component facilities and their suppliers develops quickly in the mid-2020s. All facilities are producing components with a full workforce by 2028 for the major manufacturing jobs. Supplier jobs steadily increase over time as manufacturing facilities grow the use of the supply chain, reaching the full job potential by 2034. Conversely, under the conservative scenario, the modeled job market opportunity grows slower, and the full workforce need for major manufacturing jobs is not realized until the mid-2030s. This poses a risk to domestic workforce development because fewer supplier jobs are needed by 2035 as international suppliers use their workforce to fabricate and assemble subassemblies, parts, and materials.

The major manufacturing jobs and supplier jobs at the component level for each scenario are shown in Appendix B. For the major manufacturing jobs, we used the operational dates for each major component facility based on the accelerated and conservative construction schedules and assigned several jobs in each facility based on the number of workers specified in Section 2.5. The accelerated scenario has earlier operational dates, leading to an earlier workforce need than the conservative scenario.

For supplier jobs, we use estimates shown in Appendix B and assume half the supply chain is active in the operation year of the component manufacturing facility and the full supply chain is activated in the second year of plant operation for the accelerated scenario. Under the conservative scenario, the supply chain is activated over a 5-year duration.[21] In addition, we assume under both scenarios that the supply chain for the nacelle and cable suppliers will develop later in the 2030s because it will be difficult to justify costly facility investments for nacelle internals (e.g., gearboxes and generator) and to import raw cable materials.

3.2.2.3 State-by-State Capabilities for Supplier Jobs

To characterize the current landscape of potential manufacturers in the United States who could fill the opportunity space for supplier jobs described in Section 3.2.2.2, we derived a state-by-state AIMS that identifies the existing capabilities and opportunity space to manufacture the various subassemblies and subcomponents of each Tier 1 component that comprises the domestic supply chain. We focus on state-level capabilities because state governments are not only actively engaged in attracting Tier 1 manufacturing but also have the best perspective of the strengths of the existing businesses within their borders. This type of assessment could help each state identify their best role within the supply chain.

Further, the AIMS metric illustrates the potential for regional collaboration, highlighting areas within the United States where neighboring states share competencies. The AIMS model is primarily based on the businesses registered in Supply Chain Connect, IMPLAN input-output economic data, and ongoing or planned state-level offshore wind energy supply chain activities.

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[21] Suppliers using Supply Chain Connect and during the National Supply Chain Roadmap Actions & Recommendations Virtual Workshop hosted by the National Renewable Energy Laboratory, the Business Network for Offshore Wind, the National Offshore Wind Research and Development Consortium, and the Department of Energy on July 25 and 26, 2022 stated it takes time to develop a domestic supply chain network for each component manufacturing facility to ensure certifications and requirements are known for subassemblies, parts, and materials. Based on these discussions and under an accelerated scenario, this supply chain can be developed over a 2-year period. Under a more conservative scenario, we assume this timeline is extended to 5 years.

We evaluate a state's AIMS level for the supporting supply chain of specific component (e.g., blades, nacelles, monopiles) based on the metrics in Table 13. Some metrics are collected for individual businesses and aggregated over the entire state, and others are collected at the state level.

Table 13. Description of the Metrics Used To Evaluate a State's AIMS Level in the Indirect Supply Chain for a Specific Offshore Wind Tier 1 Component

Type of Data	Metric	Source	Applicability
Individual business	Type of products manufactured	Supply Chain Connect	Comparing the business's products with the hierarchy of products for each Tier 1 component (Shields et al. 2022) indicates its relevance to offshore wind energy
	Location(s) and number of manufacturing facilities	Supply Chain Connect	The number of facilities indicates the potential production capacity of the business
	Number of workers	Supply Chain Connect	The number of workers indicates the potential production capacity of the business
	Experience in related industries	Supply Chain Connect	Experience in oil and gas, aerospace, land-based wind energy, or other industries can be transferred to offshore wind
	Existing certifications	Supply Chain Connect	Relevant certifications preferred by offshore wind OEMs are critical to becoming an approved supplier
State level	Regional Purchase Coefficient (a region's ability to meet the demand for a specific type of component)	IMPLAN	This macroeconomic indicator demonstrates the strength of the manufacturing sector beyond the subset of businesses that have registered in Supply Chain Connect
	Proximity to Tier 1 suppliers	Measured based on domestic supply chain scenario (Table 9)	Indirect supply chains and offshore wind manufacturing clusters are likely to be concentrated near Tier 1 facilities
	State activity score	Measured based on whether a state is participating in the Federal-State Offshore Wind Implementation Partnership or has funded an offshore-wind-energy-specific study that includes aspects of supply chain mapping, assessment, or strategic planning	Demonstrates a state's willingness to direct efforts and resources toward advancing their offshore wind supply chain and promoting regional coordination and collaboration

By compiling the data in Table 13 for each component, we evaluate each state's AIMS level to support the indirect supply chain for that component. We provide further details about the weighting and scoring methodology, along with limitations and caveats to the approach and the state-by-state results for each component, in Appendix B. The aggregated AIMS for all components (i.e., each state's ability to support the entire offshore wind energy manufacturing requirements) is shown in Figure 20. There is a strong concentration of offshore wind capability in North Atlantic states that are already engaged in developing offshore wind supply chains, but states throughout the country have AIMS levels that indicate they have existing capabilities that could support offshore wind manufacturing. We will use the state-by-state AIMS levels in Section 3.2.2.4 to demonstrate how supplier jobs could be distributed within the domestic supply chain scenario based on the manufacturing strengths of individual states.

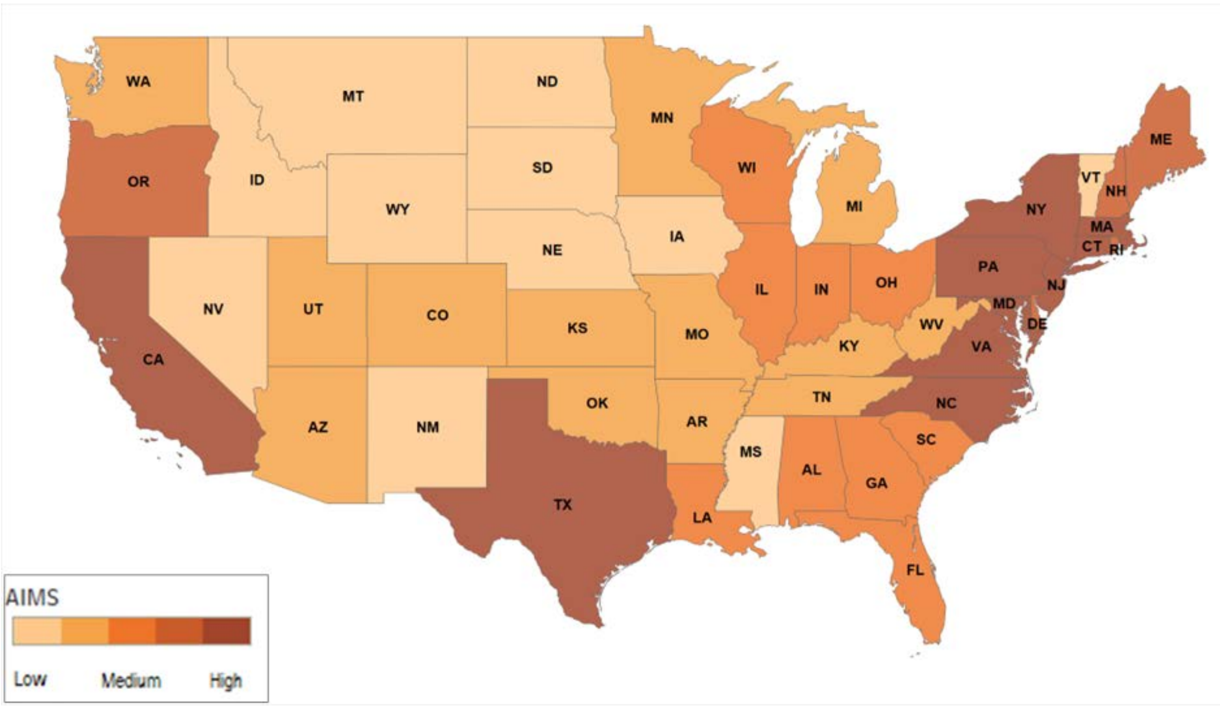

Figure 20. State adjacent industry manufacturing scale (AIMS) levels to produce Tier 2 and Tier 3 subassemblies and subcomponents for major offshore wind components for the domestic supply chain scenario

3.2.2.4 Distribution of Workforce and Economic Benefits

All geographic regions of the United States can participate in the offshore wind energy manufacturing and supply chain and realize a share of the job market opportunity and its associated economic benefits (in terms of value-add gross domestic product [GDP]). Involving more states in the supply chain can create a more diverse and robust ecosystem while benefitting these individual states; however, much of the attention on supply chain growth has focused on states in the Northeast with existing offshore wind commitments. In this section, we demonstrate that a significant opportunity exists for both coastal and noncoastal states to participate in the offshore wind energy supply chain based on their existing capabilities.

We define the job market opportunity for each state based on the total number of available jobs that need to be filled by a domestic supply chain, which we allotted to each state based on its ongoing activities that could support offshore wind manufacturing. We use the AIMS levels introduced in Section 3.2.2.3 as well as additional metrics related to the underlying economic strengths of each state and the proximity to major component facilities identified in the domestic supply chain scenario used in this report. These results are not a prediction of the jobs that each state will accrue but are intended to demonstrate that the offshore wind manufacturing workforce will not be entirely concentrated within the states that obtain Tier 1 manufacturing facilities.

The following metrics are used to determine the market opportunity for supplier jobs in each state:

- **AIMS.** Incorporates the interest and capabilities of individual companies to support the offshore wind energy supply chain as entered into Supply Chain Connect (Business Network for Offshore Wind undated).[22] A score is calculated per state based on the metrics in Table 13.
- **Similar industry capability.** Using IMPLAN Regional Purchase Coefficient (RPC) data, we created an industry aggregation scheme for each component based on related industries.[23] These RPCs provide a score that indicate a state's existing manufacturing capacity of relevant businesses who could support the offshore wind energy supply chain.
- **Proximity to scenario facilities.** Using the major manufacturing facilities locations from the scenario in Table 10, we give additional weight to offshore manufacturing capacity that could exist within a state and within regions. Based on discussions with OEMs, a priority may be given to nearby suppliers to reduce transportation logistics and costs and build regional capacity.

We average the effects of each metric to determine each state's capacity to provide subassemblies, parts, and materials for component manufacturing facilities. We then use this average score to identify the share of the overall national supplier jobs that each state could pursue based on their existing capabilities. We describe this approach and methodology in more detail in Appendix B. A state with high AIMS levels, RPC data, and proximity to supply chain facilities in the supply chain scenario therefore has a relatively higher market opportunity to realize offshore wind manufacturing supplier jobs. However, this approach still estimates a job market opportunity for states with lower relative scores, or strong capabilities in only one or two of the core metrics, because they have a demonstrated capacity to contribute to the supply chain.

Combining the major manufacturing jobs and supplier jobs for each state provides an estimate of how the job market opportunity (Figure 21) for the offshore wind supply chain could be distributed throughout the country.

[22] For more information about Supply Chain Connect, visit https://www.offshorewindus.org/supplychain/.
[23] For more information on IMPLAN's Regional Purchase Coefficient, visit https://support.implan.com/hc/en-us/articles/115009499527-Regional-Purchase-Coefficient-RPC.

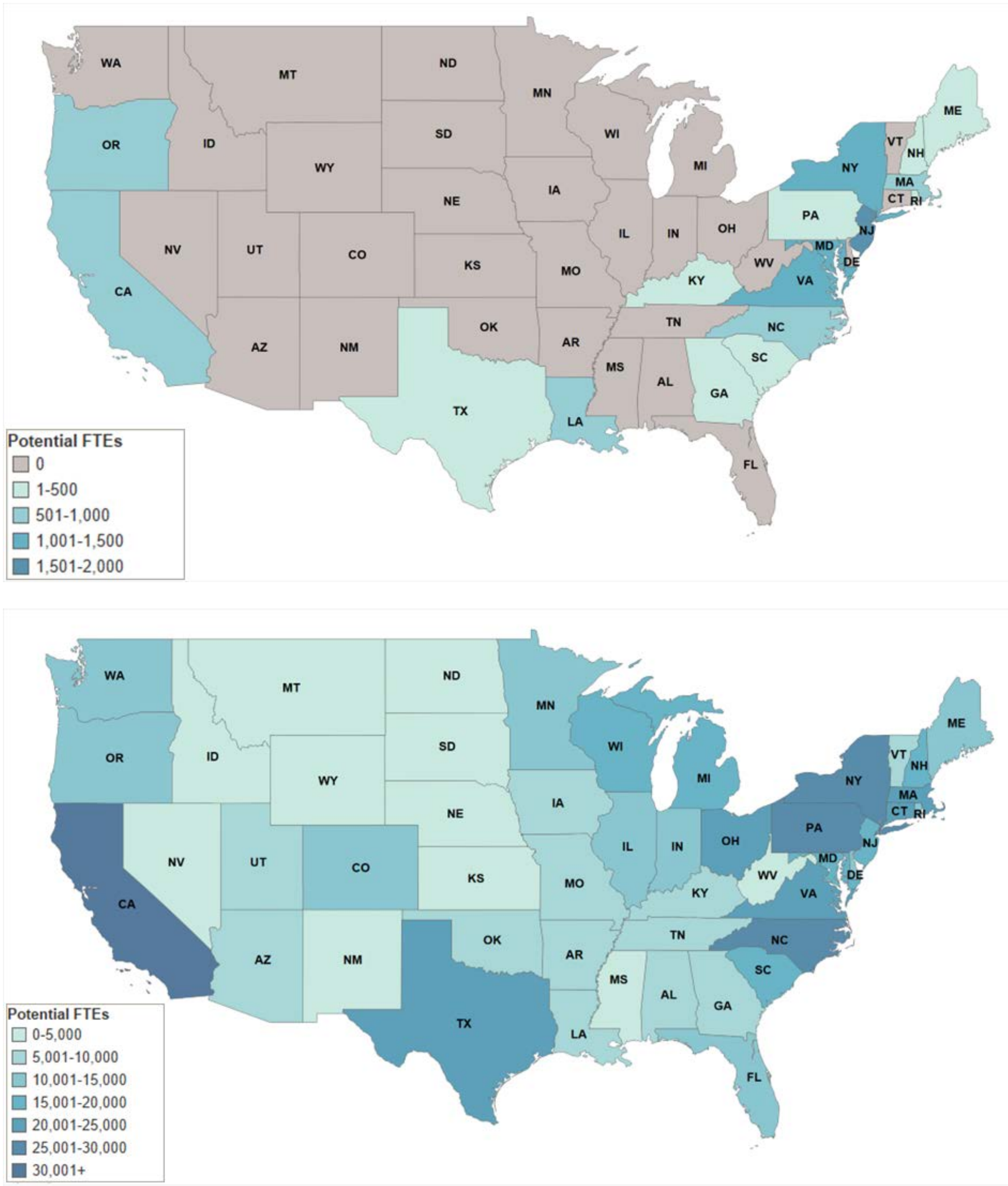

Figure 21. Job market opportunity for major manufacturing jobs (top) and the job market opportunity for major manufacturing and supplier jobs (bottom) for the domestic supply chain scenario by 2035, assuming 100% domestic content

As Figure 21 indicates, there is an opportunity across the county for jobs related to major component facilities and their suppliers. A darker shade of blue indicates a state has a larger potential for jobs and a higher likelihood of using existing capabilities to realize their share of the job market opportunity. Most critically, a significant job market opportunity exists beyond the states with the major manufacturing facilities assigned in the supply chain scenario. The top map in Figure 21 shows that these major manufacturing jobs are concentrated in a few states and that the opportunity space is typically less than 2,000 potential FTEs per state. The bottom map, which includes supplier jobs, encompasses the entire country with roughly an order of magnitude higher job opportunity space.

Finally, activating the distributed supply chain presented in Figure 21 would create a dispersed set of economic benefits throughout the country. Figure 22 shows the potential economic opportunity (as measured in value-add GDP) that could be realized by states that host manufacturing facilities and activate U.S.-based suppliers in their states. Maps that show the economic opportunity from the prescribed major manufacturing job and supplier jobs are in Appendix B.

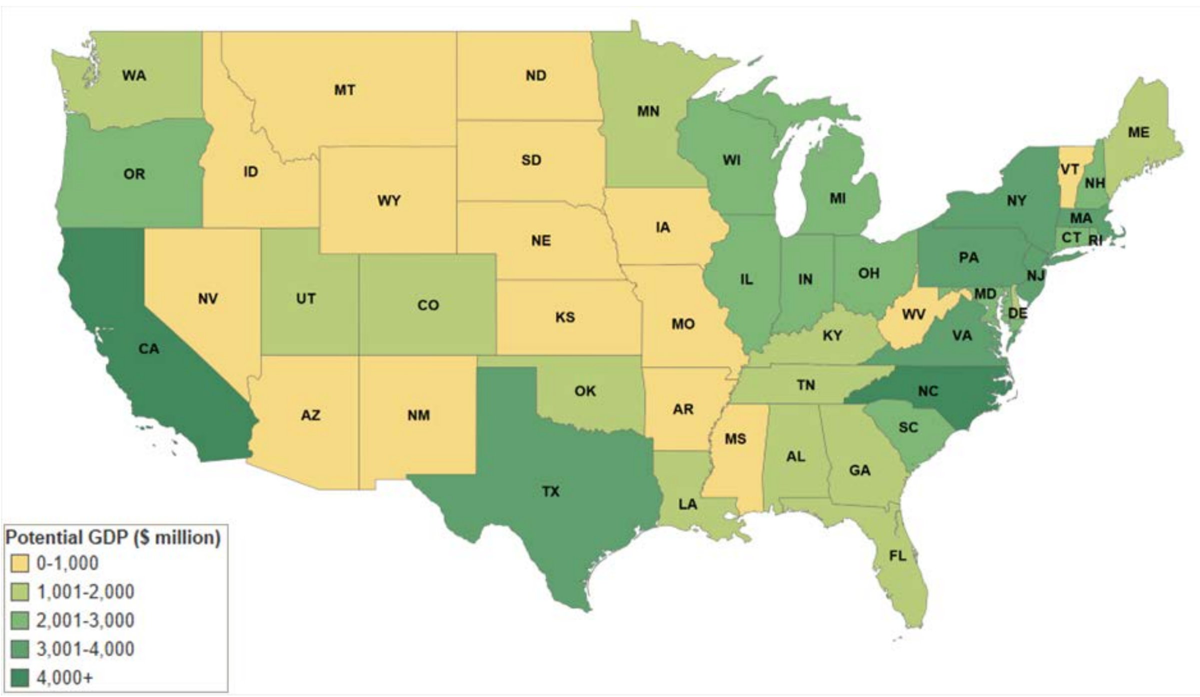

Figure 22. Total GDP ($ millions) opportunity (major manufacturing jobs [prescribed] scenario and supplier jobs) assuming 100% domestic content

The critical takeaway from this section is that investing in the major manufacturing facilities needed for a domestic supply chain would create a significant number of jobs in the states where these factories are built; however, this investment would create a significantly higher opportunity space in neighboring (and some noncoastal) states that can build upon their existing capabilities to manufacture subcomponents and subassemblies for these major components. This assessment is a preliminary step in evaluating how regional or national supply chains could develop to support the offshore wind industry and is intended to demonstrate the potential opportunity that exists for states that may not have a large market share of major manufacturing facilities (e.g., small states, states without offshore wind procurement targets, or noncoastal states). Further work is required to characterize and leverage the capabilities of these states and to develop strategic plans for how they could fill needs within a domestic supply chain. Understanding these existing capabilities, and how they can be used to create benefits throughout the United States, could lead to greater regional collaboration and coordination of supply chain planning activities.

3.2.3 Levelized Cost of Energy for Domestically Manufactured and Imported Components

The LCOE of an offshore wind energy project will be affected by where the components are manufactured. In this section, we conduct a high-level assessment of how cost premiums can impact domestically produced and imported offshore wind components to estimate how effectively a local supply chain can compete with the more established European supply chain. The primary premiums that affect component procurement costs include:

- **Factory amortization**. Building a new component fabrication facility requires an upfront capital investment of several hundred million dollars, which must subsequently be paid back to the investor. The costs of servicing this debt will ultimately be passed on to the customer (the project developer, and then the ratepayer) through an increased component cost. As most offshore wind energy manufacturing facilities in Europe are already depreciated, this cost burden will be higher for new facilities built in the United States.[24] The Advanced Manufacturing Production Tax Credits in the IRA will help offset these upfront capital costs. Furthermore, regional or national content-sharing agreements that give project developers credit for investing in facilities in multiple states instead of just the state that purchases electricity from the offshore wind project could encourage supply chain investment and make it easier to spread costs over multiple projects throughout the region.
- **Transport costs**. Transporting offshore wind energy components from factories in Europe to the United States can incur significant costs because only a limited number of these large components can fit on the deck of an oceangoing barge. This constraint requires multiple trips across the Atlantic Ocean to deliver a full order, with each leg of the trip taking several weeks. Transport costs will also be incurred to transport components from domestic facilities to a marshaling port or project site, but these costs will be significantly less than the transatlantic costs.
- **Tariffs**. Section 232 tariffs are imposed on imported steel plates, which are used to manufacture towers, monopiles, transition pieces, and semisubmersibles for offshore wind energy projects (U.S. Department of Commerce 2021). These tariffs add a 25% premium to these imported raw components but are not applied to finished components or subassemblies; for example, imported steel plates used to fabricate a monopile in the United States are subject to the tariff but a finished monopile or rolled steel cans that still need to be welded and painted are not. Antidumping and countervailing duties may also increase the prices of imported components to offset subsidies provided by the government of the exporting country, such as duties imposed on utility scale towers from Canada, Indonesia, South Korea, and Vietnam (International Trade Administration 2020)
- **Labor rates**. Manufacturing labor rates can vary significantly between countries or even within a country (like the United States) with different state or regional compensation

[24] European facilities may need to be rebuilt or expanded to produce (larger) next-generation offshore wind energy components. For this levelized cost of energy analysis, we conservatively assumed that the depreciation costs of any new or expanded European facilities are zero. If the U.S. market procures components from newly built European facilities, factory payback cost premiums on these imported components will improve the cost competitiveness of domestic manufacturing; however, it is worth noting that it is often cheaper and quicker for a manufacturer to expand an existing facility instead of building a new one, which would mean that the upfront capital investment could be lower for next-generation European facilities than for new U.S. facilities.

mechanisms and costs of living. Labor is a significant part of the manufacturing cost of offshore wind energy components, and therefore different labor rates in the country (or state) of origin can drive differences in the final sale price.

- **Additional premiums**. There are other aspects that could impact cost differentials between domestically manufactured and imported components, such as taxes, the amount of automation in the manufacturing process, and financing costs.

The first three premiums broadly apply to the entire domestic supply chain. No matter where a new component facility is in the United States, it will have to offset the initial capital investment but will reduce cost premiums associated with transportation (and, in some cases, tariffs) relative to a European facility. Differences in labor rates, taxes, or financing are more site-specific and will depend on the respective factory locations. Our interviews with offshore wind energy manufacturers indicated that the cost of U.S. labor is one of the biggest contributors to differences between domestically produced and imported components because domestic labor is often more expensive.

In this simplified analysis, we estimate the differences in the first category (broadly applicable cost premiums) between imported and domestic supply chains. We do not attempt to evaluate the second category (site-specific cost premiums, including differences in labor rates) because these results could not be generalized to the overall supply chain. Instead, we identify a capital expenditure (CapEx) margin between imported and domestic manufacturing scenarios, which could absorb net differences in U.S. and European conditions. This margin specifies how much more expensive domestic labor, financing, or other factors could be for a representative project built from a U.S. supply chain to have the same CapEx as a project built with entirely imported components.

We begin by defining the offshore wind energy project, which is based on the reference fixed-bottom project from Stehly and Duffy (2021). Instead of using the 8-MW wind turbine from Stehly and Duffy (2021), we use a 15-MW wind turbine, which will be more common technology throughout the 2020s. The parameters of the reference project are provided in Table 14.

Table 14. Parameters of a Reference Fixed-Bottom Offshore Wind Energy Project in the Northeast United States (Based on the Reference Project From Stehly and Duffy [2021])

Parameter	Value
Turbine rated power (MW)[25]	15
Number of wind turbines	40
Wind power plant capacity (MW)	600
Water depth (m)	34
Distance to shore (km)	50
Substructure type	Monopile

[25] Stehly and Duffy (2021) use seventy-five 8-MW wind turbines to define their 600-MW offshore wind power plant. We used a 15-MW turbine, which requires only 40 wind turbines for a 600-MW project.

We use the National Renewable Energy Laboratory's ORBIT model to establish baseline costs for components that will be used at the reference site (Nunemaker et al. 2020). This baseline does not include any cost premiums for supply chain investments, transport, or tariffs, and essentially assumes that a component that comes out of a factory in the northeast United States or northern Europe will have the same equivalent cost (in $2021). We then define a range of scenarios with increasing levels of domestic content between 2023 and 2030 that reflect the increasing manufacturing capacity of a domestic supply chain (as discussed in Section 3.2.1).

Finally, we apply relevant cost premiums at the component level to each scenario and aggregate the results to estimate the total impact on CapEx and LCOE. We calculate the factory amortization premium using a simple cash flow model that determines the sales premium over cost that is required to fix an internal rate of return around 8.7%, which is the average cost of equity in German industrial manufacturing reported by KPMG (Castedello and Schöniger 2019).

It is worth noting that initial investments in the domestic supply chain may require higher rates of return due to perceived risk with the U.S. pipeline, although this additional risk premium is beyond the scope of this report. The cash flow model accounts for manufacturing production tax credits for blades, nacelles, towers, and monopiles that were passed in the IRA (H.R. 5376 117th Cong. [2021-2022]). We calculate the transport cost based on estimates of the number of components that can fit on an oceangoing barge and the cost and time of each trip. We apply the 25% steel tariff to the material costs of monopiles, transition pieces, and towers. We provide a more detailed description of the methodology in Appendix B; a summary of the scenarios and the associated cost premiums is provided in Table 15.

Table 15. Scenarios for domestically manufactured and imported fixed-bottom offshore wind components.

Cost premiums for factory payback, transportation, and tariffs are identified for each scenario as a percent increase in individual component costs. Factory payback cost premiums include tax credits from the IRA (H.R. 5376 117th Cong. [2021-2022]) for blades, nacelles, towers, and monopiles.

		Commercial Operation Date			
Component	**Parameters**	*2023*	*2025*	*2027*	*2030*
Blade	Source	Imported	Domestic	Domestic	Domestic
	Factory payback		2.5%	2.5%	2.5%
	Transport	30%			
Nacelle	Source	Imported	Imported	Domestic	Domestic
	Factory payback			2.5%	2.5%
	Transport	10%	10%		
Tower	Source	Imported	Domestic (imported steel)	Domestic (imported steel)	Domestic (U.S. steel)
	Factory payback		4%	4%	4%
	Transport	20%			
	Tariff		25%	25%	
Monopile	Source	Imported	Domestic (imported steel)	Domestic (U.S. steel)	Domestic (U.S. steel)
	Factory payback		8.5%	8.5%	8.5%
	Transport	28%			
	Tariff		25%		
Transition piece	Source	Imported	Domestic (imported steel)	Domestic (imported steel)	Domestic (U.S. steel)
	Factory payback		16.9%	16.9%	16.9%
	Transport	17%			
	Tariff		25%	25%	
Array cable[26]	Source	Imported	Imported	Domestic	Domestic
	Factory payback			7.4%	7.4%
	Transport	0%	0%		
Export cable	Source	Imported	Imported	Domestic	Domestic
	Factory payback			12.8%	12.8%
	Transport	0%	0%		

[26] Cable transport costs are estimated to be a negligible percentage of the capital cost as all the cable for one offshore wind energy project can be transported on a cable-lay vessel from a European facility to a U.S. project in one or two trips.

Figure 23 shows a detailed trajectory for the costs of each component over time, represented as the percentage change in costs from the initial year with a fully imported supply chain. Wind turbine costs decrease by 7.5% as the supply chain transitions from imported to domestically produced components because the relatively significant transport costs for blades, nacelles, and towers are eliminated and the IRA helps offset the factory amortization premium.

Substructure costs (including monopiles and transition pieces) do not decrease as rapidly because they have an intermediate stage where domestic manufacturing facilities still require imported steel (which is subject to significant tariffs). The scenarios assume that U.S. steel is available for monopiles in 2027 and for all steel components in 2030, which drives the decreasing cost trend. This assumption relies on the accelerated supply chain scenario from Section 3.1.2.2; if domestic steel mills take longer to develop, few (if any) projects will be able to source steel plates for monopiles from U.S. manufacturers by 2027. Furthermore, this scenario assumes that there is sufficient competition in the domestic steel market that manufacturers fully remove the tariff premium from their steel plate prices (as opposed to simply undercutting the imposed 25% premium by a few percentage points). Still, domestically produced substructures could be nearly 10% less expensive than imported components due to reduced transport costs, eliminated tariffs, and production credits from the IRA, provided that they can eventually use domestically produced steel.

The cost of electrical infrastructure includes cables and substations; however, we assume that transport costs are negligible for offshore substations due to the high CapEx for these systems, and there is no need for building new domestic manufacturing facilities as substations will likely be built at existing shipyards. As a result, the changes in electrical system costs are entirely attributed to array and export cables. Cable costs increase by just over 11% for a domestic manufacturing scenario because the transportation costs are relatively small compared with the wind turbine and substructure components and cable manufacturing did not receive tax credits in the IRA.

Aggregating the cost differences for wind turbines, substructures, and electrical infrastructure indicates that buying components from a mature domestic supply chain could result in around 5% CapEx savings relative to importing components from Europe. This difference in CapEx corresponds to a difference in LCOE of less than 3%, which is well within the uncertainty range of the high-level assumptions we made in this analysis. However, this result assumes that there are no differences in site-specific cost premiums such as labor rates. In some cases, U.S. labor may be more expensive than European labor, which could erode or outweigh this cost margin.

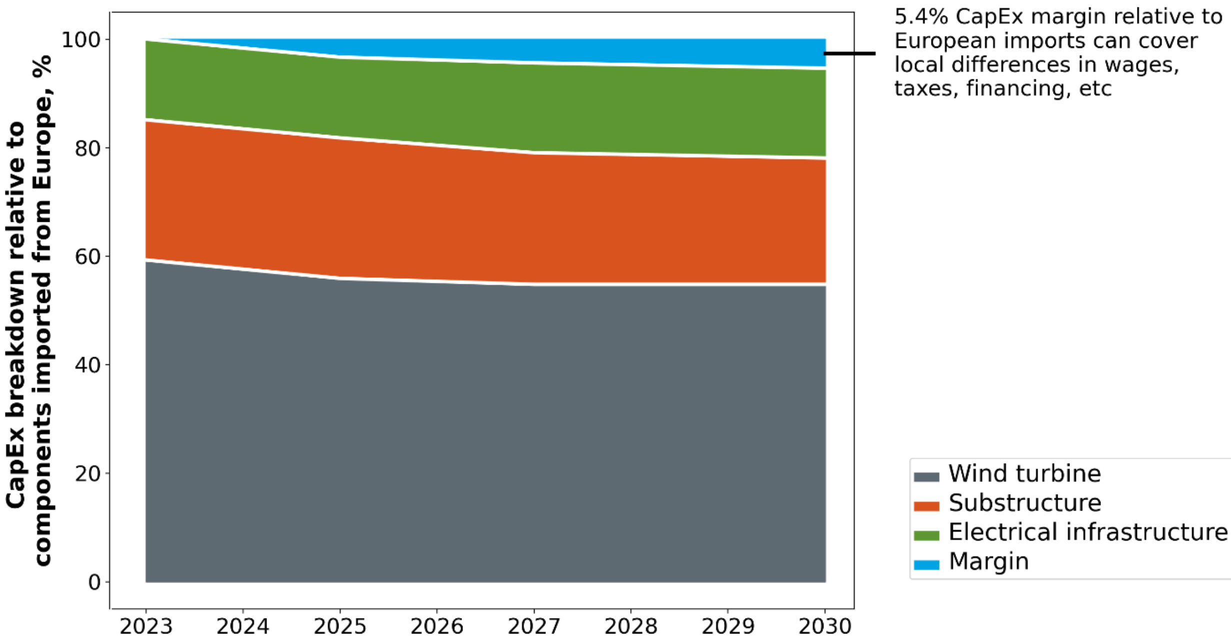

Figure 23. Percent change in component CapEx for wind turbines (including the blades, nacelle, and tower), substructure (including the monopile and the transition piece), and the electrical infrastructure (cables and substations) for scenarios with expanding domestic manufacturing capacity between 2023 and 2030

The most meaningful interpretation of the cost comparison results in Figure 23 is that the net capital investment in new manufacturing facilities for a domestic supply chain would be approximately offset by the reduced transport costs and tariffs that would be imposed on imported products. This trade-off gives domestically produced offshore wind components the opportunity to be cost competitive with imported ones. Manufacturers will still consider local labor rates as a key factor when identifying locations for new U.S. facilities in order to maintain a positive CapEx margin relative to European supply chains, provided that the required workforce quality and skills sets are available in multiple locations.

Furthermore, some components (such as cables) could be more expensive than imported components because they do not qualify for production tax credits in the IRA. As a result, the procurement costs for these components decrease the overall CapEx margin and these more expensive domestic components could be less competitive with imported components in an open market. Finally, the IRA production tax credits expire in 2032, which could result in U.S. components becoming more expensive if alternative cost reductions are not established.

The analysis in this section specifically relates to fixed-bottom projects located on the East Coast. The same trend will likely not hold for West Coast floating projects due to significant wage differences between the United States and Southeast Asia, which has advanced shipyards and factories that can manufacture most floating wind components (Shields et al. 2021). A more detailed analysis into labor rates and facility capabilities will be necessary to understand the cost/benefit trade-offs between domestic manufacturing and importing finished components or subassemblies for floating offshore wind. Investing in local supply chains may result in some higher costs but could increase the reliability of procuring components for floating wind projects, as global supply chains will be stressed to meet the demands of the entire industry (Shields et al. 2022). Building these capabilities on the West Coast would provide an opportunity for the United States to develop techniques and capabilities for cost-effectively mass-producing floating wind components to meet the anticipated high demand, which could yield cost reductions that would benefit the entire global fleet of floating wind energy projects.

4 A Road Map for an Offshore Wind Energy Supply Chain in the United States

The previous sections of this report outlined some of the challenges that need to be overcome to develop a domestic offshore wind energy supply chain and the potential impacts that such a supply chain could have. In this section, we present eight potential solutions that could help overcome these barriers and realize the benefits and resiliency of a domestic supply chain. These recommendations are based on the analysis work presented in this report along with discussions with industry representatives, state and local governments, organized labor, communities impacted by offshore wind energy development, and existing manufacturers that could support a domestic supply chain. We also discuss short-, medium-, and long-term actions to implement these potential solutions and how these steps could help develop a sustainable and robust supply chain beyond 2030 by overcoming the obstacles facing supply chain development and establishing a resilient and equitable foundation for the once-in-a-generation opportunity to create a new clean energy industry in the United States.

4.1 Potential Solutions To Alleviate Supply Chain Barriers

Continue efforts to reduce systemic risk for near-term project construction and long-term pipeline growth

A number of initiatives are already underway to mitigate the investment risk associated with uncertainty in the implementation timelines for the U.S. offshore wind pipeline. The Biden administration announced the national offshore wind target and BOEM approved the construction and operation plans for Vineyard Wind and South Fork, signaling a federal intent to develop projects using domestic supply chains and labor. BOEM has provided anticipated leasing schedules through 2025 that will expand the fixed-bottom and floating pipeline into the 2030s. Individual East Coast and West Coast states have announced offshore wind energy targets, signed offtake agreements with planned projects, and/or invested in supply chain facilities. These activities convey a stronger demand signal than has been present in the United States in recent years and are important to increasing investor confidence in new supply chain facilities.

Despite these advancements, many industry stakeholders remain cautious about the future of offshore wind energy in the United States. The viability of near-term projects (i.e., projects in the existing pipeline) will be considered a risk at least until the first commercial-scale project is successfully installed in U.S. waters. It is vital for the offshore wind industry to ensure that early projects in the pipeline such as Vineyard Wind and South Fork can overcome legal and permitting obstacles to demonstrate that large, domestic offshore wind projects can be built. These projects should continue to strengthen collaborative engagements with affected stakeholders, such as coastal communities and co-users of the ocean, that can address concerns with offshore wind energy deployment. Examples of this may include host community agreements between developers and local communities or proposed compensation to fisheries for lost revenue due to offshore wind deployment. In addition, some offshore wind energy manufacturers are hesitant to commit to new domestic supply chain facilities while predictable long-term policies related to project permitting and regulatory approval have yet to be established. A transparent, uniform, and streamlined set of project approval requirements and a clear timeline for when project developers can obtain permits after meeting these requirements would help reduce procedural delays and subsequent uncertainty in the pipeline. Ongoing government support for offshore wind energy will likely help increase investor confidence and subsequent growth of the supply chain.

As the industry evolves beyond the initial projects built in U.S. waters, the long-term pipeline needs to be continuously developed to provide a stable and predictable set of projects that will go beyond 2030. Consistently opening new lease areas that can be developed at a reasonably constant rate would help prevent the spikes and valleys in deployment that would stress domestic supply chains or lead to worker layoffs. BOEM's recent implementation of multifactor lease auctions, in which a percentage of lease sales are allocated to supply chain investment, is a meaningful way to incentivize investment in supply chain growth. Furthermore, individual states and electric utilities can continue to establish procurement targets and schedules for offshore wind energy. This provides predictability and stability, which are key for both the pipeline and offtake agreements to de-risk future supply chain investments.

Increase coordination between multiple states or regions to provide flexibility and predictability for supply chain investments

Supply chain investments in ports, vessels, and manufacturing facilities totaling around $3 billion have been made or announced in the United States (Musial et al. 2022). Many of these decisions been driven by local content requirements within offtake agreements that encourage project developers to invest in resources in the state procuring the electricity. This environment has made it difficult to develop a cohesive and strategic approach to developing supply chain facilities. Individual states also have different approaches to offshore wind development, including varying procurement mechanisms, local content definitions, permitting requirements, and incentives, which makes it more difficult to compare supply chain investments in different states.

A coordinated and standardized approach between states and federal agencies that streamlines decision-making for industry and government organizations will greatly facilitate the growth of a domestic supply chain. There are several examples of states exploring this type of collaboration, including the SMART-POWER memorandum of understanding between Virginia, Maryland, and North Carolina to develop an offshore wind hub (Maryland Energy Administration 2020); the Shared Vision between BOEM, New York, and New Jersey to responsibly and collectively develop offshore wind energy supply chains and jobs (BOEM 2022a); and the Federal-State Offshore Wind Implementation Partnership between the White House and 11 East Coast states to coordinate on supply chain development (The White House 2022a). These agreements demonstrate the interest in establishing coordinated supply chain solutions and provide a framework for more tangible action. To advance these frameworks from high level agreements to actionable supply chain decisions, several important steps that regional supply chain groups could take include:

- **Developing regional or national content agreements** that encourage investment in the domestic supply chain or workforce but are not required to be made in the state offtaking power from the offshore wind energy project. The quality of product, standards for prevailing wages and working conditions, and availability of training and apprenticeship programs in partnering states would have to be consistent throughout cooperating regions to maintain performance and safety standards.

- **Standardizing baseline regulatory and permitting environments for offshore wind supply chain activities**, including defining local (or regional) content. Location-specific regulations could be modified from these baselines instead of being developed completely independently to minimize transaction costs when conducting activities in different states.
- **Developing regional supply chain strategies based on the strengths of individual regions**. These strategies could identify the best locations for supply chain resources (e.g., ports, manufacturing facilities, workforce training centers) that can maximize benefits to local communities and offshore wind energy projects.
- **Communicating regional needs, plans, goals, and challenges to federal agencies** (particularly BOEM) to strategically expand the offshore wind energy pipeline. These communications run the risk of bias based on the perspectives of the collaborative group members; however, this risk could be mitigated by forming inclusive groups and reviewing plans with external reviewers.
- **Establishing predictable long-term plans for supply chain investment and offshore wind procurement** to provide a strong and clear demand for the industry. This step would help stabilize the industry in the event of shifting offshore wind policies or priorities at the national level, which is perceived as a risk by manufacturers.

Consider providing state and federal incentives (e.g., tax credits, public/private partnerships, grants, and loans) to de-risk investment and make domestic products more cost competitive

A domestic offshore wind energy supply chain would require constructing dozens of new manufacturing facilities, expanding or refining existing facilities, training thousands of workers, and developing new ports and vessels. These efforts would require more than $22 billion to be invested this decade, with individual ports, vessels, or manufacturing facilities each costing hundreds of millions of dollars. Each asset is a substantial undertaking for a manufacturer, port authority, or vessel operator and requires a sound business model (typically, a reliable 10-year pipeline of customers to pay off the upfront cost) to justify the investment. The products or services produced using the supply chain asset will be priced to pay off the initial investment, potentially placing them at an economic disadvantage relative to imported components. These factors may challenge the ability of some domestically produced components and services to be cost competitive with imported goods.

State and federal governments can consider the value of offering incentives, loans, or subsidies to decrease the effective upfront cost of these facilities, which could translate to reduced component costs and improved competitiveness with overseas components. Furthermore, these programs could incentivize fair wages, good working conditions, systematic training programs, and benefits to energy communities so that the offshore wind energy industry develops a stable, diverse, well-trained, and justly compensated workforce that can reliably support manufacturing and deployment over the next several decades. The following have already been proposed or implemented, which could serve as examples for future incentive programs:

- **Manufacturing tax credits**. As we discuss in Sections 2.2 and 3.2.3, the AMPTCs and the expanded Section 48C Manufacturer Tax Credits in the IRA will significantly help domestically produced wind turbines and foundations to be more cost competitive with imported components. The IRA will play a significant role in helping develop a domestic supply chain and will likely encourage more manufacturers to locate facilities in the United States. However, there are some limitations of the act that could be addressed by additional state or federal incentive mechanisms. Expanded incentive programs to consider could include:

  - Providing production tax credits for supply chain components that are not explicitly identified in the IRA, including array and export cables and Tier 2 or 3 components. Establishing tax credits for supporting components could help existing U.S. businesses pivot toward the offshore wind energy supply chain.
  - Increasing the credit for the sale price of large construction vessels to offset high fabrication costs and make these vessels more cost competitive in the global market

The AMPTCs in the IRA expire after 2032, which is a relatively short time horizon given that most offshore wind manufacturing facilities will not be online until after 2027 (even in a best-case scenario). During this time frame, the federal government should communicate regularly with offshore wind manufacturers to understand the impact of the legislation and the extent to which it has encouraged them to locate their facilities in the United States. This ongoing work to understand the effectiveness of the AMPTCs could then inform discussions about extending and/or revising the tax credits prior to their expiration date in 2032.

- **Federal loans and grants**. DOE's Loan Program Office provides access to capital, flexible financing, and project support for offshore wind energy areas such as new manufacturing facilities, vessels, or port upgrades. Additional grants have been awarded through the U.S. Department of Transportation's Port Infrastructure Development Program to facilitate port upgrades and the U.S. Department of Transportation Maritime Administration to build new vessels. The Biden administration's Bipartisan Infrastructure Law allocated $17 billion to modernize the nation's port infrastructure and waterway access. These types of programs will continue to be useful to encourage offshore wind energy investment.

- **Public/private partnerships**. Shared investments between public entities (typically state governments) and private industry (typically project developers and/or manufacturers) are effective cost-sharing mechanisms that encourage collaboration between different stakeholders. This type of partnership has been used between the state of New Jersey and EEW American Offshore Structures to develop the monopile facility at the Port of Paulsboro, and between the state of New York, Equinor, and BP to develop the South Brooklyn Marine Terminal. As states begin to coordinate on strategic supply chain planning, shared investment in these resources can become even more impactful.

- **Federal backstop programs**. Investing in offshore wind energy assets requires a consistent pipeline of customers to pay off the upfront capital. Creating funding reserves that asset owners could draw from to service their debt in the event of delays or gaps between contracts would de-risk the investment and make it easier to obtain financing. This type of program would be particularly useful to facilitate the construction of new wind turbine installation vessels, which rely on short-term contracts with individual projects and risk sitting idle and unpaid if a project is delayed.

- **Bidding credits**. BOEM implemented multiple-factor auction formats for the Carolina Long Bay lease area auctions in 2022, which allow project developers to count contributions toward domestic supply chain facilities or workforce training toward their bids for an offshore wind lease area (BOEM 2022b). These credits also extend to contributions that help existing facilities upgrade equipment or obtain new certifications to support offshore wind manufacturing. This program was also available for the California lease area auctions in December 2022 (Federal Register 2022). Continuing to offer bidding credits for future lease area auctions would help encourage project developers to invest in local resources and could be refined over time to target investments toward specific areas of high need.

An additional consideration for incentive programs is to extend these resources beyond major component manufacturers. Existing companies within the United States have skill sets and resources that could be used to support offshore wind energy but may require significant investment in new certifications, equipment, facilities, and/or workforce. Some smaller companies may also be impacted by typical contracting structures of offshore wind projects, which often do not pay vendors upon completion of an order; this disproportionately impacts women- and minority-owned businesses. Providing grants and funds to support the transition of small- and medium-sized businesses into the offshore wind industry, such as through an expansion of the National Institute of Standards and Technology Manufacturing Extension Partnership, could help develop a more robust and comprehensive domestic supply chain.

Invest in training pipelines for tradespeople to match component suppliers to an appropriately trained workforce

The offshore wind energy industry requires a large portion of basic and skilled tradespeople to assemble and fabricate major offshore wind components and supply subcomponents/subassemblies, parts, and materials. Many of the skilled trade roles that will be needed in high numbers during manufacturing and installation require multiyear training/apprenticeship programs and, in some cases, years of experience. Considering whether, for the most critical potential gaps, these training programs could be accelerated, or increased on-the-job training integrated into certain roles, may be important for aligning domestic workers with these roles. Community college and union-led training programs such as apprenticeships may be needed to meet the workforce need for manufacturing factory-level workers, port terminal crews, and vessel construction crews. Industry should consider expanding partnerships with labor unions and community colleges and providing information on job needs and timing to reduce barriers and streamline training. Basic and skilled tradespeople who support these installation and manufacturing roles will be in high demand for the offshore wind energy industry. These workers are also in high demand in other industries and require years of experience, which is often provided through apprenticeship programs. Unions have also indicated that preapprenticeship programs help attract and train underserved populations to enter the union workforce. In addition, focusing on the local workforce can simultaneously ensure communities impacted by offshore wind energy developments are benefiting economically.

Establish collaborative industry supply chain groups to combine resources and strategies for holistic supply chain development

Although different industry practitioners are inherently competitors in the offshore wind energy market, there is significant advantage to gain from collaborative efforts to develop the supply chain. Resources such as manufacturing facilities, ports, and vessels will be used by multiple project developers and creating a robust domestic supply of these assets will reduce the risk of delayed deployment due to bottlenecks in the global supply chain. Establishing a group of industry representatives to identify supply chain constraints and develop solutions that leverage existing strengths within the United States could help the industry grow strategically and efficiently. The group should not be a formal venture between project developers or manufacturers, but rather an advisory group that can facilitate knowledge sharing throughout the industry. This type of collaboration could also present an opportunity to learn from experienced international partners and accelerate the progress of the U.S. industry. A successful example of a collaborative industry group is the Offshore Wind Industry Council that was formed in the United Kingdom in 2013. This organization comprises 24 major industry groups that organized independently to drive local development of high-value components and address innovations in the supply chain. A similar organization in the United States could:

- Provide state and federal governments with plans, requirements, and specifications for supply chain facilities such as ports and component factories
- Work with state and federal governments to assess the impacts of proposed offshore wind legislation or incentives
- Evaluate the cost/benefit trade-offs of technology innovations, with a particular focus on understanding if the potential cost-of-energy benefits of continued wind turbine upsizing are outweighed by the stresses it would impose on the supply chain
- Develop a comprehensive list of vetted and approved small- and medium-sized manufacturers that can support the fabrication of major components
- Provide guidance and funding to train a new workforce and certify new manufacturing facilities
- Establish a consistent approach to incorporating equity into supply chain decision-making.

Like the recommended regional and state supply chain groups, this type of industry organization could potentially provide biased or incomplete perspectives of the most critical supply chain needs. This risk could be mitigated by encouraging a diverse group of stakeholders to join these collaborative industry groups, including manufacturers, project developers, organized labor, and supporting supply chain representatives.

Develop nimble supply chain facilities that can adapt to evolving technologies

Offshore wind energy technology has evolved rapidly in recent years as wind turbine ratings have increased to 15 MW, fixed-bottom projects have expanded to deeper waters and bigger foundations, and 79 MW of floating platform demonstration projects have been deployed. These innovations can enable lower costs, improved performance, and expansion into new offshore wind energy areas; however, they also stress existing supply chains that may need to adapt their existing facilities, workforce, or approaches to fabricate the new designs. Incorporating these new innovations into the manufacturing process will at least have an impact on production timelines as manufacturers develop new workflows, and could potentially create major disruptions if new component designs are unable to be manufactured in existing facilities.

To safeguard against these impacts, it is important for upfront investments in the supply chain to be forward-looking and to anticipate the need for growth as the industry evolves. This strategy may require manufacturers to oversize their facilities or establish long-term plans for expansion to keep pace with industry. An example of this approach is the staged development of the Nexans cable facility in South Carolina. This facility opened in 2014 to deliver underground cables, then made a second investment in 2017 to expand their capabilities to develop subsea cables, with announced plans in 2021 to make a third investment into developing high-voltage direct current subsea cables at the same location. This type of approach allows the facility to serve the short-term and longer-term needs of the industry.

Develop tailored, data-based, and incentivized approaches to prioritizing equity in supply chain development

In order to facilitate equitable outcomes for present and future supply chain activities, incentives could be created for project developers to incorporate community feedback in all project phases. These incentives could be regulatory or financial, and could be accompanied by resources for incorporating place-based equitable best practices.

To develop guides and foster positive results, decision-makers and developers should understand and be sensitive to the historic and present burdens, needs, and opportunities that exist in the communities being impacted by the offshore wind energy supply chain. This information could be gathered using data-based indicators of social, economic, and environmental conditions and supplemented with qualitative data gained through surveys, interviews, and other forms of community engagement that are accessible to community members of diverse backgrounds and experiences. To gain such accurate and critical input from community members, it would be necessary to invest in and use a suite of customizable, equitable, and data-driven best practices for inclusive community engagement and collaborative planning.

Procedural justice (fairness in the decision-making process) and distributive justice (fairness in the distribution of benefits and burdens) should both be considered for supply chain investments in a community. Procedural justice requires providing communities equitable access to decision-making processes and the ability to meaningfully impact the decisions that are made. Distributive justice is attained when communities can reliably negotiate benefits such as local hiring, economic investment, workforce development and training, support for local businesses, and mitigation of pollution and other hazards. By prioritizing actions that minimize negative impacts, provide robust long-term benefits, and center the unique context and needs of the community, the offshore wind energy supply chain could be a pathway to addressing past injustices in port communities and ensuring more balanced distribution of benefits and burdens moving forward.

Improve communication, education, and outreach throughout the offshore wind energy industry

The challenges in building a domestic offshore wind supply chain are not overly technical by nature. Instead, the difficulty is in making decisions that involve a multitude of stakeholders in an uncertain environment. These decisions will never be risk-free, but the risk can be mitigated by engaging stakeholders throughout the value chain at early stages of development and ensuring that there is consistent and transparent communication.

Communication about supply chain needs, strategies, opportunities, and best practices cannot be confined to any specific organization. Instead, information should be shared more broadly so that all agencies can make decisions with the same information and goals in mind. A particular focus of this approach should be on engaging with Tier 2 and Tier 3 suppliers throughout the United States to emphasize the magnitude of the opportunity that the offshore wind energy industry represents. Supply chain representatives from active offshore wind energy states have reported that existing local businesses are frequently unaware of planned offshore wind development or do not recognize that there is a demand for their products and services. Even for existing suppliers that are more familiar with offshore wind energy, many are faced with uncertainty due to insufficient or confusing communications. For example, some OEMs may require different certifications for the same subcomponent, which creates an unreasonable burden on the subcomponent manufacturer. Several areas of communication, education, and outreach that could be targeted throughout the industry include:

- Engaging Tier 2 and Tier 3 suppliers to increase awareness of offshore wind energy opportunities, the demand for different industry sectors, and requirements for bidding and contracting
- Sharing best practices from community engagement, permitting, and workforce training activities
- Streamlining and standardizing certification requirements for suppliers to join the offshore wind supply chain.

This potential solution is related to, but different than, the recommendations to form collaborative supply chain groups or to increase coordination between states. These groups could help to conduct outreach or facilitate communication with outside agencies, but the awareness of states' offshore wind supply chain visions would be more useful if it extends beyond their own governments and major industry players. This report can serve as a foundation to start discussing the major needs, challenges, and potential solutions for the offshore wind energy industry.

4.2 Time Frame for Implementing Potential Solutions

Developing an offshore wind energy supply chain in the next decade will require urgent and efficient decision-making throughout the industry to address the most critical gaps and bottlenecks while positioning the supply chain for sustainable growth beyond 2030. Understanding how to sequence the proposed solutions over the next few years can help prioritize resources and systematically progress toward a shared vision of a domestic supply chain. In the following tables, we outline concepts for short-, medium-, and long-term actions that form a road map for developing offshore wind energy in the United States.

Table 16. Short-Term Actions: Organizing a Strong Foundation (2023–2024)

Action and Relevant Organizations	Outcome	Impact
Convene working groups focused on regional and holistic supply chain development **Relevant Organizations:** State and federal governments, Tier 1 manufacturers, supporting suppliers, organized labor, community representatives, regulatory Organizations, project developers	The formation of actively funded groups with decision-making authority, diverse membership, established communication practices, and clear visions for supply chain development	Well-organized and empowered working groups can formalize a transparent, consistent, and strategic agenda for supply chain growth that will provide a solid foundation for further development activities and reduce uncertainty for new entrants to the supply chain
Identify locations to build the next wave of supply chain development equitably and efficiently **Relevant Organizations:** State and local governments, Tier 1 manufacturers, supporting suppliers, community representatives	Announcements and initial permitting applications for a sufficient number of facilities (e.g., factories, ports, vessels) to meet the demand of the domestic pipeline	A planned (and publicized) network of supply chain facilities that is based on local capabilities (e.g., existing workforce or suppliers, port or waterway resources, beneficial regulatory environments) and energy justice considerations (e.g., impact on host communities) will address supply chain gaps, reduce uncertainty about the needs for further investment, and allow supporting supply chains to develop in parallel with Tier 1 facilities
Continue to expand the offshore wind energy pipeline **Relevant Organizations:** BOEM, state governments	A predictable timeline for lease area sales and state procurement solicitations that extends to (at least) 2035	A stable 10-year pipeline will provide the basis for investing in supply chain facilities and expecting a reasonable return
Assess the need for and impact of incentive mechanisms beyond existing programs **Relevant Organizations:** State and federal governments, Tier 1 manufacturers, supporting suppliers, organized labor	A predictable approach for incentive programs to construct new supply chain assets (e.g., factories, ports, vessels) and produce Tier 1, 2, or 3 components that are not covered through the IRA or other existing programs	Incentives such as tax credits can offset the upfront investment in new supply chain resources, making the assets cost competitive with imported components

Action and Relevant Organizations	Outcome	Impact
Establish strategies and incentive mechanisms targeted at floating wind infrastructure **Relevant Organizations:** State and federal governments, port operators, shipyards, vessel owner/operators, Tier 1 manufacturers, supporting suppliers	A clear and consistent vision for the infrastructure needs to deploy commercial-scale floating wind, including preferred port locations, newly built vessels, and industrialization requirements for floating platforms	A common plan for floating wind infrastructure development will allow the industry to develop efficiently and strategically with buy-in from relevant states and industry sectors; this organized approach could establish the United States as a global leader in floating wind deployment
Establish curriculum and funding streams for workforce training centers **Relevant Organizations:** Organized labor, community colleges and universities, Tier 1 manufacturers, state governments	A common curriculum for offshore wind workers that is acceptable to all major offshore wind manufacturers; committed funds sufficient to open the training centers and train an initial cohort	Developing a local workforce with a common skill set as prescribed by manufacturers and other major employers will increase the economic benefits and resiliency of a domestic supply chain
Conduct outreach and education activities with existing suppliers to increase awareness of offshore wind energy opportunities **Relevant Organizations:** Tier 1 manufacturers, supporting suppliers, state governments, organized labor	Increased engagement and contracting between major manufacturers and domestic businesses	Building a bottom-up supply chain that uses and expands on the strengths of existing local businesses will make it easier to establish major component manufacturing in the United States, which will lead to a more self-reliant, cost competitive, and beneficial domestic supply chain

Table 17. Medium-Term Actions: Gaining Critical Momentum (2025–2030)

Action and Relevant Organizations	Outcome	Impact
Construct the major supply chain facilities needed to meet the demand pipeline **Relevant Organizations:** Tier 1 manufacturers, state and local governments, community representatives	A network of domestic manufacturing facilities that can support the demand from all offshore wind energy projects in the United States; a system of ports and vessels that can support annual deployment without creating significant delays	A fully domestic supply chain will de-risk deployment bottlenecks by reducing reliance on congested global supply chains and will create significant jobs and economic benefits within the United States
Continue to expand the offshore wind energy pipeline **Relevant Organizations:** BOEM, state governments	A predictable timeline for lease area sales and state procurement solicitations that extends to (at least) 2040 and potentially as far as 2050	A stable pipeline looking more than 10 years into the future will provide the basis for investing in supply chain facilities and expecting a reasonable return
Leverage national, regional, and industry working groups to share and develop best practices for supply chain activities **Relevant Organizations:** Newly formed working groups encompassing government, industry, organized labor, and community representatives	A standardized approach to community engagement, permitting, developing supporting supply chains, and adapting to evolving technologies throughout different states and supply chain sectors	Consistent approaches to supply chain activities will simplify ongoing investment, construction, and planning activities
Incorporate learning from early-stage commercial-scale projects into ongoing operations and decision-making **Relevant Organizations:** Tier 1 manufacturers, supporting suppliers, federal and state governments, community representatives, project developers	An evolved supply chain that develops in parallel with technologies and processes that are customized for the social and regulatory considerations within the U.S. market (e.g., foundation technologies to minimize pile-driving noise, refined feeder barge strategies to reduce at-sea risk, improved communication and community outreach)	Evolving a domestic supply chain to reflect local conditions will support more streamlined project deployment that addresses a wide variety of stakeholders and helps the industry better understand the future needs for supply chain resources such as ports and vessels
Train a sufficient manufacturing workforce **Relevant Organizations:** Organized labor, community colleges and universities, Tier 1 manufacturers, state governments	Workforce training centers and apprenticeship programs produce a sufficient throughput of trained workers to fill all domestic manufacturing jobs	Having a skilled trade of domestic offshore wind energy workers will encourage further investment in local manufacturing and generate jobs and economic benefits

Action and Relevant Organizations	Outcome	Impact
Evaluate procedural and impact equity metrics for early-stage commercial-scale projects and incorporate best practices into ongoing supply chain development activities **Relevant Organizations:** Community representatives, Tier 1 manufacturers, supporting suppliers, organized labor, state and local governments	Commonly used best practices that incorporate community feedback throughout the decision-making process for supply chain investment that apply frameworks that have been refined using lessons learned from early-stage projects	Correctly incentivizing realistic and meaningful equity considerations into supply chain investment will maximize benefits and minimize harm to at-risk communities, which may also reduce permitting delays and stakeholder concerns

Table 18. Long-Term Actions: Maintaining a Sustainable Industry (Beyond 2030)

Action and Relevant Organizations	Outcome	Impact
Maintain and upgrade key supply chain infrastructure to adapt to evolving technologies **Relevant Organizations:** Tier 1 manufacturers, port operators, vessel owner/operators	Existing resources developed in the 2020s (e.g., manufacturing facilities, ports, vessels, workforce training centers) remain active and capable of producing new components (e.g., larger wind turbine components, floating wind components on the East Coast), possibly with the inclusion of new innovations or automation; floating wind infrastructure continues to expand to support increasing levels of deployment	Maintaining and adapting existing facilities will reduce demand for new construction, which will reduce costs, permitting demands, and impacts on new host communities as offshore wind energy deployment continues beyond 2030
Expand supply chain infrastructure to new regions using lessons learned from early build-out **Relevant Organizations:** Tier 1 manufacturers, supporting suppliers, state governments, organized labor, community representatives	Offshore wind energy supply chain hubs that are present throughout the United States with capabilities and are customized for the specific technology, regulatory, and community needs of each region	Expanded supply chain resources will facilitate deployment in new regions, such as the Great Lakes and Gulf of Mexico, and can be developed in a sustainable and just manner that incorporates lessons learned from supply chain growth in the 2020s
Fill manufacturing gaps in supporting supply chains with domestic production **Relevant Organizations:** Supporting suppliers, organized labor	Critical subcomponents and subassemblies are primarily manufactured in the United States to decrease reliance on global supply chains	Expanding domestic manufacturing capabilities to produce critical path components that are identified during supply chain growth in the 2020s will reduce the risk of delays and will create opportunities for jobs and economic benefits

Action and Relevant Organizations	Outcome	Impact
Continue to expand the offshore wind energy pipeline **Relevant Organizations:** BOEM, state governments	A predictable timeline for lease area sales and state procurement solicitations that extends through 2050	A stable 10-year pipeline will provide the basis for investing in supply chain facilities and expecting a reasonable return

4.3 Offshore Wind Energy Supply Chain Growth Beyond 2030

The United States will likely require at least 3,000 GW of wind and solar power by 2050 to accomplish the energy transition (National Academies of Sciences, Engineering, and Medicine 2021; Larson et al. 2021). Achieving the national offshore wind target could establish a trajectory to deploy 110 GW of offshore wind energy by 2050 (The White House 2021a; Lantz et al. 2021). The $22.4-billion domestic supply chain outlined in this report would be sufficient to produce and install the majority of components needed for the 4–6 GW of offshore wind per year that would need to be deployed to reach this target, which would contribute approximately 3.7% of the total demand for renewable power in 2050. However, approximately 70% of current U.S. electricity demand comes from coastal states with limited transmission connectivity to land-based wind and solar production regions in the center of the country, which could drive a greater need for offshore wind in the nation's future energy portfolio. Supply chain planning and investment should consider the value of establishing production capabilities that can support the development of 110 GW by 2050 but should also consider the value in expanding further to achieve higher domestic offshore wind capacity. For instance, 300 GW of offshore wind energy would likely contribute around 10% of a decarbonized energy system (National Academies of Sciences, Engineering, and Medicine 2021; Larson et al. 2021).

Installing 30 GW is expected to require an investment around $100 billion (The Special Initiative for Offshore Wind 2021), suggesting that a build-out of 100–300 GW could require between $300 billion and $1 trillion to construct. At this scale, the $22.4-billion U.S. supply chain investment that we estimate in this report becomes less than 10% of the total investment required to install 110 GW by 2050. This context is important to understand that the level of investment in the supply chain, while significant, could enable an industry with vastly higher economic potential to unfold in the United States and create massive economic opportunities for the country. A domestic supply chain would also reduce reliance on imported components, workers, and materials, which would increase the resiliency of offshore wind manufacturing in the event of future supply chain shocks.

The United States must consider how this near-term investment will not only position our country to complete our own energy transition, but also how we can contribute to the global challenge of deep decarbonization by 2050. The investments that we make between now and 2030 will affect our ability to reach 2050 deployment targets and to derive meaningful economic benefits from this global transition. It is important to understand that the construction of these first 30 GW is an initial step in the energy transition and can proceed in parallel with the large-scale planning efforts required to prepare for our supply chain, transmission grid, public processes, and environmental protection of the future. These first 30 GW are essential to help the offshore wind sector learn what technologies, policies, and best practices work best in the U.S.

market. Without it, the country will not advance as quickly as is required and the ability to control our own energy security may be limited. A strategic, inclusive, and disciplined approach to developing supply chains and deploying offshore wind projects in parallel will help execute the energy transition as we develop new ways of thinking about supply chains, policy, economic development, energy justice, and environmental impacts.

5 Conclusions

A unified approach to building a domestic supply chain would help to establish port, vessel, factory, and workforce resources that can be developed in a timely, just, and sustainable manner. This report presents the significant gaps in existing infrastructure and barriers to development that will have to be overcome to achieve a domestic supply chain. These barriers include the following:

- The Biden administration, the Bureau of Ocean Energy Management, and individual state governments have made substantial progress to create a strong pipeline of planned projects and procurement targets. However, uncertainty surrounding the potential impacts of construction delays, cost overruns, legal complications, or changes in government support for offshore wind energy creates an investment risk that makes it difficult to secure financing for new supply chain facilities (e.g., factories, ports, and vessels).
- Major offshore wind manufacturing facilities can only be built in suitable ports, but construction of these facilities is constrained by limited available port space and uncertain permitting and construction timelines. Wind turbine capacities have been rapidly increasing in recent years (Musial et al. 2022), and if this trend continues, supply chain assets (including ports and vessels) designed around current technology may become obsolete or require additional investment before paying off the upfront investment.
- Existing supplier networks will be stressed to provide the required raw materials and subcomponents needed to fabricate major components.
- Existing port and vessel infrastructure is inadequate to install 30 GW of offshore wind energy by 2030.
- Some offshore wind energy components require a specialized manufacturing workforce that may not be readily available in the United States.
- Recent federal incentives such as the Inflation Reduction Act of 2022 (IRA) will help domestically produced components be cost competitive with imports from established international manufacturing facilities. However, additional incentives may be required to encourage domestic manufacturing of components or supply chain assets that are either not considered in the IRA or receive credits that are smaller than the cost premium for domestic manufacturing.
- Incorporating equity and sustainability into supply chain decision-making is resource-intensive and insufficiently incentivized, which may result in unjust outcomes for host communities.

Potential solutions to alleviate these barriers include:

- Continuing efforts to reduce systemic risk for near-term project construction and long-term pipeline growth
- Increasing coordination between multiple states or regions to provide flexibility and predictability for supply chain investments
- Considering state and federal incentives (e.g., tax credits, public/private partnerships, grants, and loans) to de-risk investment and make domestic products more cost competitive
- Establishing collaborative supply chain groups that encourage industry to combine resources and strategies for holistic supply chain development

- Investing in training pipelines for tradespeople to match component suppliers to an appropriately trained workforce
- Developing nimble supply chain facilities that can adapt to evolving technologies
- Creating tailored, data-based approaches to evaluate equity impacts of supply chain activities and encouraging engagement and investment in communities
- Improving communication, education, and outreach throughout the offshore wind energy industry.

Other key findings of this report include:

- The domestic supply chain scenario we present includes at least 34 major component manufacturing facilities, 8 East Coast marshaling ports, 2 floating wind integration ports, 4−6 dedicated wind turbine installation vessels, 4−6 dedicated heavy lift vessels, 4–8 specialized U.S.-flagged feeder barges, and a workforce of around 45,000 full-time equivalent jobs. This supply chain scenario would require an investment of around $22.4 billion and would take 6–9 years to develop.
- The decision-making, permitting, and construction time frames for major supply chain assets means that most planned resources would have to be committed to by the end of 2023 for the supply chain to be operational by 2030. Even with this accelerated schedule, projects that are planning for installation in the mid-2020s could face difficulties in sourcing components domestically as the supply chain ramps up. The resulting supply shortage indicates that the United States could have to import components for between 15 and 25 GW of projects to achieve the national offshore wind target.
- Existing port and vessel infrastructure could delay around half of the pipeline beyond 2030 if there is not new investment in marshaling ports, wind turbine installation vessels, heavy-lift vessels, and feeder barges.
- Establishing a robust and self-reliant domestic supply chain that can support sustainable growth of the industry beyond 2030 is a complementary goal to the national offshore wind target of 30 GW by 2030.
- Achieving this sustainable supply chain could help the United States create significant job opportunities and economic benefits throughout the entire country (not just in coastal states). There is a substantial workforce and manufacturing capability that can transition to the offshore wind energy industry with appropriate education, communication, and certainty about the future of the industry. Involving existing business skill sets, including organized labor, in the expansion of the supply chain will create a strong supplier network that can reduce the industry's reliance on global supply chains.
- As the supply chain expands into new locations and established manufacturing communities, there will be new opportunities for historically disadvantaged communities. Supply chain decision makers and stakeholders need to appropriately allocate resources to evaluate the potential impacts of their activities on these communities to maximize benefits and minimize harm.
- Improved communication and regional collaboration strategies will be some of the most effective means to coordinate investment strategies that leverage strengths of existing states or industry sectors, which can lead to more efficient supply chain development.

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Appendix A. Manufacturing Facility Considerations

As part of this project, the National Renewable Energy Laboratory (NREL) team conducted interviews with offshore wind energy component manufacturers to identify component specific requirements for manufacturing facilities, various barriers that could potentially delay or otherwise impact the possibility of developing and constructing these facilities, and potential solutions to address and overcome these barriers. These conversations focused on select Tier 1 and Tier 2 components and materials including blades, nacelles, towers, monopile foundations, jacket foundations, gravity-based foundations, transition pieces, floating platforms, cables, mooring rope and chain, steel plates, large castings and forgings, substations, bearings, and anchors.

Prior to the interviews, the NREL team identified numerous, component-specific requirements for manufacturing facilities that would need to be collected to understand what is needed to develop, construct, and operate a domestic offshore wind component manufacturing facility. These requirements included capital investments for production facilities and manufacturing equipment, space for buildings and storage, permitting and construction timelines, and needs related to location, portside infrastructure, and workforce.

The barrier portion of these interviews focused on the various considerations that could potentially delay or otherwise impact the possibility of developing and constructing domestic offshore wind manufacturing facilities in a time frame that allows them to contribute to the administration's goal of 30 gigawatts (GW) of offshore wind energy by 2030. Barriers that were identified during interviews were used to develop overarching barriers that are discussed and expanded upon in Section 2 of this report. The overarching barriers are used within this section of the report to introduce these considerations at a high level before discussing component-specific nuances in greater detail. Additionally, a segment of these interviews focused on potential solutions to address and overcome these barriers. Solutions that were identified during interviews are discussed and expanded upon in Section 4 of this report.

Each component write-up is designed to stand alone, so some language may seem redundant when considered from a broader perspective.

Blades

Overview and Factory Specifications

The characteristics of a representative blade manufacturing facility are listed in Table A1. From conversations with manufacturers, we observed that domestic production of this component will require a newly constructed, purpose-built facility. On-site fabrication activities include cutting and layering of fiberglass sheets into the blade mold; injecting resin; curing; assembly; incorporating components and subassemblies; trimming; prepping; painting; and finishing of the blades. Blades are then delivered to an on-site storage area until they can be transported to a marshaling yard, staging area, or directly to the project site for installation.

With a length of up to 115 meters (m) and a mass that can reach over 60 metric tonnes (t), blade manufacturing facilities must be coastally located on large parcels of land (up to 80 acres) that can accommodate fabrication, painting, and trim areas, as well as storage needs for both the finished product and component materials while having access to relatively deep channels and berths (6 m) for vessel transportation. The materials used to manufacture offshore wind blades can be transported via vessel, rail, or road.

Loading of finished components will require quayside infrastructure up to 120 m in length including heavy-lift wharfs with a bearing capacity of 50 tonnes/square meter (t/m^2) to accommodate moving blades from quayside onto vessels.

Offshore wind blade fabrication also requires investments in specialized manufacturing equipment like mold sets and resin injection systems sourced outside of the United States. Specialized equipment (i.e., blade carts and self-propelled modular transporters [SPMTs]) are also used for on-site transportation during the manufacturing process of this component. Workers will need training to operate this specialized equipment and to learn the overall blade manufacturing process.

Table A1. Factory Specifications for a Generic Blade Facility

Factory Specification	Value	Units
Throughput	225	blades/year
Investment cost	300	$ million
Permitting and construction time frame	3–5	Years
Laydown area	80	Acres
Navigation channel depth	7	m
Direct jobs	500	Full-time equivalent (FTE)/year

Required Facilities

Based on the average annual demand reported in Shields et al. (2022) and the production capacity of announced and representative blade facilities, we estimate that there is a demand for five blade facilities to support the deployment of 30 GW by 2030. One blade finishing facility (the Siemens Gamesa facility at Portsmouth Marine Terminal in Virginia) has already been announced and is expected to begin production in 2025. Another blade facility will likely need to be located on the West Coast to support the growth of the floating wind industry in the late 2020s. As these facilities come online throughout the decade, domestic blade production will be able to meet most of the average demand by 2027 and all of it by 2029. The annual throughput of these facilities (assuming the shorter permitting and construction time frame from Table A1) is compared against the average and annual demand for components in Figure A1.

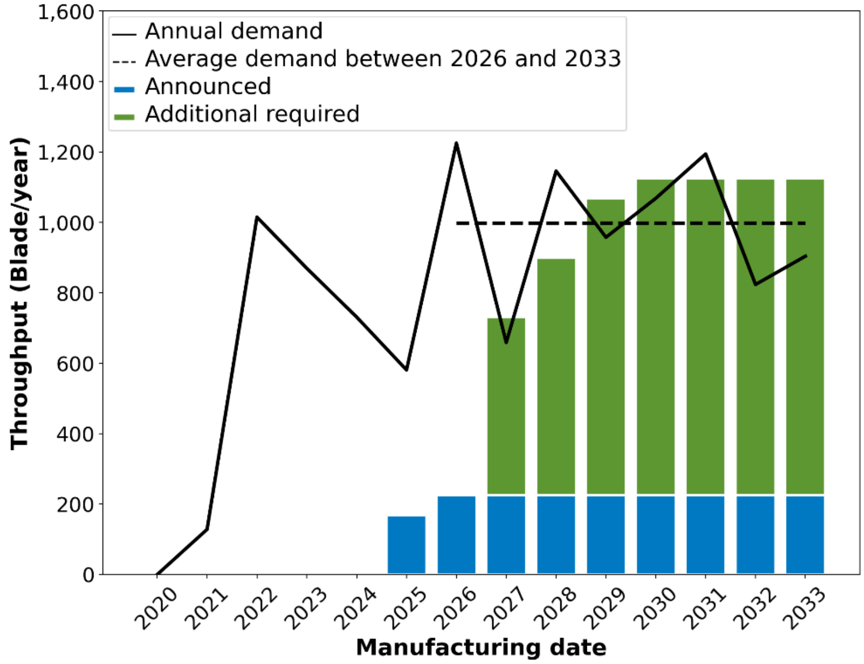


Figure A1. Comparison of average annual demand and potential production throughput for wind turbine blades. The production throughput corresponds to five blade facilities that come online by 2030

Barriers

Wind turbine blades and the associated costs and requirements related to facilities, workforce, downstream supply chain, transportation, permitting, and portside infrastructure create a unique set of barriers that could potentially impact the ability to permit, construct, and staff enough manufacturing facilities within a time frame that can meet the national goal. Wind turbine blade manufacturing will be particularly impacted by the following high-level barriers to developing a domestic supply chain:

- Building new manufacturing facilities is constrained by limited available space and uncertain permitting and construction timelines
- Some offshore wind components require a specialized workforce that may not be readily available in the United States

One of the primary issues associated with developing blade manufacturing facilities is related to site requirements. Blade manufacturing requires a coastal site with significant laydown areas due to land requirements for the various spaces used during the fabrication process, large component size, and a need for on-site storage of finished components prior to project installation or staging. The length of a finished offshore wind turbine blade further dictates site preferences, specifically related to ideal manufacturing configurations. Manufacturers prefer a site that can accommodate straight-line production that will allow blades to be transported from molding to painting and straight to quayside with limited turning requirements.

As more offshore wind installation support facilities are announced, the number of coastal sites that can be modified for offshore wind manufacturing, marshaling, and/or staging areas will decrease, resulting in the use of sites that need more significant expansions and/or upgrades.

These upgrades could include land acquisition, site grading and/or other land improvements, and bearing capacity upgrades. Costs related to quayside infrastructure depend on the portside condition of the site, but these upgrades typically require fairly significant capital investment, and time for permitting and build-out of quayside infrastructure. Any site upgrades can result in increased costs and timelines depending on site-specific characteristics, as well as any associated tribal, wildlife, or environmental sensitivities, and local permitting requirements. Additionally, any dredging to increase navigation channel depths or widths, or modification of the channel is conducted by the Army Corps of Engineers and will require congressional budget and approval before dredging activities can begin.

While offshore wind blades have a relatively low number of outsourced subassemblies and subcomponents, blade manufacturing requires large quantities of materials like epoxy resin, carbon fiber, and fiberglass. Domestic suppliers have the capability and capacity to produce these materials. Blade root fabrication could present technical challenges as component diameter can reach 6 m.

Blade manufacturing is a labor-intensive, multistep process that involves a variety of efforts that require a large number of workers conducting manual labor. This is particularly relevant for layup, prep, and other shell assembly activities, as well as grinding, trimming, and other blade finishing activities. Labor costs are location-specific and can significantly influence where a manufacturer chooses to locate a facility. Blade manufacturers identified staffing as a potential issue that will need to be addressed. Companies will need to identify, recruit, and train a new workforce, which can take significant time, effort, and cost. Similar to labor costs, domestic workforce availability is location-specific and low unemployment throughout the United States has made this a significant challenge. These workforce barriers create an opportunity for multiparty solutions between manufacturers, existing unions, state and local governments, and other public and private organizations.

Wind turbine manufacturers typically have in-house blade production capabilities, though some independent blade producers exist. The overall cost to domestically produce offshore wind turbine blades will be in direct competition with existing overseas facilities. The combination of transportation costs to import internationally produced blades, incentives from the Inflation Reduction Act (IRA), and limited capacity at existing international facilities due to expanded deployment goals in existing markets will likely encourage domestic production of these components. The impact of the IRA, particularly the Section 45X Advanced Manufacturing Production Tax Credits (AMPTCs), could depend on the operational date of the blade facility because these incentives expire in 2032. As more offshore wind turbine manufacturers secure orders for U.S. projects, the opportunity for domestic blade production will increase.

Nacelles

Overview and Factory Specifications

The characteristics of a representative nacelle assembly facility are listed in Table A2. From conversations with offshore wind turbine manufacturers, we observed that domestic assembly of nacelles will require a newly constructed, purpose-built facility. On-site assembly activities will depend on the modularity of the overall component and will likely vary between wind turbine manufacturers. Modularity is expected to evolve over time, with more nacelle components and subassemblies being domestically produced as the offshore wind energy industry matures. Once assembled, nacelles are delivered to an on-site storage area until they can be transported to a marshaling yard, staging area, or directly to the project site for installation.

With a mass that can reach over 600 t, nacelle assembly facilities must be coastally located on large parcels of land (at least 40 acres) that can accommodate assembly activities. Additionally, nacelle assembly facilities will need access to relatively deep channels and berths (10 m) for vessel transportation to import multiple modules containing preassembled components and subassemblies. Storage space will also be needed, for both the fully assembled nacelle and the imported modules containing preassembled subcomponents and subassemblies.

Through conversations with offshore wind turbine manufacturers, we learned that nacelle modules will likely be assembled in Europe using subassemblies and subcomponents from existing turbine original equipment manufacturer (OEM) supply chains that in the near term can be expanded to meet U.S. demand. These modules will then be transported to the United States via vessel. As the domestic supply chain evolves, some subcomponents and subassemblies will be domestically manufactured and modularly assembled.

Loading of finished components will require quayside infrastructure up to 500 m in length including heavy-lift wharfs with a bearing capacity of 15 t/m^2 to accommodate moving nacelles from quayside onto vessels.

Table A2. Factory Specifications for a Generic Nacelle Assembly Facility

Factory Specification	Value	Units
Throughput	100	nacelles/year
Investment cost	250	$ million
Permitting and construction time frame	3-5	years
Laydown area	40	acres
Navigation channel depth	10	m
Direct jobs	230	FTE/year

Required Facilities

Based on the average annual demand reported in Shields et al. (2022) and the production capacity of the announced and representative nacelle facilities, we estimate that there is a demand for four nacelle facilities to support the deployment of 30 GW by 2030. Two of these facilities (separate GE and Vestas facilities, both intended to be located at the New Jersey Wind Port) have already been announced. One of the new nacelle facilities will likely need to be located on the West Coast to support the growth of the floating wind industry in the late 2020s. As these facilities come online throughout the decade, domestic nacelle assembly should be able to meet average demand by 2028. The annual throughput of these facilities (assuming the shorter permitting and construction time frame from Table A2) is compared against the average and annual demand for components in Figure A2.

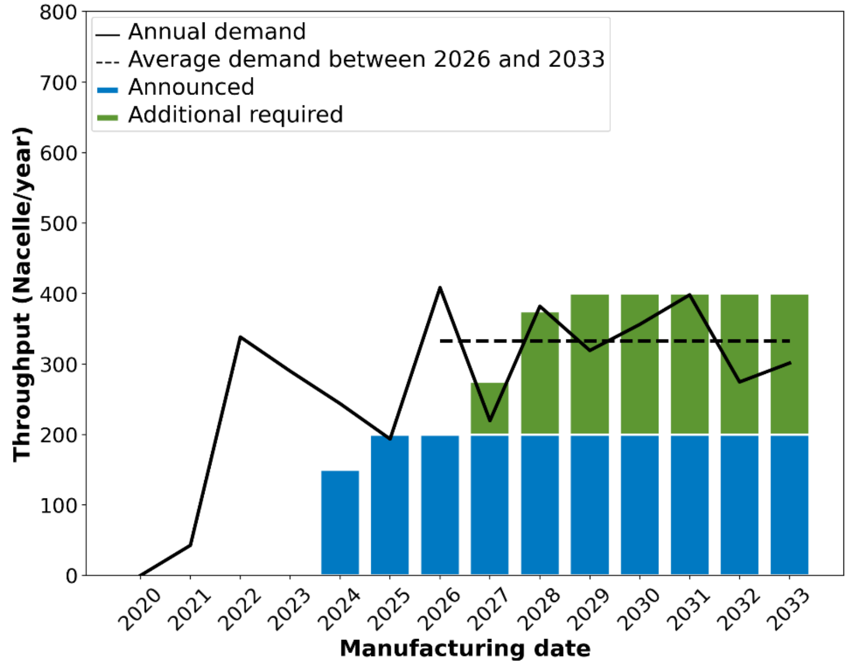


Figure A2. Comparison of average annual demand and potential production throughput for nacelles. The production throughput corresponds to four nacelle facilities that come online by 2030.

Barriers

Nacelle assembly and the associated costs and requirements related to facilities, workforce, downstream supply chain, transportation, permitting, and portside infrastructure, create a unique set of barriers that could potentially impact the ability to permit, construct, and staff enough manufacturing facilities within a time frame that can support the national goal. Nacelle assembly facilities will be particularly impacted by the following high-level barriers to developing a domestic supply chain:

- Building new manufacturing facilities is constrained by limited available space and uncertain permitting and construction timelines
- Existing supplier networks will be stressed to provide the required raw materials and subcomponents needed to fabricate major components
- Some offshore wind components require a specialized workforce that may not be readily available in the United States

One of the primary issues associated with developing nacelle assembly facilities is related to site requirements. Nacelle assembly facilities require a coastal location with significant laydown areas for buildings, finished components, and preassembled modules that house various subcomponents and subassemblies. As more offshore wind manufacturing facilities installation and support facilities are announced, the number of previously developed coastal sites that can be modified for offshore wind manufacturing, marshaling, and/or staging areas will decrease, resulting in the use of sites that need more significant expansions and/or upgrades. These upgrades could include land acquisition, site grading and/or other land improvements, and bearing capacity upgrades. As a result, costs and timelines might be increased depending on site-specific characteristics, as well as any associated tribal, wildlife, or environmental sensitivities, and local permitting requirements. Additionally, any dredging to increase navigation channel depths directly must involve the Army Corps of Engineers and will require congressional budget and approval before dredging activities can begin.

Costs related to quayside infrastructure depend on individual site conditions, but most upgrades require fairly significant capital investment, and time for permitting and build-out. Direct-drive and geared nacelles have different quayside needs as geared turbines have a higher mass that will require increased bearing capacity limitations. Bearing capacity limitations may shift as technology evolves and wind turbine capacity and nacelle mass increase from 600 t to nearly 1,000 t/nacelle. Facilities and laydown areas will need to be upgraded as domestic content increases or if assembly processes or modularity become more complex. These upgrades could involve land acquisition and other expansion activities.

While the downstream supply chain for the nacelle assembly will rely heavily on the existing European supply chain for this first iteration of offshore wind installations, it could evolve as the industry matures in the United States. For instance, offshore wind gearboxes and direct-drive systems are manufactured outside of the United States by established manufacturers who actively supply major OEMs, but these components could be domestically produced in the future. This expanded domestic production could happen in a variety of ways, such as the inclusion of new or existing domestic manufacturers, partnerships between European companies who are already part of the offshore wind energy supply chain and existing U.S. manufacturers, or the expansion of existing European companies into the U.S. market on their own.

Regardless of how they enter the U.S. supply chain, the cost of these subcomponents and subassemblies will be measured against existing supply chains that have been subsidized and paid for. The overall cost to domestically assemble offshore wind nacelles will be in direct competition with overseas manufacturers. The combination of transportation costs to import internationally produced nacelles and/or modular assemblies, incentives from the IRA, and limited capacity at existing international facilities due to expanded deployment goals in existing markets will likely encourage domestic assembly of nacelles. The impact of the IRA, particularly the Section 45X AMPTCs, could depend on the operational date of the nacelle facility because these Incentives expire in 2032.

Some cast components like bedplates and hubs could be domestically fabricated by existing companies, but the number of facilities that can be modified to produce these components is severely limited. An additional supply chain concern is the supplier qualification timeline. Interviews with offshore wind energy turbine manufacturers revealed that it currently takes 2 years for OEMs to properly validate Tier 2 and Tier 3 manufacturers and products to ensure subcomponents and subassemblies from prospective suppliers outside their existing supply chain can meet specific standards.

Offshore wind energy manufacturers identified staffing as a potential issue that will need to be addressed. Companies will need to identify, recruit, and train a new workforce, which can take significant time, effort, and cost. Domestic workforce availability is location-specific and low unemployment throughout the United States has made this a big challenge. These workforce barriers create an opportunity for multiparty solutions between manufacturers, existing unions, state and local governments, and other public and private organizations.

Towers

Overview and Factory Specifications

The characteristics of a representative tower manufacturing facility are listed in Table A3. From conversations with manufacturers, we observed that domestic production of this component will require a newly constructed purpose-built facility. On-site fabrication activities include splicing and welding of steel plates, rolling and welding of plates into cans, connecting and welding cans into flanged sections, followed by blast and coatings. Tower internals are then assembled into these sections before they are delivered to a marshalling site and temporarily stored until installation.

Though tower designs will differ depending on the type of foundation (floating or fixed-bottom), towers can have a base diameter of up to 10 m and heights that can reach over 130 m. To produce components of this size, tower manufacturing facilities must be coastally located on large parcels of land (up to 45 acres) that can accommodate fabrication, coating, and assembly buildings, as well as storage needs for both the finished product and component materials while having access to relatively deep channels and berths for vessel transportation.

Steel plates required for tower fabrication range in thickness roughly from 1” to 3.5.” Size and weight constraints limit delivery options for steel plates used in offshore wind towers. Steel mills capable of producing heavier plate will be able to ship very long, heavy plates direct to the tower facility. Additionally, specialty rail cars are being developed that could make it possible to transport these large steel plates by rail in the near future. As foundation diameters increase to accommodate larger turbines, tower diameters will also need to increase which may also require increased plate thickness.

Forklifts, cranes, and heavy load carriers are used throughout the manufacturing process to transport steel plates from storage to the roll-forming process where they are transformed into cans, and to move cans as they are fit up and welded into tower sections. Final assembly, blasting and painting, and on-site transportation of a finished tower is typically handled with SPMTs, because of the overall size and weight of the finished component. Unloading of materials, subcomponents, and subassemblies and the loading of finished components will require quayside infrastructure including heavy-lift wharfs with high bearing capacity to accommodate roll on/roll off or lifting of towers from quayside onto vessels. Some tower subcomponents and subassemblies can be shipped via rail or truck, so tower manufacturing facilities will need adequate infrastructure to support these delivery methods.

Offshore wind tower fabrication also requires investment in manufacturing equipment that is oftentimes sourced outside of the United States. Unique equipment includes hydraulic load bearing systems, turning rolls, and high-quality, precision, and volume-welding technology. Workers will need training to operate heavy machinery and specialized welding equipment.

Table A3. Factory Specifications for a Generic Tower Facility

Factory Specification	Value	Units
Throughput	100	towers/year
Investment cost	250	$ million
Permitting and construction time frame	3–5	years
Laydown area	45	acres
Navigation channel depth	10	m
Direct jobs	290	FTE/year

Required Facilities

Based on the average annual demand reported in Shields et al. (2022) and the production capacity of announced and representative tower facilities, we estimate that there is a demand for four tower facilities to support the deployment of 30 GW by 2030. One tower facility—the Marmen Welcon facility at the Port of Albany in New York—has already been announced. As part of the proposal process for Skipjack Wind II, Ørsted has committed to construct an additional tower manufacturing facility that will be located in Maryland. One of these tower facilities will likely need to be located on the West Coast to support the growth of the floating wind industry in the late 2020s. As these facilities come online throughout the decade, domestic tower production can meet average demand by 2028. The annual throughput of these facilities (assuming the shorter permitting and construction time frame from Table A3) is compared against the average and annual demand for towers in Figure A3.

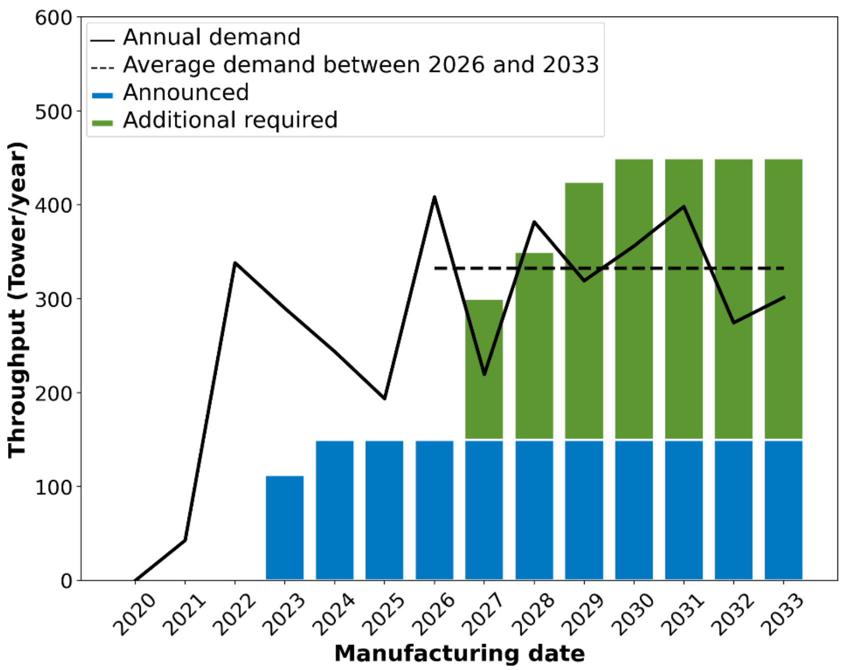


Figure A3. Comparison of average annual demand and potential production throughput for towers. The production throughput corresponds to four tower facilities that come online by 2030.

Barriers

Wind turbine towers and the associated costs and requirements related to facilities, workforce, downstream supply chain, transportation, permitting, and portside infrastructure create a unique set of barriers. These barriers could potentially impact the ability to permit, construct, and staff enough manufacturing facilities within a time frame that can support the national goal. Tower manufacturing will be particularly impacted by the following barriers to developing a domestic supply chain:

- Building new manufacturing facilities is constrained by limited available space and uncertain permitting and construction timelines
- Existing supplier networks will be stressed to provide the required raw materials and subcomponents needed to fabricate major components
- Some offshore wind energy components require a specialized workforce that may not be readily available in the United States.

One of the primary issues associated with developing offshore wind tower manufacturing facilities is related to site requirements. Offshore wind tower manufacturing facilities require a coastal location with significant laydown areas that limit the number of readily available sites where they can be built. As more offshore wind manufacturing facilities are announced, the number of previously developed coastal sites that can be easily modified for offshore wind manufacturing, marshaling, and/or staging areas will decrease, resulting in the use of sites that need more significant expansions and/or upgrades that could include land acquisition, site grading and/or other land improvements, and bearing capacity upgrades. These upgrades can result in increased costs and timelines depending on site-specific characteristics, any associated tribal, wildlife, or environmental sensitivities, and local permitting requirements. Additionally, any dredging to increase navigation channel depths directly involves the Army Corps of Engineers and will require congressional budget and approval before those activities can begin.

Another factor that may limit the number of suitable sites is whether rail infrastructure exists or can be easily extended to support the delivery of subcomponents and subassemblies. As a result, additional upgrades and subsequent costs might be required.

An additional challenge for offshore wind tower manufacturing is an inability to domestically source some key towers, subassemblies, and subcomponents. For instance, wind energy manufacturers identified a lack of domestic flange production as a challenge the industry currently faces. Until domestic suppliers are established to meet U.S. demand, flanges will need to be imported from Asia, Europe, or retrofitted Mexican facilities that are currently producing this component for land-based wind turbines. Importing these products is not expected to negatively impact existing global supply networks, but it would limit the ability to establish a complete domestic supply chain by 2030. Additionally, long distance shipping of these components will increase risks related to a project’s timeline.

Furthermore, offshore wind towers have specific material requirements in the form of 1- to 3.5-inch (in.) steel plates. Steel plates for offshore wind towers are more readily available than steel plates that are used for monopiles. While there is sufficient capacity for current demand, increased global demand driven by the emerging U.S. market and expanded European offshore wind energy goals could create adequate demand for additional domestic steel mills. Nucor is bringing a very large new plate mill online in 2023 to support increasing steel demand.

Offshore wind tower manufacturing is a multistep process that requires rolling and welding of steel plates. Workers must be trained on unique equipment that is only used for producing this component. Offshore wind tower manufacturers identified staffing as a potential issue that will need to be addressed. Companies will need to identify, recruit, and train a new workforce, which can take significant time, effort, and cost. Domestic workforce availability is location-specific and low unemployment throughout the United States has made this a big challenge. While many workers will need training, experience with heavy machinery and welding should translate to offshore wind tower manufacturing. These workforce barriers encourage multiparty solutions between manufacturers, existing unions, state and local governments, and other public and private organizations.

If a domestic supply chain for offshore wind towers is not fully realized, U.S. wind projects on the East Coast will need to import finished products from Europe. The combination of transportation costs to import internationally produced towers, incentives from the IRA, and limited capacity at existing international facilities due to expanded deployment goals in existing markets will likely encourage domestic offshore wind tower production. The impact of the IRA, particularly the Section 45X AMPTCs, could depend on the operational date of the tower facility because these incentives expire in 2032.

Monopiles

Overview and Factory Specifications

The characteristics of a representative monopile facility are listed in Table A4. From conversations with manufacturers, we observed that domestic production of this component will require a newly constructed, purpose-built facility where full fabrication of the monopile occurs. Fabrication activities include welding of steel plates, bending and welding of plates into cans, connecting and welding cans into sections, connecting and welding sections into a monopile, and blasting and coating of the monopile before the finished product is ready for deployment.

With a weight that can reach 2,500 t and base diameters that exceed 12 m, monopile facilities must be coastally located on large parcels of land (up to 100 acres) that can accommodate fabrication and storage needs for both the finished product and component materials while having access to deep-draft navigation channels (8 m) and berths for vessel-bound transportation. Steel required for fabricating offshore wind monopile foundations arrives at manufacturing facilities as flat plates with a width more than 4.3 m, length up to 15 m, thickness of more than15 cm, and a weight of up to 40 t. The steel plates used in monopiles are typically too large for transportation via rail or road, so this material must be delivered via barge.

Forklifts, cranes, and heavy-load carriers are used throughout the manufacturing process to transport steel plates from storage to the roll-bending process where they are transformed into cans, and to move cans as they are assembled and welded into sections. Final assembly, blasting and painting, and on-site transportation of a finished monopile will require SPMTs due to the overall size and weight of the finished component. The monopile is always in the horizontal position during manufacturing.

Loading and unloading of materials and components will require quayside infrastructure including heavy-lift wharfs with high bearing capacity to accommodate roll on/roll off of monopiles from quayside onto vessels.

Fabricating monopile foundations also requires large investments in specialized welding and manufacturing equipment that is sourced outside of the United States. Unique equipment includes flame cutting tables, turning rolls, and high-volume welding technology. The first generation of a domestic monopile manufacturing workforce will be trained in Europe at existing facilities before they return to the United States and disseminate this knowledge to the larger workforce. Workers will need to be certified to operate the unique welding equipment that uses a submerged arc welding process.

Table A4. Factory Specifications for a Generic Monopile Facility

Factory Specification	Value	Units
Throughput	100	monopiles/year
Investment cost	410	$ million
Permitting and construction time frame	2−4	years
Laydown area	80−100	acres
Navigation channel depth	8	m
Direct jobs	550	FTE/year

Required Facilities

Based on the annual demand for monopiles from Shields et al. (2022) and the production capacity of a representative monopile manufacturing facility from Table A4, we estimate that there is a demand for two monopile factories to support the deployment of 30 GW by 2030. Two facilities have already been announced: the EEW American Offshore Structures facility at the Port of Paulsboro in New Jersey, and a US Wind facility at Tradepoint Atlantic in Maryland. The EEW facility broke ground in 2021 and the US Wind facility is expected to begin construction in 2024 and enter service in 2025. These two facilities will likely be sufficient to meet the average demand for the U.S. pipeline, although there may be individual years in which the cumulative production capacity does not meet the annual demand.

Some of these deficits will occur in the early parts of the 2020s, when monopiles are being fabricated for early pipeline projects such as Vineyard Wind. As a result, these components will have to be sourced internationally. As the industry transitions toward more floating wind projects in the 2030s, the demand for fixed-bottom foundations may decrease (as shown in Figure 1). This reduced demand may be temporary if the Bureau of Ocean Energy Management introduces further lease areas that are more viable for fixed-bottom projects, but also suggests that monopile facilities should consider flexibility when developing their facilities so that they can also support aspects of the floating wind industry (for example, rolling buoyant columns for floating platforms). The annual throughput of these facilities (assuming the shorter permitting and construction time frame from Table A4) is compared against the average and annual demand for monopiles in Figure A4.

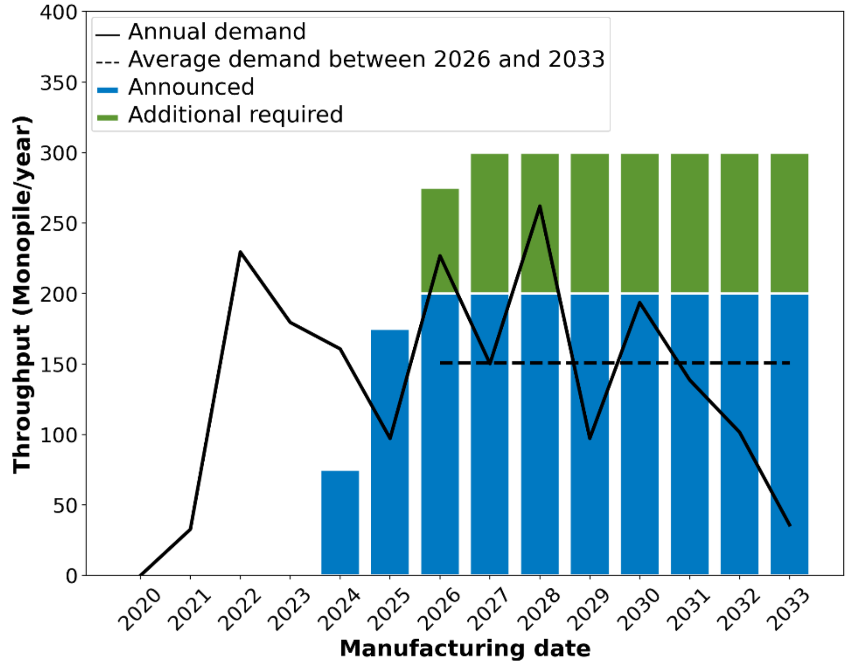


Figure A4. Comparison of average annual demand and potential production throughput for monopiles. The production throughput corresponds to two monopile facilities that come online by 2030.

Barriers

Monopile foundations and the associated costs and requirements related to facilities, workforce, downstream supply chain, transportation, permitting, and portside infrastructure create a unique set of barriers that could potentially impact the ability to permit, construct, and staff enough manufacturing facilities within a time frame that can support the deployment of 30 GW by 2030. Monopile manufacturing will be particularly impacted by the following high-level barriers to developing a domestic supply chain:

- Building new manufacturing facilities is constrained by limited available space and uncertain permitting and construction timelines
- Existing supplier networks will be stressed to provide the required raw materials and subcomponents needed to fabricate major components
- Some offshore wind components require a specialized workforce that may not be readily available in the United States.

One of the primary issues associated with developing monopile foundation manufacturing facilities is related to site requirements. Monopile manufacturing facilities require a coastal location with significant laydown areas, which limits the number of readily available sites. Additionally, monopile foundations are expected to increase in tonnage (up to 3,000 t in the near term, with iterations expected to reach 4,000 t or more in the long term) and size, which can further impact site requirements for companies that are looking to future-proof facilities from technological advancements. As more offshore wind installation support facilities are announced, the number of previously developed coastal sites that can be used for offshore wind manufacturing, marshaling, and/or staging areas will decrease, resulting in the use of sites that need more significant expansions and/or upgrades that could include land acquisition, site grading and/or other land improvements, and bearing capacity upgrades. These upgrades can result in increased costs and timelines depending on site-specific characteristics, any associated tribal, wildlife, or environmental sensitivities, and local permitting requirements. Additionally, any dredging to increase navigation channel depths directly involves the Army Corps of Engineers and will require congressional budget and approval before those activities can begin.

The ability to source steel plates in a timely and cost-effective manner may also be a challenge for monopile foundation manufacturing. There are limited manufacturers who can produce the steel plates in the sizes required, using the thermo-mechanical control process that is used for monopile foundations. High international demand for this product creates a need for manufacturers to place orders as early as possible. Internationally sourced steel plates are subject to Section 232 tariffs, resulting in a 25% increase in cost. Domestic steel producers currently have limited capability to produce plates that can be used to fabricate monopile foundations, reinforcing the need for expanded domestic steel production capabilities.

Wind energy manufacturers also identified a lack of domestic flange production as a challenge the industry currently faces. Until domestic suppliers are established to meet U.S. demand, flanges will need to be imported from Asia, Europe, or retrofitted Mexican facilities that are currently producing this component for land-based wind turbines. Importing these products is not expected to negatively impact existing global supply networks, but it would limit the ability to establish a complete domestic supply chain by 2030. Additionally, long-distance shipping of these components will increase risks related to a project’s timeline.

Monopile foundation manufacturing is a multistep process that requires rolling and welding of steel plates. Workers must be trained on unique equipment that is only used for producing this component. Monopile manufacturers will need to identify, recruit, and train a new workforce, which can take significant time and effort. Skilled workforce availability is location- specific and low unemployment has made this a significant challenge.

Project developers may want to take advantage of the existing European supply chain, but there are three issues associated with importing finished monopiles. First, due to facility, space, and equipment constraints, it is difficult to increase capacity from existing European monopile manufacturers. Second, European capacity will be consumed with providing monopiles to European projects. Third, transatlantic shipping costs from Europe to the United States are nearly $1 million per monopile. These added costs and timeline considerations have the potential to make domestically manufactured monopile foundations cost and timeline competitive.

Jackets

Overview and Factory Specifications

The characteristics of a representative jacket facility are listed in Table A5. From conversations with manufacturers, we observed that jacket foundations are likely to be built at preexisting shipyards or portside fabrication facilities. On-site fabrication activities include assembly and welding of tubular steel into jacket foundation sections, connecting and/or welding sections and transition pieces into a jacket structure, connecting secondary steel, and blasting and coating of the jacket before the finished product is ready for deployment.

With a mass of more than 1,000 t and a height that can exceed 85 m, jacket foundations must be manufactured at coastally located fabrication facilities. These facilities must feature large parcels of land (up to 100 acres), with no overhead obstructions like bridges to accommodate fabrication, assembly, storage, and transportation needs for both the finished product and component materials while having access to relatively deep channels and berths for vessel transportation.

Steel tubulars required for jacket fabrication have a diameter of no more than 10 feet and are made from steel with a plate thickness of one-half to 2 in. The steel used to fabricate these tubulars are more readily available than steel plates used to make monopile foundations or offshore wind towers. Steel tubulars can already be produced domestically from any part of the country and transported to the fabrication yard via rail, road, or vessel. Additionally, some jacket foundation designs require pin piles to fix the foundation to the seabed. Pin piles are rolled from steel plates and can be more than 80 m long with a 3.5- to 5-m diameter.

Forklifts, cranes, and heavy load carriers are used throughout the manufacturing process to transport steel tubulars from storage so they can be assembled and welded into sides. Final assembly, blasting, painting, and on-site transportation of a finished jacket foundation will require SPMTs because of the overall size and weight of the finished component.

Loading of finished components will require quayside infrastructure including heavy-lift wharfs with high bearing capacity to accommodate loading jacket foundations from quayside onto vessels. Most existing steel/shipyards have this infrastructure in place. Some jacket foundation subcomponents and subassemblies can be shipped via rail or truck, so jacket manufacturing facilities will need adequate infrastructure to support these delivery methods.

Fabricating jacket foundations requires minimal equipment investments, but the process is labor-intensive and will require a trained workforce. In some regions (primarily the Gulf of Mexico) there may be workers who have similar welding experience from previous work in the oil-and-gas industry.

Table A5. Factory Specifications for a Generic Jacket Facility

Factory Specification	Value	Units
Throughput	50	jackets/year
Investment cost	10	$ million
Permitting and construction time frame	N/A	years
Laydown area	80−100	acres
Navigation channel depth	8	m
Direct jobs	550	FTE/year

Required Facilities

Based on the average annual demand reported in Shields et al. (2022) and the production capacity of representative jacket facilities, we estimate that one jacket facility would be sufficient to support the deployment of 30 GW by 2030. This estimate is based on average demand from 2026–2033, although a higher demand may exist before 2026 as several projects are planned in water depths that are appropriate for jackets. As this demand decreases after 2026, it is unlikely that multiple facilities would be built to service the peak demand as they would be underutilized in the second half of the decade. Although no specific offshore wind jacket facilities have been announced, these structures can be produced at standard shipyards with some modifications. The annual throughput of such a facility is compared against the average and annual demand for jackets in Figure A5.

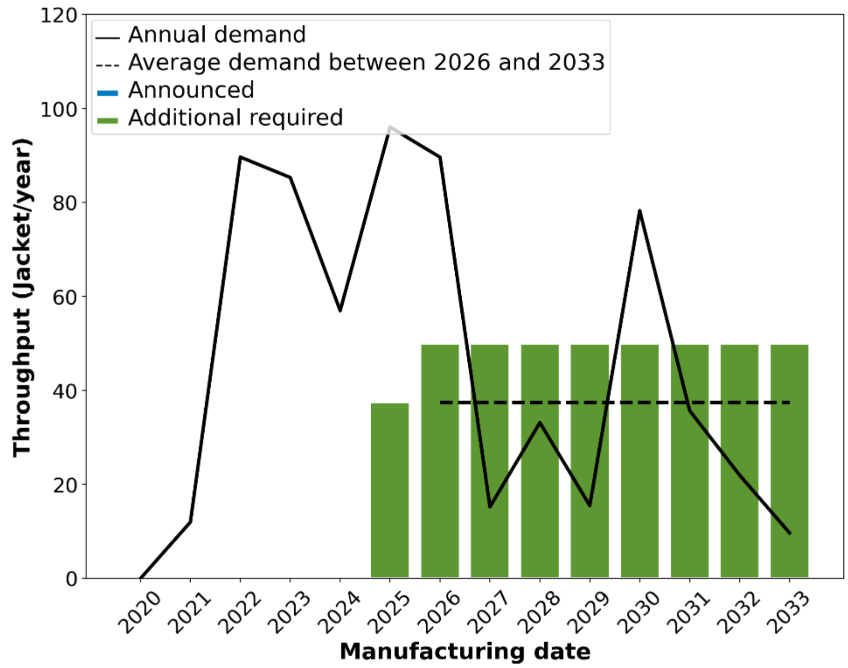


Figure A5. Comparison of average annual demand and potential production throughput for jackets. The production throughput corresponds to one jacket facility that comes online by 2030.

Barriers

Jacket foundations and the associated costs and requirements related to workforce, downstream supply chain, transportation, and portside infrastructure, create a unique set of barriers that could potentially impact the ability to permit, construct, and staff enough manufacturing facilities within a timeframe that can support the deployment of 30 GW by 2030. Jacket foundation manufacturing will be particularly impacted by the following high-level barriers to developing a domestic supply chain:

- Existing supplier networks will be stressed to provide the required raw materials and subcomponents needed to fabricate major components
- Some offshore wind components require a specialized workforce that may not be readily available in the United States.

Offshore wind jacket fabrication is a multistep, labor-intensive process that requires the assembly and welding of steel tubulars. While some of this work is semiautomated, the fabrication process for jacket foundations has conventionally been a one-off process, so serialization will need to be introduced before production efficiencies can be realized. Manufacturers of this component identified staffing as a potential issue that will need to be addressed. Companies will need to identify, recruit, and train a new workforce, which can take significant time, effort, and cost. Domestic workforce availability is location-specific and low unemployment throughout the United States has made this a big challenge. While many workers will need training, experience with heavy machinery and welding should translate to offshore wind jacket manufacturing. These workforce barriers encourage multiparty solutions between manufacturers, existing unions, state and local governments, and other public and private organizations.

Existing steel/shipyards for jacket foundations require adequate space for component storage and overhead clearance for component transportation. Jacket foundations must be vertically stored, so the overall footprint of a jacket foundations base (>20 m) will limit how many can be stored at a given site. Jacket manufacturers require a 100-acre site, with more than half of that acreage being dedicated to storage. Additionally, any potential site will need to have an air draft of 60 m or higher because jacket foundations cannot be horizontally shipped. As a result, many sites with bridges or other overhead obstructions will not be suitable for jacket fabrication.

Jacket foundations have a relatively low number of subassemblies and subcomponents, and require materials that are mostly widely available, namely steel. Wind energy manufacturers also identified a lack of domestic flange production as a challenge the industry currently faces. Until domestic suppliers are established to meet U.S. demand, flanges will need to be imported from Asia, Europe, retrofitted Mexican facilities that are currently producing this component for land-based wind turbines. Importing these products is not expected to negatively impact existing global supply networks, but it would limit the ability to establish a complete domestic supply chain by 2030. Additionally, long-distance shipping of these components will increase risks related to a project's timeline.

Jacket foundations will not be imported from other countries due to cost of transport, but this component will be directly competing with domestically produced monopile foundations. If a domestic supply chain for jacket foundations is not fully realized, developers will increasingly rely on monopile foundations, which may not be suitable for all sites. Plus, they have their own supply constraints.

Gravity-Based Foundations

Overview and Factory Specifications

The characteristics of a representative gravity-based foundation (GBF) facility are listed in Table A6. From conversations with manufacturers, we observed that domestic GBF manufacturers will require a fabrication yard with quayside infrastructure and access to wet and/or dry storage. GBFs are inherently different from monopile and jacket fixed-bottom foundations because they can be integrated with the wind turbine at the marshaling port and then transported and installed without the need for wind turbine installation vessels or heavy-lift vessels. The global shortage of these specialized vessels is a strong value proposition for considering GBFs. GBFs are simply ballasted at their final location at the project site to lower them to the bottom of the ocean, which means that there is no need to drive steel piles into the seafloor. As a result, they create significantly less noise during installation than monopiles or jackets and may reduce the acoustic impact on marine mammals. GBFs have not captured significant market share in the global wind energy market (they represent around 10% of installed foundations (Musial et al. 2022) because of their large size, requirements for specific types of soil and seafloor conditions, and perceived higher cost than monopiles.

No construction and operation plans filed by offshore wind energy project developers in the United States currently consider GBFs as a preferred foundation option; however, we include a minor demand for GBFs in our pipeline because of the potential value that they could provide the U.S. market by reducing reliance on specialized installation vessels and reducing the noise impact on the environment. Further study is required to understand the cost-competitiveness of GBFs relative to monopiles and jackets in the United States, and funded research projects that focus on this topic indicate it is an area of interest for future projects (National Offshore Wind Research and Development Consortium 2021).

Fabrication activities depend on the design of the GBF, where the component is being manufactured (e.g., dry dock, barge, or quayside) and whether concrete subassemblies (slabs) are precast off-site. In general, the structural component of the GBF is formed out of cast concrete that is manufactured and poured at a port (which could be the marshaling port or a nearby fabrication port). Prestressing cables are typically included within the concrete slabs for additional strength. The GBF structures can be massive, with base diameters on the order of 50 m (Shields et al. 2022) and production ratios of 3-4 units per month may be achieved. As a result, GBF facilities require significant storage area to keep completed structures ready for wind turbine integration. GBFs that are designed to be buoyant can use "wet storage" areas in a protected harbor to keep completed structures anchored or resting on the seafloor until they are ready to be joined with a wind turbine.

Installation processes for GBF concepts can vary. Some GBF are installed on the offshore site prior to the installation of the wind turbine. In some instances, wind turbines are assembled on top of the GBF at the quayside prior to transport and installation at the project site. Full quayside assembly requires a large ring or crawler crane capable of lifting the wind turbine components on top of the GBF. During this process, the GBF could be afloat or ballasted to rest on the seafloor next to the quayside. Following the integration of the wind turbine and the GBF, the assembly is partially ballasted and towed to the project site using tugboats. As a result, manufacturing ports will need deep-draft navigation channels and berths for vessel-bound transportation.

Cranes and other heavy-lifting equipment are used throughout the manufacturing process. SPMTs and skidding systems may also be used due to the overall size and weight of the finished component. In addition, heavy-lift vessels/barges and tugs may be needed to load-out or transport finished components.

Loading and unloading of components will require quayside infrastructure including heavy-lift wharfs with high bearing capacity (12 t/m^2) to accommodate roll on/roll off of the GBF from quayside onto vessels or into water for transport to the final site. Alternatively, construction of GBS on top of floating barges may also be considered.

Table A6. Factory Specifications for a Generic Gravity-Based Foundation Facility

Factory Specification	Value	Units
Throughput	50−60	GBF/year
Investment cost	50	$ million
Permitting and construction time frame	1−2	years
Laydown area	50-60	acres
Navigation channel depth	12	m
Direct jobs[27]	300	FTE/year

Required Facilities

Based on the production capacity of representative GBF facilities, we estimate that one would be sufficient to support the deployment of 30 GW by 2030. As we describe in the previous section, we do not anticipate GBF deployment in the early part of the decade and these foundations are included to present a potential alternative to monopiles and jackets. As a result, we assign one GBF facility to the supply chain instead of directly comparing with the component demand from Shields et al. (2022). Although no specific offshore wind GBF facilities have been announced, these structures can be produced at standard ports or shipyards with some modifications.

Barriers

GBFs and the associated costs and requirements related to facilities, workforce, downstream supply chain, transportation, permitting, and portside infrastructure create barriers that could potentially impact the ability to permit, construct, and staff enough manufacturing facilities within a time frame that can support the national target. GBF manufacturing will be particularly impacted by the following:

- Building new manufacturing facilities is constrained by limited available space and uncertain permitting and construction timelines

One of the primary issues associated with developing GBF manufacturing facilities is related to the site requirements to manufacture large concrete structures. Large component size will require significant laydown areas for wet or dry storage, which limits the number of readily available sites. An additional factor that will limit the number of suitable portside locations for manufacturing and assembly of GBF is the navigational depth and bearing capacity requirements

[27] We provide job estimates for a GBF facility that can produce 3–4 units per month using 2–3 production lines. An alternate GBF facility concept where dozens of structures are built in parallel has been used for European projects and could potentially create thousands of direct jobs to build all foundations for an offshore wind project concurrently (Durakovic 2022, Fried et al. 2022). More research is required to understand how to design a commercial GBF facility and what the spatial requirements would be for such a facility.

for this component. Furthermore, sites with overhead obstructions may also be a concern depending on manufacturing method, which can further limit the availability of suitable sites.

As more offshore wind installation support facilities are announced, the number of previously developed coastal sites that can be modified for offshore wind energy manufacturing, marshaling, and/or staging areas will decrease. As a result, sites may need more significant expansions and/or upgrades that could include land acquisition, site grading and/or other land improvements, and bearing capacity upgrades. These upgrades can increase costs and timelines depending on site-specific characteristics, any associated tribal, wildlife, or environmental sensitivities, and local permitting requirements. Additionally, any dredging to increase navigation channel depths directly involves the Army Corps of Engineers and will require congressional budget and approval before those activities can begin.

An additional challenge for GBF manufacturing is an inability to immediately and locally access concrete because of limited suppliers and future commitments to other industries. New batch mobile or temporary batch plants may need to be developed near GBF manufacturers to address this need. Concrete manufacturers may lack experience with marine logistics which could create opportunities for workforce training. GBF installations also require a massive volume of scour protection. High-density rock is preferred to the extent that some project developers have considered scenarios in which this type of rock will be imported from other countries to accommodate the demand.

Transition Pieces

Overview and Factory Specifications

The characteristics of a representative transition piece manufacturing facility are listed in Table A7. From conversations with manufacturers, we observed that domestic transition piece manufacturers will require a newly constructed, purpose-built facility where full fabrication of the transition piece occurs. On-site fabrication activities include assembly and welding of steel plates, bending and welding of plates into cans, and integration of some secondary steel (i.e., brackets, boat landings, and ladders). The transition piece is then blasted and coated before final assembly of secondary steel and other auxiliary equipment (e.g., external working platform, grating, lights, suspended internal platform, switchgear, and any other transmission-related equipment). The finished transition pieces are then typically stored before being delivered to a marshaling site before being installed.

With a diameter that can be more than 8.5 m and heights that can reach over 30 m, transition piece manufacturing facilities must be coastally located on parcels of land that can accommodate buildings for fabrication, coating, and assembly. These parcels must also have room to store for both the finished product and component materials while having access to relatively deep channels and berths for vessel transportation. While the facility could be located on its own parcel of land, it could also be co-located at a tower manufacturing facility to leverage duplicative resources like workforce, manufacturing processes, and plate rolling equipment.

Similar to the steel plates used in offshore wind towers, the steel plates required for transition piece fabrication are 2 to 3 in. thick and are too large for transportation via rail or road, so this material must be delivered via barge. Current domestic steel producers have the capability to produce plates for offshore wind transition pieces, but demand for other components (namely monopile foundations and towers) will require additional domestic steel mills or imports from other countries.

Forklifts, cranes, and heavy-load carriers are used throughout the manufacturing process to transport steel plates from storage to the roll-bending process where they are transformed into cans, and to move cans as they are assembled and welded into transition pieces. Final assembly, blasting and painting, and on-site transportation of a finished transition piece will require SPMTs due to the overall size and weight of the finished component (more than 700 t). Unloading of materials, subcomponents, and subassemblies and the loading of finished components will require quayside infrastructure including heavy-lift wharfs with high bearing capacity to accommodate loading transition pieces from quayside onto vessels. Some subcomponents and subassemblies can be shipped via rail or truck, so tower manufacturing facilities will need adequate infrastructure to support these delivery methods.

Offshore wind transition piece fabrication also requires investments in manufacturing equipment that is sourced outside of the United States. Unique equipment includes turning rolls, and high-quality, precision, and volume welding technology. Workers will need training to operate heavy machinery and specialized welding equipment.

Table A7. Factory Specifications for a Generic Transition Piece Facility

Factory Specification	Value	Units
Throughput	100	transition pieces/year
Investment cost	200	$ million
Permitting and construction time frame	2–3	years
Laydown area	45	acres
Navigation channel depth	10	m
Direct jobs	300	FTE/year

Required Facilities

Based on the average annual demand reported in Shields et al. (2022) and the production capacity of announced and representative transition piece facilities, we estimate that there is a demand for two transition piece facilities to support the deployment of 30 GW by 2030. One facility (the Smulders facility at the Port of Albany in New York) has already been announced. As these facilities come online throughout the decade, domestic transition piece production can meet the average demand by 2026. The annual throughput of these facilities (assuming the shorter permitting and construction time frame from Table A7 is compared against the average and annual demand for components in Figure A6.

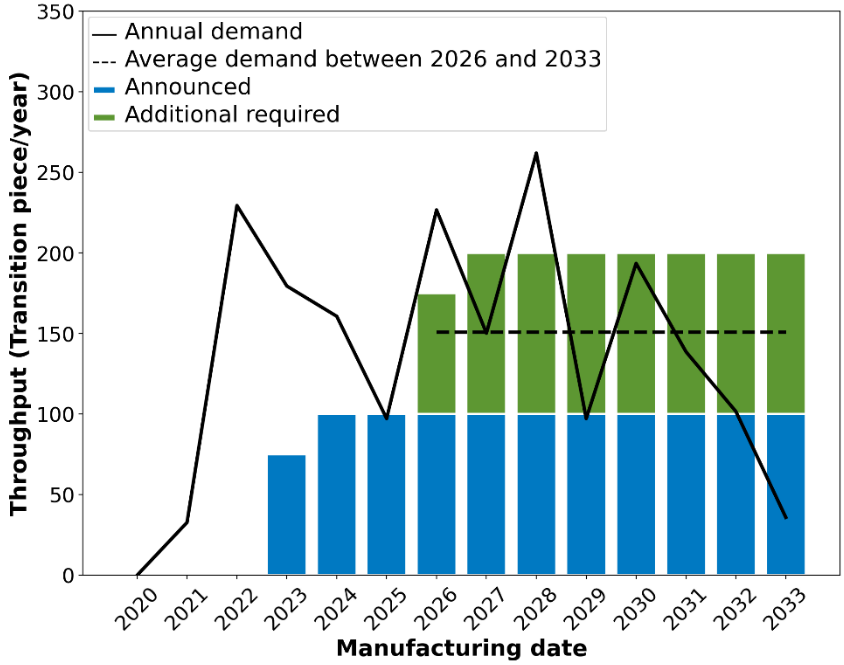


Figure A6. Comparison of average annual demand and potential production throughput for transition pieces. The production throughput corresponds to two transition piece facilities that come online by 2030.

Barriers

Wind turbine transition pieces and the associated costs and requirements related to facilities, workforce, downstream supply chain, transportation, permitting, and portside infrastructure create barriers that could potentially impact the ability to permit, construct, and staff enough manufacturing facilities within a time frame that can support the deployment of 30 GW by 2030. Transition pieces and towers have similar components and manufacturing processes. While these two components will have comparable barriers, they will be experienced at different magnitudes because transition pieces are smaller and lighter. Transition piece manufacturing will be particularly impacted by the following:

- Building new manufacturing facilities is constrained by limited available space and uncertain permitting and construction timelines
- Existing supplier networks will be stressed to provide the required raw materials and subcomponents needed to fabricate major components
- Some offshore wind components require a specialized workforce that may not be readily available in the United States.

One of the primary issues associated with developing offshore wind transition piece manufacturing facilities is related to site requirements. These facilities require a coastal location with significant laydown areas, which limits the number of readily available sites. As more offshore wind manufacturing facilities are announced, the number of previously developed coastal sites that can be easily used for offshore wind manufacturing, marshaling, and/or staging areas will decrease, resulting in sites that need more significant expansions and/or upgrades. These upgrades could include land acquisition, site grading and/or other land improvements, and bearing capacity upgrades. As a result, costs and timelines may be increased, depending on site-specific characteristics, any associated tribal, wildlife, or environmental sensitivities, and local permitting requirements. Additionally, any dredging to increase navigation channel depths directly involves the Army Corps of Engineers and will require congressional budget and approval before those activities can begin.

An additional factor that may limit the number of suitable sites is whether road and rail infrastructure exist or can be easily extended to support the delivery of subcomponents and subassemblies. As a result, additional upgrades—and subsequent costs—may be required.

An additional challenge for offshore wind transition piece manufacturing is an inability to domestically source some key subassemblies and subcomponents. Wind energy manufacturers also identified a lack of domestic flange production as a challenge the industry currently faces. Until domestic suppliers are established to meet U.S. demand, flanges will need to be imported from Asia, Europe, or retrofitted Mexican facilities that are currently producing this component for land-based wind turbines. Importing these products is not expected to negatively impact existing global supply networks, but it would limit the ability to establish a complete domestic supply chain by 2030. Additionally, long-distance shipping of these components will increase risks related to a project's timeline.

Beyond that potential limitation, the domestic transition piece supply chain is not expected to rely on other imported subcomponents and subassemblies for the long term as U.S. capabilities grow over time. Additionally, short-terms imports of subcomponents and subassemblies are not expected to negatively impact existing supplier networks.

Though subcomponents and subassemblies are limited concerns, offshore wind transition pieces have specific material requirements in the form of 2- to 3-in. steel plates whose domestic production is limited. Like the steel plates for offshore wind towers, steel plates for transition pieces are more readily available than those used for monopile foundations. While there is sufficient global capacity for current demand, increased global demand driven by the emerging U.S. market and expanded European offshore wind goals could create adequate demand for additional domestic steel mills.

Offshore wind transition piece manufacturing is a multistep process that requires rolling and welding of steel plates. Workers must be trained on unique equipment that is only used for producing offshore wind components. Manufacturers of this component identified staffing as a potential issue that will need to be addressed. Companies will need to identify, recruit, and train a new workforce, which can take significant time, effort, and cost. Domestic workforce availability is location-specific and low unemployment throughout the United States has made this a significant challenge. While many workers will need training, experience with heavy machinery and welding should translate to offshore wind transition piece manufacturing. These workforce barriers encourage multiparty solutions between manufacturers, existing unions, state and local governments, and other public and private organizations.

Floating Platforms

Overview and Factory Specifications

Floating wind technologies have not reached the same level of market stability as fixed-bottom substructures. Semisubmersible platforms comprise around 80% of the announced global floating wind pipeline (Musial et al. 2022), although dozens of prototype concepts exist at various levels of technology maturity (ABS Group 2021). Floating platform designs can vary significantly depending on the type of platform (i.e., spar or semisubmersible) and manufacturability (e.g., concrete and steel platforms). Steel semisubmersibles are often considered to be the most likely platforms to be used in early deployment on the West Coast due to their relatively shallow draft, hydrodynamic stability, and technological maturity (Beiter et al. 2020; Musial et al. 2022).

Expanding the floating wind industry into the 2030s will likely see the development of alternate technologies, including concrete semisubmersibles in the Gulf of Maine (Musial et al. 2020). Further investigation into the supply chain requirements for these new concepts will be needed, although one potential advantage of concrete floating platforms is that they can be manufactured and assembled quayside without the need for significant steel materials or labor (ABS Group 2021). In this report, we do not specify the type of floating platform that will be used for early phases of floating wind deployment. For our purposes, it is sufficient to describe high-level manufacturing facility requirements that will be roughly similar for different types of steel platforms. See ABS Group (2021) for a more in-depth discussion of alternate design concepts.

We assume a scenario for domestic floating platform production in which the platforms are assembled at an integration and marshaling port near the project site. Floating platform components, such as buoyant columns, plates, and trusses, can be manufactured at existing shipyards and shipped to the integration site via barge. Fabrication activities for these components include cutting and welding of steel plates, bending and welding or joining of these plates into columns, welding pipe steel into the trusses, blasting, and painting. At the assembly site, the trusses are fitted to the columns in a dry dock or on a semisubmersible barge and either welded or bolted together before being fit with secondary and tertiary steel, electrical equipment, piping, and instrumentation. The wind turbine is then mounted on the finished floating platform and towed to the installation site. A commonly stated goal of the floating wind industry is to assemble and install one floating wind turbine system per week, which will require significant advances in industrialized designs and integration methods.

The final mass of the floating platform can be around 3,000 t for a 15-megawatt wind turbine with a front profile that could be 100 m wide (Allen et al. 2020). The magnitude of steel plate required corresponds to around 2 million t of steel for 10 GW of floating wind projects. This demand will likely require additional steel mills to be built in the United States in the 2030s to support this broad deployment.

The steel required for fabricating a floating platform typically does not need to be as thick as the steel needed for monopile fabrication, with plate thicknesses of 3–4 inches. Port operations will still require forklifts, gantry cranes, and heavy-load carriers to transport components, and large gantry cranes or quayside mounted ring or crawler cranes will be needed to join the columns and trusses and then integrate the wind turbine. Quayside infrastructure will likely require heavy-lift wharfs to accommodate these operations. Requirements may be reduced if the floating platforms are assembled on semisubmersible barges; however, these barges are in short supply on the U.S. West Coast and may require new builds.

The major question facing domestic floating platform production is the level of component fabrication that will take place in the United States. Existing shipyards on the West Coast can fabricate the major components of a steel floating platform, such as General Dynamics NASSCO in San Diego. However, the cost of components built at these facilities could be significantly higher than those that are imported from Southeast Asia due to the lower wages and more advanced shipyards in the region.

It is likely that Tier 2 components such as columns and trusses will be built at a distributed network of shipyards to reduce risk of delays; some of these facilities could be located in the United States, and the capacity of these shipyards could grow over time as domestic production becomes more automated and cost effective (which may adversely impact the number of jobs created). For the purposes of this study, we identify the number of floating platform assembly facilities that will be needed (which will be located at floating wind marshaling ports) but we do not specify the source of the subassemblies. A more detailed study into the trade-offs between cost, local content, port infrastructure, and risk of delays is required to understand how the supporting supply chain for floating platforms can evolve.

We present the characteristics of a representative floating platform assembly facility in Table A8. The production of floating platforms requires minimal facility investments, but adequate portside infrastructure is required. Locations suitable for floating platform fabrication and assembly will become more readily available in parallel with West Coast port upgrade and expansion activities. As a result, it is difficult to disentangle the costs and time to develop a semisubmersible facility from the port upgrade costs. Therefore, we assign a cost of $100 million and an additional permitting and construction time frame of 1 year to account for new equipment (e.g., large cranes, dry docks, and/or floating platform barges) and additional port development activities (such as permitting and creating wet storage areas to stage completed floating platforms).

Table A8. Factory Specifications for a Generic Floating Platform Facility

Factory Specification	Value	Units
Throughput	50	floating platforms/year
Investment cost	100	$ million
Permitting and construction time frame	1	years
Navigation channel depth	12	m
Direct jobs	240	FTE/year

Required Facilities

Floating platform demand through 2030 will largely be driven by the location of available lease areas, which will be confined to the California Coast (Federal Register 2022). For this report, we assume that the central and northern coasts of California will each require a separate integration port and, therefore, a separate floating platform manufacturing facility as well. Beyond 2030, it is likely that all floating wind regions will require a marshaling port, which could include Oregon, northern California, central California, the Gulf of Mexico, Central Atlantic, and the Gulf of Maine. Because much of this capability will be needed after 2030, we did not conduct a detailed supply/demand assessment. Further analysis will be required to understand how floating platform production could evolve along with floating wind port development.

Barriers

Floating platform manufacturing will be particularly impacted by the following:

- Building new manufacturing facilities is constrained by limited available space and uncertain permitting and construction timelines
- Existing port and vessel infrastructure is inadequate to install 30 GW of offshore wind energy by 2030
- Additional incentives beyond the IRA may be required to encourage domestic manufacturing of components or supply chain assets which are either not considered in the IRA or receive credits that are smaller than the cost premium for domestic manufacturing

One of the major challenges with developing floating platform manufacturing capabilities is that they need to be located at floating wind marshaling ports that do not yet exist in the United States. As a result, planning will have to be incorporated into the development of the ports. This challenge becomes increasingly complicated due to the uncertain technology and level of industrialization of the floating platforms. Many of the port design parameters, such as the quayside manufacturing spaces and the navigation channel dimensions, will be sized to accommodate specific floating substructure design envelopes. It will be important for the industry to align on the most viable substructure types and to develop ports to allow competition between different manufacturers while also getting the infrastructure ready for the first phase of project construction by 2030.

Finding solutions to the competing effects of local job creation and developing cost-competitive projects will be critical to setting up a sustainable floating wind industry on the West Coast. There is potential for technology and supply chain innovation to resolve this problem by developing industrialized, mass-produced, and cost-competitive platforms domestically. The U.S. Department of Energy is leading an initiative to accelerate the market readiness of these industrialized platforms and the surrounding infrastructure needed for commercial-scale deployment (DOE Wind Energy Technologies Office 2022b).

The analysis conducted in Section 3.2.3 for fixed-bottom components suggests that the cost difference between imported and domestic components is on the order of 5%–10% (depending on local prevailing wages). The difference between floating platforms manufactured in South Korea and the U.S. West Coast could be as high as 50% (Shields et al. 2021), or even higher if the domestic platforms require imported steel (which would be subject to 25% Section 232 tariffs). The substructure and foundation are the largest cost contributors to floating wind capital expenditures (Stehly and Duffy 2021), and so a factor of 2 difference between domestic and imported components will be a major driver of levelized cost of energy for the project. It is likely that West Coast states will incentivize local content requirements as the initial legislation highlighted the opportunity of developing local workforce and economic benefits (California Legislature 2021). Additionally, the IRA will further reduce domestic costs for producing this component throughout the lifetime of this incentive.

Cables

Overview and Factory Specifications

The characteristics of a representative cable production facility are listed in Table A9. From conversations with manufacturers, we observed that domestic cable producers will require a newly constructed, purpose-built facility. On-site production activities include importing raw materials, processing materials into subcomponents, twisting multiple single-core cables, applying nonconducting layers and armor reinforcement, and storing cables in on-site turntables until loaded onto a cable-laying vessel for installation.

Cable specifications and manufacturing processes depend on a variety of elements including cable voltage capacity, transmission type (high-voltage alternating current [HVAC] or high-voltage direct current [HVDC]) and whether the project is fixed bottom or floating. Regardless of the cable specifications, facilities must be coastally located on large parcels of land (up to 45 acres) that can accommodate production activities and storage for both the finished product and component materials while having access to relatively deep channels and berths for vessel transportation.

Multiple materials are also required in the production of this component including lead alloy, copper, aluminum, polypropylene, and polyethylene. Special equipment is needed throughout the production process. For instance, raw copper is machine processed using specialized equipment to a smaller diameter wire before being stranded with other more copper wires resulting in a single conductor. Facility requirements also play an important role. Many cabling facilities require an on-site excursion tower to hold the conductor vertically so other materials like insulation can be applied and set during the manufacturing process. These towers can be more than 450 feet tall. Once the conductor is assembled, it is stored to complete a chemical reaction before additional copper, insulation, and jacketing are added to finish the production process.

Unloading materials and loading finished components will require quayside infrastructure including load- and non-load-bearing wharfs to load cables from storage turntables onto vessels. Some cable subcomponents and subassemblies can be shipped via rail or truck, so cable production facilities will need adequate infrastructure to support these delivery methods.

Table A9. Factory Specifications for a Generic Cable Facility

Factory specification	Value	Units
Throughput	550 (array) 250 (export - HVAC) n/a (export - HVDC)	km/year
Investment cost	350	$ million
Permitting and construction time frame	5−6	years
Laydown area	45	acres
Navigation channel depth	10 (array) 10 (export)	m
Direct jobs	230	FTE/year

Required Facilities

Based on the annual demand from Shields et al. (2022) and the production capacity of announced and representative cable facilities, we estimate that there is a demand for two array cable facilities and four export cable facilities (one of which would be HVDC) to support the deployment of 30 GW by 2030. One array cable facility (the Hellenic facility at Tradepoint Atlantic in Maryland) and two export cable facilities (the Nexans facility in Goose Creek, South Carolina, and the Prysmian facility in Brayton Point, Massachusetts) have already been announced. The Nexans facility is already operational. Cable facilities take a particularly long time to permit and construct, which means that most cables will have to be sourced internationally until 2027–2028. The annual throughput of these facilities (assuming the shorter development time frames listed in Table A9) is compared against the annual and average demand for components in Figure A7.

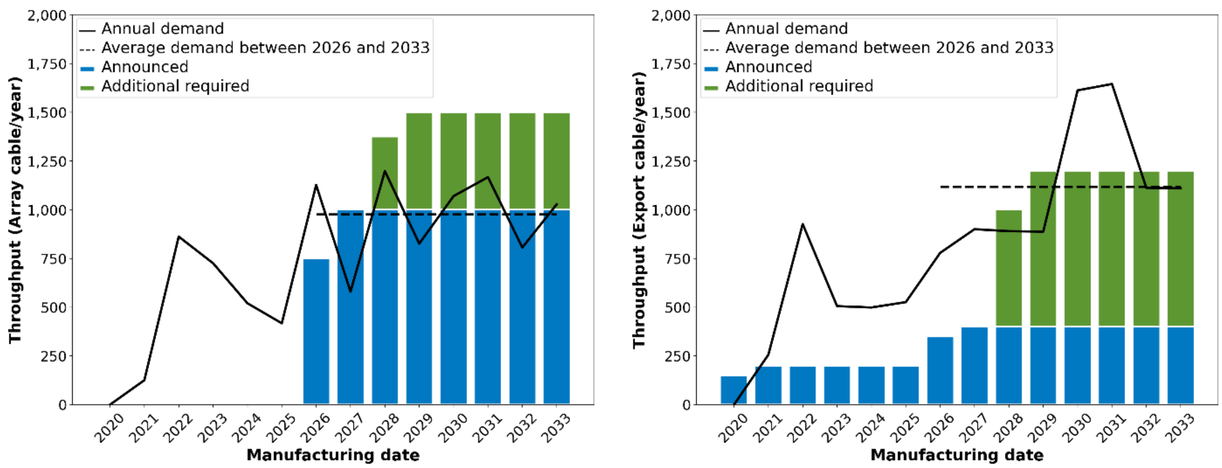


Figure A7. Comparison of average annual demand and potential production throughput for array cables (left) and export cables (right). The production throughput corresponds to two array cable facilities and four export cable facilities (three HVAC, one HVDC) that come online by 2030.

Barriers

Cable production and the associated costs and requirements related to facilities, workforce, downstream supply chain, transportation, permitting, and portside infrastructure create a unique set of barriers that could potentially impact the ability to permit, construct, and staff enough manufacturing facilities within a time frame that can support the deployment of 30 GW by 2030. Cable production will be particularly impacted by the following:

- Building new manufacturing facilities is constrained by limited available space and uncertain permitting and construction timelines
- Some offshore wind components require a specialized workforce that may not be readily available in the United States
- Existing supplier networks will be stressed to provide the required raw materials and subcomponents needed to fabricate major components
- Additional incentives beyond the IRA may be required to encourage domestic manufacturing of components or supply chain assets which are either not considered in the IRA or receive credits that are smaller than the cost premium for domestic manufacturing

One of the primary issues associated with developing offshore wind cable production facilities is related to site requirements. Offshore wind cable production facilities require a coastal location with significant laydown areas. As more offshore wind manufacturing facilities are announced, the number of previously developed coastal sites that can be easily modified for offshore wind manufacturing, marshaling, and/or staging areas will decrease, resulting in the use of sites that need more significant expansions and/or upgrades that could include land acquisition, site grading and/or other land improvements, and bearing capacity upgrades. These upgrades can increase costs and timelines depending on site-specific characteristics, any associated tribal, wildlife, or environmental sensitivities, and local permitting requirements. Additionally, any dredging to increase navigation channel depths directly involves the Army Corps of Engineers and will require congressional budget and approval before those activities can begin.

An additional factor that may limit the number of suitable sites is whether road and rail infrastructure exists or can be easily extended to support the delivery of materials. This could result in additional upgrades and subsequent costs depending on existing transportation infrastructure.

Offshore wind cable production requires some materials that are not domestically sourced. For instance, the lead alloy and plastics used to manufacture cables are produced in markets outside of the United States. Importing these products will negatively impact existing global supplier networks as all the markets will be competing for the same resources and yet it will not be sufficient to incentivize new green field domestic facilities to produce these materials. Along with the costs related to the construction of new cable production facilities, the sourcing, including import duties, and transportation of these materials will add costs to the final product that could make domestically sourced cables more expensive than those that are internationally sourced.

Offshore wind cable production is a multistep process that requires operating machines and other specialty equipment for wire drawing, conductor stranding, cable insulation extrusion, wire screening, cable sheathing, cable assembly, cable armoring, high-voltage testing, storage, and transpooling at the marine terminal. Cable manufacturers identified staffing as a potential issue that will need to be addressed. Companies will need to identify, recruit, and train a new workforce, which can take significant time, effort, and cost. Domestic workforce availability is location-specific and low unemployment throughout the United States has made this a significant challenge. These workforce barriers encourage multiparty solutions between manufacturers, existing unions, state and local governments, and other public and private organizations.

Mooring Rope and Chain

Overview and Factory Specifications

The characteristics of representative mooring chain and rope production facilities are listed in Table A10. From conversations with manufacturers, we observed that domestic producers will likely require a newly constructed, purpose-built facility where full industrial production of these components occurs. There may be an opportunity to expand some existing rope facilities, but for the purposes of this report we assume a new facility is needed. On-site production activities for mooring chains include importing raw materials (e.g., steel bars), and the cutting, heating, and bending of the steel bar around an existing link. The bent steel bar is then welded into a link, which is followed by trimming, inserting the stud, ultrasonic testing, heat treatment, load testing, final inspection, testing, and shipping.

For mooring ropes, on-site production activities depend on whether the rope is made from synthetic yarn or wire. The manufacturing process includes mechanical twisting of materials into strands that are then mechanically braided into rope. Multiple ropes are combined to form a core that is then overbraided with polyester jacket before being inspected, spliced, and spooled. Wire rope production involves twisting wire strands into cables that are then twisted with other cables to form a wire rope.

Regardless of whether a facility is producing mooring chains or ropes, it must be located near good waterways to accommodate shipping large quantities of finished product to project marshaling sites or staging areas. Unloading materials and loading finished components will require infrastructure including load- and non-load-bearing wharfs to accommodate loading of chains and ropes from storage onto vessels.

Table A10. Factory Specifications for Generic Mooring Rope and Mooring Chain Facilities

Factory Specification	Value	Units
Throughput	2,000 (chain) 2,000 (rope)	km/year
Investment cost	$500 (chain) $50 (rope)	$ million
Permitting and construction time frame	4–5	years
Laydown area	50	acres
Navigation channel depth	~10	m
Direct jobs	110 (chain) 110 (rope)	FTE/year

Required Facilities

We estimate the amount of mooring rope and chain based on the total number of floating turbines required in the annual demand presented by Shields et al. (2022). We assume that each floating turbine requires three mooring lines, each comprised of 600 m of chain and 1,000 m of rope. These lengths approximately correspond to a semitaut mooring system for a floating platform in water that is 800 m deep, as described in Cooperman et al. (2022). Based on this annual demand and the production capacity of representative chain and rope facilities, we estimate that there is a demand for one mooring chain facility and one mooring rope facility to support the deployment of 30 GW by 2030.

No facilities have currently been announced in the United States. The annual throughput of these facilities is compared against the annual and average demand for components in Figure A8. These results show that the rope and chain facilities should far exceed the demand for the initial wave of floating offshore wind projects but should be well-positioned to support the growth of the floating wind industry beyond 2030. While demand for mooring ropes could be met by a new domestic facility, existing mooring rope capacity can support the offshore wind industry, but these facilities would likely require workforce, equipment, and operational expansions and upgrades.

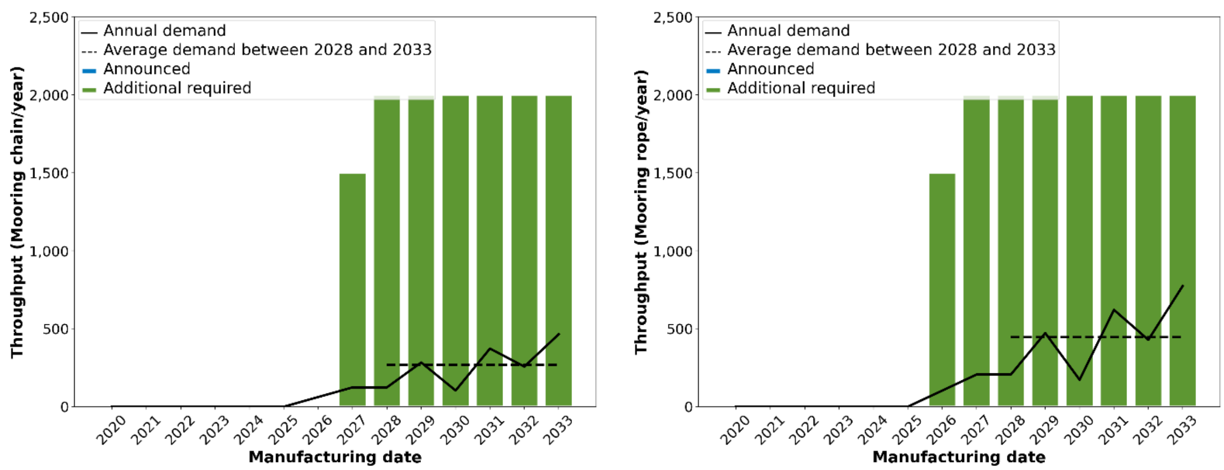


Figure A8. Comparison of average annual demand and potential production throughput for the mooring chain (left) and mooring rope (right). The production throughput corresponds to one mooring chain facility and one mooring rope facility that come online by 2030.

Barriers

Mooring line and mooring chain production and the associated costs and requirements related to facilities, workforce, downstream supply chain, transportation, permitting, and portside infrastructure create barriers that could potentially impact the ability to permit, construct, and staff enough manufacturing facilities within a time frame that can support the deployment of 30 GW by 2030. Mooring line and mooring chain production will be particularly impacted by the following:

- Building new manufacturing facilities is constrained by limited available space and uncertain permitting and construction timelines

- Existing supplier networks will be stressed to provide the required raw materials and subcomponents needed to fabricate major components
- Some offshore wind components require a specialized workforce that may not be readily available in the United States.

One of the primary issues in terms of building new facilities to produce mooring chains and ropes is the uncertain permitting and construction timelines. Land acquisition, site grading, and/or other land improvements can result in increased costs and timelines depending on site-specific characteristics, any associated tribal, wildlife, or environmental sensitivities, and local permitting requirements.

Supplier networks may also be a challenge for mooring chain production. The main input for chain fabrication is bar stock. Annually producing 2,000 kilometers of mooring chain will require large quantities of steel bars. U.S. steel manufacturers may have difficulties meeting this demand given overall steel needs for offshore wind energy and other industries.

Additionally, mooring rope production requires a workforce with requisite splicing skills, which could be a major constraint for ramping up synthetic rope production. These workforce barriers encourage multiparty solutions between manufacturers, existing unions, state and local governments, and other public and private organizations.

Steel Plates

Overview and Factory Specifications

The characteristics of a representative steel plate mill are listed in Table A11. From conversations with manufacturers, we observed that domestic producers of steel plates will require a newly constructed, purpose-built facility where full fabrication of the plate occurs. Steel plates for monopile foundations are produced using a thermo-mechanical control process that uses a specialized rolling stand to reduce plate thickness. The unfinished product is then processed through an accelerated cooling stand to quench the steel and freeze microstructures in place. This process induces stress into the steel and increases strength without increasing alloy content.

Steel required for the fabrication of offshore wind monopile foundations arrives at manufacturing facilities as flat plates with a width up to 4.3 m, length up to 15 m, thickness up 14 centimeters and a weight of up to 40 t. The steel plates used in monopiles are typically too large for transportation via rail or road, so this material must be delivered via barge.

Mills must be located on large parcels of land (up to 300 acres) that can accommodate fabrication and storage needs for both the finished product and materials while having access to deep-draft navigation channels (10 m) and berths for vessel-bound transportation.

Forklifts, cranes, and heavy-load carriers are used throughout the manufacturing process to transport steel plates. Loading and unloading of materials and components will require quayside infrastructure including heavy-lift wharfs with high bearing capacity to accommodate loading of plates to vessels.

Table A11. Factory Specifications for a Generic Steel Plate Facility

Factory Specification	Value	Units
Throughput	1,000,000	t/year
Investment cost	2,000	$ million
Permitting and construction time	5	years
Laydown area	300	acres
Navigation channel depth	10	m
Direct jobs	460	FTE/year

Required Facilities

We estimate the amount of steel plate based on the total number of monopiles, transition pieces, and floating platforms required in the annual demand presented by Shields et al. (2022). We assume that each monopile requires 2,500 t of steel plate, each transition piece requires 900 t of steel plate, and each floating platform requires 3,000 t of steel plate. Based on this annual demand and the production capacity of representative and announced steel mills, we estimate that there is a demand for two steel mills to support the deployment of 30 GW by 2030. One steel mill (the Nucor facility in Brandenburg, Kentucky) has already announced that some of their expanded production line will be dedicated to offshore wind energy components; however, this is only a fraction of the potential output of a dedicated steel mill. As these facilities come online throughout the decade, domestic steel production should be able to meet the average demand by 2027. The annual throughput of the announced and additional required facilities is compared against the annual and average demand for components in Figure A9.

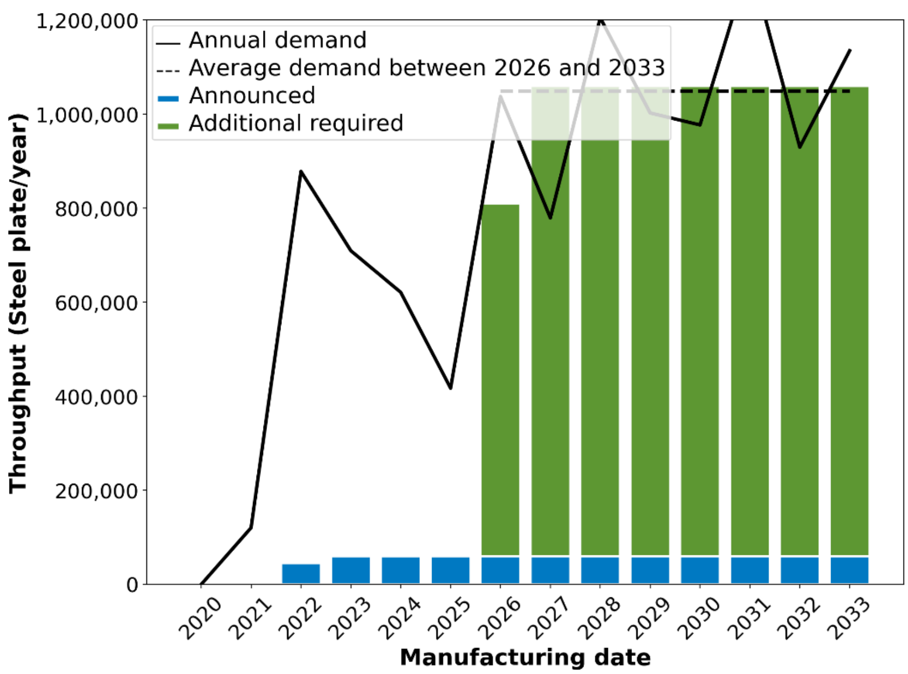


Figure A9. Comparison of average annual demand and potential production throughput for steel plates. The production throughput corresponds to two steel plate facilities that come online by 2030.

Barriers

Steel plates and the associated costs and requirements related to facilities, workforce, component transportation, and policy create barriers that could potentially impact the ability to permit, construct, and staff enough production facilities within a time frame that can support the deployment of 30 GW by 2030. Steel plate production will be particularly impacted by the following:

- Building new manufacturing facilities is constrained by limited available space and uncertain permitting and construction timelines
- Some offshore wind components require a specialized workforce that may not be readily available in the United States
- Additional incentives beyond the IRA may be required to encourage domestic manufacturing of components or supply chain assets which are either not considered in the IRA or receive credits that are smaller than the cost premium for domestic manufacturing

One of the primary issues associated with developing monopile foundation manufacturing facilities is related to site requirements. Steel plate mills require a location with significant laydown areas that has access to waterways, which limits the number of readily available sites. Many sites will require land acquisition, site grading, and/or other land improvements. These conditions can increase costs and timelines depending on site-specific characteristics, any associated tribal, wildlife, or environmental sensitivities, and local permitting requirements.

The ability to source steel plates for monopile foundations in a timely and cost-effective manner may also be a challenge. There are limited manufacturers who can produce the steel plates in the sizes required, using the thermo-mechanical control process that is required for monopile foundations. High international demand for this product creates a need for manufacturers to place orders as early as possible. While domestic capacity does exist, it is not sufficient to meet demand created by the 30-GW-by-2030 goal, so manufacturers will still need to import some steel plates from international markets. As wind turbine size increases, plate thickness will also need to increase, which further limits the number of existing suppliers and could increase reliance on the international supply chain.

Concerns related to cost competitiveness of domestically produced steel plates do exist, but policies are in place to address these issues. If internationally sourced, steel plates could be subject to Section 232 tariffs, resulting in a 25% increase in cost. To avoid these tariffs, some manufacturers are using a phased production approach that will import steel cans instead of plates, because steel cans are not subject to these tariffs; however, this creates additional transportation costs and extended lead times that make domestically produced steel plates even more cost competitive.

Steel plate production is a multistep process that involves the melting, pouring, rolling, and cooling of steel to form a plate that can be used for an offshore wind monopile. Workers must be trained on unique equipment that is used to produce this component. Manufacturers of this component identified staffing as a potential issue that will need to be addressed. Companies will need to identify, recruit, and train a new workforce, which can take significant time, effort, and cost. Domestic workforce availability is location-specific and low unemployment throughout the United States has made this a significant challenge. These workforce barriers encourage multiparty solutions between manufacturers, existing unions, state and local governments, and other public and private organizations.

Large Castings and Forgings

Overview and Factory Specifications

The characteristics of a representative foundry for large cast component (e.g., bedplates and hubs) and a forge for large forged components (e.g., flanges) are listed in Table A12. From conversations with manufacturers, we observed that domestic production of cast and forged components will require newly constructed, purpose-built facilities where full production of these components occurs. On-site foundry activities include importing raw materials and creating component-shaped pockets, or cavities that are coated with sand to create a barrier that allows the cooled casting to be removed. Metal is then melted in the furnace and poured into a cavity where it rests until the material cools and solidifies. Once the casting is cool, workers remove it from the cavity to clean and grind rough surfaces before the casting is heat-treated (if required) and sandblasted. Melting metal is an energy-intensive process that creates emissions that are regulated at the federal level. Additionally, the casting process uses a silica-based sand. Silica has health risks and is regulated on the federal level, so the industry is looking to transition away from this material toward a ceramic-based material. Spent foundry sand that is not reclaimed must be disposed of, or it can be repurposed as material in asphalt.

On-site production activities for forged components like flanges include importing raw materials, heating and manipulating metal into a specified shape before cooling, machining, drilling, sandblasting, and painting or metalizing the final component.

There are limited foundries and forges in the United States that can currently make large cast or forged components. Though facilities that produce these large components can be in noncoastal states, component size, availability of adequate rail infrastructure, and proximity to the customer will ultimately determine transportation requirements and site locations.

Table A12. Factory Specifications for Generic Casting and Forging Facilities

Factory Specification	Value	Units
Throughput	Varies depending on component	bedplates/year hubs/year flanges/year
Investment cost	110	$ million
Permitting and construction time frame	2–4	years
Laydown area	10	acres
Navigation channel depth	N/A	m
Direct jobs	240	FTE/year

Required Facilities

For this report, we assume that forgings and castings will each require a separate manufacturing facility. Given the demands on the market, one foundry and one forge would likely be sufficient to meet the demand of the U.S. pipeline. It is difficult to project the location and development timeline of these production facilities (particularly castings) due to permitting uncertainty related to environmental concerns. If these facilities are built in the United States, market competition may drive demand for additional facilities beyond the ones prescribed in this report.

Barriers

Cast and forged component production and the associated costs and requirements related to facilities, workforce, downstream supply chain, transportation, permitting, and transportation infrastructure create barriers that could potentially impact the ability to permit, construct, and staff enough production facilities within a time frame that can support the deployment of 30 GW by 2030. Large cast and forged production will be particularly impacted by the following:

- Building new manufacturing facilities is constrained by limited available space and uncertain permitting and construction timelines
- Some offshore wind components require a specialized workforce that may not be readily available in the United States
- Incorporating equity and sustainability into supply chain decision-making is resource-intensive and insufficiently incentivized, which may result in unjust outcomes for host communities
- Additional incentives beyond the IRA may be required to encourage domestic manufacturing of components or supply chain assets which are either not considered in the IRA or receive credits that are smaller than the cost premium for domestic manufacturing

The primary issue in terms of building new foundries to produce hubs and bedplates is uncertain permitting timelines. Many states have strict environmental permitting requirements for foundries. Though technological advancements have improved foundry emissions, the environmental permitting process is a major challenge for foundry expansion/development in the United States. Whether produced domestically or internationally, the emissions from these facilities can have local impacts that should be considered in terms of equity and sustainability. Cast components that are produced in foundries are critical components for offshore wind energy. As such, we include these components as part of our domestic supply chain scenarios and assume that new processes, technologies, policies, and regulatory practices will be developed to satisfactorily mitigate environmental concerns while enabling domestic manufacturing of these key components.

Workforce availability is also a challenge for foundries and forges. Manufacturers of these components identified the staffing of a new facility as a potential issue that will need to be addressed. Companies will need to identify, recruit, and train a new workforce, which can take significant time, effort, and cost. Domestic workforce availability is location-specific and low unemployment throughout the United States has made this a significant challenge. These workforce barriers create an opportunity for multiparty solutions between manufacturers, existing unions, state and local governments, and other public and private organizations.

Domestically manufactured castings and forged components are in direct competition with international facilities that have low labor costs and less-stringent environmental regulations, which can impact cost competitiveness for domestic production.

Other Components

Offshore Substations

Because a limited number of substations are used per project (between one and three), orders are singular in nature, which limits opportunities for serialized manufacturing of this component within the domestic supply chain. Additionally, while some substations will be domestically produced, they could also be imported from Asia, where most substations are currently being fabricated and assembled.

Based on conversations with manufacturers, we observed that domestically produced substations are likely to be fabricated and assembled at preexisting shipyards or portside fabrication facilities. These facilities do not require substantial upgrades or significant investment to fabricate and assemble this component. Overhead obstructions like bridges will need adequate clearance to accommodate fabrication, assembly, storage, and transportation needs for the finished product. The site will also need access to relatively deep channels and berths for vessel transportation. Most existing steel/shipyards have quayside infrastructure in place to support fabrication efforts and to import power conversion equipment.

Fabricating substations requires minimal equipment investments, but the process is labor-intensive and will require a trained workforce. In some regions (primarily the Gulf of Mexico) there may be workers who have similar welding experience from previous work in the oil-and-gas industry.

Manufacturers of offshore wind energy components identified the staffing of a new facility as a potential issue that will need to be addressed. Companies will need to identify, recruit, and train a new workforce, which can take significant time, effort, and cost. Domestic workforce availability is location-specific and low unemployment throughout the United States has made this a significant challenge. These workforce barriers can encourage multiparty solutions between manufacturers, existing unions, state and local governments, and other public and private organizations. While many workers will need training, experience with heavy machinery and welding should translate to the fabrication of offshore wind topside structures.

Most of the power conversion equipment for substations is currently manufactured in Europe. Domestic production of these components may occur in the future but is not currently expected within the 2030 time frame. Power conversion components are highly specialized and need to meet marinization requirements to be used in the offshore environment. Given the relatively small number of substations that are needed for the U.S. market, there may not be a case for a U.S. power conversion supply chain in addition to existing international facilities that can already meet increased demand for these components. As the domestic supply chain for substations matures, some power conversion subcomponents and subassemblies could be manufactured domestically and shipped via rail or truck, so shipyards and portside fabrication facilities will need adequate infrastructure to support these delivery methods.

Integrating power conversion components into the topside structure has varying levels of difficulty that is dependent on the complexity of the system and overall distance from shore. While U.S. workers are equipped to install alternating current systems that are relatively close to shore, direct current systems will require a workforce that is not currently available in the United States.

Bearings

From conversations with manufacturers, we observed that bearings used for wind energy are uniquely large, so domestic production of bearings will require newly constructed, purpose-built facilities. On-site production activities include importing raw materials, heating rolling, machining, heat treating, hard turning, and grinding of steel before adding rollers and cages to finish assembly of the final bearing.

Bearing production facilities for offshore wind applications are dedicated assets with a singular product. In fact, different facilities will be needed to manufacture various types of offshore wind bearings. For instance, differences in design and manufacturing processes means main bearings cannot be produced in the same facility as yaw and pitch bearings. Generally speaking, production facilities for yaw, main, and pitch bearings require large amounts of floor space to accommodate component transportation during the fabrication process. Additionally, facilities need specialized equipment to produce bearings, such as grinding assets and heat-treating furnaces. This equipment can be one-half to two-thirds of the overall capital investment for the facility.

Because large bearings for offshore wind energy applications can be transported via rail or road, facilities that produce these large components can be in noncoastal states.

According to interviews with bearing manufacturers, a variety of factors make it unlikely that new domestic bearing production facilities will be built to support the deployment of 30 GW by 2030. First, the global supply chain has enough bandwidth to service the U.S. market. Second, nacelle assembly will use a modular process that utilizes the existing offshore wind supply chain. Third, bearing production facilities for offshore wind energy are dedicated assets with no use outside of the industry, meaning it is unlikely for new facilities to be built until there is sufficient global demand.

Any bearing production facilities built in the United States will require 4–5 years for construction and permitting. Construction and permitting activities could include land acquisition, site grading, and/or other land improvements. Timelines will depend on site-specific characteristics, any associated tribal, wildlife, or environmental sensitivities, and local permitting requirements. Simultaneously, manufacturers will need to identify and/or develop a domestic supply chain that can support U.S. production of these components. The overall cost to domestically produce offshore wind turbine bearings will be in direct competition with existing overseas facilities.

Anchors

We assume that anchors are likely to be built at preexisting shipyards or portside fabrication facilities. On-site fabrication activities depend on the type of anchor but could include rolling of steel into canisters for suction bucket anchors, and/or assembling and welding of subcomponents (e.g., fluke and shank) into a drag-embedded anchor.

Suction bucket anchors can be 15 m in height and 5 m in diameter, whereas drag-embedded anchors can be anywhere from 20 to 40 t depending on wind turbine size. Anchors can be produced domestically from any part of the country and transported to the marshaling site via rail, road, or vessel. Forklifts and cranes are used throughout the manufacturing process to transport materials and/or subcomponents from storage so they can be assembled and welded into a finished component before being transported to on-site storage areas. The fabrication of anchors requires minimal equipment and facility investments. This investment is estimated to be approximately $5 million.

Appendix B. Analysis Methodologies

This appendix provides detailed descriptions of the various methodologies used throughout the report to evaluate the impact of a domestic supply chain on different metrics.

Marshaling Port and Installation Vessel Bottlenecks

We developed a new Python-based model to simulate the deployment of the projects in the East Coast pipeline, which was based on the National Renewable Energy Laboratory's (NREL's) Offshore Renewables Balance-of-system and Installation Tool (ORBIT) cost and logistics model (Nunemaker et al. 2020). ORBIT is a process-based model that simulates the installation of individual projects on an hourly timescale. Each installation process (such as loading out components onto the vessel, transporting to the site, and assembling components at site) is modeled and compared against wind and wave time series to estimate delays when the conditions exceed operational weather limits. A standard ORBIT model prescribes a set of vessels that are used for the installation sequence.

In order to consider the bottlenecks faced by the overall pipeline, we developed the Concurrent ORBIT for shared Resource Analysis Library (CORAL) model. CORAL defines an ORBIT configuration file for each project in the pipeline, but instead of assigning specific vessels to each project, there is a common repository of a finite set of wind turbine installation vessels (WTIVs), heavy-lift vessels (HLVs), and feeder barges. Furthermore, the port activity is also moved to higher-level simulation so that only one project can access a berth at the marshaling port at a given time. If any of the installation vessels or port resources are unavailable at the time that a project plans to start construction, then delays accrue until the required assets become available. The primary output of the model is a Gantt chart showing the actual installation windows and accrued delays for each project, which provides an estimate of the total installed capacity by the end of 2030.

The steps for setting up and running the CORAL model include the following:

1. Define a static list of characteristics for each project in the pipeline, including capacity, planned start date, and assigned marshaling port. Additional project characteristics, such as water depth and distance to port, are taken from Musial et al. (2022). Project capacity is also based on the values in Musial et al. (2022), with some adjustments based on the baseline deployment pipeline provided in Phase 1 of the supply chain road map (Shields et al. 2022). These parameters are listed in Table B1.
2. Define port and vessel resource scenarios that prescribe when the resources are available for project installation.
3. Run CORAL to calculate the actual start date and installation time of each project. Aggregate the installed capacities per year to estimate the total deployment by the end of 2030.

Table B1. Project Parameters and Assigned Marshaling Ports for East Coast Projects Used in the Deployment Simulation

Project Name	Capacity (megawatts [MW])	Planned Start Date	Assigned Marshaling Port	
			Baseline scenario	*U.S. WTIV and U.S. Feeder scenarios*
Vineyard Wind 1	800	2023	New Bedford	New Bedford
South Fork	132	2023	New London	New London
Revolution Wind	704	2023	New London	New London
Sunrise Wind	924	2024	New London	New London
Bay State Wind	2,000	2028	New London	New London
Park City Wind	804	2027	New Bedford	Salem
Commonwealth Wind	1,232	2028	New Bedford	Salem
Beacon Wind 1	1,230	2029	South Brooklyn	South Brooklyn
Beacon Wind residual	1,200	2029	New Bedford	Arthur Kill
Mayflower Wind 1	804	2025	New Bedford	New Bedford
Mayflower Wind 2	400	2026	New Bedford	New Bedford
Mayflower Wind residual	800	2028	New Bedford	New Bedford
CIP Massachusetts	1,607	2033	New London	Salem
Empire Wind 1	816	2027	South Brooklyn	South Brooklyn
Empire Wind 2	1,260	2028	South Brooklyn	South Brooklyn
Mid-Atlantic Offshore Wind	523	2029	New Jersey Wind Port	New Jersey Wind Port
OW Ocean Winds East	868	2030	South Brooklyn	South Brooklyn
Attentive Energy	964	2029	New Jersey Wind Port	New Jersey Wind Port
Community Wind	1,387	2029	Tradepoint Atlantic	Arthur Kill
Atlantic Shores Offshore Wind Bight	924	2029	New Jersey Wind Port	New Jersey Wind Port
Invenergy Wind Offshore	934	2029	Tradepoint Atlantic	Arthur Kill
Atlantic Shores Offshore Wind 1	1,510	2026	New Jersey Wind Port	New Jersey Wind Port
Atlantic Shores Offshore Wind residual	1,500	2030	New Jersey Wind Port	New Jersey Wind Port
Garden State Offshore Energy	1,000	2029	New Jersey Wind Port	New Jersey Wind Port
Ocean Wind 1	1,100	2025	New Jersey Wind Port	New Jersey Wind Port
Ocean Wind 2	1,148	2027	New Jersey Wind Port	Arthur Kill
Skipjack 1	120	2025	Tradepoint Atlantic	Tradepoint Atlantic
Skipjack 2	808	2026	Tradepoint Atlantic	Tradepoint Atlantic
MarWin	248	2025	Tradepoint Atlantic	Tradepoint Atlantic
Momentum Wind	846	2026	Tradepoint Atlantic	Tradepoint Atlantic
Coastal Virginia Offshore Wind	2,640	2024	Portsmouth	Portsmouth
Kitty Hawk 1	1,000	2025	Portsmouth	Portsmouth
Kitty Hawk residual	1,500	2026	Portsmouth	Portsmouth
TotalEnergies Renewables USA	667	2030	Portsmouth	Portsmouth
Duke Energy Renewables Wind	670	2030	Portsmouth	Portsmouth

Most projects in the pipeline have not identified their marshaling ports, so we developed a set of assumptions to assign each one to a specific port. These assignments are not intended to be a prediction of which port will correspond to each project but are reasonable judgements of possible port selections per project. Each individual project's marshaling port is selected based on the following ranked criteria:

1. Public announcements that the project will stage out of a specific port
2. Investments or host community agreements between the project developer and a port, such as Ørsted's agreement with New London State Pier (Office of Governor Ned Lamont 2021) or Equinor's agreement to develop South Brooklyn Marine Terminal (Equinor 2022)
3. Ports in the state associated with the offshore wind energy project (as defined in Musial et al. 2022)
4. The closest proximity port to the project site.

These assigned ports are reflected in Table B1 for both the Baseline, U.S. WTIV, and U.S. Feeder scenarios (described in Section 3.1.1). The difference between the scenarios is that there are additional marshaling ports available in the expanded infrastructure scenario (Arthur Kill Terminal, the Port of Salem, and a second marshaling berth at New Jersey Wind Port).

Other key assumptions and caveats to the analysis include:

- We only simulate monopile and wind turbine installation, assuming that cables and other components can be installed without creating significant bottlenecks. This decision was based on interviews with project developers who have expressed their highest concerns about the availability of WTIVs, HLVs, and feeder barges to install foundations and wind turbines.
- Monopiles are installed using HLVs and wind turbines are installed using WTIVs.
- Projects staged out of South Brooklyn Marine Terminal and New Bedford Marine Commerce Terminal use feeder barges due to air draft and hurricane barrier size limitations, respectively. In the U.S. WTIV scenario, all other projects assume that the U.S.-flagged WTIV or HLV loads components directly at port.
- Monopiles cannot be installed between January and April due to pile-driving restrictions during the North Atlantic right whale migration season.
- CORAL assumes that enough monopiles, transition pieces, and wind turbines are staged at the marshaling port so that there are no delays due to manufacturing constraints.
- Investment costs in new WTIVs and marshaling ports are set to be $500 million and $400 million, respectively.
- We assume that 2.5 gigawatts (GW) of floating offshore wind will be installed by the end of 2030, meaning that installing anything more than 27.5 GW on the East Coast makes it possible to achieve the national offshore wind target.

Fabrication Port Screening

The manufacturing facilities that will comprise an offshore wind supply chain will primarily be located at fabrication ports because of the size of the components they produce. Therefore, we needed to identify a port for each fabrication facility in the pipeline scenarios to better understand the demand for port facilities and investment, as well as the regional distribution of jobs and benefits arising from the supply chain. We developed a set of criteria for identifying ports that could serve as fabrication ports for each major fixed-bottom offshore wind component. We also assign locations for floating offshore wind components but recognize that these facilities will need significant port upgrades and that existing ports on the West Coast do not meet the criteria. This set of criteria are used to screen a database containing relevant port specifications and to provide a list of feasible ports for each component. From this list of feasible ports, we apply a second list of port preferences to select a port for each required manufacturing facility. Finally, we assign construction timelines and upgrade costs to each port that would be needed to address spatial constraints or limitations. In this appendix, we provide greater detail about the screening and downselection process.

Ports Database

We developed a list of over 100 East Coast and Gulf of Mexico ports and compiled publicly available data from individual port websites, Google Earth images, and National Oceanic and Atmospheric Administration maps. For each port, we collected the following data:

- State
- Laydown area (acres): the available space at a port
- Quayside length (meters [m]): the length of the quay for vessels to dock and load/unload components; a quay can include multiple berths
- Berth depth (m): the water depth at the berth
- Channel depth (m): the average water depth in the center of the navigation channel leading from the port to the open sea
- Bearing capacity (metric tonnes [t]/square meter [m^2]): the rated weight concentration that can be supported at a location within a port facility
- Air draft restriction height (m): the distance between the navigation channel and any obstruction (such as a bridge) along the pathway to the ocean. This restriction limits the height of vessels or components that can be transported from the port.

If any data were unavailable for a particular port, we treated this gap as a constraint of the port; for example, many ports do not list bearing capacity on their public documentation. Therefore, we assume that these ports will need to invest in bearing capacity upgrades to support offshore wind energy activities.

Port Characteristic Screening

We developed a set of screening criteria for each offshore wind component with input from industry practitioners. Table B2 lists the physical port requirements preferred by original equipment manufacturers (OEMs); we focus on fixed-bottom components here as this is the pressing concern for developing a supply chain by 2030.

Table B2. Fabrication Port Requirements for Fixed-Bottom Offshore Wind Components

Component	Laydown Area (acres)	Quayside Length (m)	Channel/Berth Draft (m)	Bearing Capacity (t/m^2)	Air Draft (m)
Blade	80	120	6	15	25
Nacelle	40	500	10	15	25
Tower	45	150	10	7.5	25
Monopile	100	500	8	12	25
Jacket	80	150	8	15	60
Gravity-based foundation	10	500	10	15	250
Cable	45	150	6	15	50
Transition piece	50	500	10	15	40
Steel plate	300	500	10	15	25
Flange	50	150	6	15	25
Foundry	50	150	6	15	25

We compare the ports in the database to the preferred criteria in Table B2 and identify which characteristics of each port meet the criteria. We allow 25% leeway in the requirements so that existing ports that are "close" to the requirements for a component are not screened out; for example, if a blade OEM prefers 80 acres of laydown area, we look for ports with at least 60 acres (75% of the preferred value).

In addition to the physical characteristics screening, we add two further criteria onto each port. First, we identify if the port is in a state that has confirmed offshore wind energy goals, such as procurement targets or announced investments (because we assume that supply chain investments are more likely to be concentrated in states that are actively involved in offshore wind energy). Second, we identify if the port already has committed supply chain investments (because we assume that the port may not have space for additional facilities). Ports that are in states with offshore wind energy goals and do not have competing supply chain investments are given preference in the screening.

The screening process results in a list of ports that are most suitable for each component. No ports meet all criteria, so we search for the ports that meet the highest number of criteria for each component and identify which categories will require upgrades prior to being used as a fabrication port.

Port Preferences

Using the list of suitable ports for each component, we manually select a port for each manufacturing facility in the domestic supply chain scenario. We prioritize ports for each component based on the list of criteria provided in Table B3; the interpretation of these criteria is that these are the preferences that a manufacturer might consider when selecting a fabrication location for a new factory.

Table B3. Preferential Scoring Criteria for Assigning a Factory to a Port

Preferred Port Characteristic	Justification
Higher laydown area	OEMs prefer larger laydown areas to provide a larger storage buffer and alleviate project delays
Location in lower-wage regions for workforce-intensive components	Our interviews with manufacturers indicate that labor rates are a significant driver in their decision-making process. In this assessment, we allow manufacturing ports to be in states with lower wages than the Northeast states, where most offshore wind energy development has been concentrated; however, it is important to note that any location for these manufacturing facilities should provide good working conditions, prevailing wages, and appropriate training programs for their employees in alignment with the Biden administration's policies for clean energy manufacturing (H.R. 5376, 117th Congress 2021−2022)
Less congestion	Major shipping ports are too busy to accommodate offshore wind manufacturing and tend to be focused on their existing business models
Approximately even distribution of supply chain resources between different states	Offshore wind energy projects are distributed throughout the region and local content requirements make it likely that there will be supply chain investments in each state that is procuring power from these projects

We use these preference criteria to have a somewhat systematic approach for assigning a suitable fabrication port for each supply chain facility.

Construction Cost and Timeline Estimates

The final step in the fabrication port assignment process is taking the list of ports in the domestic supply chain scenario and estimating the time and cost needed to upgrade the port. We use the following high-level assumptions about the construction that needs to take place at each port, which we derived with input from coastal and civil engineers with experience designing offshore wind ports in the United States:

- Permitting and construction time: 3 years (only for the port—does not include time to build the manufacturing facility)
- Port and factory construction overlap: 1 year (factory construction can begin 1 year before the port facility is fully complete)

- Cost for permitting and designing the new port facility: $100 million
- Cost to expand laydown area: $100 million
- Cost to extend quayside length or add berths: $50 million
- Cost to dredge the berth area and navigation channel: $100 million
- Cost to increase bearing capacity: $50 million.

These are very high-level estimates and more detailed, site-specific designs would be required to develop fabrication ports; however, we include these estimates to indicate the necessary cost magnitude and time frames involved to develop the port facilities for supply chain resources.

State Adjacent Industry Manufacturing Scale

We aggregate data from the Business Network for Offshore Wind's Supply Chain Connect database along with the IMPLAN input-output economic model and other sources to evaluate the state-level adjacent industry measurement scale (AIMS) for the indirect supply chains for individual components. In this appendix, we provide the detailed methodology for aggregating the data and assigning the scores, present detailed results, and summarize the major limitations and challenges to the approach.

Methodology

The AIMS is calculated for each state in the United States and for each major offshore wind component described in this report. The AIMS score (SAIMS) comprises four contributing factors: a Supply Chain Connect score (SSCC), a proximity score (SP), a regional purchase coefficient score (SRPC), and a state activity score (SA):

$$S_R = S_{SCC} + S_P + S_{RPC}$$

$$S_{AIMS}=S_{SCC}+[(1+S_A)(S_P+S_{RPC})]$$

The Supply Chain Connect score weights the capabilities of individual businesses that have registered in the database that have identified their ability to manufacture a specific subassembly or subcomponent in the indirect supply chain for a Tier 1 part. SSCC is defined by:

$$S_{SCC} = \sum \left(n_{facilities} + n_{facilities}\left[\alpha_1 x_{workforce} + \alpha_2 x_{exerience} + \alpha_3 x_{certification}\right]\right)$$

where

- $n_{facilities}$ is the number of manufacturing facilities that the business owns within the state
- $x_{workforce}$ is a discrete score for the number of employees in the company. $x_{workforce}$ is discretized so that:
  - $x_{workforce} = 0.33$ if there are less than 50 employees
  - $x_{workforce} = 0.67$ if there are 50–250 employees
  - $x_{workforce} = 1$ if there are more than 250 employees

- $x_{experience}$ is a discrete score that identifies a business's experience in related industries. $x_{experience}$ is discretized so that:
  - $x_{experience} = 0$ if the business has no related experience
  - $x_{experience} = 0.33$ if the business has oil-and-gas experience
  - $x_{experience} = 0.67$ if the business has land-based wind energy experience
  - $x_{experience} = 1$ if the business has offshore wind energy experience
- $x_{certification}$ is a discrete score that identifies a business's relevant certifications. $x_{certification}$ is discretized so that:
  - $x_{certification} = 0$ if the business has not identified any relevant certifications
  - $x_{certification} = 1$ if the business has identified one or more relevant certifications
- α_1, α_2, and α_3 are weighting factors that prioritize the more significant underlying metrics with weights of 0.25, 0.35, and 0.4, respectively. This weighting indicates that a business's certifications are most important, followed by its experience in related industries, followed by the size of its workforce.

The scores for each business in the state that manufactures subassemblies or subcomponents required for a specific Tier 1 component (per Shields et al. 2022) are then summed.

The state activity scores are measured on a binary scale where:

- $S_A = 1$ if a state is participating in the Biden administration's announced Federal-State Offshore Wind Implementation Partnership or has funded an offshore-wind-specific study that includes aspects of supply chain mapping, assessment, or strategic planning
- $S_A = 0$ if a state is not participating in the Biden administrations announced Federal-State Offshore Wind Implementation Partnership nor has funded an offshore-wind-specific study that includes aspects of supply chain mapping, assessment, or strategic planning.

The proximity and regional purchase coefficient (RPC) scores are calculated using:

$$S_P + S_{RPC} = n_{sub} + n_{sub}(\beta_1 x_p + \beta_2 x_{RPC})$$

where

- n_{sub} is the total number of subcomponents and subassemblies required for a Tier 1 component, as described in Shields et al. (2022)
- x_p is a discrete proximity score that identifies the distance from the state to a Tier 1 manufacturer defined in the domestic supply chain scenario (Section 3.1.2). x_p is discretized so that:
  - $x_p = 0.33$ if the OEM is within 500 miles
  - $x_p = 0.67$ if the OEM is within 250 miles
  - $x_p = 1$ if the OEM is in the same state

- x_{RPC} is the state's regional purchase score for the relevant manufacturing industry as defined by IMPLAN
- β_1 and β_2 are weighting factors that prioritize the more significant underlying metrics with weights of 0.25 and 0.75, respectively. This weighting indicates that the RPC score (or the existing strength of the manufacturing sector in the state) is most important, followed by the proximity of the state to Tier 1 facilities.
- In the event a major offshore wind energy component does not have a proximity score, only the state's regional purchase score is used in addition to the Supply Chain Connect score to determine each AIMS.
    - The resulting formula in the outline scenario:

$$S_R = S_{SCC} + [(S_A+1)\ S_{RPC}]$$

- $S_{RPC} = n_{sub} + n_{sub}\,(x_{RPC})$.

The subsequent AIMS level is calculated and discretized using the following system:

- AIMS level = high if S_{AIMS} is greater than 0.75
- AIMS level = medium if S_{AIMS} is between 0.5 and 0.75
- AIMS level = low if S_{AIMS} is less than 0.5.

The resulting state-by-state scores for each component are shown in Table B4 (L is low, M is medium, and H is high).

Table B4. State AIMS Levels To Contribute to the Supporting Supply Chain for Major Offshore Wind Components

State	Blades	Nacelles (GB)	Nacelles (DD)	Generators (GB)	Generators (DD)	Monopiles	Jackets	TP	Towers	Cables	Array Cables	Export Cables	OSW Substations	Flanges	Bed Plates	Steel Plates	GBF	Semisubmersible Platforms	Mooring Rope	Mooring Chain	Drag Anchors	Dynamic Array Cables	Dynamic Export Cables	Suction Caissons
AL	M	L	M	M	L	H	M	M	M	M	L	L	M	H	M	H	M	M	M	L	M	L	L	M
AK	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
AZ	L	L	L	M	L	L	L	L	L	M	L	L	L	M	L	M	M	L	L	L	M	L	L	L
AR	L	L	L	L	M	L	L	L	L	L	M	M	L	L	H	L	L	L	H	M	L	M	M	L
CA	H	H	H	H	H	H	H	H	H	H	H	H	H	H	M	H	H	H	M	H	H	H	H	H
CO	M	L	L	L	M	L	L	L	L	L	L	L	L	L	L	L	L	L	M	L	M	L	L	L
CT	H	H	H	H	H	H	H	H	H	H	H	H	H	H	M	H	H	H	H	H	H	H	H	H
DE	M	H	H	M	M	M	M	M	L	M	H	H	H	M	M	L	M	M	M	M	M	H	H	M
FL	L	M	M	M	M	M	M	M	M	M	L	M	M	L	L	M	H	M	M	L	M	L	M	L
GA	M	M	M	L	L	M	M	M	M	M	M	M	M	H	L	H	M	M	M	L	L	M	M	L
HI	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
ID	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
IL	M	M	M	H	M	M	M	M	H	M	M	M	M	H	M	H	M	H	L	M	L	M	M	M
IN	M	M	M	M	M	M	L	L	H	M	L	L	M	H	M	M	L	M	L	M	L	L	L	L
IA	L	L	L	L	M	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	M
KS	L	L	L	M	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
KY	L	M	M	L	L	L	L	L	M	L	L	L	L	M	L	M	L	L	L	L	L	L	L	L
LA	L	L	L	L	L	M	M	M	M	L	L	L	M	M	H	L	M	L	H	H	H	L	L	H
ME	M	H	H	H	H	M	M	M	L	H	M	H	H	L	H	L	H	M	H	H	H	M	H	H
MD	H	H	H	H	H	H	H	H	H	H	H	H	H	M	M	M	H	H	M	M	H	H	H	H
MA	H	H	H	H	H	H	H	H	H	H	H	H	H	M	H	M	H	H	H	H	H	H	H	H
MI	M	M	L	M	L	L	L	M	L	L	M	L	L	L	M	L	L	L	L	M	L	M	L	M
MN	L	L	L	L	M	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	M
MS	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
MO	L	L	M	M	L	L	L	L	M	M	L	L	M	L	L	L	L	M	L	L	L	L	L	L
MT	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
NE	L	L	L	L	L	L	L	L	L	L	L	L	L	M	L	M	L	L	L	L	L	L	L	L
NV	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
NH	M	H	H	H	H	M	H	H	M	H	H	H	M	L	M	L	M	H	M	M	H	H	H	M
NJ	H	H	H	H	H	H	H	H	H	H	H	H	H	M	H	M	H	H	H	H	M	H	H	H
NM	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
NY	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
NC	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
ND	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
OH	H	M	M	L	M	H	H	H	H	M	M	M	M	M	H	H	M	M	L	H	M	M	M	M
OK	L	L	L	L	L	L	L	L	L	L	L	L	L	L	H	L	L	L	H	M	M	L	L	M
ORE	H	M	M	H	H	H	H	H	M	M	M	M	H	L	M	M	H	H	M	M	H	M	M	H
PA	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
RI	M	H	H	M	H	M	M	M	M	H	H	H	H	L	M	L	M	M	H	M	M	H	H	M
SC	H	M	M	M	M	M	M	M	M	M	M	M	M	H	H	H	M	M	H	H	L	M	M	L
SD	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
TN	M	L	L	L	L	L	M	L	M	M	M	M	L	M	M	M	L	L	M	M	M	M	M	L
TX	H	M	M	M	M	H	H	H	H	H	H	H	M	H	H	H	H	H	H	H	H	H	H	H
UT	L	L	L	L	L	L	L	L	L	L	L	L	L	M	L	M	L	L	L	L	M	L	L	M
VT	L	L	L	L	L	L	L	L	L	L	M	M	L	L	L	L	L	L	M	L	L	M	M	L
VA	H	H	H	H	H	H	H	H	H	H	H	M	H	H	H	H	H	H	M	H	H	H	M	H
WA	M	M	L	L	L	M	M	M	L	L	M	M	L	M	L	M	M	M	L	L	M	M	M	L
WV	L	L	L	L	L	L	L	L	L	L	M	M	L	L	L	L	L	L	L	L	L	M	M	L
WI	L	M	M	M	M	M	M	M	M	L	L	L	M	H	L	H	M	M	L	M	L	L	L	M
WY	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L

Key takeaways

Through the assessment, the results confirmed that for the most part, states with established offtake agreements and current projects in the pipeline contain more companies with an interest in supplying the industry. Central-Atlantic and North-Atlantic states like Massachusetts, New York, New Jersey, Virginia, North Carolina, and Maryland scored well for all but a few components produced in major manufacturing facilities. Further, states with smaller populations that have demonstrated actions toward developing the offshore wind energy supply chain in these areas like Connecticut, Rhode Island, Maine, and Delaware received strong AIMS. Suppliers in these areas are more aware of the opportunities offshore wind energy presents; therefore, they have a better understanding of where they might fit in and are poised to play a role in the supply chain. Because the offshore wind industry has been established in these markets longer than others, the excitement has translated into greater capacity for supply chain development and more potential jobs.

Emerging offshore wind markets like the Gulf of Mexico and West Coast show promise for many of the high-impact components because of the strength of existing manufacturers as well as steel and heavy industry fabricators. Within the Gulf states, Texas had extremely high scores, ranking first for many of the high-impact components, translating to a great potential for that state to develop an offshore wind workforce. Louisiana, Florida, and Alabama also ranked well for many of the high-impact components, especially for fabricating jackets, transition pieces, monopiles, and more. Much like Texas, California also ranked high. Washington followed by Oregon scored medium for many of the high-impact components, but also received high scores for a few.

In addition, with an existing automotive industry and a history of manufacturing, states in the Midwest and along the Great Lakes demonstrate strong supply capabilities for certain components such as nacelles. Ohio and Illinois both received high or medium scores for many of the categories. It is important to note that many states without established offshore wind energy policies showed high scores for offshore wind capacity. Georgia and Tennessee are prime examples, showing that the industry's supply chain has the potential to reach beyond the states with existing projects.

Some additional findings from the study include:

- Many companies in the domestic manufacturing supply chain can fabricate the secondary steel needed for subcomponents and subassemblies related to personnel access and equipment, such as dockings, work platforms, ladders, and other secondary steel components.
- There are many domestic manufacturers capable of serving as suppliers of subassemblies and subcomponents for the three foundation types studied in the road map (monopiles, jackets, and gravity-based foundations) throughout several regions in the United States.
- While the United States has many companies with the ability to forge or cast flanges, there are currently no companies that can cast flanges in the size and specifications required by the industry.
- The West Coast maintains a base of domestic manufacturers with capabilities for floating-specific components. California and Oregon received high AIMS scores for almost all the floating offshore wind components. Washington scored above average for most of these components as well. This is important, as the topography of the West Coast demands floating offshore wind.
- While the Gulf of Mexico and the West Coast have only recently begun to attract offshore wind energy development, they demonstrate a readiness beyond what would be anticipated considering the relative infancy of those markets. As excitement about offshore wind energy increases in these regions, the existing manufacturing workforce can be reskilled to unlock the potential of the supply chain while proving an opportunity to expand and grow educational programs in these regions. However, many of the inland states surrounding these markets scored toward the bottom with their AIMS score for many components. As offshore wind expands on the West Coast and in the Gulf of Mexico, inland states could play a role in the supporting supply chain but much engagement needs to occur for them to capitalize on the economic opportunity.
- Developing policies that advance the industry and collaboration with other states will decrease the gap between a state's capacity to leverage existing suppliers and its current offshore wind capability.

- In many circumstances, for fixed-bottom substructures, the materials and workers associated with steel plate and secondary steel subcomponent fabrication can support floating designs as well.
- The Gulf of Mexico rated highly for many of the mooring components, which could be attributed to the existing expertise supporting the oil-and-gas industry. Heavy fabrication is required for many floating components so there is an existing strong network in the Gulf of Mexico.
- The size and mass of some of these components limit the number of suppliers that can manufacture them. Many existing suppliers can supply anchors or mooring rope or chain but do not have the capability to manufacture these items in the size and specifications required for floating offshore wind.
- From anecdotal conversations and materials reviewed, it is important for a port facility to support serial fabrication, assembly, and installation of floating platforms for a large-scale utility project.

Limitations and Challenges With Supply Chain Connect Data

One of the key contributions to AIMS levels is the data contained in Supply Chain Connect, which requires each registrant to self-report business information in multiple categories. Developing a national-scale database with this type of information is challenging; some of the limitations, and their effects on the subsequent analysis, include:

- **User-driven data**. Companies that register in the database are the source of the data and there are no requirements on how much or little information a supplier provides in their profile. While the Business Network for Offshore Wind asks registrants to provide information about the number of workers or certifications that are held by the organization, that data are not required.
- **Category selection**. We discovered that organizations sometimes selected categories that they source outside their facility and use to manufacture or fabricate their own product. An example of this is steel plate. We found many instances where the company that registered for the steel plate category was not a steel mill but rather a steel fabricator who produces fabricated steel components using steel plates.
- **Workforce**. One of the factors in assessing each state's AIMS was the workforce size in each of a company's facilities. However, Supply Chain Connect does not include the number of workers at each facility. In situations where a company provides its workforce size and has one or more facilities, no information exists about the allocation of the workforce between facilities. To account for this lack of data, instead of scoring an exact number of employees, we assigned organizations as either small, medium, or large.
- **Throughput, capacity, and capability**. Supply Chain Connect does not ask for throughput for many high-impact components and as a result there was not enough data on throughput capacity of each facility.
- **Production at individual facilities.** Supply Chain Connect is unable to capture the exact type of products manufactured at each facility. For organizations with more than one production facility and multiple registered categories, we are unable to identify the precise type of component(s) manufactured at each facility.
- **Different levels of Supply Chain Connect exposure to various regions**. The data were influenced by the differing levels of exposure to the offshore wind industry across the

country. Certain regions have had much more exposure to the industry, resulting in some states and regions having a larger number of organizations in Supply Chain Connect compared to regions without that exposure.
- **Unavoidable loss of context when translating qualitative data into quantitative measurements**. There is no established or "correct" way to assess a supplier's readiness to contribute to the offshore wind energy supply chain. As a result, we took a first approach by using the best available and most comprehensive data available. This is a starting point and is expected to evolve over time as individual states conduct assessments of their own capabilities that can support the offshore wind industry.
- **Not representing the entire supply chain**. This study only focuses on manufacturing and does not include an assessment of state readiness to supply services for the industry.
- **Differing level of granularity between components**. During the selection process, we identified a variety of components, some Tier 1, Tier 2, and Tier 3. The number of subcomponents/subassemblies under each component varied on a case-by-case basis.
- **Contract manufacturers**. Throughout the research and preparation of this study, we discovered areas of the supply chain that were not represented within the AIMS assessment but have the potential to play a crucial role in the development of the U.S. offshore wind industry. The Supply Chain Connect profile review uncovered several manufacturers/fabricators located across the country that can be characterized as contract or custom manufacturers. Rather than using serial production or maintaining a set catalog of specified products, these types of companies work with clients to create custom or bespoke products on a project-by-project basis. Depending on the facility size or equipment on-site, these organizations can produce a variety of the components that ultimately end up in an offshore wind farm. Foundries, fabrication facilities, machine shops, and precision welders are a few of the many types of companies that fall into the custom manufacturing category.

Because of the lack of information on specific products produced, it is difficult to assign categories or subcomponents to these companies and were therefore not included in this study. However, many of the manufacturers indicate their ability to serve wind, renewable energy, marine, infrastructure, oil and gas, industrial, and other relevant industries. Contract manufacturers are an example of existing strengths within the U.S. manufacturing supply chain that may not be represented in the AIMS assessment. Further research on areas like contract manufacturers may be necessary to fully understand the capabilities of the domestic supply chain in relation to serving the offshore wind energy industry.

Regional Distribution of Jobs and Economic Benefits

Figure B1 provides an approximation of how the jobs estimates will be spread over time using the accelerated and conservative scenarios detailed in Section 3.1.2.2. The number of direct component jobs is an average of the workforce data for each component collected as part of industry survey efforts with the direct jobs estimated using NREL's Jobs and Economic Development Impact model. The number of direct jobs per component facility is in Table B5. We assigned these direct jobs per facility to the operational date for the scenarios and assumed this level of workforce would support the demand pipeline over time.

Table B5. Number of Direct Jobs Per Component Manufacturing Facility

Component	Direct Jobs Per Facility
Blades	500
Nacelle	230
Towers	290
Monopile	550
Jacket	550
Gravity-based foundation	300
Transition piece	300
Array cable	230
Export cable	230
Steel plates	460
Casting (e.g., bedplate)	240
Flange	190
Floating platform	240
Stationkeeping (e.g, mooring rope/chain)	110

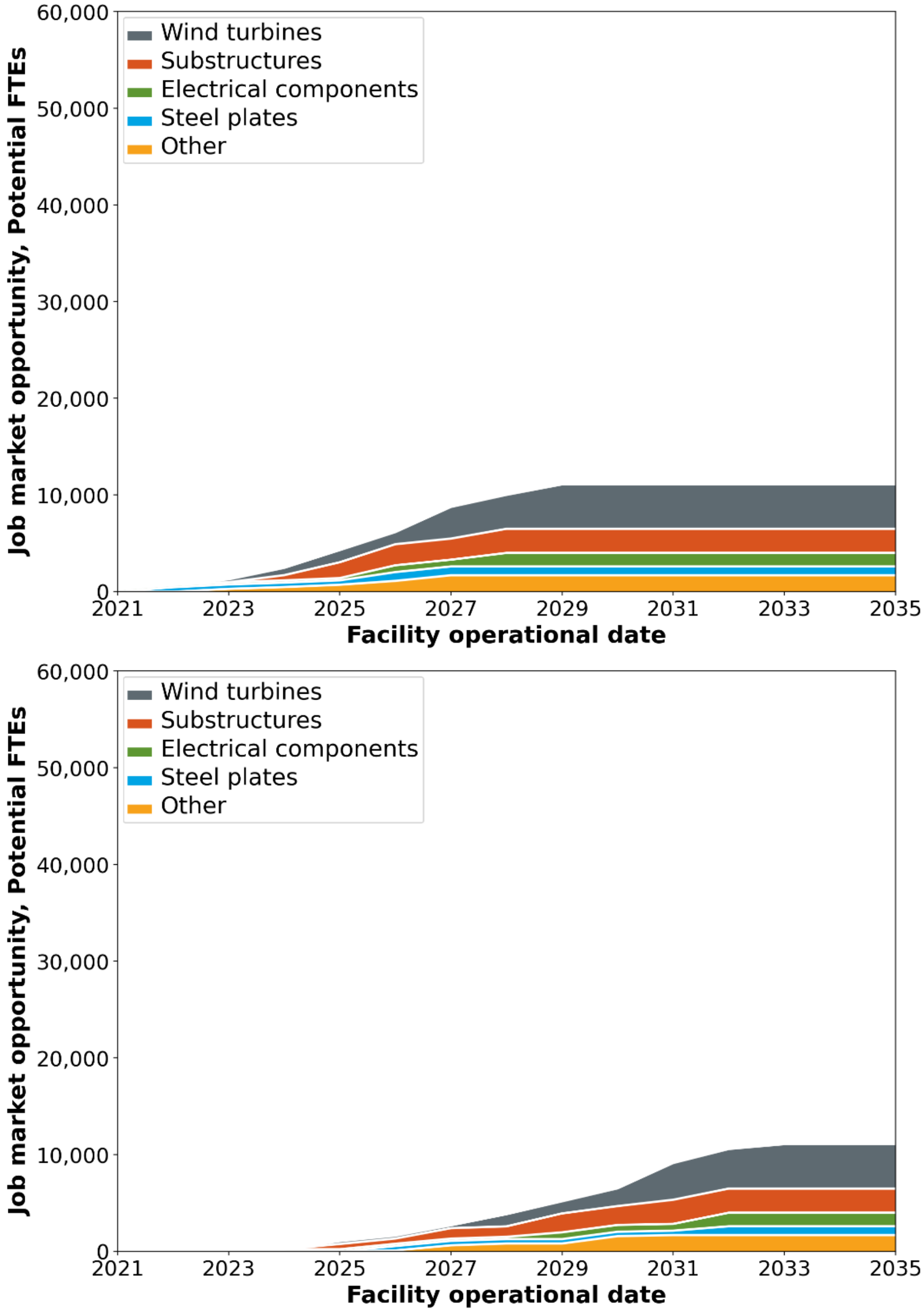


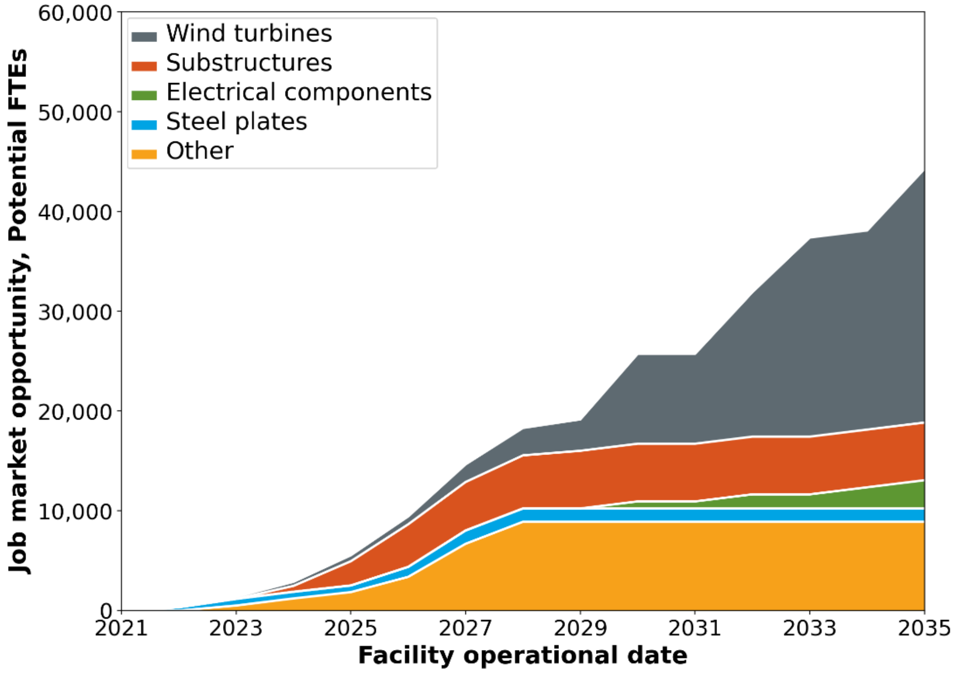
Figure B1. Major manufacturing jobs (prescribed) over time for each component in an accelerated (top) and conservative (bottom) scenario assuming a 100% domestic workforce

FTE: full-time equivalent

For supplier jobs in Figure B2, we use the estimates shown in Table B6 and assume half the supply chain is active in the operation year of the component manufacturing facility and the full supply chain is activated in the second year of plant operation for the accelerated scenario. Under the conservative scenario, the supply chain is activated over a 5-year duration. In addition, we assume the suppliers for the nacelle and cable suppliers will develop later in the 2030s under both scenarios because it will be difficult to justify costly facility investments for nacelle internals (e.g., gearboxes and generator) and to import raw cable materials.

Table B6. Number of Supplier Jobs Per Component

Component	Supplier Jobs
Blades	1,900
Nacelle	16,000
Generator	5,800
Towers	1,600
Monopile	3,500
Jacket	1,300
Gravity-based foundation	1,000
Transition piece	2,000
Array cable	1,000
Export cable	2,000
Offshore wind substation	200
Steel plates	1,300
Casting (e.g., bedplate)	900
Flange	400
Floating platform	3,100
Mooring rope/chain	400
Drag embedment anchor	1,500
Suction caisson	1,800



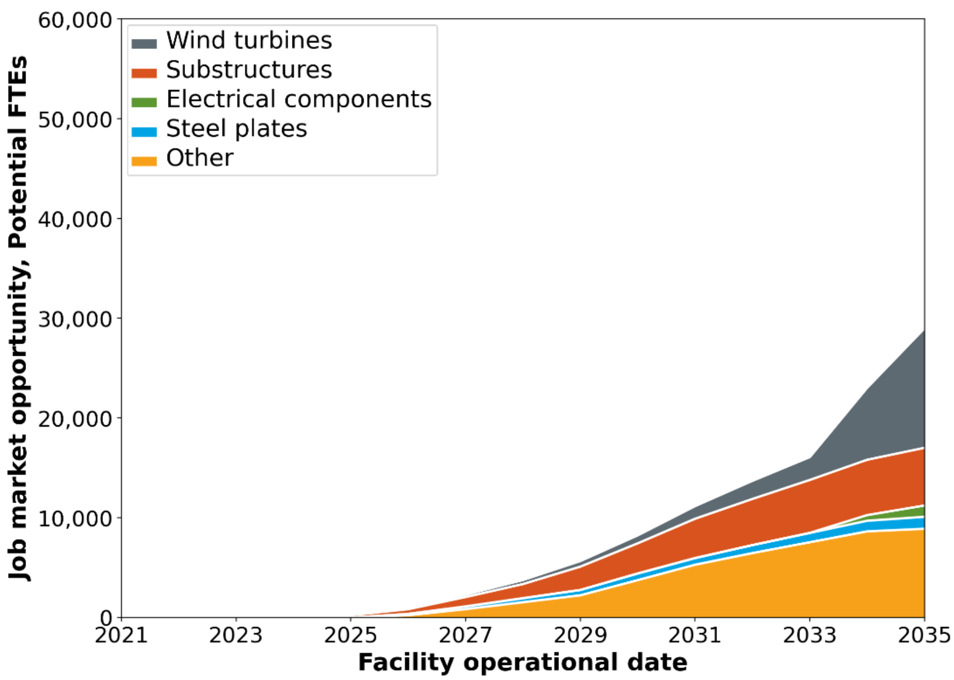


Figure B2. Indirect supplier jobs over time for each component in an accelerated (top) and conservative (bottom) scenario assuming a 100% domestic workforce

In Section 3.2.2.4, we defined three metrics to evaluate the existing capabilities that each state could leverage to capture a portion of the job market opportunity. The metrics included the state's AIMS, similar industry capability, and the proximity to facilities defined in the domestic supply chain scenario. Figure B3 shows the scores for all three metrics for all states. We summed the scores calculated for each component in each state, with even weighting for each metric. These metrics indicate a state's capacity to provide subassemblies, parts, and materials for component manufacturing facilities.[28]

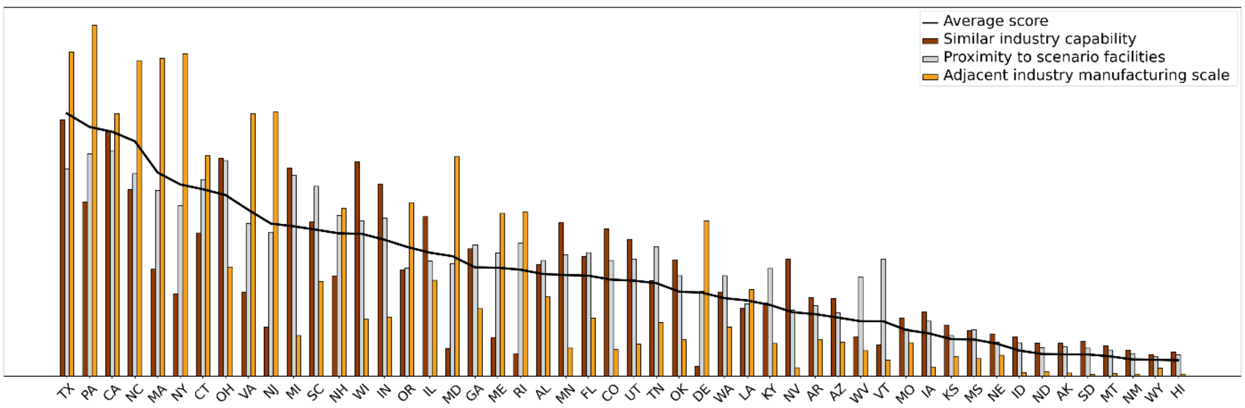


Figure B3. Scoring levels that affect supplier jobs based on AIMS, similar industry capability within states, and proximity to scenario manufacturing facilities

We highlight Ohio as an example to help interpret Figure B3. Ohio has an existing automotive industry and a history of manufacturing along the region that was once dominated by industrial manufacturing (known as the "Rust Belt"; from New York to the Midwest), which results in a high score for similar industry capability. It is also close to steel plate facilities like Nucor in Brandenburg, Kentucky, and other manufacturing facilities on the East Coast. However, Ohio has less-established offshore wind energy policies and its suppliers may have less awareness of the offshore wind supplier opportunities. To increase their potential jobs, Ohio could conduct a detailed state assessment to highlight opportunities for in-state businesses capable of supporting the offshore wind energy supply chain.

We then multiply the average score (shown in Figure B3) by the total number of available direct and indirect supplier jobs to define the opportunity space for supplier job creation in each state. In other words, the reported supplier jobs represent a percentage of the total number of national available jobs that could be targeted by each state based on their existing capabilities. This metric is essentially a relative comparison between states that indicates the market for their services within the offshore wind industry. Specifically, not all the potential job share for each state will be realized within the state because shares of jobs will vary as the supply chain matures. As the

[28] The bar's height indicates the magnitude of the potential opportunity, with higher bars indicating a greater opportunity for participation and jobs in the offshore wind energy supply chain. States where the yellow bar (AIMS) exceeds the red bar (similar industry capability), and grey bar (proximity to scenario facilities) may be well-suited to realize their full opportunity for jobs. The difference between the yellow bar and red bar indicates room for industries to support the offshore wind supply chain. A detailed state assessment may reveal potential suppliers. When the grey bar exceeds the red bar, a state is located near a major component facility and has existing industries that could participate in the supply chain by reducing barriers to providing subassemblies, parts, and materials.

supply chain develops and states or businesses commit to the offshore wind energy industry, these jobs will appear in the states and regions that create the most welcoming environment.

We then define the job market opportunity as the major manufacturing jobs (prescribed) added to the supplier jobs market opportunity. For instance, we calculate the job market opportunity based on the major manufacturing jobs (prescribed) and supplier jobs, as shown in Table B7. Based on the accelerated and conservative scenarios, monopiles are expected to support no major manufacturing jobs in Ohio. However, Ohio would still have a market opportunity to provide supply chain subcomponents, parts, and materials for monopiles, so it has the space to create 2,100 supplier jobs. Whereas in New Jersey, the major monopile facility could support 550 jobs, with a potential to support 1,300 supplier jobs for a total opportunity of 1,850 jobs.

Table B7. Demonstration of Total Job Market Opportunity Calculation for Monopiles in Ohio and New Jersey

Available Supplier Jobs	State	Supplier Job Metrics	Score	Supplier Jobs	Average Supplier Jobs	Major Manufacturing Jobs (prescribed)	Job Market Opportunity
3,600	Ohio	Adjacent industry manufacturing scale	0.38	1,400	2,100	0	2,100
		Similar industry capability	0.69	2,400			
		Proximity to scenario facilities	0.72	2,600			
	New Jersey	Adjacent industry manufacturing scale	0.43	1,500	1,300	550	1,850
		Similar industry capability	0.15	500			
		Proximity to scenario facilities	0.51	1,800			

The major manufacturing jobs (prescribed) would be the total number of jobs if distinct suppliers or facilities are built in the state prescribed in the accelerated and conservative scenarios. In other words, the number of workers to support a facility in the chosen state.

By combining the job potential for every component within each state, we arrive at an estimate of the job market opportunity for the offshore wind industry. We can contrast this with the manufacturing jobs at each Tier 1 component facility, which will be concentrated at ports in coastal states (see Figure B4). Although the specific distribution of supplier jobs is specific to the supply chain metrics we use in this report, the key takeaway is that a major opportunity space exists beyond just Tier 1 facilities.

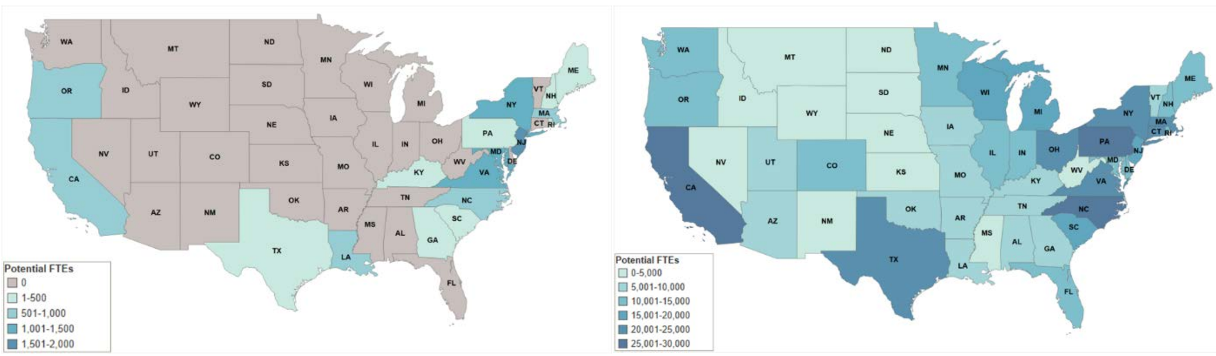


Figure B4. Major manufacturing jobs (prescribed) (left) and supplier jobs (right) for a 100% domestic supply chain assumption

We present the same information in Figure B5 showing the major manufacturing jobs that are prescribed in the domestic supply chain scenario and supplier jobs assigned to each state in the domestic supply chain; however, unlike in Figure B4, we include a range for the supplier jobs corresponding to the high and low bounds of the supplier jobs based on 25% and 100% domestic content from Section 3.2.2.4. We use this approach to convey the uncertainty surrounding the effectiveness in each state in supporting the offshore wind energy supply chain, which may be weighted toward any of the different metrics we provide as the industry develops. Although a significant range of supplier jobs exists for each state, these supplier jobs significantly outnumber the jobs from major component facilities.

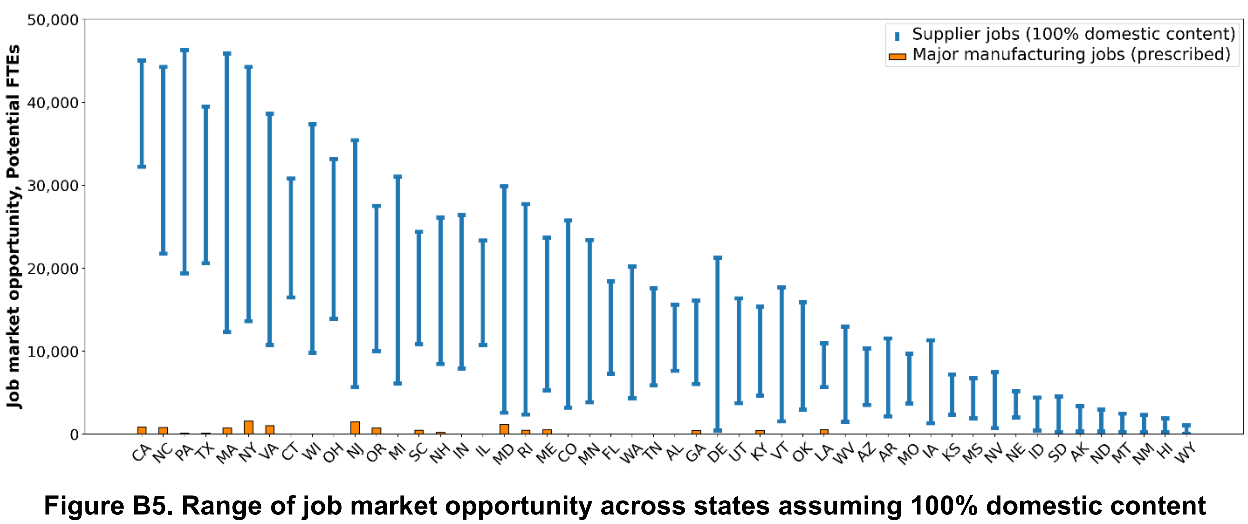


Figure B5. Range of job market opportunity across states assuming 100% domestic content

Figure B6 shows the potential gross domestic product (GDP) opportunity from the major manufacturing economic scenario. Again, most of the opportunity is concentrated along the coasts.

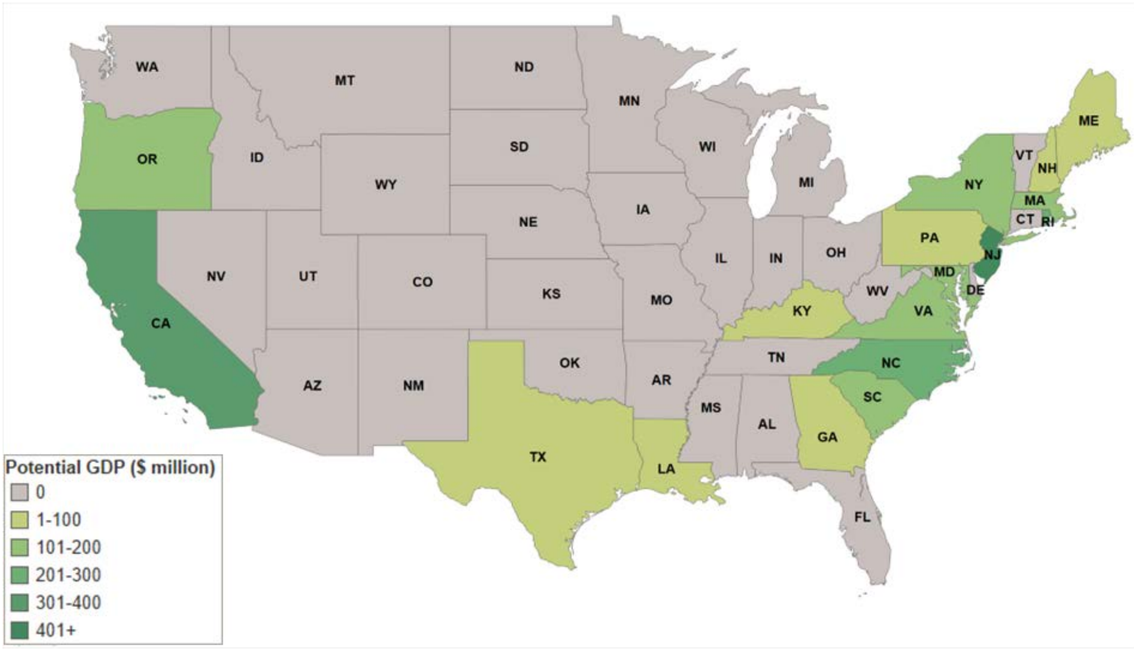


Figure B6. Major manufacturing GDP ($ millions) opportunity assuming 100% domestic content

Figure B7 shows the potential GDP opportunity as a result of the suppliers being activated for a 100% domestic supply chain.

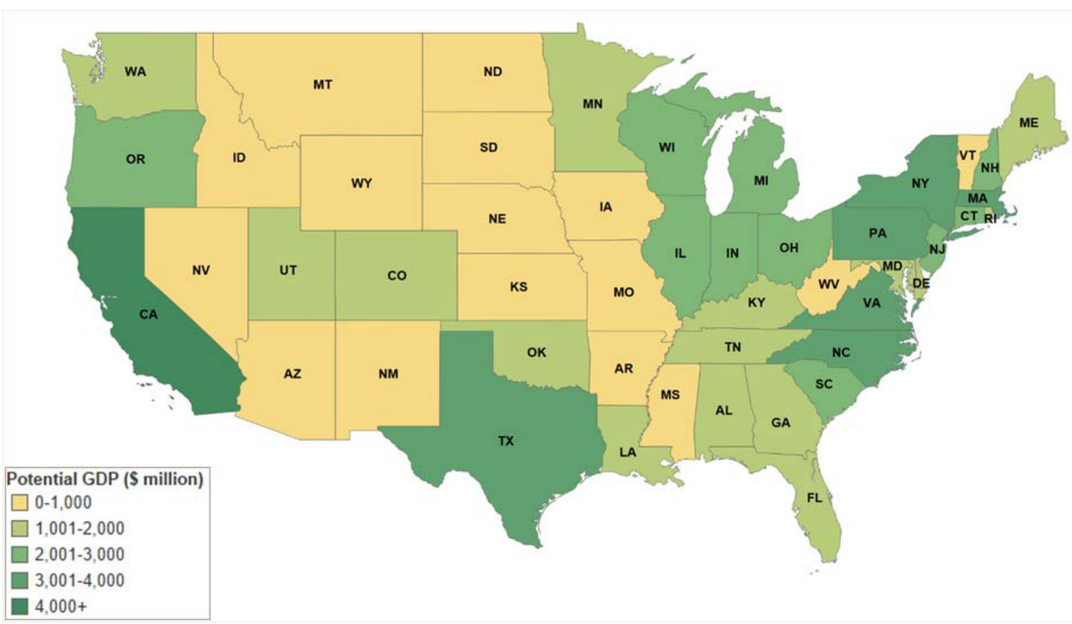


Figure B7. Suppliers GDP ($ millions) opportunity assuming 100% domestic content

Levelized Cost of Energy Assessment of Domestic and Imported Components

We evaluate the impact of moving offshore wind component manufacturing to the U.S. by establishing a baseline cost for a fixed-bottom reference project and then introducing cost premiums for factory payback, transport from Europe, and/or tariffs based on the prescribed source of each major component within the scenario. In this section, we provide further details about estimating the baseline costs and cost premiums.

Baseline Costs

We establish the baseline costs for the reference project using NREL's ORBIT cost model (Nunemaker et al. 2020). We supplement the standard output of ORBIT with details from NREL's Wind-Plant Integrated System Design & Engineering Model (WISDEM®) to provide a more granular breakdown of the wind turbine capital costs (ORBIT typically defines the overall cost of the wind turbine, and we require this cost to be split into blade, nacelle, and tower costs for this analysis). The baseline costs for the reference project are provided in Table B8. We include the capital costs of major components as well as soft costs (e.g., insurance, financing, contingency, commissioning, and decommissioning bonds) and project costs (e.g., lease area auction costs, site assessments, and development costs), which comprise a significant portion of the overall project capital expenditures (CapEx).

Table B8. Component Cost Breakdowns (in $2021) for the Reference Fixed-Bottom Offshore Wind Project Used in the Levelized Cost of Energy Analysis

Component	Cost
Blade	175.6
Nacelle	356.5
Tower	210.8
Other wind turbine components	560.4
Substructure (monopile and transition piece)	503.6
Export cable	88.4
Array cable	105.0
Offshore substation	165.0
Installation	313.5
Project costs	252.1
Soft costs	543.1
Total CapEx	**3,274.5**

The baseline value for CapEx can be thought of as the cost to procure and install all of the offshore wind power plant components as if they were all produced at the marshaling port (i.e., with no additional costs for transport, tariffs, or factory amortization). In order to compare the scenarios of imported components and domestic supply chains, we then introduce cost premiums for each of the three major cost adders.

Factory Amortization

Domestically produced components will require new manufacturing facilities, and the upfront capital costs of these facilities will be distributed over the price of the manufactured components.

We have developed estimates for the investment costs in new manufacturing facilities, which are provided in Section 2.5. We developed a cash flow model to determine the required sales premium over cost for each component that would be required to pay back the initial capital investment in a new manufacturing facility. The cash flow model incorporates the effects of the Inflation Reduction Act production tax credits for blades, nacelles, towers, and monopiles. We assume that some parameters are the same for all factories, such as the technical life, although in reality these will likely vary between individual factories. Because we set up this high-level model so that it can be generalized throughout the supply chain, we do not attempt to assign different financing parameters for each facility. The common assumptions for each component that go into this model are defined in Table B9.

Table B9. Component Assumptions for the Factory Payback Cash Flow Model.

Parameter	Units	Blade	Nacelle	Tower	Monopile	Transition Piece	Array Cable	Export Cable
Facility construction cost	$ million	250	250	250	350	250	400	400
Cost per unit	$ million	0.87	5.35	3.15	2.87	1.44	0.4 ($ million /kilometer [km])	0.8 ($ million /km)
Production capacity	#/year	275	100	100	100	100	500 (km/year)	200 (km/year)
Manufacturing production credit	$/watt	0.02	0.05	0.03	0.02	0	0	0
Wind turbine ratine	MW	15						
Facility technical life	years	25						
Depreciation asset life	years	7 (asset class 33.4 or 34.0)						
Maintenance CapEx share of sales	%	2						
Debt share	%	70						
Interest rate	%	4						
Debt life	Years	20						
Tax rate (federal and state)	%	26						

The model outputs the annual cash flows from a representative facility over the 25-year technical life. We determine the free cash flow (which accounts for net income, depreciation, construction cost, maintenance CapEx, and debt service). We then solve for a sales premium over cost, which fixes the levered internal rate of return at approximately 8.8%, which we source from the literature as a reasonable rate of return for cost of equity for industrial manufacturing. (We use the internal rate of return as the discount rate in the cash flow model, which fixes the net present value of the investment at zero).

The structure of the cash flow model is summarized for monopiles in Table B10 using a sales premium over cost of 8.5%, which outputs a levered internal rate of return of 8.7%.

Table B10. Representative Cash Flow Model for Monopiles (First 7 Years of Operation)

	Year							
Parameter	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Units (#)		100	100	100	100	100	100	100
Sales price per unit ($ million)		3.11	3.11	3.11	3.11	3.11	3.11	3.11
Sales ($ million)		311	311	311	311	311	311	311
Manufacturing production credit ($ million)		30	30	30	30	30	-	-
Cost per unit ($ million)		(2.87)	(2.87)	(2.87)	(2.87)	(2.87)	(2.87)	(2.87)
Costs ($ million)		(287)	(287)	(287)	(287)	(287)	(287)	(287)
Earnings before interest, taxes, depreciation, and amortization (EBITDA)		**24**	**24**	**24**	**24**	**24**	**24**	**24**
Depreciation ($ million)		(50)	(50)	(50)	(50)	(50)	(50)	(50)
Straight line (midyear) (%)		14%	14%	14%	14%	14%	14%	14%
Earnings before interest and taxes (EBIT)		**(25.6)**	**(25.6)**	**(25.6)**	**(25.6)**	**(25.6)**	**(25.6)**	**(25.6)**
Interest ($ million)		(9.8)	(9.5)	(9.1)	(8.8)	(8.4)	(8.0)	(7.6)
Manufacturing production credit ($ million)		30.0	30.0	30.0	30.0	30.0	-	-
Taxes ($ million)		-	-	-	-	-	-	-
Net income ($ million)		**(5.4)**	**(5.1)**	**(4.7)**	**(4.4)**	**(4.0)**	**(33.6)**	**(33.2)**
Net operating loss balance ($ million)		*(35.4)*	*(70.5)*	*(105.2)*	*(139.6)*	*(173.6)*	*(207.2)*	*(240.4)*
Tax credits ($ million)		*(30.0)*	*(60.0)*	*(90.0)*	*(120.0)*	*(150.0)*	*(150.0)*	*(150.0)*
Net income ($ million)		(35.4)	(5.1)	(4.7)	(4.4)	(4.0)	(33.6)	(33.2)
Depreciation ($ million)		50.0	50.0	50.0	50.0	50.0	50.0	50.0
Construction cost ($ million)	(350.0)							
Maintenance CapEx ($ million)		(6.2)	(6.2)	(6.2)	(6.2)	(6.2)	(6.2)	(6.2)
Debt ($ million)	245.0	(8.2)	(8.6)	(8.9)	(9.3)	(9.6)	(10.0)	(10.4)
Project free cash flow ($ million)	**(105.0)**	**0.1**	**30.1**	**30.1**	**30.1**	**30.1**	**0.1**	**0.1**
Internal rate of return (levered) (%)	**8.7**							

Using this cash flow model for all relevant components provides the sales premium over cost for a domestically produced component using a newly constructed facility listed in Table B11.

Table B11. Sales Premium Over Cost for Major Fixed-Bottom Offshore Wind Components Used in the LCOE Analysis

	Blade	Nacelle	Tower	Monopile	Transition Piece	Array Cable	Export Cable
Sales premium over cost (%)	2.5	2.5	4	8.5	16.9	19.0	23.1

Transport Costs

Components produced in Europe will incur transportation costs to ship to the United States via an oceangoing barge. The size of offshore wind energy components limits the number that can fit on a barge, which then requires multiple, trans-Atlantic trips to deliver all of the components for the wind power plant. We determine the transport cost premium per component by estimating the number of trips required and then distributing the total vessel costs over the number of components.

Table B12. Oceangoing barge vessel and transit estimates for transporting components from Europe to the United States.

Parameter	Value	Units
Cargo capacity	10,000	t
Deck space	3,600	m^2
Transit speed	7	km/hr
Day rate	0.05	$ million/day
Mobilization cost	0.5	$ million
Demobilization cost	0.5	$ million
Travel distance	5,000	km
Travel time	30	days
Cost per trip	1.5	$ million

We determine how the $1.5-million vessel cost per trip is distributed over individual components based on the number of components that could fit on the deck of the vessel. These estimates are based on the approximate footprint and mass of the components or were provided directly by OEMs. The resulting transport estimates and cost premiums for wind turbine and substructure components are provided in Table B13.

Table B13. Transport Cost Premiums for Trans-Atlantic Component Trips

Component	Cost Per Component ($ million)	Total Number in Project	Number Per Trip	Total Transport Cost ($ million)	Transport Premium Per Component ($ million)	Transport premium per component (%)
Blade	0.87	162	12	42.7	0.263	30.3
Nacelle	5.35	54	6	27.8	0.515	9.6
Tower	3.15	54	5	33.7	0.625	19.8
Monopile	2.87	54	4	42.7	0.790	27.5
Transition piece	1.44	54	14	12.9	0.239	16.7

We treat array and export cables slightly different than the wind turbine and substructure components as they are more likely to be collected from a European factory by a cable-lay vessel and taken directly to the project site for installation. As a result, the costs premium is based on the day rates of a cable-lay vessel instead of an oceangoing barge. These vessels can carry a cable carousel with at least 5,000–7,000 t of cable, and newer-generation vessels can have multiple carousels with 7,000–10,000 t of capacity (Prysmian Group 2019). For this assessment, we conservatively assume that a cable-lay vessel can carry 5,000 t of cable.

We estimate the mass of array cable needed for a project by calculating the product of the number of wind turbines, a 1-km distance between turbines, and a linear density of 42.5 t/km from ORBIT (Nunemaker et al. 2020). We estimate the mass of export cable needed for a project by calculating the product of the distance to shore, two cables, and a linear density of 90 t/km from ORBIT (Nunemaker et al. 2020). Finally, we assume the cable-lay vessel transits at the same rate as the oceangoing barge (7 km/hr) and costs $120,000/day. The resulting premium per component is calculated in Table B14. The relatively low number of trips and high baseline cost of the cables results in a negligible transport premium for cables.

Table B14. Transport Cost Premiums for Trans-Atlantic Cable Trips

Component	Cost Per Component ($ million/km)	Mass of Cable (t)	Number of Carousels Required	Total Transport Cost ($ million)	Transport Premium Per Component ($ million/km)	Transport Premium Per Component (%)
Array cable	0.4	1,600	1	7.2	0.0045	0.2
Export cable	0.8	9,000	2	14.4	0.0016	0.1

We do not assign transportation costs to offshore substations as we assume that they will be assembled at U.S. ports or shipyards (with imported power conversion components) in all scenarios.

Tariffs

Section 232 tariffs are applied to raw steel imports. We impose a 25% cost premium on the raw materials for monopiles, transition pieces, and towers.

Limitations and Caveats

The assessment we conduct in this report is a high-level estimate of the cost competitiveness between domestic and imported components. The results we present are subject to the following limitations and caveats:

- Additional research is required to understand how location-specific labor rates impact the cost of individual components and their competitiveness in an open market
- We do not consider different taxes for domestic or imported components
- We do not consider recent inflationary pressures on component costs
- We do not consider the possibility of sourcing components from Asia for the East Coast market because of the prohibitive cost and schedule impacts of shipping parts through the Panama Canal
- The number of components assigned to an oceangoing barge is conservative. In reality, multiple configurations of components can be used (for example, blades can be loaded above deck and nacelles can be loaded in the cargo hold). We select a more conservative loading configuration to put an upper bound on transport costs.
- Further study is needed to understand how higher costs of U.S.-flagged construction vessels may impact LCOE.

Appendix C. Certifications

Table C1 lists some of the critical offshore wind energy certifications that have been identified through Supply Chain Connect for offshore wind manufacturing.

Table C1. List of Relevant Certifications for Tier 2 and 3 Suppliers in the Offshore Wind Energy Industry

Acronym	Name	Type	Company/ Person/ Product	Definition
ABS MA	American Bureau of Shipping Manufacturing Assessment (ABS MA)	Quality	Company	ABS provides classification, technical, and regulatory services for the marine industry. ABS audits the quality-control systems and the manufacturing processes, then issues a manufacturing assessment certificate that is valid for 5 years, subject to changes in applied standards or product design. Verification of valid Product Design Assessment (PDA) certificates as well as International Organization for Standardization (ISO) 9001 quality system certification or equivalent are prerequisites.
AISC QMS	American Institute of Steel Quality Management Standards (AISC QMS)	Quality	Company	Quality standard for the structural steel industry focused on the fabrication and erection process. Confirms that participants adhere to program criteria and have the personnel, organization, experience, documents procedures, knowledge, equipment, and commitment to perform fabrication.
ANSI	American National Standards Institute (ANSI)	Most are safety	Company	The institute oversees the creation, promulgation, and use of thousands of norms and guidelines that directly impact businesses in nearly every sector—from acoustical devices to construction equipment, dairy and livestock production to energy distribution, and many more. ANSI is also actively engaged in accrediting programs that assess conformance to standards—including globally recognized cross-sector programs such as the ISO 9000 (quality) and ISO 14000 (environmental) management systems.
API Q1	American Petroleum Institute (API)	Quality	Company	API Spec Q1 is a company-level certification based on the standard developed by API titled, “Specification for Quality Management System Requirements for Manufacturing Organizations for the Petroleum and Natural Gas Industry.” Companies must submit their quality manual for approval and host an on-site audit conducted by an API official. Companies must have a quality system in place at least 4 months prior to submitting an application. The quality manual must implement each review and risk-mitigation item outlined in the standard, and the full system must be audited every year to ensure continued conformance to the requirements.

Acronym	Name	Type	Company/ Person/ Product	Definition
APQP4Wind	Advanced Product Quality Planning (APQP)	Quality	Company	APQP4Wind is a nonprofit organization that has created an advanced product quality planning methodology specific to the global wind energy industry. This method has been designed by leading international wind turbine manufacturers and suppliers with the aim of standardizing, simplifying, and strengthening the quality planning and product approval process in the industry. The APQP methodology's origins are related to the automotive industry; however, the Wind Denmark organization adapted the project from the automotive sector to the business areas and specifications of the wind energy industry.
AS9100 Rev D	Aerospace Standard 9100 Revision D	Quality	Company	AS9100 is a company-level certification based on a standard published by the Society of Automotive Engineers titled, "Quality Systems-Aerospace-Model for Quality Assurance in Design, Development, Production, Installation and Servicing." AS9100 has now been replaced by AS9100C. The AS9100 standard includes ASQ 9001:2000 requirements with additional requirements specific to the aerospace industry; organizations will be evaluated against this standard to become AS9100 certified.
ASME BPVC-III-1	American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (BPVC) Code Section III, Division 1: Rules for Construction of Nuclear Facility Components and U.S. Nuclear Regulatory Commission Regulations	Quality	Company	ASME Boiler and Pressure Vessel Certification is a company-level certification of a manufacturer's or assembler's quality control system in accordance with the ASME BPVC Sections I, IV, VIII, X, and/or XII. This certification is for companies who are involved in the design, fabrication, assembly, and inspection of boiler and pressure vessel components during construction.
ASME BPVC-VIII-1	ASME PRT Certification: Construction of Pressure Vessels Division 1	Quality	Company	ASME Boiler and Pressure Vessel Certification is a company-level certification of a manufacturer's or assembler's quality control system in accordance with the ASME BPVC Sections I, IV, VIII, X, and/or XII. This certification is for companies who are involved in the design, fabrication, assembly, and inspection of boiler and pressure vessel components during construction.

Acronym	Name	Type	Company/ Person/ Product	Definition
ASME BPVC-VIII-2	ASME PRT Certification: Construction of Pressure Vessels Division 2	Quality	Company	ASME Boiler and Pressure Vessel Certification is a company-level certification of a manufacturer's or assembler's quality control system in accordance with the ASME BPVC Sections I, IV, VIII, X, and/or XII. This certification is for companies who are involved in the design, fabrication, assembly, and inspection of boiler and pressure vessel components during construction.
ASME PP	ASME Power Piping (PP) stamp certification	Quality	Product	“PP” stamp certification authorizing the welding, fitting, manufacture, and installation of piping and components that attach to external piping used for power boilers and pressure vessels. The PP stamp is governed by ASME Code Section B31.
ASME U	ASME “U” stamp certification	Quality	Product	The ASME U stamp is an indication of quality for pressure vessels. It ensures that the design, fabrication, inspection, and testing of pressure vessels conform to ASME’s guidelines. The ASME U stamp is provided on the body or the nameplates of the pressure vessels as a certification to meet ASME requirements. Globally, more than 100 countries use the ASME BPVC code for the pressure vessel design and U-stamped vessels follow the requirements of ASME Section VIII Division 1. In many countries, for pressure vessel installations in human occupancy, the ASME U stamp is a must. ASME U stamp is a mandatory requirement of most insurance companies, and is accepted under all jurisdictions. In addition, it is sometimes a requirement for approvals by local regulating agencies.
ASTM	American Society for Testing and Materials (ASTM)	Quality	Company	ASTM International, formerly known as American Society for Testing and Materials, is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services.
AWS Certified	American Welding Society (AWS) Certification of Welding Inspectors	Professional licensing	Person	In the United States, welder qualification is performed according to AWS D1.1, ASME Section IX and API 1104 standards, which are also used in some other countries. Some states have their own welder qualifications that supersede AWS qualifications, but most defer to AWS, ASME or API.
AWS D1.1	AWS Certification of Welding Inspectors	Structural welding code – steel	Person	AWS D1.1 covers the welding requirements for any type of welded structure made from the commonly used carbon and low-alloy constructional steels. Clauses 1 through 11 provide rules for the regulation of welding in steel construction.
AWS D1.2	AWS Certification of Welding Inspectors	Structural welding code – aluminum	Person	AWS D1.2 covers the welding requirements for any structure made from aluminum structural alloys, except for aluminum pressure vessels and pressure piping. Clauses 1 through 8 provide rules for the regulation of welding in aluminum construction.

Acronym	Name	Type	Company/ Person/ Product	Definition
AWS D1.3	AWS Certification of Welding Inspectors	Structural welding code – sheet steel	Person	AWS D1.3 covers the requirements associated with welding sheet steel having a minimum specified yield point no greater than 80 ksi [550 megapascals]. The code requirements cover any welded joint made from the commonly used structural quality.
AWS D1.4	AWS Certification of Welding Inspectors	Structural welding code – steel-reinforcing bars	Person	AWS D1.4 covers the requirements for welding steel-reinforcing bars in most reinforced concrete applications. It contains rules for regulating welding steel- reinforcing bars and provides suitable acceptance criteria for such welds.
CCM	CCM (Certified Construction Manager)	Professional licensing	Person	Construction management as a professional service that applies effective management techniques to the planning, design, and construction of a project from inception to completion for the purpose of controlling time, cost, and quality. The CCM certification program is accredited through ISO 17024 for standard certification of personnel as administered in the United States by ANSI.
CSA	Canadian Standards Association (CSA)	Safety or performance	Product	International certification. The CSA Group is a certification company that was founded 100 years ago in Canada; however, it is now respected internationally as being an indication that a product's been dependently tested and certified. It shows consumers that the product meets recognized standards for safety or performance in many countries. Unlike the United Laboratories certification, CSA is widely regarded and respected around the world.
EN 1090	European Standards 1090	Quality	Company	EN 1090 standards govern the execution and conformity assessment of steel and aluminum structures and comprise the following European standards that implement the requirements of the Construction Products Regulation for steel and aluminum structures: • EN 1090-1: Requirements for conformity assessment for structural components (CE marking) • EN 1090-2: Technical requirements for the execution of steel structures • EN 1090-3: Technical requirements for the execution of aluminum structures

Acronym	Name	Type	Company/ Person/ Product	Definition
GWO BST **GWO FA** **GWO FAW** **GWO MH** **GWO SS** **GWO WAH**	Global Wind Organization (GWO) (BST) Basic Safety Training GWO FA (First Aid) GWO FAW (Fire Awareness) GWO MH (Manual Handling) GWO SS (Sea Survival) GWO WAH (Working at Height)	Safety	Person	The GWO Basic Safety Training is mandatory for technicians, site managers, Health, Safety and Environment (HSE) staff, subcontractors, and so on. It is relevant for all people working on a site. The training includes five modules: GWO WAH, GWO FAW, GWO FA, GWO MH, and GWO SS. The first four modules are needed to work onshore. In order to work offshore, all five modules are needed.
IATF 16494	International Automotive Task Force (IATF) 16494	Quality	Company	This certification means that a company maintains a quality management system that fully conforms to IATF 16949:2016. This IATF standard defines quality system requirements for use in the automotive supply chain. It is based on ISO 9001:2015, as well as original equipment manufacturer (OEM) customer-specific requirements. Adherence to this standard means that OEMs and suppliers can have confidence that a company's products for the automotive market will continue to offer consistent quality, performance that meets expectations, and a reliable source of supply.
IATF 16949	International Automotive Task Force (IATF) 16949	Quality	Company	Developed by the International Automotive Task Force, IATF 16949 certification is a mandatory industry requirement that aligns automotive quality management systems throughout the world. While ISO 9001 touches on nonconformity and corrective action, IATF 16949 focuses on additional issues like problem solving, error proofing, and warranty management systems.
IEC 614000	International Electrotechnical Commission (IEC) 614000	Quality	Product (wind turbine)	IEC 61400 is an international standard published by IEC regarding wind turbines. IEC 61400 is a set of design requirements made to ensure that wind turbines are appropriately engineered against damage from hazards within the planned lifetime. The standard concerns most aspects of the wind turbine life from site conditions before construction, to turbine components being tested, assembled, and operated. Some of these standards provide technical conditions verifiable by an independent third party, and as such are necessary to make business agreements so wind turbines can be financed and erected.

Acronym	Name	Type	Company/ Person/ Product	Definition
IECRE System	IEC System for Certification to Standards Relating to Equipment for Use in Renewable Energy Applications (IECRE System)	Safety	Company	The IECRE System aims to facilitate international trade in equipment and services for use in renewable energy sectors while maintaining the required level of safety.
IEEE	Institute of Electrical and Electronics Engineers (IEEE)	Quality	Person	An IEEE credential is a guarantee of educational quality. IEEE maintains a registry of all credentials awarded, making accounting to state licensing boards easier for engineers.
ISO 14001:2015	International Organization for Standardization (ISO) 14001 (Environmental Management)	Environmental management	Company	Part of the ISO 14001 family of international standards covering environmental impact and the reduction of greenhouse gas emissions, ISO 14001 is the standard that covers the design and implementation of an (Environmental Management System (EMS). This is a framework designed to measure and improve the way natural resources are used and disposed of by an organization. It is a generic standard, which means it applies to organizations of all shapes and sizes. In some industries, like construction or manufacturing, the business benefits are very clear— greater resource efficiency and waste management means lower costs. But even in smaller businesses or service industries, 14001 certification shows an organizational commitment to the environment and more effective use of the world's resources. The essential difference between ISO 14001 and Occupational Health and Safety Assessment Series (OHSAS) 18001 is that ISO 14001 focuses on managing an organization's impact on the external environment, whereas OHSAS 18001 focuses on managing an organization's internal environment to ensure a safe and healthy workplace.
ISO 3834	ISO 3834	Quality	Company	ISO 3834 is the international standard for quality requirements for the fusion welding of metallic materials. ISO 9001 states that, where necessary, special processes shall be identified, and the ISO 3834 standard is an excellent way to meet this requirement.

Acronym	Name	Type	Company/ Person/ Product	Definition
ISO 45001	ISO 45001 (Health & Safety)	Health and safety	Company	ISO 45001 is the world's international standard for occupational health and safety, issued to protect employees and visitors from work-related accidents and diseases. ISO 45001 certification was developed to mitigate any factors that can cause employees and businesses irreparable harm. Its standards are the result of great effort by a committee of health and safety management experts who looked closely at other approaches to system management—including ISO 9001 and ISO 14001. In addition, ISO 45001 was designed to take other existing occupational health and safety standards, such as OHSAS 18001, into account, as well as the (International Labour Organization (ILO) labor standards, conventions, and safety guidelines. Especially geared toward senior management, ISO 45001 has the goal of helping businesses provide a healthy and safe working environment for their employees and everyone else who visits the workplace.
ISO 9001:2015	ISO 9001:2015 (Quality)	Quality	Company	ISO 9001:2015 has become the standard for most manufacturing companies. After numerous mishaps, particularly with offshore suppliers, it became clear that purchasing companies needed verification that their suppliers were playing by the rules. Many industries, such as medical, require their manufacturing partners to have this certification. Manufacturing companies who operate by ISO standards clearly show suppliers they are committed to using the highest-quality standards in their production processes. Implementing the ISO 9001 standards involves cooperation and feedback from internal and external stakeholders. Companies go through a rigorous assessment before implementing the quality management principles throughout the organization. To help with the process, companies hire a certification body (audit firm) to help them create a plan and comply with the standards. Implementation could cost thousands of dollars in fees depending on the size of the business. Also, there is a cost to re-allocating internal resources to assist with the certification. Once certified, ISO requires regular audits to ensure the standards are maintained.
ISO 9015	ISO 9015	Quality	Company	ISO 9015-2:2016 specifies microhardness testing on transverse sections of welded joints of metallic materials with high hardness gradients.

Acronym	Name	Type	Company/ Person/ Product	Definition
UL	Underwriter Laboratories (UL)	Safety	Product	Origin: United States and Canada; UL is a third-party certification company that has been around for over 100 years. Their mark indicates products are safe for workers and customers to use. Think of them as a safety organization that establishes standards for new products across various industries. For example, electronic components are often UL certified to show that they can handle safe levels of electrical current as promised.