U.S. DEPARTMENT OF ENERGY

Pathways to Commercial Liftoff: Offshore Wind

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Comments

The Department of Energy welcomes input and feedback on the contents of this Pathway to Commercial Liftoff Report. Please direct all inquiries and input to liftoff@hq.doe.gov. Input and feedback should not include business sensitive information, trade secrets, proprietary, or otherwise confidential information. Please note that input and feedback provided is subject to the Freedom of Information Act.

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Executive Summary

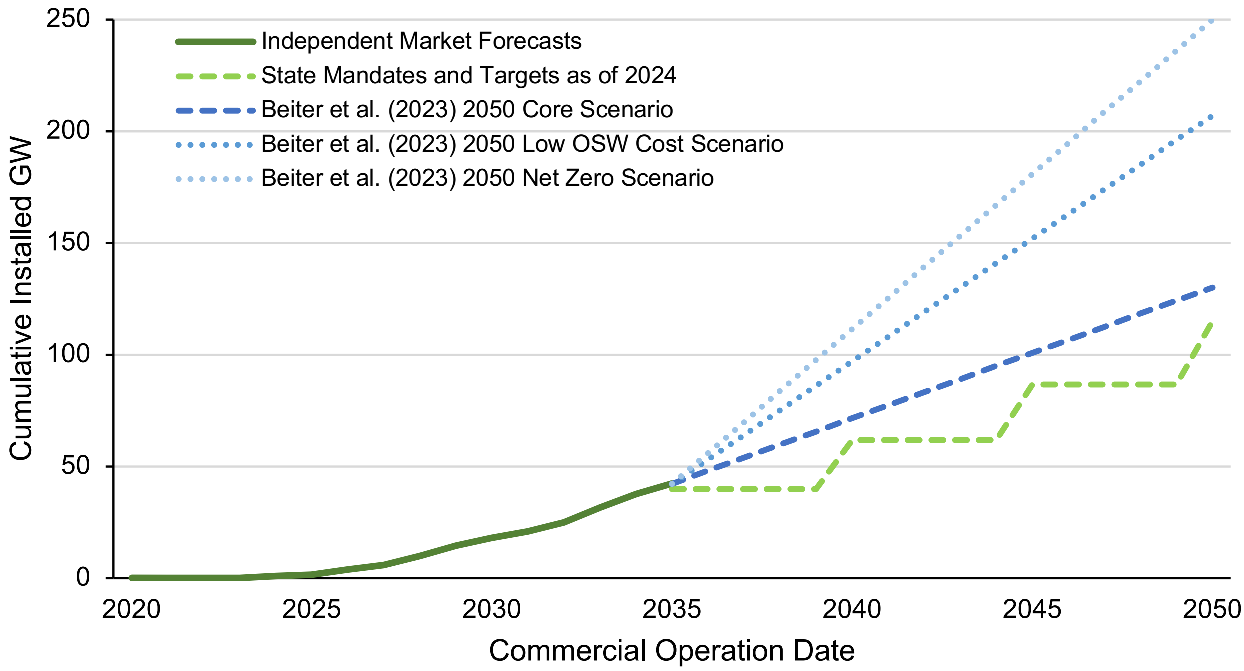
The U.S. offshore wind (OSW) market is at an inflection point. Offshore wind can deliver tens of gigawatts (GWs) of clean power to East Coast load within this decade, with approximately 250 MW operational, 5 GW under construction, and over 10 GW total approved for construction as of April 2024. In the next few years, an additional 5-10 GW of projects have a path to reach Final Investment Decision (FID) and begin construction. These early mover investments in enabling infrastructure, continued procurement commitments, and experience deploying projects over the next few years will demonstrate and foster the long-term deployment of offshore wind across the U.S..

Despite facing macroeconomic challenges, the sector is adapting, and improved risk mitigation is being built into industry planning. The primary driver of recent offtake cancellations—macroeconomic headwinds—will be de-risked going forward through new offtake solicitations, and global increases in offshore wind cost inputs and interest rates have begun to stabilize. Moreover, states and developers are making significant progress to refine best practices for project procurement, coordinated transmission upgrades, and early supply chain development investments. State leadership has been and will remain fundamental to advancing offshore wind development, planning, and supply chain investments.

Offshore wind power can play a critical role in both near-term and long-term decarbonization of the U.S. energy system. Decarbonizing to tackle the climate crisis while meeting electricity load growth will require fast deployment of clean sources. Offshore wind promises to help meet demand growth by providing near-term deployment at scale, particularly for land-constrained coastal demand centers that have limited clean electricity alternatives and might otherwise need to add new natural gas or delay fossil fuel retirement.

Longer term, offshore wind can deliver over 100 GW clean power by 2050. With ~50 GW-worth of U.S. seabed already leased to developers, early project deployment advancing rapidly, and additional lease areas planned for auction, there is a clear path to scaling deployment over the next several decades across the U.S.

E.S. Figure 1 – U.S. OSW deployment: ~40 GW projected by 2035, and over 100 GW targeted by 2050



Data Sources: BNEF, ERM Grip, 4C Offshore, Beiter et. al. 2023, DOE analysis[1]

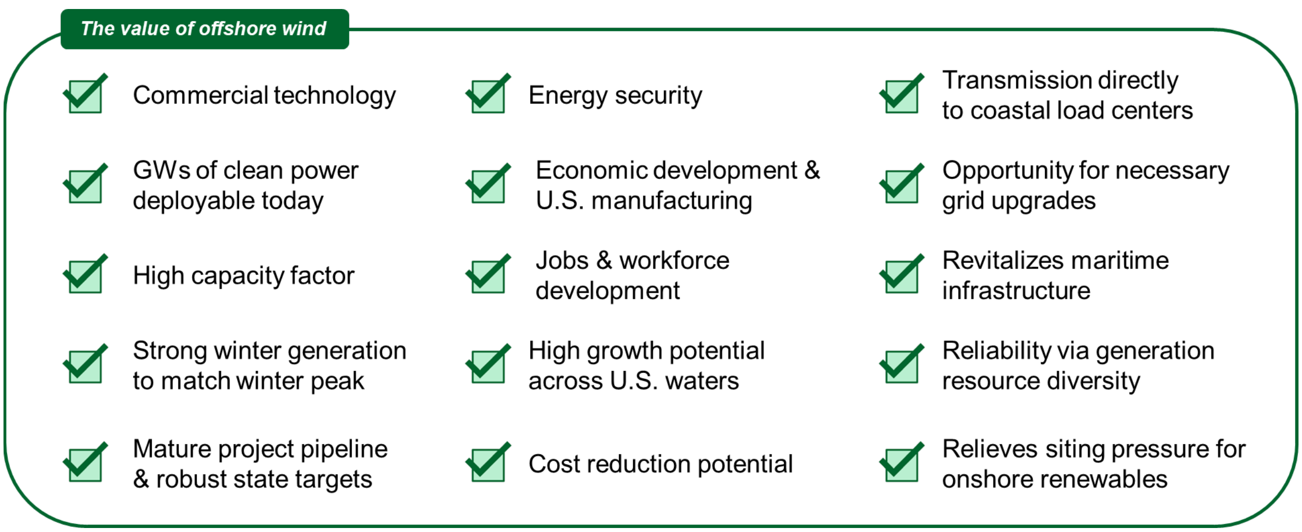
1 Growth curves assume steady 2035-2050 deployment, except for state targets scenario (based on target date and capacity)

Current industry market forecasts project ~40 GW built by 2035. Meeting the 115 GW cumulative 2050 state targets would then require annual deployments of 5 GW per year—achievable with a 25% increase above projected deployments in the next decade.

The value of offshore wind

Offshore wind has a compelling and distinctive value proposition that complements other clean resources. It supports grid reliability and resource diversity, with average capacity factors higher than those typical of onshore wind and solar PV projects, and a complementary production profile particularly suited to meet winter load growth (acute in colder climates, where electrification will drive higher winter peaks). Offshore wind helps relieve siting pressure for land-based clean power and transmission infrastructure, connecting directly to coastal population centers with high electricity demand. It can also drive economic development, providing sustainable opportunities for jobs, manufacturing, and revitalized legacy maritime and grid infrastructure. The sector also has long-term cost reduction potential as the industry scales in the U.S.

E.S. Figure 2 – Offshore wind value proposition



Floating wind technology will offer the ability to scale across U.S. geographies. Floating technology unlocks offshore wind deployment in water depths >200 ft, key for geographies such as the West Coast and Gulf of Maine. Floating wind has long-term potential to serve electricity demand across the East and West Coasts, the Great Lakes, Hawaii, and the Gulf of Mexico. Floating OSW can be an essential tool to help decarbonize these regions, especially in areas where the potential for fixed-bottom OSW, onshore renewables, or other clean sources (e.g., nuclear, out-of-state imports) is limited.

Market outlook: Recent cost challenges and path forward

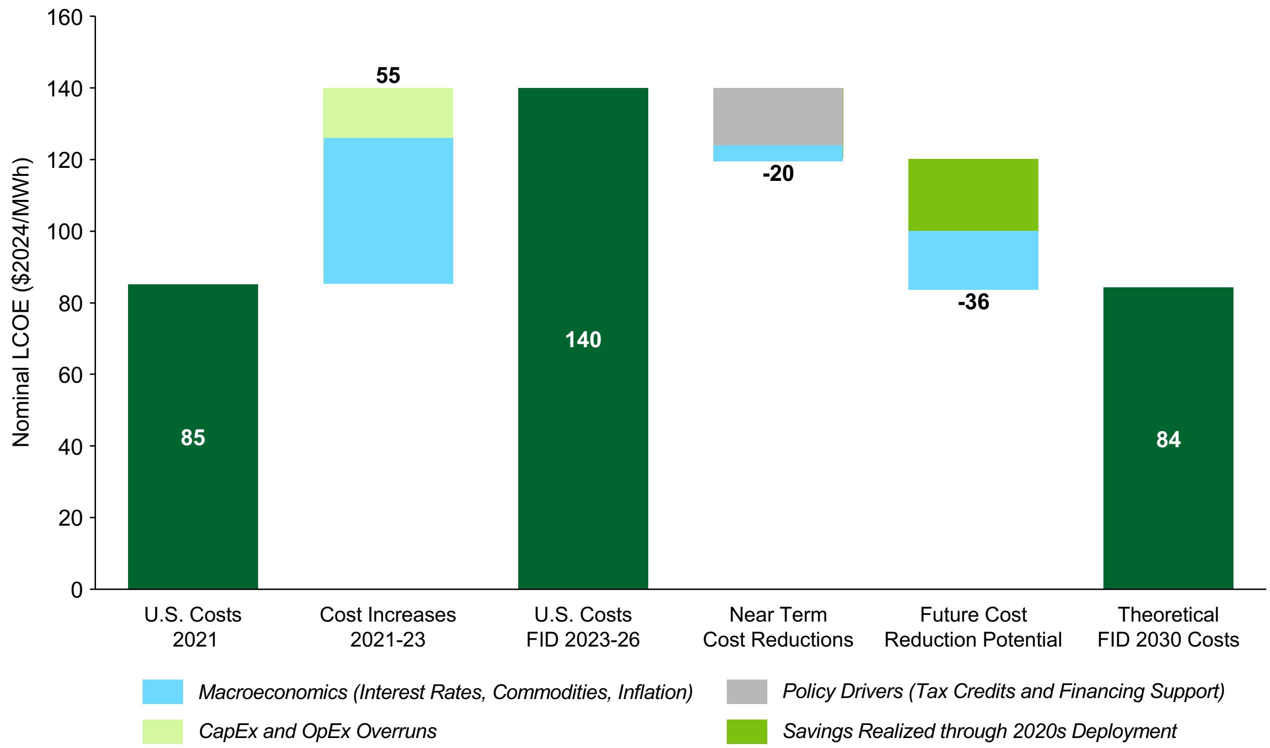
Early mover projects faced a "perfect storm" of challenges and have provided valuable lessons on how to sequence and structure investments for a sustainable offshore wind industry. The levelized cost of energy (LCOE) of U.S. OSW projects rose from approximately $85 to $140 per MWh from 2021 to the end of 2023, though individual projects vary. Cost increases were driven by rapid inflation of equipment costs, rising interest rates, supply chain constraints, and schedule delays. Because these changes occurred during the 3- to 5-year interval between state procurement (locking in fixed revenues) and final investment decision (locking in project costs) many projects canceled offtake contracts as their costs grew to exceed their secured offtake prices. Projects targeting FID in 2023-26 have seen the greatest risk exposure, while the longer-term pipeline has less risk of cancellation due to (1) 2020s project and infrastructure buildout (2) stabilizing macroeconomic headwinds, and (3) risk mitigations by states and developers.

Lessons learned from the challenges of the past few years will shape the market moving forward. These include ongoing efforts by states and industry to refine project and supplier procurement, fostering regional collaboration for supply chain and transmission planning, and government investments to support necessary enabling infrastructure.

LCOEs below $100/MWh ($2024) are possible for fixed-bottom projects by FID 2030, enabled by project deployment and associated supply chain and infrastructure development. Costs are dependent on macroeconomic conditions, state and federal offshore wind policy, offtake design, and the number of early movers that reach FID and begin construction in the next few years.

The figure below provides a framework to understand near-term cost reduction opportunities, showing a pathway to $84/MWh for projects reaching FID in 2030 and beyond. Given inherent uncertainties (e.g., macroeconomic conditions), these estimates should not be interpreted as a cost forecast.[2] The cost figures quoted below reflect 30-year technical LCOEs (not offtake prices) and are consistent with recent project rebids.

E.S. Figure 3 – Historical cost increases for a representative 2020s project, and cost reduction levers for future projects (FID 2030+)



Data source: DOE analysis, quarterly earnings reports, public utilities commission filings

The path to long-term cost reductions begins with deploying a critical mass of projects today.

While costs are important, offtake prices reflect a broad array of value provided by projects. Offshore wind is a central pillar of decarbonizing coastal demand centers, and offtake costs reflect not only the cost to generate clean power, but also the cost to deliver power to coastal load centers (transmission) and the opportunity to revitalize maritime infrastructure and economies.

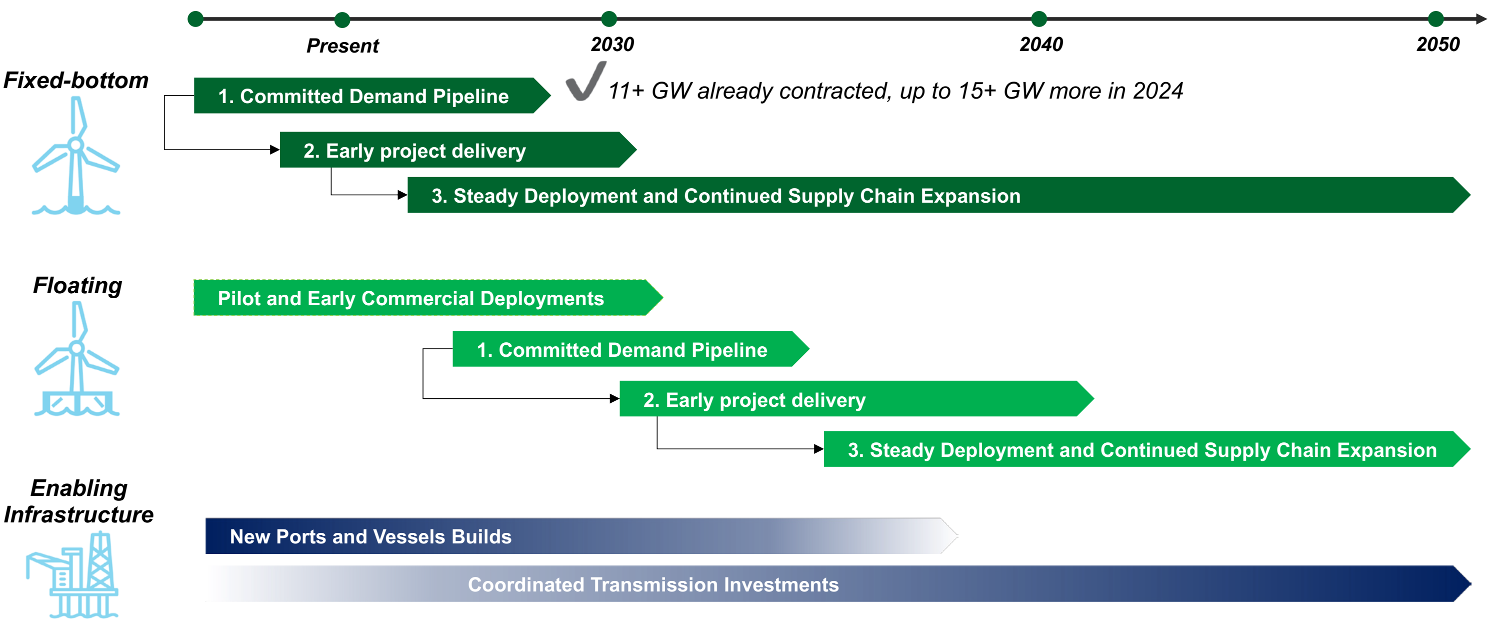
2 For perspective, the BNEF U.S. offshore wind forecast projects a ~40% LCOE reduction from 2023-2035.

Pathway to Commercial Liftoff

Liftoff defined: U.S. offshore wind will achieve "liftoff" when the sector is actively contributing to state decarbonization targets, with a sustained project pipeline and regular deployment.

The sector will leverage OSW-ready maritime infrastructure, an ecosystem of suppliers with U.S. experience, and a streamlined and predictable project development and offtake process, all to produce competitive cost levels and steady sector expansion.

E.S. Figure 4 – Pathway to Liftoff



Full-scale offshore wind liftoff will proceed in three overlapping phases: (1) A committed demand pipeline, (2) early project delivery, and (3) steady deployment and continued supply chain expansion.

1. **Committed Demand Pipeline**: demand certainty for long-term OSW offtake agreements is critical to unlock private investment into offshore wind development, supply chains, and long-term transmission buildout.
2. **Early Project Delivery**: deploying the first 10-15 GW of U.S. projects will offer the industry valuable experience with U.S. development and construction processes, and these early movers will help fund the key enabling infrastructure and supply chain investment necessary to facilitate long-term buildout.
3. **Steady Deployment and Continued Supply Chain Expansion**: once the industry has gained momentum with new projects consistently delivered on time and on budget, the industry can continue to expand and deploy GWs of projects annually to reach long-term decarbonization goals.

In the fixed-bottom wind market, phase 1 is on track for liftoff, phase 2 is underway, and phase 3 will follow soon.

The floating wind market is earlier stage. The path to floating wind liftoff requires early planning for infrastructure (ports, assembly yards, transmission), establishing demand frameworks, and adaptive ecosystem management. Taking these actions now can help keep active U.S. developments on-track as innovation and early-movers continue to lead to long-term sector maturity and cost reductions globally.[i] These investments and planning are required today to unlock floating wind as a tool for U.S. decarbonization.

Enabling infrastructure will be key to liftoff, across both fixed-bottom and floating wind markets. This includes critical supply chain links: the availability of ports and vessels will set the annual deployment potential of the U.S. market, and widespread expansion across component supply chains will be required to support growing demand both in the U.S. and abroad. Transmission buildout is also key: offshore wind projects face interconnection risks and cost challenges today, and long-term planning can de-risk future deployment and help build a more resilient and efficient grid long term.

The federal government is also working to support Offshore Wind Liftoff, through long-standing programs and new resources made available through the Bipartisan Infrastructure Law and the Inflation Reduction Act.

Challenges & solutions underway

Challenge	Solutions Underway
1. **Recent offtake cancellations,** driven by macroeconomic conditions, create timing uncertainty and funding gaps for sector buildout.	• Competitive procurements ("re-bids") for 2020s projects that secured offtake pre-2023 • Revised projects that are deliverable under current market conditions, and that reaffirm commitments to fund long-term enabling infrastructure needs (vessels, ports, etc.)
2. **Current market structures** expose the sector to exogenous risks and require early mover projects to carry the costs and execution complexity of long-term industry buildout needs.	• Improved sequencing of offtake with permitting & project FID • Offtake refinements to incorporate risk mitigations and prioritize project deliverability • Targeted investments in enabling infrastructure, especially during the pre-FID funding gap
3. **Industry lacks market visibility** to plan long-term investment cases, especially for supply chain needs.	• Clear procurement schedules that provide demand visibility and consistency • Collaboration to support supply chain and transmission buildout on a regional level • Industry consensus on technology specifications and standards for supply chain buildout
4. **Transmission risks development bottlenecks and grid inefficiencies** via onshore interconnection, offshore project design, and wider network buildout.	• Coordinated POI identification and solicitations for onshore upgrades across multiple OSW projects • OSW project sizes and standards tailored to low-cost offshore transmission and efficient interconnection • Mobilization of interregional transmission planning

The offshore wind sector faces four major challenges it must overcome to achieve liftoff. Many solutions are already underway, following leadership from state energy agencies, and learnings across the industry. The table below synthesizes this progress—efforts that will remain essential for consistent long-term deployment.

The sector today is poised for liftoff, beginning with the 10-15 GW of projects with a path to reach FID in the next few years. These projects will lay the foundation for consistent long-term deployment, decarbonization, and economic benefit across the country.

Key Terminology & Abbreviations

Capacity factor: The ratio of the electrical energy produced by a generating unit for the period compared to the electrical energy that could have been produced at continuous full power operation during the same period.

CapEx: The "capital expenditure" required to construct a project, from final investment decision to commercial operation date

COD: "commercial operation date," which marks the date a project is fully commissioned and delivering full power to the grid

DevEx: The "development expenditure" required to bring a project from initial developer site control to FID

DOE: The United States Department of Energy

EEJ: Energy and Environmental Justice

FID: "Final Investment Decision," the stage gate at which a project generally moves from development to financial close and construction. For an offshore wind project, this typically falls roughly 2-4 years before COD.

GHG: Greenhouse gas

HVAC: High Voltage Alternating Current (AC)

HVDC: High Voltage Direct Current (DC)

Indigenous Knowledge is a body of observations, oral and written knowledge, innovations, practices, and beliefs developed by Tribes and Indigenous Peoples through interaction and experience with the environment[3]

IRA: The Inflation Reduction Act (Public Law 117-169)

ISO: "Independent system operator," an independent, federally regulated entity established to coordinate regional transmission in a non-discriminatory manner and ensure the safety and reliability of the electric system

ITC: Investment Tax Credit

LCOE: "Levelized cost of energy," a simple measure of energy production costs over a project's lifetime. It is calculated based on the net present value of lifetime costs and energy generation.

LPO: The Department of Energy Loan Programs Office

O&M: "Operations & Maintenance"

Offtaker: An entity that buys the product being produced by a project or uses the services being sold by a project, which in the case of the offshore wind market is often electric power and environmental attributes purchased by state agencies.

OpEx: The operational expenditure required to maintain and operate a project across its lifetime

OREC: "Offshore Renewable Energy Credit," a type of renewable energy credit that represents the environmental attributes for a unit of offshore wind energy. Some states award OREC offtake contracts rather than PPAs, but these OREC terms are structured to offer projects long-term revenue certainty, similarly to a PPA.

OSW: Offshore wind

PPA: "Power Purchase Agreement," a long-term contract between an electricity generator and an offtaker.

POI: "Point of Interconnection," the onshore injection point and interface between an OSW project and the grid

PTC: Production Tax Credit

R&D: Research and development

ROW: Right-of-Way (e.g., for cable corridors)

RTO: "Regional transmission organization," an electric power transmission system operator that coordinates, controls, and monitors a multi-state electric grid

WACC: Weighted Average Cost of Capital

WTG: Wind Turbine Generator

WTIV: Wind Turbine Installation Vessel

3 Indigenous Knowledge is applied to phenomena across biological, physical, social, cultural, and spiritual systems. Indigenous Knowledge can be developed over millennia, continues to develop, and includes understanding based on evidence acquired through direct contact with the environment and long-term experiences, as well as extensive observations, lessons, and skills passed from generation to generation. Indigenous Knowledge is developed by Indigenous Peoples including, but not limited to, Tribal Nations, Native Americans, Alaska Natives, and Native Hawaiians. Each Tribe or Indigenous community has its own place-based body of knowledge that may overlap with that of other Tribes.

Purpose of Liftoff Reports

Liftoff reports describe the market opportunity, current challenges, and potential solutions for the commercialization of interdependent clean energy technologies. Liftoff reports are an ongoing, DOE-led effort to engage directly with energy communities and the private sector across the entire clean energy landscape. Their goal is to catalyze rapid and coordinated action across the full technology value chain.

Reports will be updated regularly as living documents and are based on best-available information at time of publication. For more information, see Liftoff.Energy.gov

Objectives and Scope of this Liftoff report on Offshore Wind

These reports are meant for a diverse audience of stakeholders who can help accelerate liftoff for offshore wind. For the audience unfamiliar with offshore wind, this report aims to build foundational understanding of the value proposition, market trends, market outlook, and drivers of success of this technology and sector. Among more experienced audiences, the report aims to catalyze and organize a dialogue between DOE, energy corporations, policymakers, utilities, ISOs/RTOs, research organizations, advocacy groups, and more around challenges and potential solutions for liftoff. Building on this report, future efforts can include near-term actions as well as continued analysis and longer-term roadmaps for scaling offshore wind deployment.

This report is organized as follows:

Chapter 1: Overview & Value Proposition introduces offshore wind technology and summarizes its value proposition, including the overall deployment potential.

Chapter 2: Offshore Wind Technology & Market Outlook summarizes the U.S. project pipeline and near-term deployment forecasts, analyzes recent market trends, and provides an outlook for offshore wind cost reduction potential.

Chapter 3: Pathway to Commercial Liftoff describes the opportunity for offshore wind to reach liftoff this decade and outlines the key conditions required to reach liftoff, including detail on priorities for enabling infrastructure such as transmission and supply chain.

Chapter 4: Market Challenges & Solutions Underway discusses 4 key challenges associated with commercial liftoff and associated solutions underway in the market.

Chapter 5: Metrics & Milestones suggests metrics for leading indicators, lagging indicators, and key outcomes for tracking offshore wind liftoff.

Chapter 1: Overview & Value Proposition

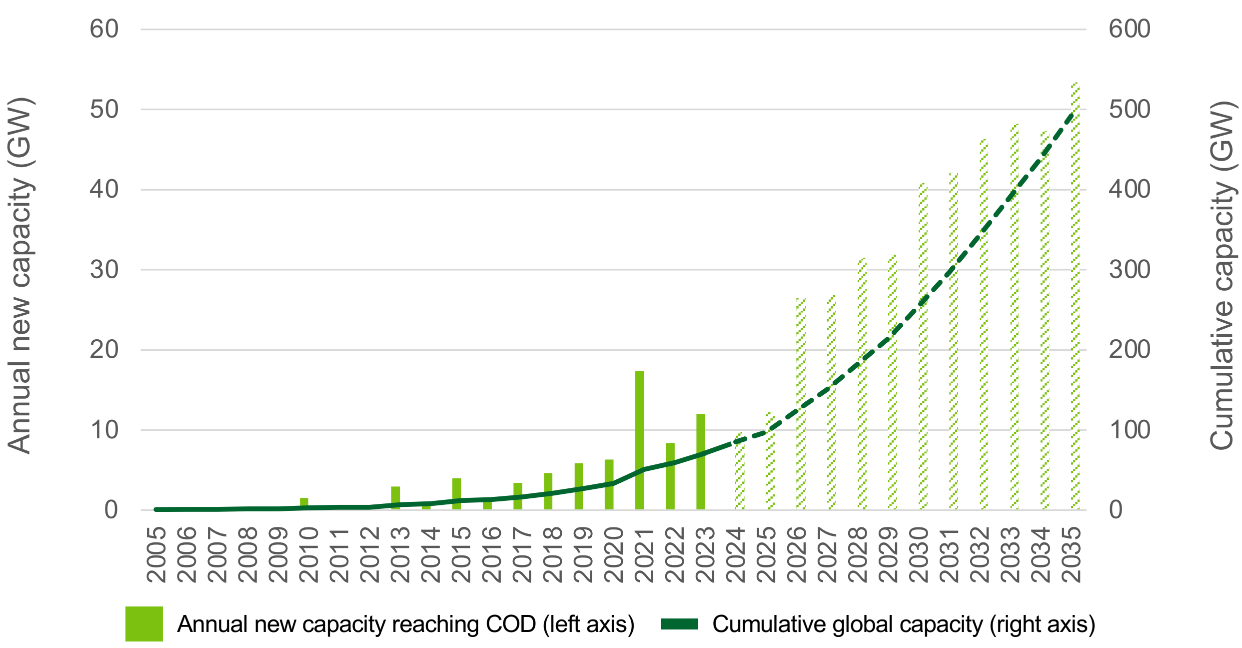
Key Takeaways:

- Offshore wind can play a key role in decarbonizing coastal U.S. electricity generation—it is a commercially mature technology with a high capacity factor and a production profile well suited to complement other renewable sources and meet winter load growth.
- Offshore wind relieves siting pressure for land-based clean power and transmission infrastructure; projects connect directly to coastal energy demand centers and drive economic development.
- Offshore wind presents a speed and scale of deployment in key regions that is unlikely to be achieved by other clean energy sources alone, especially for near-term markets.
- Leading market forecasts project that ~40 GW of U.S. offshore wind will be built by 2035, and deployment has the potential to scale to over 100 GW by 2050. The near-term deployment of offshore wind at scale can help drive faster decarbonization for regions that may otherwise need to prolong reliance on fossil fuels.

Technology Background

Offshore wind is a commercially mature technology with deployment at scale globally—roughly 70 GW is operational globally today. The global market has scaled by over 10X in just the past decade and is projected to grow another fivefold over the next 10 years. In the U.S. today, approximately 200 MW is operational with roughly 5 GW of projects under construction as of April 2024.

Figure 1 – Global cumulative offshore wind capacity: Deployment to date and projected



Data Source: 2023 DOE OSW Market Report through 2028 (future projections based on developer-announced CODs); BNEF market forecast 2029-2035

Offshore wind farms generate electricity from groups of turbines, which are mounted on top of towers supported by a base foundation. Foundations are either fixed to the seafloor ("fixed-bottom OSW") or, in water depths beyond roughly 200 feet, floating platforms. Fixed-bottom foundations are directly connected to the seafloor (most commonly via monopile or jacket structures) and floating platforms use mooring lines connected to anchors installed in the seabed.[ii]

Much of the analysis in this report focuses on the fixed-bottom market, as it represents the majority of deployment today, but floating wind is discussed in callout boxes throughout the report—it will play an increasingly important role as the global and U.S. floating markets mature, and deeper waters come into focus to reach deployment and decarbonization goals.

Compared to wind over land, wind over water is generally higher speed, more consistent, and less turbulent. Marine logistics also allow for more efficient larger turbines than can be installed onshore, with 11 to 15 MW turbines planned for most of the near-term offshore wind project pipeline (compared to 3-3.5 MW onshore). With a technical resource potential exceeding 4,200 GW in water depths up to 1,300 meters (m), offshore wind could theoretically meet today's U.S. electricity demands by more than three times.

The Value of Offshore Wind

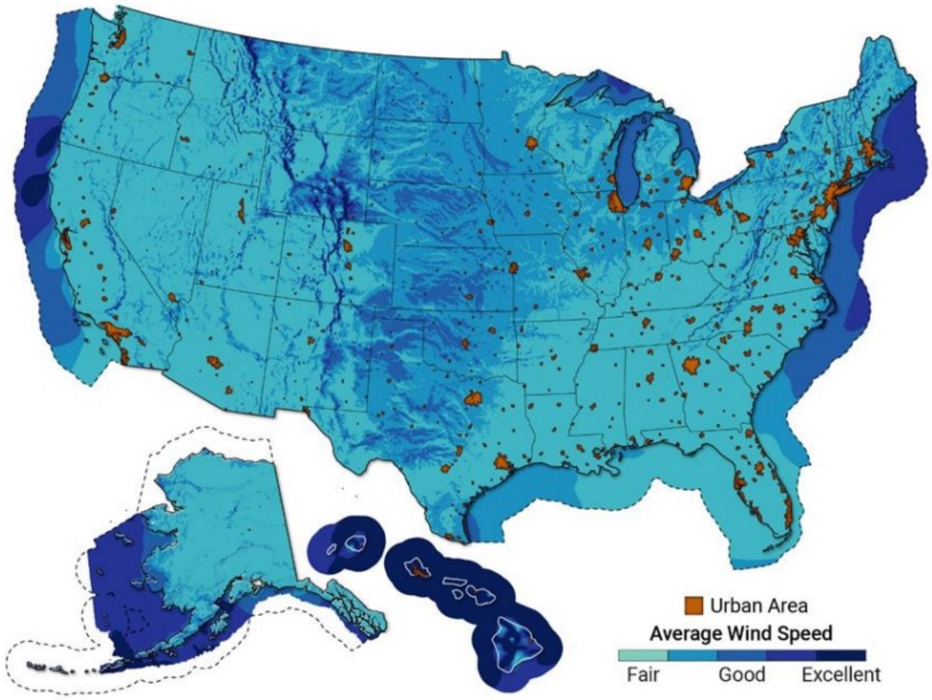
Critical role for decarbonization

Offshore wind's value proposition complements other clean resources. The need for offshore wind expands based on emissions reduction targets, load growth, and the availability and cost of alternative clean power sources—which often have limitations to scaling economically to serve coastal load.

Proximity to energy demand

Offshore wind resource can be found directly adjacent to coastal population centers with high energy demand. Offshore wind projects typically include miles of subsea cables to transport power onshore, so the scope of an offshore wind project necessarily includes transmission infrastructure to deliver clean power to coastal regions. This offshore transmission buildout also offers a new pathway for networked inter-regional transmission long term (see Chapter 3).

Figure 2 – Offshore wind resource is adjacent to urban areas with high energy demand



Source: National Renewable Energy Laboratory; DOE 2023 Advancing Offshore Wind Energy in the United States

Large scale to support clean energy goals and relieve onshore constraints

Offshore wind relieves siting pressure for land-based clean power and transmission infrastructure. Growing siting conflicts and the depletion of favorable sites onshore increase the need for OSW. Especially in the Northeast, where the bulk of mature OSW projects are today, onshore wind and solar buildout has lagged behind that of other U.S. regions due largely to siting constraints (see "the value of near-term deployment" below). Offshore wind can also reduce the need for new onshore transmission to deliver clean power to the coast; bulk transmission buildout on land is constrained by siting challenges and successful projects can take 10+ years build.

Clean power generation and energy mix can shift meaningfully with the addition of relatively few offshore wind projects. Due to economies of scale, a single offshore wind farm is usually between 800 MW and 2,000 MW. Moreover, states have the ability to drive OSW project development and can procure GWs of offshore wind at a time; many coastal states see OSW as critical in their decarbonization plans and have established mechanisms to competitively procure large volumes of OSW.

Tens of GW of shovel-ready deployments today

Offshore wind (OSW) is uniquely positioned to deploy tens of GWs of clean power to East Coast energy demand centers this decade. States already have 16+ GW under contract as of April 2024, with up to ~15 GW to be awarded in 2024 alone. This near-term deliverability at scale is one major part of offshore wind's value: it is a commercially ready technology with a growing global market, ready to deploy at scale.

Moreover, grid planning by system operators assumes offshore wind buildout this decade for decarbonization and grid reliability; the 2020s project pipeline will provide near-term greenhouse gas (GHG) reductions. These projects will become a critical source of power generation, reliability, and decarbonization this decade – clean alternatives are unlikely be delivered at equivalent scale or speed.

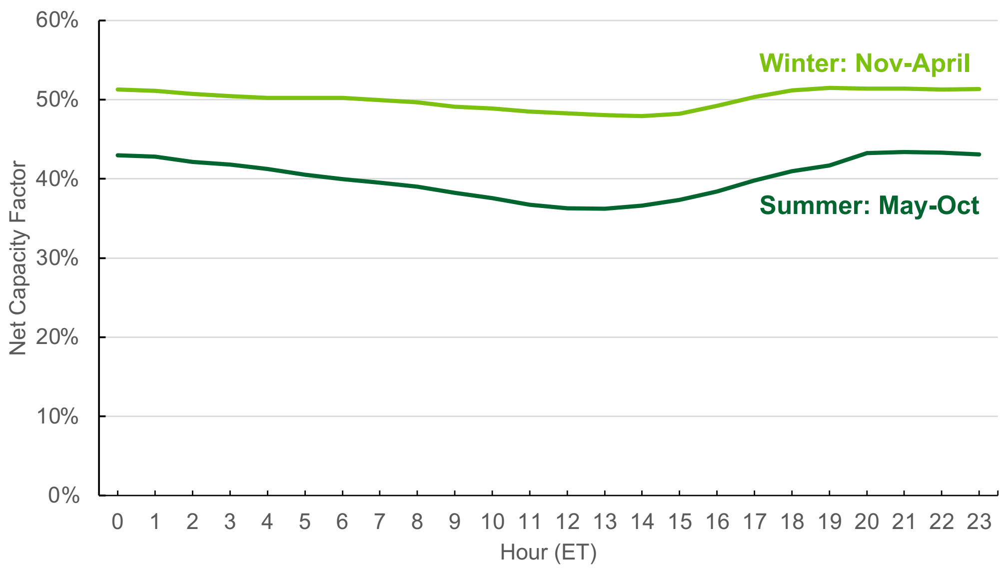
System-level value

Offshore wind capacity offers system-level value to the grid. It supports grid reliability and resource diversity, with average capacity factors higher than typical onshore wind and solar PV projects. Offshore wind also complements onshore renewables' production profiles, with its relatively stable intraday capacity factor, and highest production in winter months.

With its relatively high average capacity factor during mornings and evenings, offshore wind can support other balancing resources to serve wider grid balancing needs in a decarbonized grid (e.g., smoothing the "duck curve"). These reliability benefits can be augmented with the addition of energy storage adjacent to offshore wind interconnection points, with behind-the-meter storage offering additional benefits back to offshore wind farms themselves (e.g., black-starts).

The North American Electric Reliability Corporation (NERC) projects peak winter demand to increase an estimated 91 GW by 2033; a path consistent with net-zero emissions economy wide by 2050 would require even greater peak demand growth from electrification and domestic manufacturing.
Some Northeast ISOs are forecasting winter peak demand may overtake summer peak demand by 2035

Figure 3 – Offshore Wind Winter vs Summer Capacity Factor in the Northeast (for representative 45% CF site)



Data Source: Global Wind Atlas.

Note: values represent a linear scaling of hourly wind resource averages to capacity factor

Economic Development

Offshore wind drives economic development nationwide. The sector creates opportunities for sustainable job creation, new domestic manufacturing, and continued investments to revitalize legacy maritime infrastructure (e.g., ports, vessels, coastal manufacturing).

Achieving the administration's goal of 30 GW by 2030 would translate to more than 77,300 employed workers in jobs induced by offshore wind activity, capital investments in offshore wind energy projects of more than $12 billion per year, and 5-10 new manufacturing plants. This would include jobs across the supply chain, construction, project development, and operations. Infrastructure investments also include construction and operations & maintenance (O&M) ports, coastal manufacturing, and large installation vessels for a total of approximately $11 billion needed by 2030 to support the manufacture, transport, and installation of major offshore wind energy components.

Cost-competitive generation

Offshore Wind has sustained cost reduction potential as the sector continues to grow in the U.S. (discussed in detail in Chapter 2). However, costs are only part of the story—offtake prices reflect a broad array of value provided by projects. Offshore wind is a central pillar of decarbonizing coastal demand centers, and offtake costs reflect not only the cost to generate clean power, but also the cost to deliver power to coastal load centers (transmission) and the opportunity to revitalize maritime infrastructure and economies.

Comparing offshore wind to onshore equivalents at face value LCOEs is an incomplete picture of OSW's costs and value. Two key considerations include:

- Offshore wind offtake contracts ("PPAs") include transmission to load centers and economic development investments, which are excluded from PPA prices for most onshore generation.
- National U.S. cost benchmarks for onshore renewables are also weighted towards lower costs inland regions (Midwest, South, West) due to lack of onshore build in places like the Northeast.

Thus, comparing OSW costs to national onshore wind and solar benchmarks is not representative, and overlooks the added value of OSW that is capitalized in offshore wind PPAs.

In addition to the value monetized through project PPAs, offshore wind presents secondary benefits to the grid much like other clean generation sources. A study of the East Coast estimated offshore wind has additional value of $61 to $111+ per MWh due to wider system effects as more low-marginal cost renewables are added to the grid, suppressing electricity and gas prices.
This value would be realized as savings captured by energy consumers, and present an added value beyond that of OSW's electricity generation.

Continued cost reductions long term could also offer opportunities for broader economy-wide decarbonization efforts through co-generation—hybrid energy systems whereby offshore wind power supports behind-the-meter or off-grid application, industrial decarbonization, or non-electricity products (e.g., green hydrogen application).

The Role of Floating Wind

Roughly two-thirds of U.S. OSW potential (80% globally) exists in waters too deep for fixed-bottom foundations. Harnessing this resource requires floating OSW technology—turbines on floating platforms anchored to the seabed with mooring lines. Floating wind is moving from a pre-commercial to commercial phase and can deliver tens of GW of clean power to coastal regions.

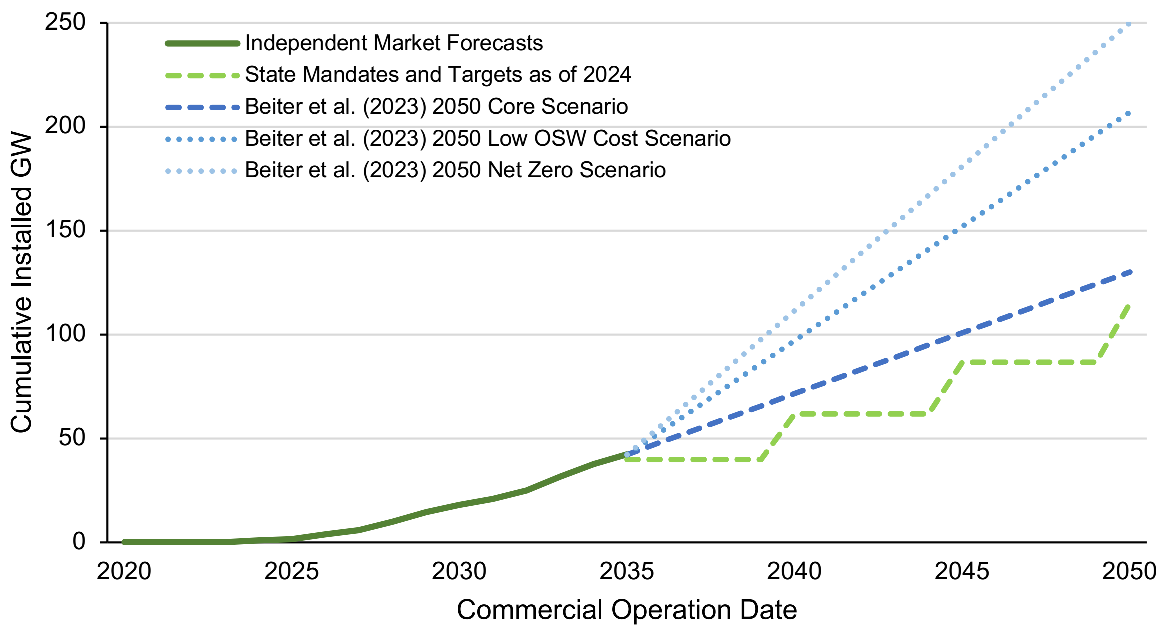
Floating wind is the only OSW resource available for key geographies, namely California and Gulf of Maine, with long-term potential to serve electricity demand across the East and West Coasts, the Great Lakes, and the Gulf of Mexico. Floating wind can be an essential tool to help decarbonize these regions, especially in areas where the potential for fixed-bottom OSW, onshore renewables, or other clean sources (e.g., nuclear, out-of-state imports) is limited. Investments and planning are required today to unlock floating wind as a tool for U.S. decarbonization, and to position the U.S. as a deployment leader in the global floating wind market.

	Fixed-bottom	Floating
Water depths	Shallower than ~ 200 ft water depth	Deeper than ~ 200 ft water depth
Cost	LCOEs ~ $130-150 per MWh today, with a path to <$100 per MWh by FID 2030 (see Chapter 2)	Higher than fixed bottom today, with potential to converge long term
Technology Maturity	Commercial projects deployed at scale (70,000+ MW installed globally)	Deployed pre-commercially (~250 MW installed globally)
Regional Potential	East Coast, Gulf of Mexico, some Great Lakes	All U.S. waters and the Great Lakes

Deployment Potential

Offshore wind can deliver over 100 GW clean power by 2050. With approximately 50 GW of seabed already leased to developers, early project deployment advancing, and additional lease areas planned for auction, there is a clear path to scaling deployment over the next several decades across multiple U.S. regions.

Figure 4 – U.S. OSW deployment: ~40 GW projected by 2035 and over 115 GW targeted by 2050



Data Source: BNEF, ERM Grip, 4C Offshore, Beiter et al. 2023, DOE Advancing Offshore Wind Energy in the United States

Note: State forecasts include state targets and mandates across the U.S., including East Coast, West Coast, and Gulf of Mexico

Current industry market forecasts extend through 2032-35 based on existing pipeline projects' status and expected CODs. For detail on near-term forecasts, see "the U.S. market today" section in Chapter 2.

After 2035, modeling and government targets suggest that total capacity could reach 100+ GW by 2050 in a decarbonized future. Today, state targets surpass 115 GW in total by 2050; individual state goals range from 1-2 GW on the low end, up to 25 GW, with target years ranging from 2030 to 2050—and many states considering offshore wind buildout do not have deployment goals today. Some state goals include procurement mandates; of the total ~115 GW of state targets, ~46 GW is mandated.

Current industry market forecasts project ~40 GW built by 2035, an average deployment of 4 GW/year over the next 10 years. *Meeting the 115 GW cumulative 2050 state targets would then require annual deployments of 5 GW per year—achievable with only a 25% increase above projected deployments in the next decade.*

A 100+ GW offshore wind future is corroborated by a recent study in *Nature* assessing OSW buildout. Modeling found OSW providing 133 GW by 2050 under a scenario with 95% power sector decarbonization by 2050, with ~250+ GW of OSW deployed in a net-zero energy system.

The primary drivers that determine total OSW deployment over the long term were found to be: (1) the extent of decarbonization, (2) load growth, (3) siting constraints, both on new onshore clean generation and potential offshore deployment, (4) onshore transmission expansion, and (5) the long-term cost trajectories for offshore wind and other technologies. As increased demand for clean energy drives saturation of high-quality sites for onshore renewables, particularly in regions with onshore siting constraints (e.g., the Northeast), the need for OSW increases. Modeling shows deployment initially concentrated off the East Coast and then scaling in other regions (West Coast, the Great Lakes, etc.). In all studied scenarios, most offshore wind capacity is deployed in the Northeast, with >20% of Northeast power demand met by OSW in 2050.[1]

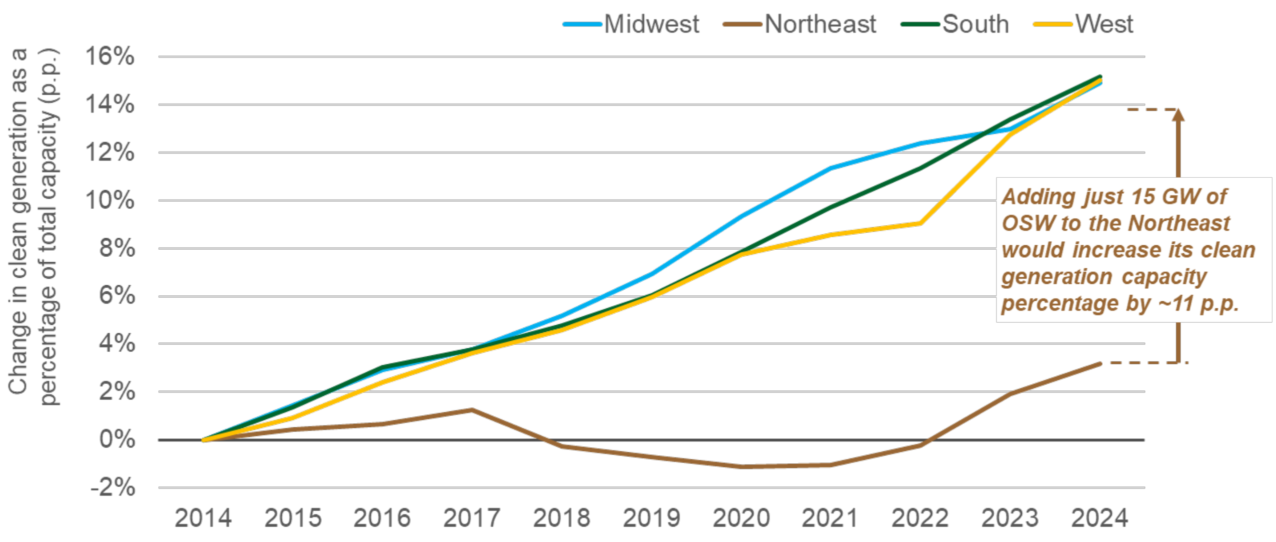
The value of near-term deployment

Decarbonizing while matching load growth will require fast deployment of clean sources. State renewables targets require new clean generation to meet near-term decarbonization targets, and alternatives to OSW are particularly limited in the areas with mature offshore wind developments—the East Coast. Load growth compounds the need to deploy clean capacity from new sources rapidly.

OSW can help meet load demands by providing near-term deployment at scale, particularly for regions that would otherwise need to prolong reliance on fossil fuels. In geographies that lag in renewables deployment (typically due to siting or transmission challenges), generation capacity added over the past decade has been mostly natural gas.

The figure below shows the increase in clean energy capacity as a percentage of total installed capacity (the change over time, represented as a percentage point increase). Over the past decade, the Northeast increased clean capacity by only 3 p.p. (from 30% to 33%), adding only net ~6 GW of clean generation, primarily solar. During this same time period, the Northeast added ~25 GW in gas capacity.

Figure 5 – Increase in clean energy capacity as a percentage of total capacity (percentage point increase), by census region



Data Source: U.S. Energy Information Administration (EIA) EIA-860 Annual Electric Generator Report (Historical State Data) and EIA Electric Power Monthly Table 6.2A. Regions shown are U.S. Census Regions; clean energy generation capacity is calculated as a percentage of total generation capacity each year; chart shows the percentage point change in this metric over time.

Adding just 15 GW of the Northeast would increase its clean power percentage by 11 percentage points. This would increase clean generation in the Northeast from a total of ~33% clean capacity in January 2024 (including solar PV, onshore wind, nuclear, and hydropower), to ~44% clean generation. *Adding 30 GW of OSW to the Northeast in the next 10 years, as is achievable based on the current project pipeline, would bring its total clean generation capacity to over 50%.*

Chapter 2: Offshore Wind Technology & Market Outlook

Key Takeaways:

- U.S. projects have faced cost pressures in recent years: The cost of U.S. projects rose from ~$85/MWh LCOE in 2020 to ~$140/MWh at the end of 2023, driven by increasing interest rates, inflation, and supply chain issues.
- Projects targeting final investment decision in 2023-26 saw the greatest risk exposure, due to recent cost increases (e.g., capex inflation 30-60%, and interest rates climbing to 5%+, a particular challenge given OSW projects' sensitivity to the cost of capital).
- The longer-term pipeline (offtake awarded in 2024 and beyond) has less risk of cancellations—developers now factor the current cost landscape project plans, the rapid and unprecedented cost headwinds are stabilizing, and some states are incorporating inflation risk-sharing mechanisms into offtake terms.
- The cost curve can bend. East Coast fixed-bottom offshore wind costs could be driven down to below $100/MWh within 5-10 years. Future projects may benefit from updated guidance for tax incentives, selected LPO support for qualifying projects, declining commodity prices, decreasing interest rates, supply chain buildout, deployment experience, and technology improvements.
- Failure to build projects today would risk delaying cost reductions and extending risk exposure to the longer-term project pipeline, freezing investments, and pushing an industry with both short-term and long-term decarbonization momentum into dormancy.

Current state: U.S. Market Today

The market today is at an inflection point, as the industry's foundation is built out through the first commercial-scale deployments. Constructing the 10-15 GW of projects with a path to reach Final Investment Decision (FID) in the next few years will establish the viability and promise of U.S. offshore wind. Credibility of the U.S. offshore wind market with investors, developers, states, and stakeholders depends on successful execution of a critical mass of planned East Coast projects. Future cost reductions require upfront investments, steady buildout rates and consistent utilization of constrained assets (e.g., ports); delaying buildout would delay the path to lower costs.

This chapter discusses near-term deployment projections, recent market turbulence (with an emphasis on cost and risk challenges faced by early U.S. projects), and the market outlook moving forward.

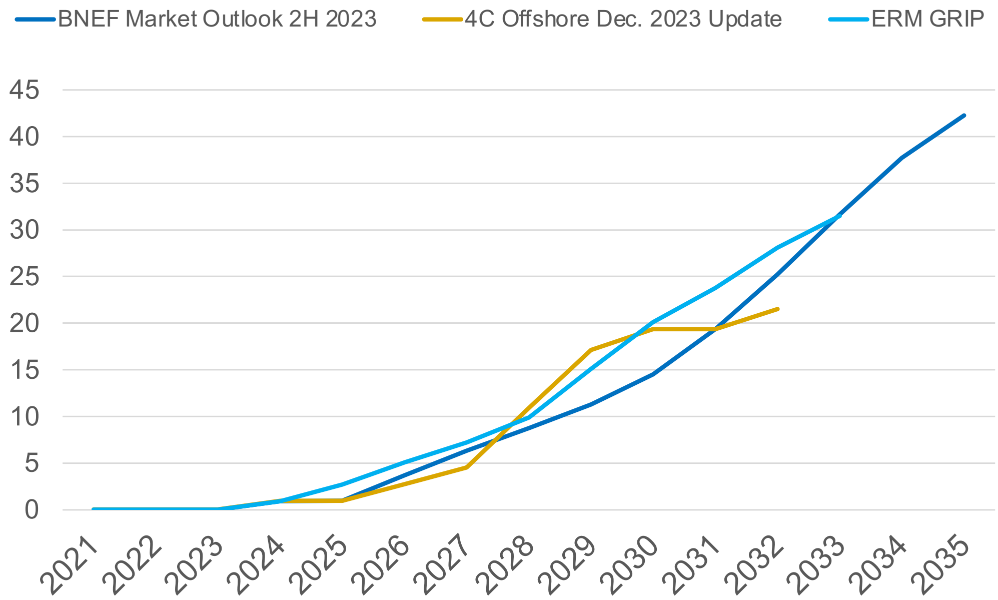
Near-term deployment forecasts

U.S. offshore wind is expected to scale quickly this decade. The below chart shows three independent forecasts for offshore wind energy deployment in the U.S. through the mid-2030s, illustrating the high degree of expected market growth. All three forecasts show rapid installation ramping up over the next five years. (Variability between the three forecasts may be associated with interpretations of the year, size, location, and likelihood of future projects.)

These forecasts are built on the real-world project pipeline and state procurement targets set in statute—they generally account for recent offtake cancellations and rebids (as a snapshot in time as of the forecasts' publication). The majority of forecasted 2020s buildout is concentrated in seven East Coast states, but other states and regions are likely to follow quickly. The exact size and speed of U.S. offshore wind build-out will depend on the availability of installation vessels and port infrastructure, proactive onshore and offshore grid planning and upgrades, and sustained market demand (see discussion of long-term modeling in Chapter 1), as well as continued regulatory efficiency.

The Biden-Harris Administration is continuing to advance the goals of 30 GW of offshore wind by 2030 and 15 GW of floating offshore wind by 2035, and forecasts for the late 2020s and early 2030s can continue to shift based on specific project commission dates.

Figure 6 – Near-term U.S. offshore wind deployment: Industry forecasts as of Q1 2024[4]



Note: Forecasts extend only through 2032-35, due to limited visibility into project pipeline beyond ~10 year time horizon

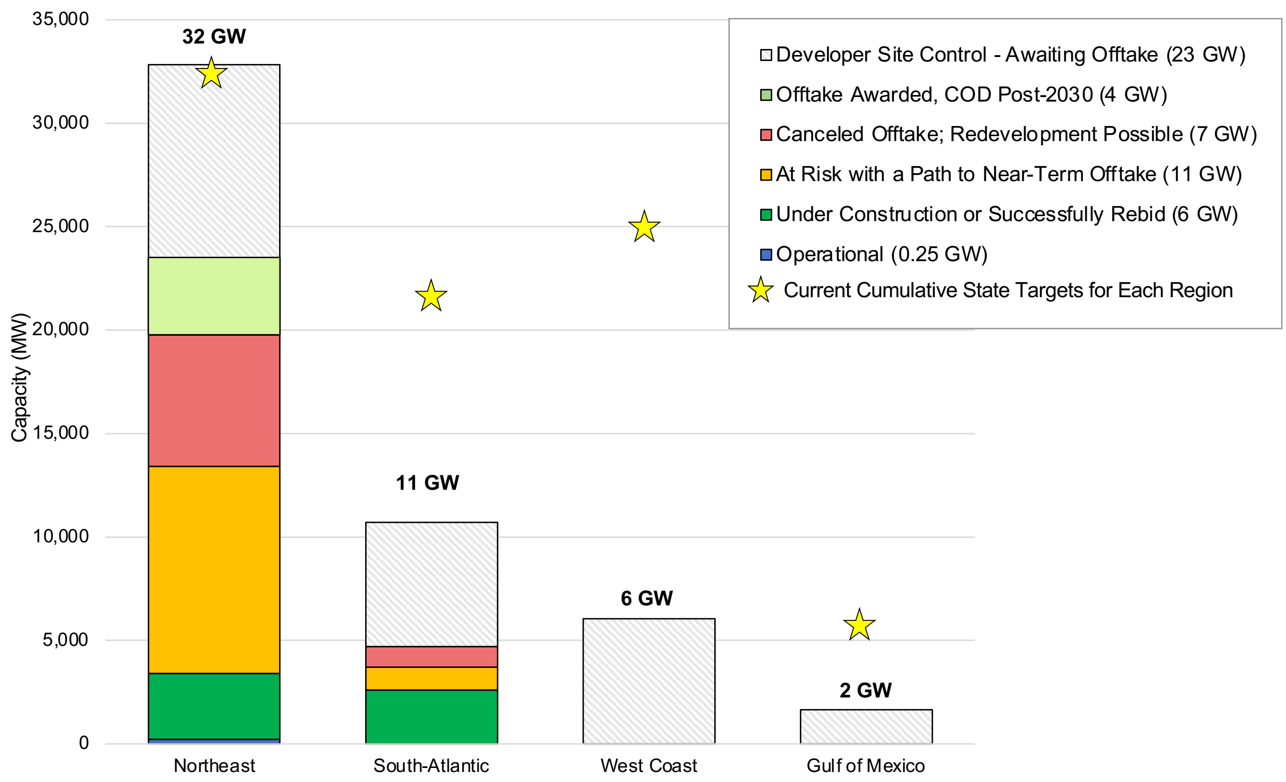
Data Source: BNEF Market Outlook, 4C project pipeline, ERM project pipeline

Approximately 250 MW are operational and 5 GW are under construction as of April 2024. In the next few years, an additional 5-10 GW of projects have a path to reach Final Investment Decision (FID) and begin construction. The full U.S. project pipeline today includes roughly 50 GW of seabed under developer control; projects are grouped by region and status in the below figure.

Some projects remain at risk and may not be viable under their original offtake terms—due primarily to macroeconomic cost pressures discussed in detail below. In some cases, projects have canceled offtake contracts after their developers determined the project is not financially viable under its original terms. Many of the at-risk projects have a clear path to "re-bid" in 2024—re-securing offtake by submitting a new project proposal under a competitive state offtake solicitation. Those that do not can still be redeveloped in the future.

4 Note: Forecasts extend only through 2032-35, due to limited visibility into project pipeline beyond ~10 year time horizon

Figure 7 – U.S. project pipeline: April 2024 snapshot



Note: Northeast refers to Northeast census region (states from ME to NJ), South Atlantic relates to South Atlantic census division (MD to FL)
Source: DOE Analysis

Long term, the industry is expected to continue scaling significantly, supported by cost reductions and increased demand for low-carbon energy.

Floating Offshore Wind – Market Status:

- **Potential in the U.S.** – Like fixed-bottom, hundreds of GW of floating wind could be deployed in the U.S. Floating technology unlocks OSW deployment in water depths >200 ft and in turn expands the geographies that can be served by OSW (e.g., West Coast and Gulf of Maine); state floating goals total ~36 GW; ME and CA likely to lead on procurement this decade followed by commercial-scale projects as soon as the early 2030s.
- **Global trajectory –** The floating wind industry is scaling globally over the next 10-15 years from large pilots to commercial-scale; the global market is forecast to deploy 20 GW by 2035 (BNEF H2 2023). The first 200+ MW scale projects globally are targeting CODs around 2030, after some projects experienced 1- to 2- year delays for due to a combination of cost increases, delayed pre-commercial deployments, and delayed policy frameworks abroad. Slower global deployment has implications for U.S. deployment, as commercial scale deployments abroad will de-risk U.S. projects.

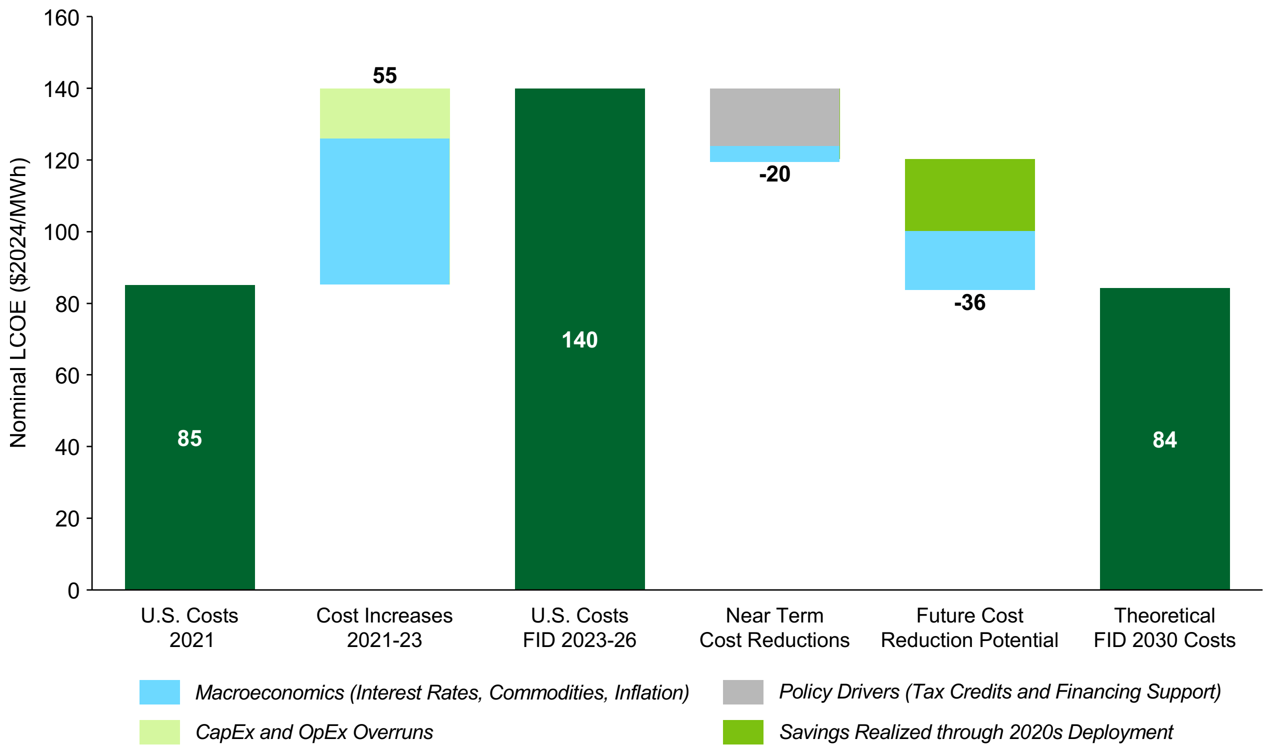
Offshore Wind Costs

Early mover projects faced a "perfect storm" of challenges and have provided valuable lessons on how to sequence and structure investments for a sustainable OSW industry. The LCOE of U.S. projects rose from ~$85 to ~$140 per MWh from 2021 to the end of 2023 (assuming consistent 30% ITC), though individual projects vary. Cost increases were driven by rapid inflation of equipment costs, rising interest rates, supply chain constraints, and schedule delays. Because these changes occurred during the 3- to 5-year interval between state procurement (locking in revenues) and final investment decision (locking in project costs) many projects canceled offtake contracts as their costs grew to exceed their secured offtake prices. Projects targeting FID in 2023-26 saw the greatest risk exposure, while the longer-term pipeline has less risk of cancellation due to (1) 2020s project and infrastructure buildout (2) stabilizing macroeconomic headwinds, (3) risk mitigations by states and developers, and (4) federal policy including support from the Inflation Reduction Act.

LCOEs below $100/MWh ($2024) are achievable for fixed-bottom projects by FID 2030, enabled by project deployment and associated supply chain and infrastructure development. Costs are dependent on macroeconomic conditions, state and federal offshore wind policy, offtake design, and the number of early movers that reach FID and begin construction in the next few years.

The path to long-term cost reductions begins with deploying a critical mass of mature projects today.

Figure 8 – Historical cost increases for a representative 2020s project, and cost reduction levers for future projects (FID 2030+)



Data source: DOE analysis, quarterly earnings reports, public utilities commission filings

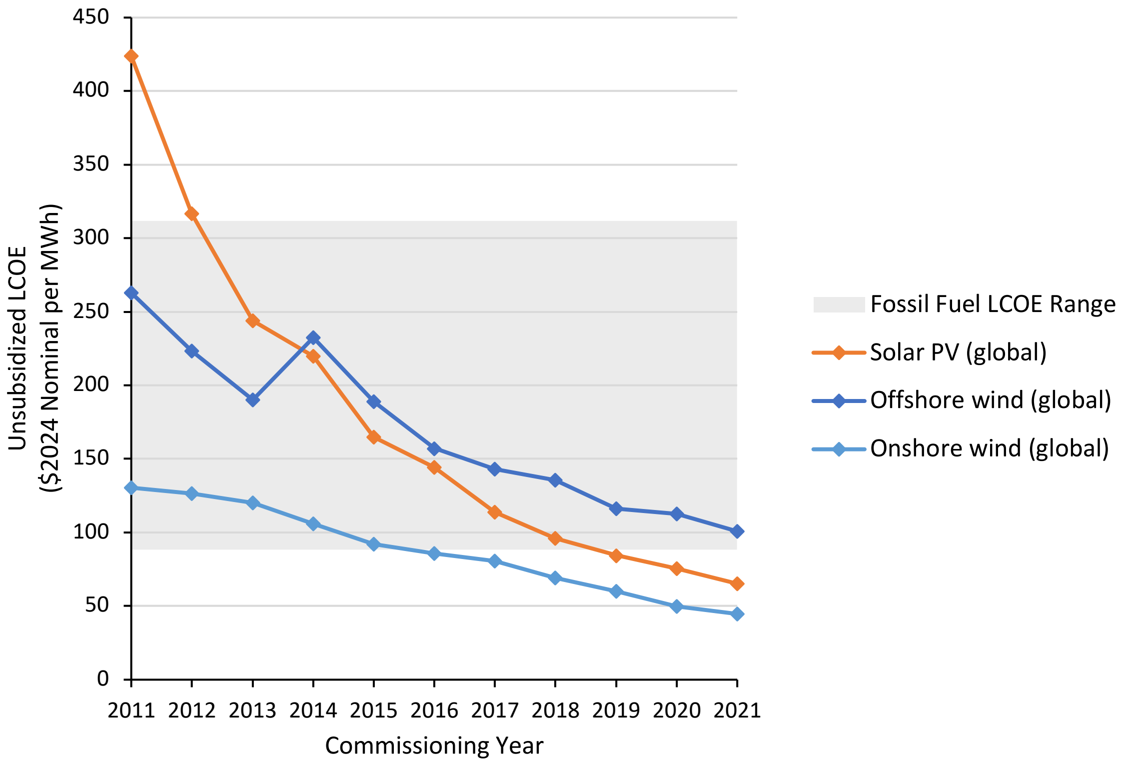
LCOE Primer: Interpreting cost figures in this report

The LCOEs quoted in this report are all nominal $2024 30-year LCOEs—a simplified metric excluding revenue escalation (considering CapEx and OpEx, as well as tax burdens and benefits, e.g., tax credits). LCOE is a simple measure of energy production costs over a project's lifetime, while offtake prices represent actual financial remuneration to projects over a set contract period. LCOE is a valuable proxy for offtake prices and trends and is an effective metric for comparisons of OSW costs across projects and markets. LCOE and bid prices are easily conflated and misinterpreted – it is important to ensure a consistent framework to evaluate costs. Given variations in terms between projects, it is impossible to compare face-value offtake prices across U.S. projects or international markets. In addition, offtake prices are often determined at auctions where market conditions, developer strategy, financial structuring, and perceived risks impact bidding behavior.

Global Context: Historical Cost Reductions

Globally, the cost and risk of offshore wind development has decreased significantly over time as deployment has scaled. As total installed capacity scaled from 3 GW in 2011 to 33 GW in 2021, the average LCOE of projects decreased by roughly 60%—projects reaching COD in 2011 cost ~$252/MWh on average, while projects reaching COD in 2021 had an average cost of $102/MWh (unsubsidized $2024 nominal LCOEs).

Figure 9 – Global offshore wind project costs have declined as deployment has scaled



Data Source: Renewable Power Generation Costs in 2022 (irena.org)

Note: For consistency, values are adjusted from $2022 real to $2024 nominal with a CPI factor of 1.05 and a real-nom factor of 1.21

Historically, cost reductions have been realized through a combination of supply chain learning & efficiencies, de-risked construction, technology innovations, reduced financing costs, and turbine & plant upsizing. The U.S. market has benefitted significantly from global deployments, but U.S. early movers face higher costs as discussed below.

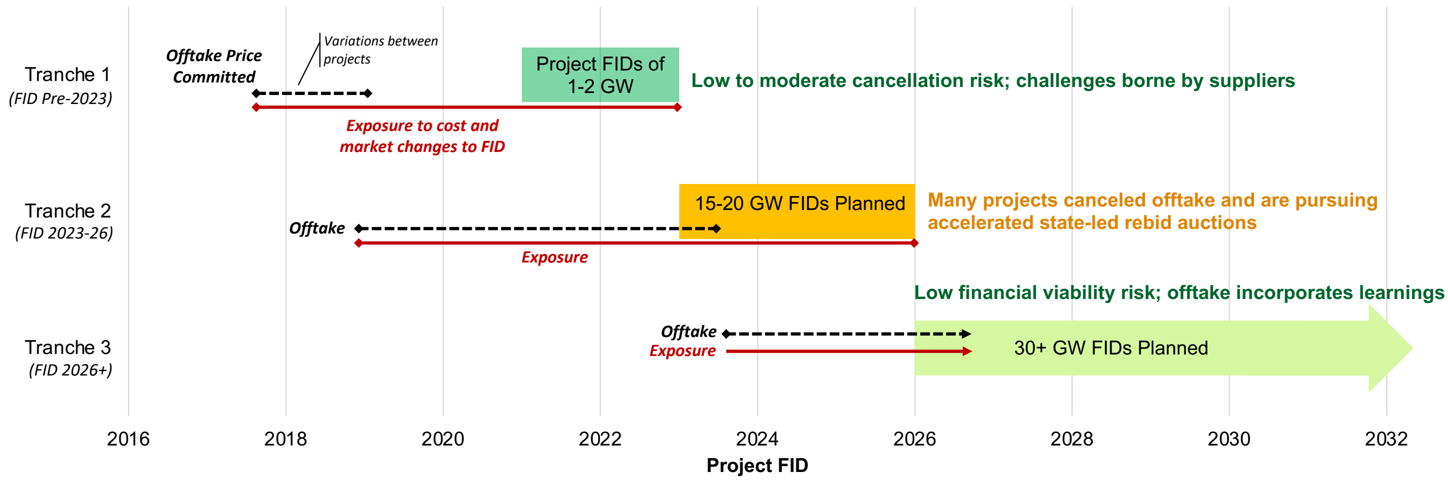
Cost Increases: Recent Market Turbulence

Projects affected by market shifts

Projects have historically committed to revenue pricing several years before securing binding costs from suppliers. This gap results from the 3-to-5 year interval between states' offtake price commitment (signing a PPA or OREC contract) and the point at which developers could make a final investment decision, or FID. Projects for which this timing gap overlapped with the dramatic shifts in the global economy were subject to extreme cost pressures. During this interval between offtake and FID, projects were exposed to changes to market conditions, such as inflation, supply chain disruptions, and interest rate increases.

In the figure below, projects are grouped into "tranches" based on their offtake and FID timelines. Whether this interval falls before, during, or after (Tranches 1, 2, and 3) the challenges experienced in 2022-2023 largely dictates the level of risk exposure for a project. These three tranches help characterize the pipeline throughout this report:

Figure 10 – Projects grouped by timing of offtake price commitment and FID



Source: DOE Analysis

- **Tranche 1** projects achieved Final Investment Decision (FID) before 2023 and were less exposed to cost pressures globally. Because of signed contracts, macroeconomic challenges had the greatest impact on suppliers (impacting their risk appetite for commodities exposure going forward), while costs were largely locked in for developers (though construction risks remained).

- **Tranche 2** projects are slated for FID from 2023 to 2026 (COD 2025 to 2030) and have been experiencing higher risk of offtake cancellation, because projects are negotiating supplier pricing now, with revenues committed prior to cost pressures.

- **Tranche 3** projects are those with offtake (revenues committed) in 2023 and beyond (post-macro pressure). This longer-term pipeline is less at risk of cancellations—developers now factor the current cost landscape into bids, and some states are incorporating inflation risk-sharing mechanisms into offtake terms. However, failure to execute Tranche 2 may shift industry stand-up risks and costs to Tranche 3.

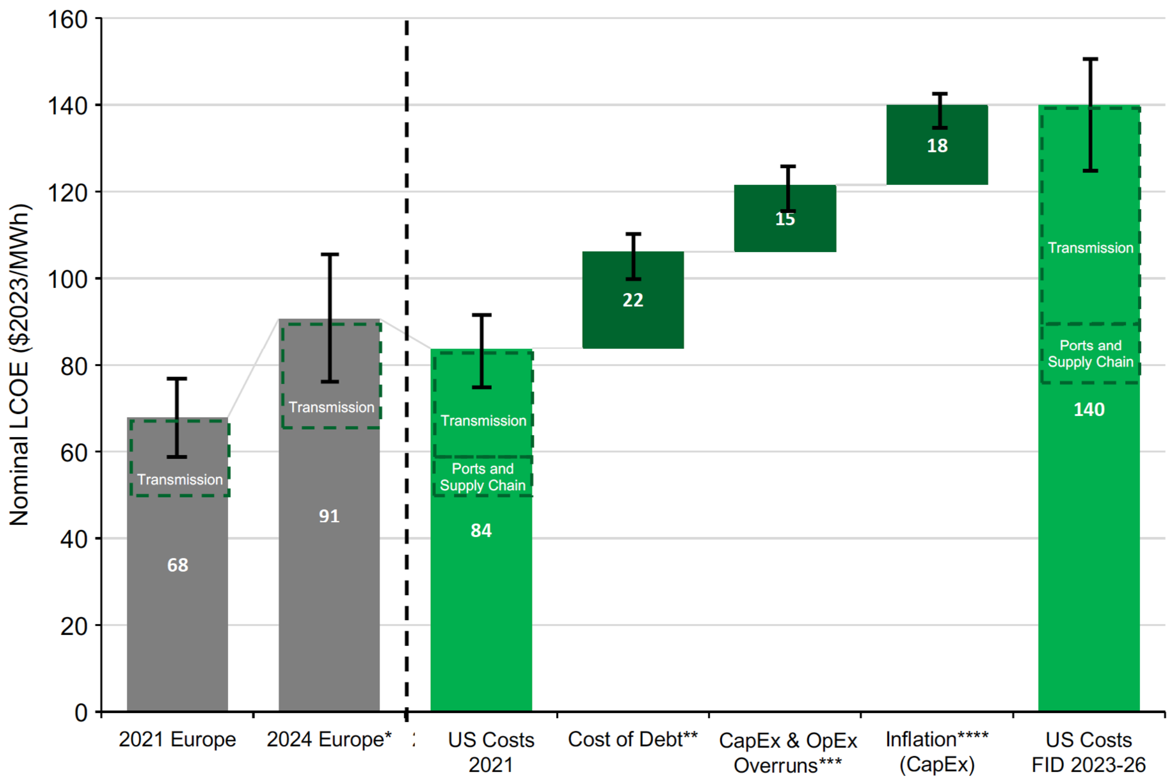
The challenges faced by Tranche 2 have been a focus of the industry in the past year. The following pages go into detail on the cost trends that impacted these projects, along with a pathway to cost reductions.

Cost pressures

Every project experienced financial pressures differently depending on its offtake terms, developer strategy, and project maturity, and these factors have stabilized and are better mitigated today. From 2021 to the end of 2023, the LCOE of U.S. projects rose from ~$85 to ~$140 per MWh (individual projects vary) due to increasing interest rates (driving up the cost of capital), inflation, and CapEx & OpEx overruns driven by supply chain issues.

Tranche 1 and some early Tranche 2 projects are being delivered under 2021 LCOE levels. The below chart shows a generic view of cost increases faced by Tranche 2 projects (making FID in 2023-26) from 2021 to the end of 2023. As shown in the waterfall chart below, these three primary drivers of cost increases were roughly equal in magnitude—each contributed to about one-third of the cost increase experienced by industry during this time period, though individual project experiences can vary widely.

Figure 11 – Historical cost increases affecting "Tranche 2" projects, 2021-2024



Data source: DOE analysis, quarterly earnings reports, public utilities commission filings

* *Note: High uncertainty. European experiences vary by project and country, and offtake mechanisms are often inflation-indexed, unlike in the U.S. (e.g., UK's offtake mechanism). LCOE values here include transmission from offshore substation to onshore POI.*

** *Cost of equity not considered, on the assumption that an offtake price bid is based on a nominal hurdle-rate commitment*

*** *Includes all CapEx and OpEx increases not related to indexed inflation, e.g., supply chain bottlenecks and previously unforeseen budget additions (esp. port, grid, vessels, local set-up, etc.).*

**** *Estimated using NYSERDA's NY3 offshore wind inflation index (see below)*

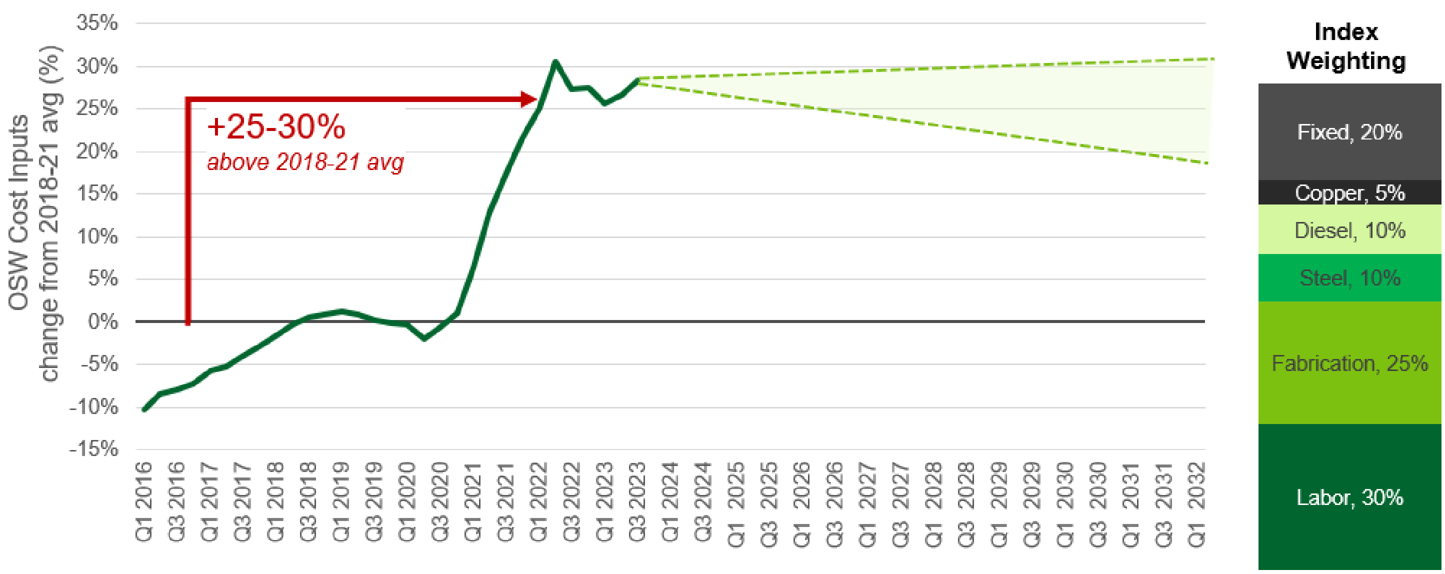
- **Cost of debt:** Offshore wind is highly sensitive to cost of capital a ~2% increase in cost of capital leads to a ~20% increase in LCOE (as assumed in above). Interest rates (and in turn, OSW cost of capital) spiked in 2022 and remain elevated, increasing 3-5 p.p. from recent levels. Interest rates have stabilized over the past year, and market forecasts project decreases moving forward. The forward curve for the Secured Overnight Finance Rate (SOFR) provides a market outlook for the cost of capital moving forward, representing a weighted average across multiple scenarios. The SOFR forward curve shows the cost of capital declining to ~3.50%, down from 5.31% today.

- **CapEx and OpEx overruns**: U.S. projects, especially first movers, were structurally more expensive than European projects, and the industry underestimated these higher costs—due to higher soft costs, industry setup costs (e.g., ports), onshore costs (grid, landfall, cables) and complex logistics (trans-Atlantic shipping, Jones Act compliance, etc.). Tight schedules and complicated logistics amplified knock-on delays and cost overruns across the supply chain.
- **Inflation**: Key commodities for offshore wind spiked in mid-2021 and remain elevated globally, increasing equipment costs. These are exogenous risks, which can be partially mitigated by hedging, risk-sharing mechanisms in offtake contracts, and condensing project timelines. Many commodities key to OSW have begun to stabilize (see figure below).

These cost pressures were experienced by OSW markets globally, and by other sectors domestically. Compared to the global market, LCOEs for U.S. offshore wind were roughly 25% higher than in Europe in 2021—primarily due to European projects benefitting from a more mature supply chain, simpler construction logistics, and less expensive onshore costs (landfall, cables, ports, interconnection). As indicated in the chart, Tranche 2 U.S. project LCOEs include port and supply chain contributions that are not typically required for projects in mature European offshore wind markets.

The figure below shows inflation of key inputs to offshore wind equipment costs over the past several years. The index used below aims to represent how inflation impacts offshore wind, though a wide range of commodities can impact OSW component pricing, and several different the indices are in use by states today. For the purposes here, costs have been normalized to the average index value from 2018-21—the period in which at-risk projects bid offtake prices.

Figure 12 – Composite trend of underlying offshore wind cost inputs; normalized to 2018-21 avg baseline

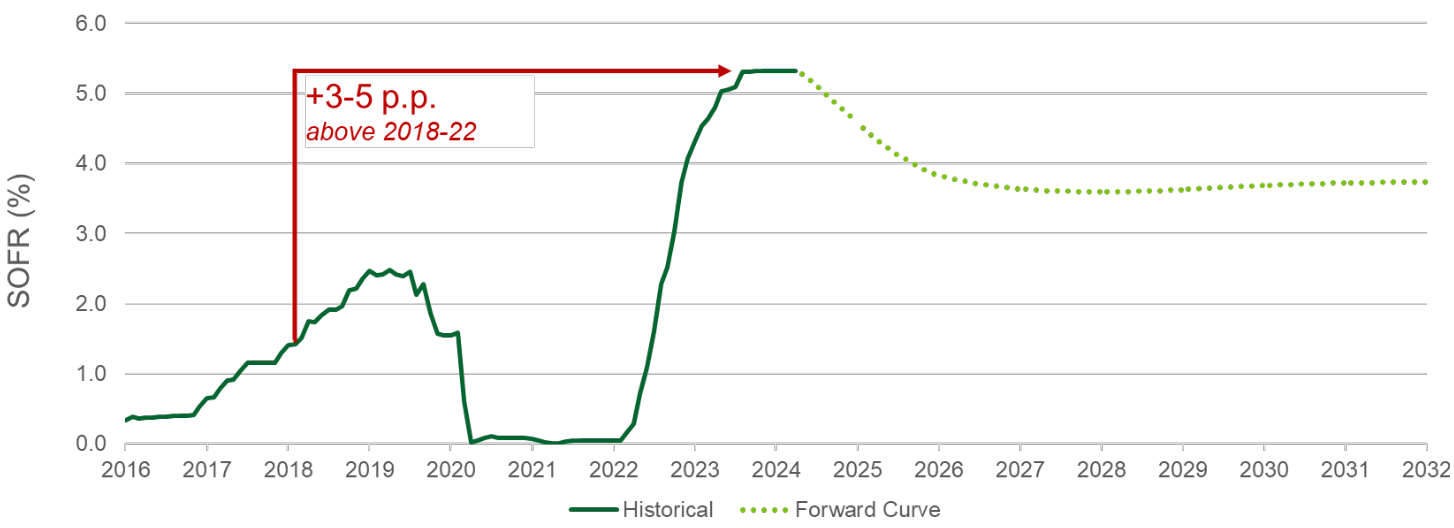


Data Source: NYSERDA and DOE Analysis

Note: This curve is based on the commodities in NYSERDA's inflation adjustment mechanism—an OSW-inflation metric introduced to help de-risk projects' inflation exposure (there are several different indices in use by states—see Chapter 4).

The figure below shows how interest rates changed during the offtake-FID timing interval for tranche 2 projects, using the Secured Overnight Financing Rate (SOFR) as a proxy for changes in offshore wind financing costs.

Figure 13 – Changes in financing costs over time (SOFR %)

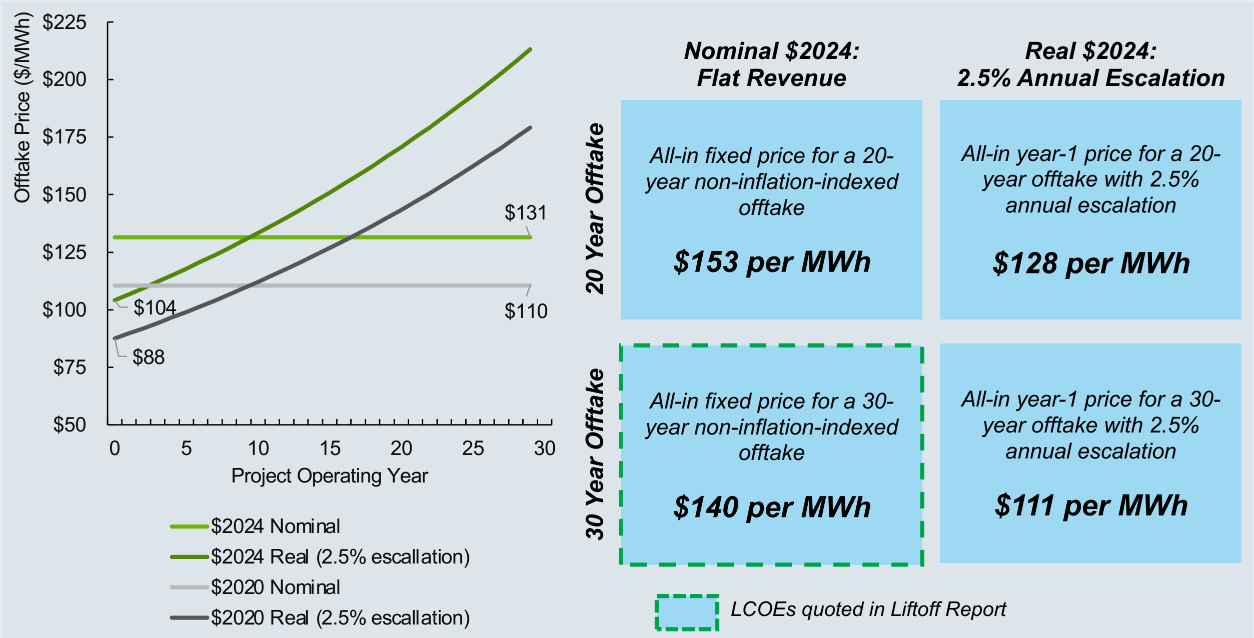


Data Source: Historical data FRED SOFR Index 04/2018-present, Fed Funds Effective Rate prior; Pensford SOFR forward curve

LCOE versus Offtake Terms

Across the U.S. market today, states quote offtake prices using different financial terms. The figure below shows a representative crosswalk of the nominal 30-year LCOEs quoted in this report to other common conventions for quoting OSW costs: real vs nominal, and 20 vs 30 year contracts. The LCOEs quoted in this report are closest to a NY-style OREC price (in contract length and nominal terms), but other states often quote offtake prices using different dollar-years, or in real-terms—by their year-1 values, with a 1-3% escalator (e.g., observed on projects in NJ and New England). All considered, DOE's LCOEs are consistent with recent project rebids.

Figure 14 – Four ways to show the same 30-year LCOE:



Source: DOE Analysis

Cost reductions: Market Outlook

LCOEs below $100/MWh ($2024) are achievable for fixed-bottom projects by FID 2030, enabled by prior supply chain and infrastructure development. Costs are dependent on macroeconomic conditions, state and federal offshore wind policy, offtake design, and the number of early movers that reach FID and begin construction in the next few years. The resulting impacts on competitively awarded offtake prices is secondarily impacted by auction design. The path to long-term cost reductions begins with deploying a critical mass of mature projects today.

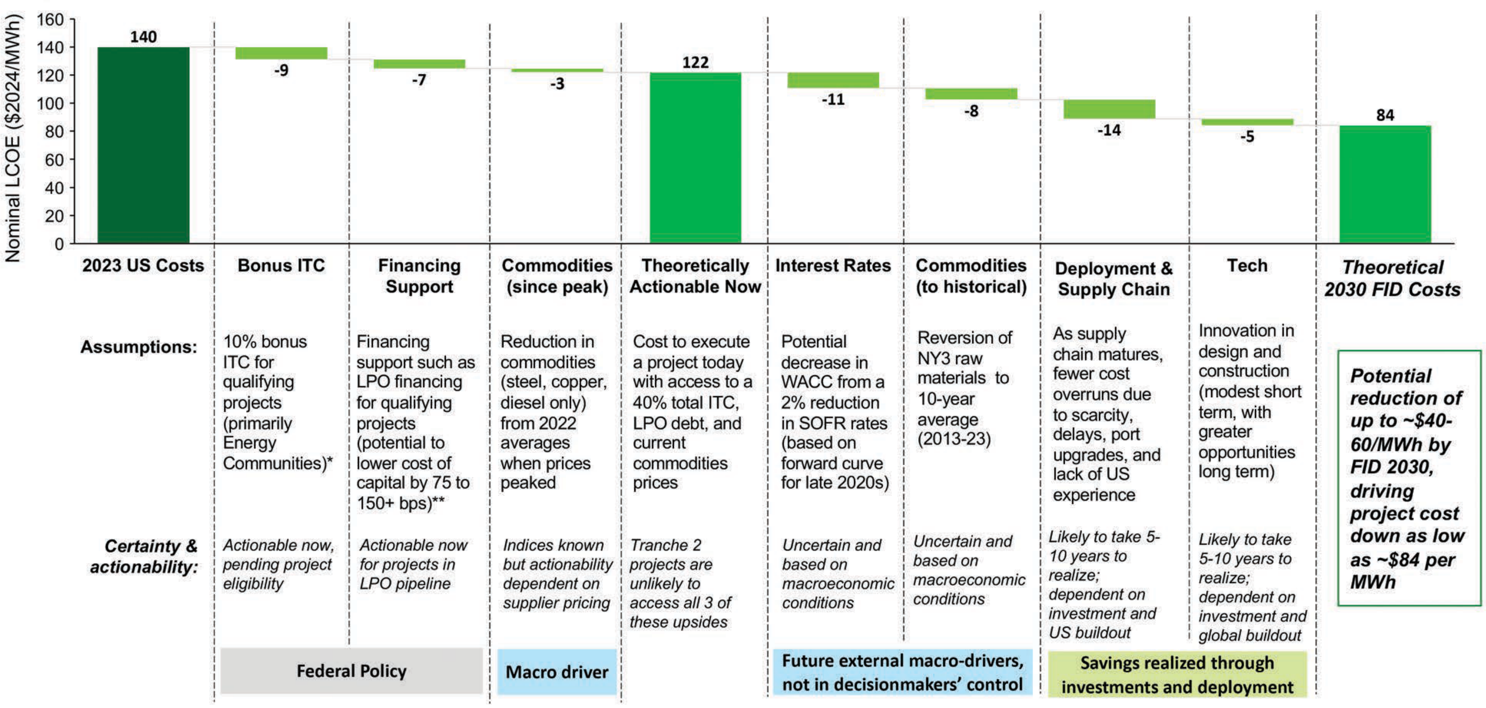
U.S. cost reduction potential through FID 2030

Three overarching levers present opportunities for cost reductions over the next 5-10 years: policy drivers, macroeconomic drivers, and deployment.

The figure below shows the cost reduction potential of a representative wind farm with an LCOE of $140 per MW ($2024 nominal) in late-2023. Combined, these levers could bring fixed-bottom LCOEs below $100 by FID 2030. This list is not exhaustive and there is inherent uncertainty in the precise and varied impact each factor will have on a given project.

This figure is not a cost forecast, particularly given the inherent uncertainty in exogenous factors like macroeconomic conditions, but rather a framework to understand the cost reduction opportunities with the greatest potential impact by FID 2030. The BNEF U.S. offshore wind forecast projects a ~40% LCOE reduction from 2023-2035 (driven by 20-25% cost reductions each in CapEx, OpEx, and financing).[iii]

Figure 15 – Cost reduction potential for fixed bottom projets reaching Final Investment Decision by 2030



Source: DOE Analysis

** Industry expects additional 10% bonus ITC for Domestic Content may be realized for selected projects by late 2020s, but with value primarily captured by the supply chain (limited impact on project LCOEs).*

*** This $7 reduction assesses a 130 bps reduction in cost of debt alone. Additional benefits may include potential higher leverage and better terms (e.g., recourse), which may add substantial added value (weighed against potential added compliance costs and slower financing processes).*

The figure above shows the combined result if each of these individual forces materialize for a project reaching FID by 2030. Notably, the individual impact of each driver is greater if not all cost reductions materialize together (see appendix for individual impact). This is because cost reductions are generally realized as a percentage reduction in project cost (i.e., a reduction in relative cost of capex rather than absolute dollars). When all cost reduction measures are realized in concert, the relative contribution of each is lessened.

Three overarching levers present opportunities for cost reductions over the next 5-10 years: policy drivers, macroeconomic forces, and deployment.

- **Policy drivers**: Projects can seek financial support from federal, state, and tribal programs including tax credits, financing, and grant programs. Policy drivers assumed in the LCOE waterfall include the value of 10 p.p. bonus on top of the 30% Investment Tax Credit (ITC)—where the 30% base assumes prevailing wage and registered apprenticeship requirements are met—as well as financing support (such as LPO debt). The Inflation Reduction Act added two relevant ITC bonuses of up to 10 p.p. each (Domestic Content and Energy Communities), but immediate access to projects most at risk in 2023 was a challenge due to (1) uncertainty in 2023 about project eligibility (additional guidance has now been issued),[iv] (2) a lack of sufficient domestic supply chain, and (3) projects that were too mature to alter siting or contracts. Financing support, such as debt for qualifying projects from LPO or other entities has the potential to lower the cost of debt by 75 to 150+ basis points, and may present additional benefits in leverage and terms.
- **Macroeconomic forces**: Inflation and interest rates have potential to reduce LCOEs 20-40% alone; while the timing and magnitude of shifts is uncertain, most market forecasts expect more favorable macroeconomic conditions moving forward. As global commodities markets stabilized, some reduction in raw materials from 2022-23 peaks has already been realized, with more possible. However, there will likely be some lag between commodity prices and supplier quotes, due to risk, uncertainty, and pricing strategies.
- **Deployment**: Construction experience, mature ports and supply chain, and technical improvements all present cost reduction potential. The figure above assumes cost reductions from both supply chain buildout (leading to fewer cost overruns, delays, required infrastructure upgrades, and inefficiencies), as well as technology improvements (via innovation in design and construction).

While there are significant opportunities for cost reduction, a backdrop of rapid increase in global deployment mean that demand is expected to outpace and drive growth in existing supply chains. This imbalance during global supply chain ramp-up may put temporary upward pressure on costs as suppliers scale-up while recouping from recent losses following commodity squeezes and warrantee claims. In turn, this presents opportunities for U.S. supply chain buildout.

Near-term outlook

How these opportunities for cost reductions translate to offtake bid prices, and ultimately prices to ratepayers, depends on both market conditions and bidding behavior. Developer bidding behaviors vary by project and auction but are often impacted by: (1) perceived market risks to project delivery, and the level of risk mitigation in offtake structures, (2) competitive dynamics such as the number of bidders and the opportunity cost of losing, (3) developers' global and U.S. portfolio strategy, and (4) states bid-scoring criteria such as how local content investments are valued.

The cost outlook for projects moving forward will also be impacted by government decisionmakers. Key considerations include:

- **Project location:** Projects sited in shallower waters, closer to shore, with direct cable routes, tends to reduce costs. There are limited such locations, in part because the federal leasing process seeks to identify sites with fewer impacts on co-users, such as viewshed, marine navigation, fisheries, and cultural resources.

- **Project design:** Large-scale (1.2 GW+) and optimally laid-out projects (e.g., WTG spacing) reduce costs and increase energy output. Procuring large projects reduces cost, though optimal layouts can impact other constituencies (e.g., maritime navigation) and marine resources. Avoidance, minimization, and mitigations tactics can preserve co-use and conservation needs while maximizing potential production and minimizing costs.
- **Local manufacturing:** Mandatory investments (e.g., ports) aside, developers' local content commitments to win offtake can impact the costs and risks associated with individual projects (especially near-term), as facilities are challenged to compete with globally mature supply chains, even after factoring in shipping costs and tax credits. While there may be cost impacts near term, local investments foster longer term returns by helping establish a reliable domestic supply chain.
- **Risk mitigation:** Indexing offtake to macroeconomic and transmission risks can increase utility (and by extension, ratepayer) exposure to these risks but can generate lower price bids; ratepayers share the upside potential from improved macroeconomic conditions.

Offtake prices may appear lower or higher depending on financial terms, the scope of the project (e.g., whether transmission infrastructure is solicited separately), and on the availability of other funding sources for enabling infrastructure (e.g., grants). Notably, LCOEs are not offtake prices; the table below summarizes some of the key considerations for comparing these metrics.[v]

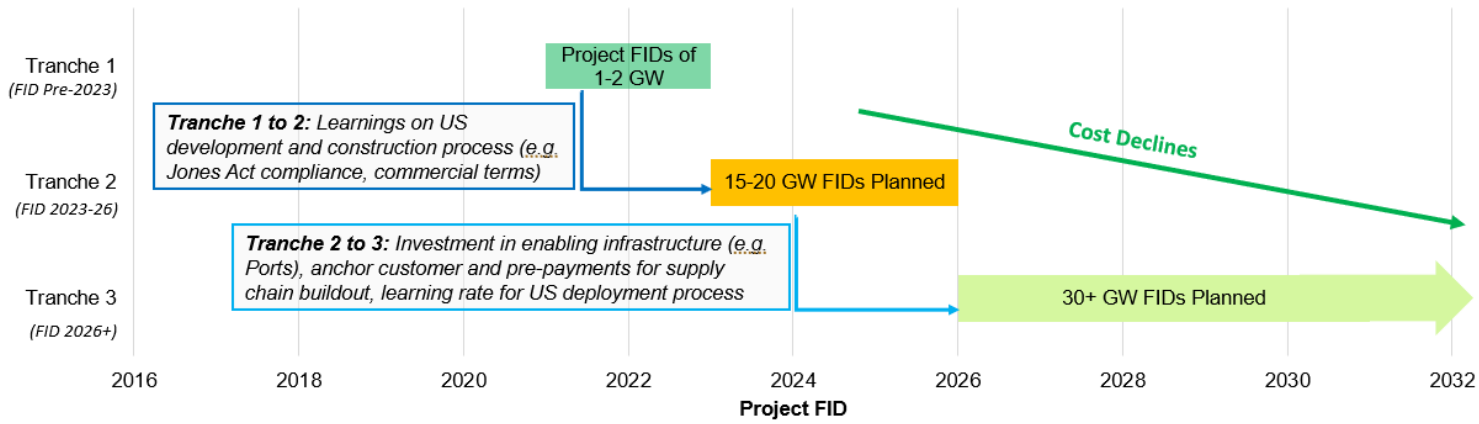
Table 1: LCOE vs. Offtake prices

	LCOE	Offtake Prices
Tenor (length)	Tied to project life, generally 30 or 35 years	Varies by state, generally 20-25 years
Escalation	Typically quoted in real terms, estimated in nominal values in this report for consistency with offtake terms.	Typically priced in nominal terms, with potential for a set 1-3% escalator, or inflation-indexation. May be described in either real or nominal terms.
Cost Scope	May or may not include supporting investments in supply chain and grid, or market fees (included in this report's analyses)	Typically includes project commitments to fund supply chain and grid upgrades, as well as federal 2% revenue lease fee
Revenue Scope	Encompasses total lifetime remuneration to a project	Excludes merchant tail and other potential revenues (capacity, RECs, etc.)
Uncertainty	Assumes no revenue uncertainty	Potential basis risk between zonal and nodal pricing, and merchant tail

Deployment is critical

While recent headwinds have increased project costs in the near-term, there would also be a cost to inaction—placing the medium- and long-term cost reductions and benefits of deployment at risk. Supply chain cost reductions and technology improvements result from project deployment and the associated experience efficiencies and process innovation.

Figure 16 – Buildout today will drive cost declines



Source: DOE Analysis

Technology innovation has also been a major driver of cost reductions historically, particularly from increasing turbine scale. Given the rapid pace of turbine scaling has outpaced associated supply chain development, savings from increasing WTG sizes will likely see diminishing returns (see Chapter 4). For projects under development for delivery through the rest of this decade, long lead times mean some tech innovation is baked into offtake bids and further cost reductions from R&D are likely to be modest. In the longer term, there remains significant potential for innovation to reduce offshore wind costs.

Federal Resources Supporting Liftoff

The Department of Energy and other federal agencies are also working to support Offshore Wind Liftoff, both through long-standing programs and new resources made available through the Bipartisan Infrastructure Law and the Inflation Reduction Act. The Inflation Reduction Act includes a set of provisions that benefit OSW among other renewables, including provisions related to OSW leasing, transmission, and tax credits (both new and extended).[vi] Below is a summary of key incentives, programs, and other resources available today.

Table 2: Key federal resources available to support the offshore wind ecosystem

	OSW Projects	Supply Chain	Transmission
Tax Credits	Production Tax Credit for Electricity from Renewables (Section 45) Investment Tax Credit for Energy Property (Section 48) Clean Energy Investment Tax Credit (Section 48E) Clean Energy Production Tax Credit (Section 45Y) 10% Energy Community Bonus	Advanced Manufacturing Production Credit (Section 45X) Qualifying Advanced Energy Project Credit (Section 48C) *10% Domestic Content bonus (Section 48)*	*Currently there is no tax credit for standalone transmission, but an OSW project's power conditioning and transfer equipment can qualify under proposed Section 48 regulations.*[vii]
Infrastructure Grant Programs		DOT's Nationally Significant Multimodal Freight & Highways Projects (INFRA) DOT's Port Infrastructure Development Program	DOE's Transmission Siting & Economic Development program under IRA Section 50152
R&D Grant Programs	Wind Energy Technologies Office (WETO) ARPA-E	National Offshore Wind R&D Consortium	

Table 2: Key federal resources available to support the offshore wind ecosystem *(continued)*

Consortiums, Coordination, and Technical Assistance	Federal-State Offshore Wind Implementation Partnership National Offshore Wind R&D Consortium	Federal-State Offshore Wind Implementation Partnership National Offshore Wind R&D Consortium	Federal-State Offshore Wind Implementation Partnership National Offshore Wind R&D Consortium Tribal Nation Offshore Wind Transmission Technical Assistance Program.
Debt Financing	*Loan Programs Office (LPO)*	*Loan Programs Office (LPO)* DOT's Federal Ship Financing Program (Title XI)	*Loan Programs Office (LPO)* DOE's Transmission Facilitation Program

The Inflation Reduction Act (IRA) establishes emissions-based, technology-neutral ITCs and PTCs available to all types of power facilities with zero or net-negative carbon emissions. These technology-neutral clean electricity tax credits in IRA begin phasing out either after 2033 or when total greenhouse gas emissions in the power sector decline to at least 75% below 2022 levels—whichever comes later. The IRA also offered new pathways to monetize tax credits (e.g. transferability), which may improve industry's access the tax credits discussed in this report.[viii]

Offshore wind project developers can claim either the Clean Energy Investment Tax Credit (ITC) or the Clean Energy Production Tax Credit (PTC).[ix] Every project developer has a unique set of considerations when determining how to leverage the IRA tax credits. Generally, offshore wind projects choose to pursue the ITC, which provides a tax credit equal to 30% of the eligible capital costs of a project in year 1 of operation for projects that meet prevailing wage and registered apprenticeship requirements in the construction, alteration, and repair of the project.[x]

Both the ITC and PTC have bonuses for siting projects in energy communities and for the use of domestic content. For the PTC, these bonuses are worth 10% of the value of the PTC each. For the ITC, these bonuses are worth 10 percentage points each—an offshore wind project eligible for both bonus and that meets prevailing wage and registered apprenticeship requirements could receive a 50% ITC in total.

The energy community bonus credit provides a bonus of 10% (PTC) or 10 percentage points (ITC) for qualifying clean energy investments in energy communities. In March 2024, Treasury released additional guidance to drive investment to energy communities. This guidance clarifies two pathways through which offshore wind projects can seek to qualify for this bonus credit, by attributing their nameplate capacity to either:

- Any land-based power conditioning equipment that conditions energy generated by the project for transmission, distribution, or use before the energy is transmitted to the point of interconnection (or one of the multiple points of interconnection, for projects with multiple points of interconnection), or
- Any supervisory control and data acquisition (SCADA) equipment used to monitor and control an offshore wind project located in a qualifying energy community project port. A qualifying port is one located in an energy community that an offshore wind project has a long-term relationship with and staffs to provide essential functions to the offshore wind project.[xi]

The March 2024 Energy Communities Bonus Credit guidance also expands the fossil fuel industry codes that are used to determine one category of energy community under the IRA; this clarification could open up additional energy communities for offshore wind projects to invest in and qualify for the bonus credit.

The domestic content bonus provides an additional incentive to grow domestic manufacturing, in the form of a 10% (PTC) or 10 percentage point (ITC) bonus. To qualify: (1) iron and steel components must be produced in the U.S. and use 100% steel and iron manufactured in the U.S. (for offshore wind, iron and steel components include towers and jacket foundations), (2) a threshold percentage of the total costs of manufactured products must be manufactured in the U.S.

Two additional tax credits exist that support domestic manufacturing of offshore wind components.

The **Advanced Manufacturing Production Tax Credit**, or **45X**, provides incentives for domestic manufacturing of eligible clean energy components and production of applicable critical minerals, including certain wind energy components.

Table 3: 45X support for component manufacturing

	Credit amount		**Theoretical 45X value**
	$/Watt	**$/MW**	*Estimated % of component cost*
Per Blade	$0.02	$20,000	10-20%
Nacelle	$0.05	$50,000	5-10%
Tower	$0.03	$30,000	10-20%
Wind Turbine Total	$0.14	$140,000	5-10%
Monopiles	$0.02	$20,000	2-5%
Floating foundation	$0.04	$40,000	2-5%
OSW vessels	10% of sale price	N/A	N/A

Source: DOE, NREL Analysis

The relative value of 45X weakens as inflation increases, given that 45X levels are set in absolute terms with no inflation adjustment mechanism. The credit is scheduled to phase down by 25% per year for components sold after Dec. 31, 2029, such that the credit will no longer be available to eligible clean energy components sold after December 31, 2032.

The **§48C Advanced Energy Project Credit**, or **48C**, provides an investment tax credit of up to 30% to support new manufacturing facilities for selected projects; manufacturers must complete a competitive application process in order to receive a 48C award. The first round of 48C allocations ($4 billion) was awarded in March 2024, and included awards for the manufacturing of offshore wind components.

Manufacturers must choose to claim a tax credit under either 45X or 48C for a given facility; they are not allowed to "stack" both of these credits for the same facility. Given that funding gaps are primarily for up-front capital, among other considerations, some manufacturers of 45X eligible components may benefit more from seeking 48C support. Manufacturers of components not supported by 45X (e.g., subsea cables, monopile-grade steel) would also benefit from a 48C award.

Upcoming application opportunity for manufacturers

The Department of Treasury has announced that they will soon issue a notice for the second round of allocations for the §48C Qualifying Advanced Energy Project Credit.

Chapter 3: Pathway to Commercial Liftoff

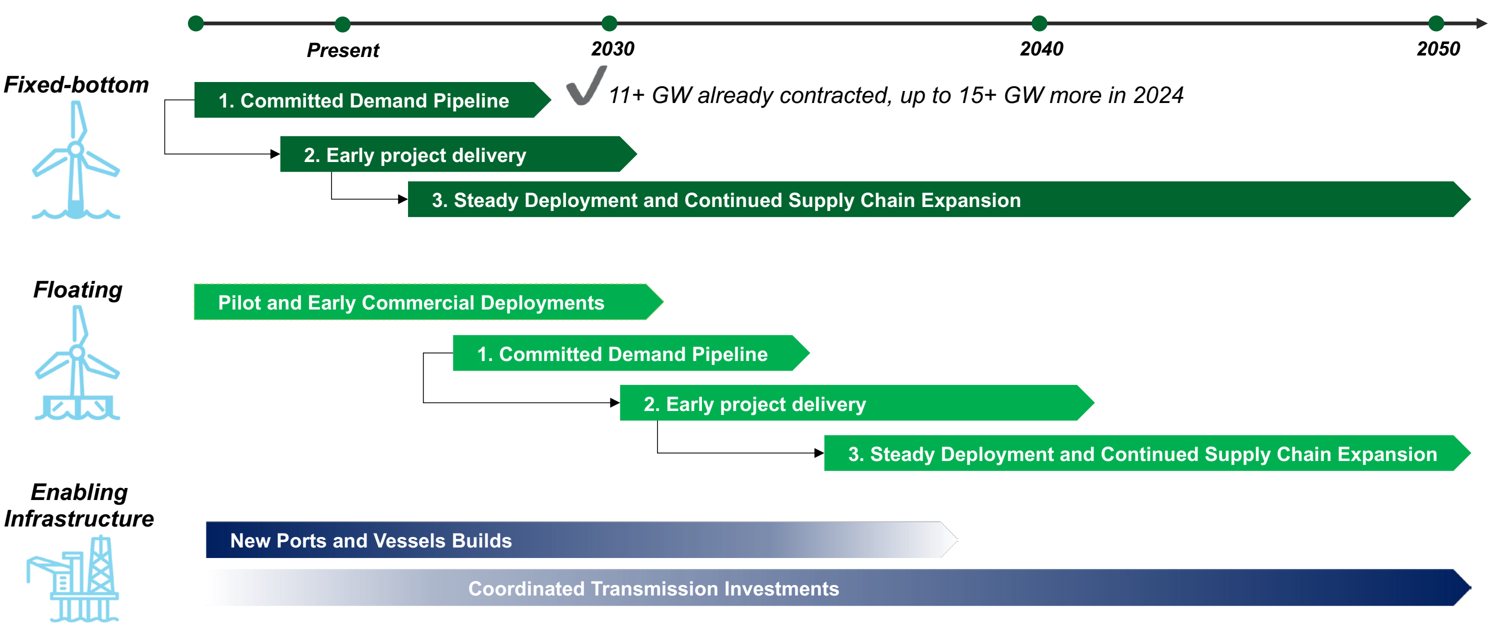
Key Takeaways:

- OSW Liftoff can be achieved in less than 10 years, driven by deployment of projects in the 2020s, several of which are under construction today. Liftoff requires steady deployment, enabled by continued refinements to project sequencing and funding.
- OSW projects face interconnection risks and cost challenges today. Long-term planning of onshore networks promises to de-risk future deployment. OSW buildout unlocks a new pathway to interregional transmission with potential to drive a more resilient and efficient grid long term.
- Ports and vessels are essential enabling infrastructure whose availability will set the annual deployment potential of the U.S. market. OSW liftoff will continue to unlock wider supply chain investments which can be catalyzed by projects seeking up-front support from federal and state resources to accelerate and de-risk supply chain buildout.

Offshore Wind Liftoff

U.S. offshore wind will achieve "liftoff" when the sector is actively contributing to decarbonization targets, with a sustained project pipeline and regular deployment. The sector will leverage OSW-ready maritime infrastructure, an ecosystem of suppliers with U.S. experience, and a streamlined and predictable project development and offtake process, all to produce competitive cost levels and steady sector expansion.

Figure 17 – Pathway to Liftoff



Full-scale offshore wind liftoff will proceed in three overlapping phases: (1) A committed demand pipeline, (2) early project delivery, and (3) steady deployment and continued supply chain expansion.

In the fixed-bottom wind market, phase 1 is on track for liftoff, phase 2 is underway, and phase 3 will follow soon. The floating wind market is earlier stage (see call-out box below). Although they are at different stages today, floating wind will build directly on the deployment and supply chain of fixed-bottom wind this decade. In places with access to both fixed bottom and floating wind resource, industry expects fixed bottom sites to be developed first due to lower costs.

1. **Committed Demand Pipeline**: Demand certainty for long-term OSW offtake agreements is critical to unlock private investment - and enable effective transmission planning. The industry exists today due to states' commitments to procuring offshore wind energy, and the tens of GWs of offshore wind projects awarded long-term offtake contracts over the past several years. In addition to states' installation targets, a clear OSW procurement schedule lets industry optimize project timelines and sizes and create smooth demand pipeline for supply chain investment. Today, industry sees risks of a stop-and-start build cycle due to a lack of demand consistency, which is also a barrier to investment in vessels and manufacturing facilities. Potential solutions to provide a consistent demand pipeline are discussed in Chapter 4.

2. **Early Project Delivery**: Deploying 10-15 GW in the mid-2020s will offer the industry valuable lessons on U.S. development and construction processes, and these early movers will help fund the key enabling infrastructure and supply chain investment necessary to facilitate long-term buildout.

3. **Steady Deployment and Continued Supply Chain Expansion**: Once the industry has gained momentum and new projects are being consistently delivered on time and on budget, the industry can continue to deploy GWs of projects annually to reach long-term decarbonization goals. This consistent deployment will drive cost declines, unlock offshore wind markets outside early movers on the East Coast, and enable the continued growth of a mature U.S. OSW supply chain. The supply chain path to liftoff is discussed in detail below, and potential solutions to risk allocation are discussed in Chapter 4.

Floating Wind: the Critical Path to Commercial Scale

Floating Offshore Wind – Liftoff Perspective:

Reaching GW-scale projects and scaling up floating deployment in the U.S. will require work along the following parallel tracks:

- **Technical validation:** Refine and consolidate technical designs and prove out technology at scale. Much of this will happen globally, but some may benefit from U.S. precommercial deployment. Tech validation will be geography specific (e.g., ~100-300m water depths in Gulf of Maine vs. 500m+ ultra-deep waters on West Coast).
- **Enabling infrastructure:** Build local infrastructure required for floating wind, with regional-level investments made separately and in advance of individual projects themselves. Essential infrastructure includes (1) marshalling ports and foundation assembly yards, and (2) onshore transmission networks. Some local supply chain development will also be required, likely with separate up-front investment needs.
- **Demand certainty:** Send strong demand signals, with a clear offtake timeline and mechanism, including a clear, multi-phase sequence of offtake, with long and bankable revenue sources as a part of technology-specific awards. States should expect higher costs for the initial tranche of projects and work with the market to ensure clear expectations and tolerances.
- **Commercial ecosystem:** Build investor confidence, de-risk project-scale financing, and bring market to maturity via improved contracting interfaces, insurance, and repeated deployment. Ensure future deployment is informed by the first phase of development through adaptive management focused on environmental monitoring and cultural resource protection.
- **Stakeholder & permitting:** High-quality stakeholder and tribal engagement, along with permitting pathways prove-out will be critical before deployment can scale.

Key enabling actions today – The path to floating wind liftoff requires early planning for infrastructure (ports, assembly yards, transmission) and establishing demand frameworks in order to keep active U.S. developments on-track as innovation and early-movers continue to lead to long-term sector maturity and cost reductions. These investments and planning are required today to unlock floating wind as a tool for U.S. decarbonization.

See Appendix for additional details on the critical path to floating wind liftoff.

3A. Project Delivery

To achieve U.S. OSW liftoff, 10-15 GW of planned projects must reach Final Investment Decision and commercial operation (from ~250 MW operational and ~5 GW under construction today). Shovel-ready East Coast projects will unlock essential industry set-up needs, supporting billions of dollars of necessary investments in supply chain and workforce. For those deployments that do not move forward, these costs and risks will be pushed to future projects. The credibility of the U.S OSW market with investors, developers, states, and stakeholders depends on successful execution of a critical mass of planned East Coast deployments.

After recent offtake challenges, states have made significant progress to competitively award updated offtake contracts (see Chapter 4, Section 1 for detail). These "re-bids" are essential to ensure offshore wind liftoff and achieve state and national decarbonization goals.

3B. Transmission

Consistent long-term offshore wind deployment depends on a stable framework for transmission development. As with other generation sources, transmission represents both a need and an opportunity to invest in a more resilient grid**.** Long term, the coastal grid across the country is insufficient to accept the level of incoming power from planned offshore wind buildout to meet state targets and national decarbonization goals. The current interconnection approach may be manageable for the 2020s pipeline, but post-2030, interconnection challenges present a long-term hurdle to development and private investment in offshore wind projects.

There is broad consensus of the need for better coordinated onshore network upgrades and better offshore planning, including planning (1) across projects within each state, (2) between states within the same power market, and (3) inter-regionally between power markets.

Transmission needs for OSW Liftoff can be addressed by continuing efforts to:

- Upgrade existing onshore networks to expand coastal grid capacity
- Streamline and coordinate POIs and landfall locations by region
- Maximize the use of constrained ROWs and POIs with efficient cable sizes and cross-project planning
- Improve interconnection and network upgrade processes to minimize cost and timeline uncertainty
- Tackle cost allocation, a primary barrier to determine business cases and offer a framework for procurement that values transmission needs
- Continue to improve environmental review and permitting frameworks at a state and federal level, and increase developer awareness of siting and permitting resources and requirements, particularly related to cable ROWs and landfall sites
- Develop the U.S. HVDC ecosystem to enable collaboration and standardization between ISO/RTOs/ utilities, supply chain planning, and workforce training
- Support global supply chain expansion to meet demand for HVDC cables and converter stations (see supply chain discussion below)

A full list of recommended actions for offshore wind transmission can be viewed in **An Action Plan for Offshore Wind Transmission Development in the U.S. Atlantic Region**. The plan also assesses multiple transmission topologies and includes recommendations for interregional coordination.

The full Atlantic Offshore Wind Transmission Action Plan is available here.

Several specific solutions can help solve near- and long-term transmission challenges for offshore wind— these are discussed in detail in Chapter 4, Section 4. This includes planning and coordination for both onshore upgrades and offshore transmission.

The Value of Networked Offshore Transmission:

- Monetary benefits of offshore transmission networking come from reduced curtailment, reduced usage of higher-cost generators, and contributions to resource adequacy.
- Offshore transmission networks contribute to grid reliability by enabling resource adequacy and helping manage the unexpected loss of onshore grid components (contingencies).

- The benefits of offshore transmission networks outweigh costs by a ratio of 2 to 1 or more in the Atlantic Offshore Wind Transmission Study. Offshore networks that link power markets inter-regionally (inter-regional transmission) provide the highest value.

Liftoff in context: Existing federal resources to support offshore wind transmission

DOE, along with other federal agencies and states, are already advancing planning and action on transmission needs for offshore wind. Key federal initiatives include the National Transmission Needs Study, Atlantic Coast Offshore Wind Transmission Activities, West Coast Offshore Wind Transmission Activities, Gulf of Mexico Offshore Wind Transmission Literature Review and Gaps Analysis, and national activities such as the Agency Collaboration: U.S. Department of Energy Offshore Wind Energy Strategy and the Tribal Nation Offshore Wind Transmission Technical Assistance Program.

For an in-depth exploration of regional transmission needs for the Atlantic Coast, readers are encouraged to reference An Action Plan for Offshore Wind Transmission Development in the U.S. Atlantic Region and the Atlantic Offshore Wind Transmission Study.

3C. Supply Chain

Global OSW demand is growing quickly—global suppliers can meet U.S. demand for most components for the Tranche 1 and 2 projects, but widespread supply chain expansion is required to support growing demand in the U.S. and abroad. Today, U.S. manufacturing for offshore wind components is limited and mature U.S. projects are dependent on global sourcing (primarily from Europe). In addition to scale-up of U.S. supply chains, much of this gap could be met by suppliers in Asia and the Middle East, who are already helping meet European demand today. Imbalance in global supply and demand for OSW components may put cost and risk pressure on U.S. projects.[xii]

U.S. offshore wind supply chain needs and path to scale are discussed extensively in the 2023 NREL report, "A Supply Chain Road Map for Offshore Wind Energy in the United States"; discussion here draws heavily on that report, as well as recent interviews with industry experts.

Scaling U.S. offshore wind deployment will require a combination of upgrading port infrastructure, building or repurposing vessels for construction and operations, supporting a secure global component supply chain, and building domestic component manufacturing. The U.S. supply chain has seen over $10B announced in supply chain investments in the past 4 years as the OSW pipeline grows and government incentives support the buildout of domestic manufacturing. Despite this momentum, few Tier 1 factories[5] are yet fully operational. The U.S. also has one wind turbine installation vessel (WTIV) under construction, and several supporting vessels for construction and operations, but significantly more vessels are needed to achieve states' near and long-term buildout goals. Many announced supply chain facilities face challenges to completion and are working to overcome demand uncertainty and funding shortfalls, exacerbated by the uncertain timelines of some Tranche 2 projects.

With the successful rebids many Tranche 2 projects and rebounding industry confidence in consistent U.S. deployment, significant planned and future chain investments are expected to materialize—but gaps and bottlenecks may remain. U.S. supply chain buildout should be targeted to ports and vessels (key enabling infrastructure), facilities manufacturing components for which domestic production is key to unlocking incentives (namely, the domestic content bonus), and facilities manufacturing components that are particularly undersupplied globally. Specific needs are highlighted in the table below. Supply chain buildout priorities should focus on supply chain security, project economics, and economic development, but do so without delaying deployment.

5 See The Demand for a Domestic Offshore Wind Energy Supply Chain (Shields et al, 2022). Tier 1, 2, and 3 components refer respectively to finished components, subassemblies, and subcomponents for offshore wind projects.

For new-build supply chain assets, government support will continue to be integral: regional economic development efforts, plus federal support (e.g. LPO financing, competitive grants, §48C Advanced Energy Project Credit), and additional collaboration through initiatives such as the Federal-State Offshore Wind Implementation Partnership all offer opportunities for supply chain players to seek public support (see additional details in Chapter 4).

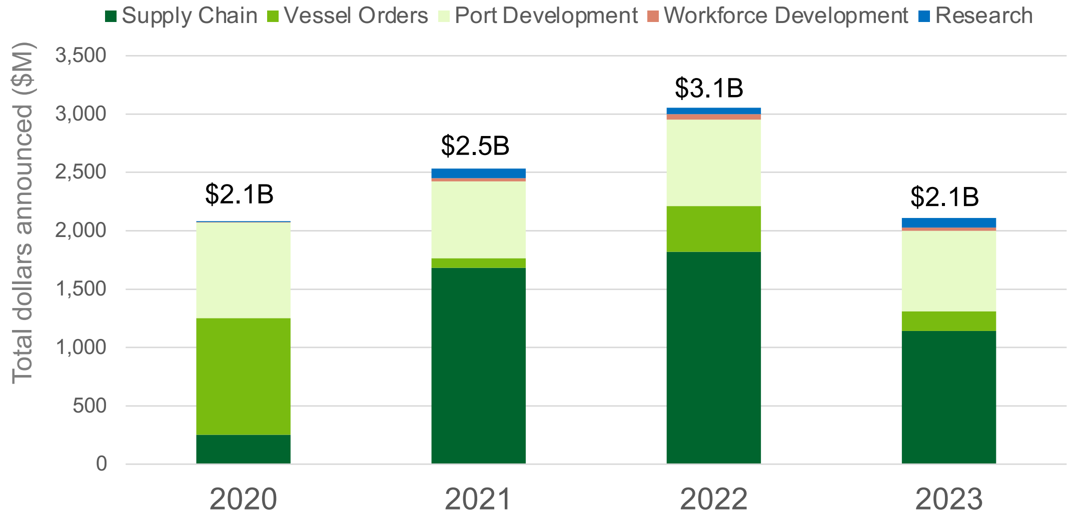
Table 4: Critical path infrastructure and manufacturing opportunities

Category	Purpose	Needs
Critical Path to Liftoff	*Essential enabling infrastructure required to build U.S. projects*	**Domestic ports** – Construction ports are essential enabling infrastructure, and the number of suitable facilities will determine the rate of OSW buildout possible in each region of the U.S. Many port facilities are identified and some are operational today, but additional investment is required for industry liftoff and equitable outcomes.[xiii] O&M ports are also essential, but typically have less demanding requirements and are faster and less expensive to develop. For floating wind, assembly yards will also be critical. **Domestic vessels** – Like ports, vessel shortages could constrain buildout rate. Additional specialized vessels are needed to deliver the volume of OSW projects planned today. Acute global needs include jack-up wind turbine installation vessels (WTIVs), foundation installation vessels (FIVs), and cable laying vessels (CLVs). Jones-Act compliant vessels are essential for U.S. construction and operation. Today's U.S. projects often use feeder barges for installation; the first U.S. WTIV is under construction. **Workforce partnerships & training centers** – OSW construction and operations, including specialized component manufacturing will require a skilled workforce; training efforts require lead time to preemptively train and certify workforce. Partnerships with community colleges, union-led training programs, and others play a key role in workforce development.[6]
Opportunities & Risk Mitigation	*Opportunities for supply chain security, economic development, and to leverage subsidies; without U.S. buildout, these components can be sourced internationally, but at risk of global market undersupply or other constraints*	**Towers and jackets** – key to unlocking domestic content bonus (see Chapter 2 for details). U.S. supply chains exist today for limited volumes of jackets. No U.S. facilities are operational for OSW towers today, but multiple planned projects expect to come online in the next five years. **Monopiles, transition pieces, and monopile-grade steel** – significant shipping costs and global supply constraints. **Blades and nacelles** – opportunity to increase local content to help projects qualify for domestic content bonus. **Subsea cables and substations** – face global shortage, especially for HVDC equipment: HVDC substations from global supply chain are fully booked through 2032. Substations are challenged by shortages in large power transformers, HVDC converters, and offshore topside structure assembly yards, as well as cost and lead time for new manufacturing. Subsea cables are manufactured in the U.S. today, but more is needed to meet demand

While the industry has seen many announcements for domestic manufacturing in recent years, actual buildout has lagged. Announcements tap into existing manufacturing bases and will continue to generate economic benefits—not only within the states where OSW development occurs, but nationally as sub-components are sourced from a range of supplies.

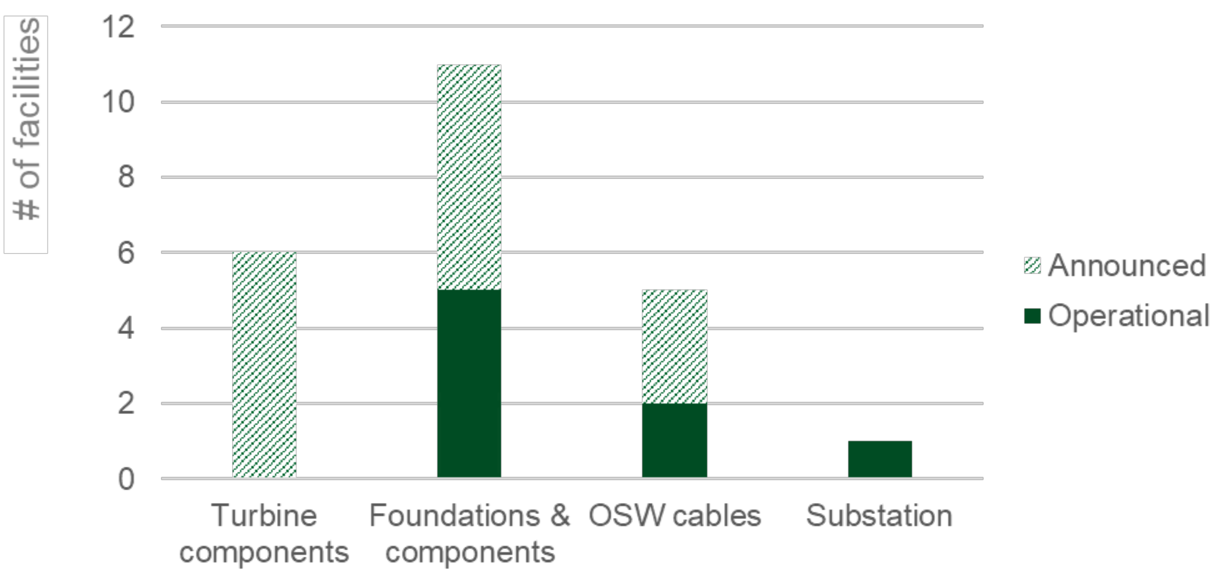
6 Several community colleges are establishing programs focused on skills and knowledge required for offshore wind; see next section, "Workforce and Energy & Environmental Justice," for detail.

Figure 18 – Recent supply chain investments, based on manufacturing announcements



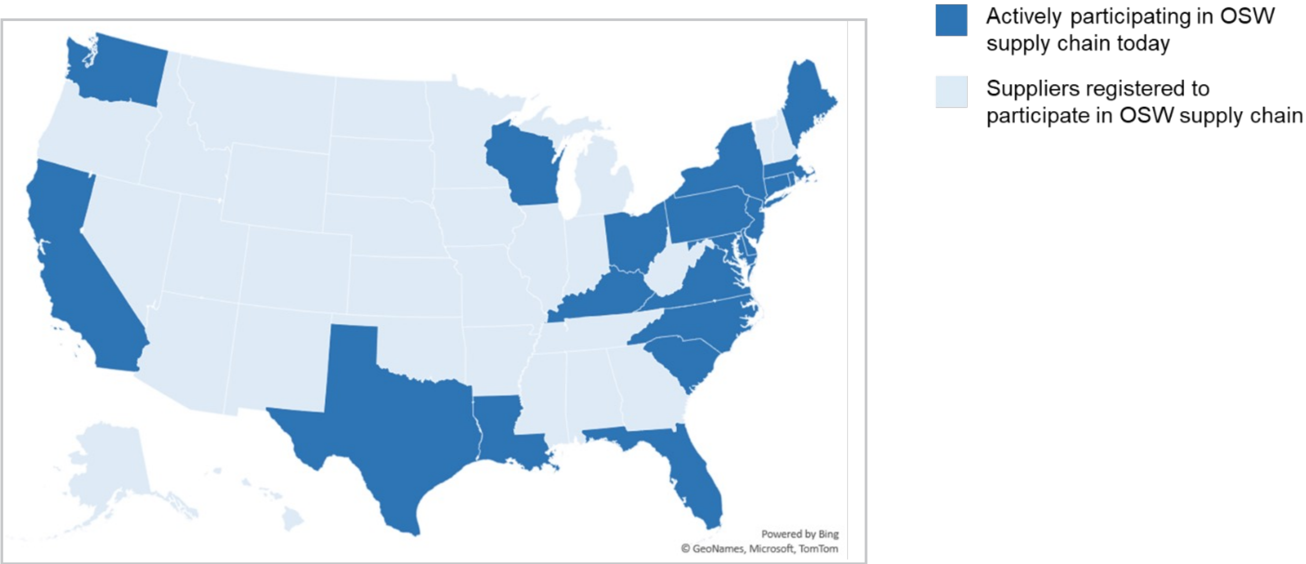
Data Source: Oceantic 2024 Offshore Wind Market Report

Figure 19 – Announced and operational manufacturing facilities for offshore wind components[7]



7 Note: Numbers in chart represent facilities with specialized OSW expertise or experience (e.g., additional existing manufacturers exist capable of producing custom orders or tier 2 components)

States with planned OSW manufacturing facilities
Based on investments to date



NREL Offshore Wind Supply Chain tracker (accessed April 2024); DOE Offshore Wind Market Report (2023); Oceantic Network 2024 U.S. Offshore Wind Market Report; ACP Interactive Map: The Economic Benefits of Offshore Wind[xiv]

Workforce and Energy & Environmental Justice (EEJ)

Offshore wind deployment can continue to provide notable benefits including grid reliability and resilience, clean energy access and affordability, pollution reduction for populated coastal load centers, high-paying jobs, and tax revenue to local communities. This is especially important for low-income communities or communities of color that often face high levels of energy burden and energy poverty, limited or no access to clean energy, and high exposure to pollution from fossil fuel power plants, particularly via air quality in urban load centers served by OSW. For example, downstate New York (the region where OSW farms will connect) was powered by 89% fossil fuels in 2022, in contrast to upstate New York, where clean sources make up 91% of electricity supply.[xv] For such regions, OSW is an integral part of a just transition to clean energy. As articulated below, it is also critical to ensure that new projects have sustained community engagement, to optimize benefits such as new job creation for the local community, and to address any concerns (e.g., increased industrial activity).

Additional workforce and EEJ considerations for OSW are integrated throughout this report, including stakeholder and tribal nation engagement, decarbonization, grid reliability, job creation and workforce development. Market development considerations should be assessed through the lens of how different communities or groups will be impacted, how impacts will interact with (potentially alleviating or exacerbating) existing burdens, and how communities can inform decision-making. This will ensure more just and equitable deployment and enable industry success.

Workforce and Training Partnerships

Offshore wind projects are complex and require an extensive, varied, and well-trained workforce. Educational institutions, state and tribal governments, labor organizations, industry and others are already partnering to help improve and ensure skilled workforce availability and training, working to understand the opportunities and requirements of the industry and to develop and expand education and training programs to meet those needs. However, gaps remain in fully understanding and meeting workforce requirements at a national level. Equitably developing a diverse workforce will require intentional efforts and active planning to remove barriers to a highly trained workforce.

Key areas for workforce development span a wide range of roles throughout the life of an offshore wind farm, including project development, manufacturing and supply chain, ports and staging, maritime construction, and O&M. Jobs will range from product engineers, to certified maritime construction workers, to wind turbine technicians supporting O&M activities.

Community college programs, and union training programs, apprenticeships and pre-apprenticeships are already playing a role in workforce development and continue to support the industry as it scales. Several community colleges are establishing programs focused on skills and knowledge required for offshore wind.

A number of states require project labor agreements (PLAs) for public works, infrastructure or energy projects, which may also include local hiring provisions as well as provisions for workforce training and recruitment. Some project developers have also entered into PLAs or other partnerships with labor organizations to address key workforce, training and project coordination challenges. Projects can also prioritize recruitment and training within underserved communities—some are already doing this. Continued developer commitments to workforce training will enable the scaling of a high-quality workforce.[xvi]

Additionally, the sector can leverage skills, workforce, and workforce training infrastructure from existing industries such as offshore oil and gas, energy, utilities, construction, and maritime sectors, and to create opportunities within the communities most impacted by offshore wind energy development to support future deployments of offshore wind plants and associated infrastructure. See additional details on building a robust offshore wind workforce in the NREL 2022 U.S. Offshore Wind Workforce Assessment.

Stakeholder Engagement & EEJ

Ensuring offshore wind projects support energy and environmental justice (EEJ) is critical not only as a moral imperative, but because project success depends on it. OSW regulatory and offtake procurement processes today necessitate extensive community engagement and EEJ considerations. The industry must continue to prioritize these efforts to ensure just outcomes and success of the industry. Engaging in early, frequent, transparent, and two-way dialogue with stakeholders across the OSW value chain creates the greatest likelihood of project success. A lack of stakeholder buy-in can spur opposition to projects, which contributed to delays for some Tranche 1 and 2 projects. Stakeholder engagement should continue to be a priority from early project siting and development through to decommissioning.

In addition to instituting stakeholder engagement, there are many ways for projects to maximize benefits and minimize harm in line with EEJ goals and principles. Much of today's energy and industrial infrastructure is located in communities of color, tribal communities, and working-class communities; new energy infrastructure should prioritize social and environmental responsibility alongside economic benefits. This will require meaningful engagement with local communities, tribes, and labor unions, real engagement on EEJ concerns, career-track workforce development, and diversity, equity, inclusion, and accessibility.[xvii]

The sector should also seek to reduce environmental impacts on marine ecosystems and wildlife, and mitigate impacts on ocean co-uses. For additional detail on research and planning to support these goals, see the Department of Energy's "Advancing Offshore Wind Energy in the U.S." strategy document.

Tribal Equities and Partnership

Tribal engagement that recognizes tribal sovereignty and Indigenous Knowledge is key to OSW success. Early engagement during wind energy area identification, port development, siting, design, construction planning, and environmental monitoring presents opportunities for collaboration and economic development to foster sustainable and predictable buildout.[xviii] The federal government is working across agencies to advance regular and meaningful Tribal engagement in the Federal decision-making process.

Tribes across the country share centuries of histories with energy and industrial development which have eroded the trust needed to build out the next generation of energy projects. Tribes are sovereign governments with treaty and reserved rights, including to U.S. waters. Tribes also hold historically deep connection to coastal waters nationwide both for sustenance and ceremonies, including areas that were once dry land occupied by indigenous peoples. These connections survive in the oral histories and practices of Tribes today.

Indigenous knowledge, which includes traditional ecological knowledge, has been built over millennia of fishing, and other interactions with the natural environment. The value of this knowledge has been recognized by the federal government[xix], and in the context of OSW can inform the design and monitoring of projects. This knowledge is often nuanced and historically informed and can augment monitoring plans to look beyond keystone species.

Some Tribes have also voiced interest in becoming investment partners for renewable energy infrastructure to deliver win-wins for communities, developers, and investors. These partnerships could offer a mutually beneficial opportunity for development of offshore wind projects and supply chains across the country. Tribes offer holistic insights which can inform project design, and create resilient projects with deep community buy-in. Tribes can bring new sources of investments, workforce development, and ecological knowledge which are all needed to build out an industry that is regenerative. Tribes are increasingly participating directly in climate equity investments, including as investors in utility-scale renewables and transmission developments.[xx,xxi] Such projects can seek to access additional sources of federal support, such as loans[xxii], tax credits and procurement incentives[xxiii], alongside Tribal capital.

Chapter 4: Market Challenges & Solutions Underway

Key Takeaways:

- Competitive procurements for projects that secured offtake pre-2023 can unlock key investments in enabling infrastructure and continue to put the industry on the path to liftoff.
- Efforts to shorten the offtake-FID time interval, de-risk projects through procurement reforms, and fill funding gaps for enabling infrastructure will mitigate deployment risks facing the sector today.
- Consistent OSW procurement schedules and cross-state collaboration on supply chain and transmission planning will enable efficient and bankable industry buildout.
- Coordinated solicitations for onshore upgrades, OSW projects tailored to efficient transmission design, and mobilization of interregional transmission planning can lead to more efficient grid outcomes and de-risk OSW deployment.

Challenge	Solutions Underway
1. Recent offtake cancellations, driven by macroeconomic conditions, create timing uncertainty and funding gaps for sector buildout.	• Competitive procurements ("re-bids") for 2020s projects that secured offtake pre-2023 • Revised projects that are deliverable under current market conditions, and that reaffirm commitments to fund long-term enabling infrastructure (vessels, ports, etc.)
2. Current market structures expose the sector to exogenous risks and require early mover projects to carry the costs and execution complexity of **long-term industry** buildout **needs.**	• Improved sequencing of offtake with permitting and project FID • Offtake refinements to incorporate risk mitigations • Targeted investments in enabling infrastructure, especially during the pre-FID funding gap
3. Industry lacks market visibility to plan long-term investment cases, especially for supply chain needs.	• Clear procurement schedules that provide demand visibility and consistency • Collaboration to support supply chain and transmission buildout on a regional level • Industry consensus on technology specifications and standards for supply chain buildout
4. Transmission risks development bottlenecks and grid inefficiencies via onshore interconnection, offshore project design, and wider network buildout.	• Coordinated POI identification and solicitations for onshore upgrades across multiple OSW projects • OSW project sizes and standards tailored to low-cost offshore transmission and efficient interconnection • Mobilization of interregional transmission planning

U.S. offshore wind market development efforts first began in the early 2000s. Since then, the sector has overcome significant barriers and challenges faced by pioneer project developments (e.g., costs, compliance with U.S. policy, bankability, construction contracting). Continuous effort to de-risk and overcome these challenges mean that many of these risks no longer pose a fundamental barrier to liftoff.

Today, the offshore wind sector faces four major challenges it must overcome to achieve liftoff. Many solutions are already underway, following leadership from state energy agencies and learnings across the industry. The remainder of this chapter synthesizes this progress—efforts that will remain essential for consistent long-term deployment.

Challenge #1: Recent offtake cancellations, driven by macroeconomic conditions, create timing uncertainty and funding gaps for sector buildout

Challenge	Solutions Underway
1. Recent offtake cancellations, driven by macroeconomic conditions, create timing uncertainty and funding gaps for sector buildout.	• Competitive procurements ("re-bids") for 2020s projects that secured offtake pre-2023 • Revised projects that are deliverable under current market conditions, and that reaffirm commitments to fund long-term enabling infrastructure needs (vessels, ports, etc.)
2. Current market structures	
3. Industry lacks long-term market visibility	
4. Transmission	

Sustained project deployment is dependent on the successful FID and completion of early mover projects. In addition to the macroeconomic pressures these projects saw during their offtake-FID interval, they have often faced higher costs due to the need to fund early investment in enabling infrastructure such as local supply chain facilities (e.g., via up-front financing or prepayments for components). Higher offtake prices reflect these costs and will support long-term industry buildout.

For shovel-ready supply chain announcements ready to begin construction, the uncertain future of some Tranche 2 projects disrupted order books and delayed anchor customer contract signing and pre-payments (further discussed in Challenge #2 below). As a result, some manufacturing facilities are in a holding pattern and are at risk of not moving forward without renewed confidence in early mover projects (enabled by the solutions discussed below).[8]

Early mover projects have also seen greater execution complexity and the "teething issues" of first-of-a-kind deployment in the U.S. Lessons learned from these projects will help de-risk future deployment.

Figure 20 – Challenges from early mover projects

Solution: Competitive procurements ("re-bids") for 2020s projects.

Accelerated re-bid solicitations will ensure that projects that are no longer viable under their original offtake contracts have a path to deployment. States and industry are already taking significant steps to resolve these early mover challenges and ensure projects move forward today. For example, New York has successfully re-awarded 1.8 GW OSW projects that will become operational in the next few years,[xxiv] and New England plans to award up to several GW of near-term projects this summer under a coordinated multi-state solicitation and expedited selection process.[xxv]

8 Supply chain uncertainty in turn creates challenges for the offshore wind projects, which may be relying on U.S. manufacturing facilities to supply key components and enable qualification for the domestic content ITC bonus.

Solution: Revised projects that are de-risked and deliverable under current market conditions.

Developers should ensure that project proposals can be delivered under current market conditions, in both re-bid solicitations and moving forward. Proposed project schedules and budgets must remain competitive while also minimizing risk and ensuring deliverability.

Offtake mechanisms can also incentivize low project delivery risk. By nature, competitive solicitations reward low costs and high economic development—winning bids are often ambitious with limited contingency for unforeseen challenges. Bid scoring criteria such as project viability/deliverability metrics, along with cancellation fees, tend to penalize overly ambitious projects. To avoid overly ambitious projects, states can continue to consider the weighting of these metrics and fees in solicitation structures.

Securing offtake contracts for projects with a path to FID in the next few years will also help stimulate investments in supply chain. As the 2020s pipeline stabilizes, developers will in turn drive demand for the supply chain assets that are relying on these projects as anchor customers. This will in turn de-risk the next tranche of project deployment.

Challenge #2: Current market structures expose the sector to exogenous risks and require early mover projects to carry the costs and execution complexity of long-term industry buildout needs

Challenge	Solutions Underway
1. Tranche 2 offtake cancellations	
2. Current market structures expose the sector to exogenous risks and require early mover projects to carry the costs and execution complexity of long-term industry buildout needs.	• Improved sequencing of offtake with permitting and project FID • Offtake refinements to incorporate risk mitigations • Targeted investments in enabling infrastructure, especially during the pre-FID funding gap
3. Industry lacks long-term market visibility	
4. Transmission	

Recent market turbulence was in part due to risk exposures that can be limited moving forward, even if an uncertain macroeconomic environment persists. In the past, competitive offtake solicitations have set fixed revenues years before project costs could be secured, with limited risk mitigation built into contracts. As discussed in Challenge #1, offtake revenues for early mover projects were also a primary engine to fund long-term ecosystem buildout: namely the enabling infrastructure of ports, vessels, and supply chain. These assets, which typically have long operational lifetimes and payback periods, required investments on the order of hundreds of millions of dollars tied to individual OSW projects, prior to the OSW project reaching FID.[9]

This combination of market structures amplified project deployment risks by closely linking funding sources and timelines.

9 Many plans for U.S. supply chain assets, particularly manufacturing facilities, have been based on individual offshore wind projects' local content commitments. As a result, many manufacturing facilities have been tied to specific projects, depending on developers for equity or prepayments to fund facility construction. This interdependence also stacks project risks given the co-dependency of these paired OSW projects and their supply chain developments. If one of the two assets is delayed, as was experienced by offtake cancellations in 2023, the connected OSW project or supply chain asset faces increased risk as well. A similar dynamic applies to onshore grid reinforcements. Upgrades to OSW projects' onshore power injection points must begin years before project COD. Onshore grid upgrades are traditionally funded project-by-project through the interconnection queue process, creating timing risks for project delivery. The costs and timelines for completing these interconnection upgrades range widely and are typically unconfirmed until near-FID, years after revenue prices to cover these costs are locked-in.

Figure 21 – Risk mitigation measures focus on three main areas of risk

In navigating recent market turbulence, the sector has already made significant progress in adopting risk mitigation measures, led by states with early mover projects. These efforts will benefit U.S. offshore wind both today and in the long term.

Solution: Improved sequencing of offtake with permitting and project FID

Shortening the offtake-FID timing interval and improving sequencing and predictability will help limit risk exposure. After recent market disruptions, developers have expressed increasing reluctance to participate in auctions where they would bear years of unmitigated cost exposure after revenues are secured.

A concentration of federal permitting approvals in 2023 (Record of Decision on ~7 GW with others issued and anticipated in 2024) led to a consolidation of FIDs planned in 2023-25. The federal government has made significant progress in building capacity and improving processes and interagency coordination for project reviews in the last several years, and additional gains are in progress through efforts to further optimize siting and regulatory reviews. These efforts will reinforce transparent and efficient federal permitting timelines through continued process improvements and collaboration with industry (emphasizing shared responsibilities of timeliness and durable review), that can help de-risk development. They will also facilitate improved synchronization with offtake sequencing and state and federal permitting to reduce risk exposure in the gap between procurement and FID.

States are also working to compress this timing interval moving forward—for example by prioritizing procurement from mature projects. Beyond these efforts, more efficient project development should naturally facilitate a compression of this timing gap as the industry matures. The need to tighten this timing gap will also lessen as risk mitigation measures for macroeconomic uncertainties are adopted in offtake terms (see below).

Solution: Offtake refinements to incorporate risk mitigations

In addition to the need to compress the offtake-FID timing interval as described above, another important solution to mitigate the risk of future project cancellations is adopting and refining revenue adjustment mechanisms.

Key risks to mitigate include macroeconomic uncertainties and uncertain interconnection costs. Several states have already started to incorporate indexation for macroeconomic and transmission cost uncertainties into recent offtake solicitations. The sector is continuing to refine these mechanisms to de-risk projects while protecting ratepayers. These risk mitigations will also foster competition between developers by minimizing the extent to which projects are priced based on variations in developers' macroeconomic outlooks and risk tolerances.

- **Macroeconomic adjustments** put forward by states today take the form of one-time inflation adjustment mechanisms for offtake revenues from bid date to project execution. Inflation indexation is common for many OSW offtake mechanisms globally, particularly in Europe, which has helped to reduce the extent of contract cancellations abroad. Among the various indices proposed, offtake prices may be adjusted based on commodity prices, manufacturing costs, interest rates, and labor costs (see Chapter 2 for discussion of recent inflation trends).

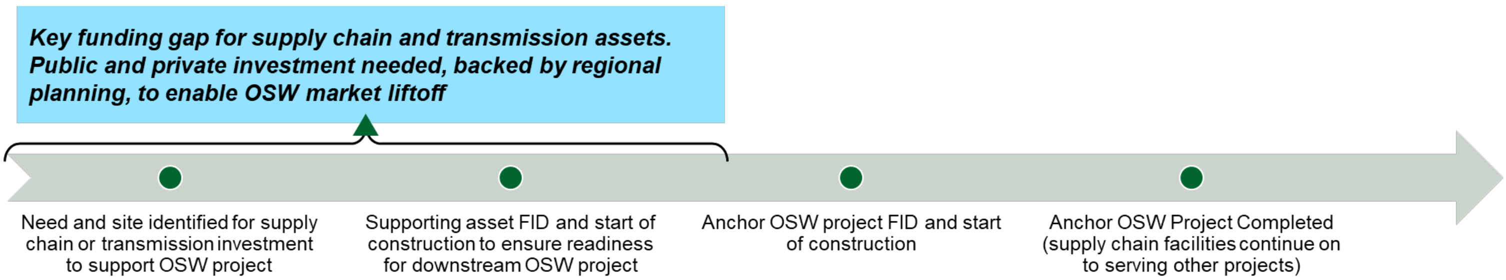
- **Interconnection cost-sharing** occurs today via either a cost-share for necessary upgrades in OREC terms, or independent state transmission solicitations as described in Challenge 4 below. Abroad, OSW transmission needs are traditionally handled by local grid operators (especially for onshore transmission) with less downstream risk and uncertainty for OSW project development.

As articulated in greater detail below, continuing to refine the procurement of local supply chain assets and transmission can further disentangle risk profiles between individual project contracts and industry-wide needs for enabling infrastructure.

Solution: Fill the pre-FID funding gap by investing in enabling infrastructure

Ports, vessels, and manufacturing facilities typically require construction and investment prior to their anchor-customer reaching FID. This is increasingly true for onshore grid reinforcements as well. Targeted government support can facilitate the early stages of development for supply chain and transmission pre-OSW project FID, in turn stimulating private investment. The figure below shows the sequencing of enabling infrastructure investment relative to offshore wind project deployment.

Figure 22 – The pre-FID funding gap for enabling infrastructure



Source: DOE

Globally, it is uncommon for individual project cost and scope to include this level of investment in enabling infrastructure, especially through pre-FID project expenditures. A reliance on these types of investments risks positioning the U.S. market, particularly early movers, as a high-risk market in developers' international OSW portfolios, which could impact their portfolio-level investment decisions.

See additional details on transmission needs in Challenge 4, and detail on supply chain below.

Both existing and new government support programs can help de-risk and fill funding gaps for ports, vessels, manufacturing facilities pre-anchor customer FIDs. Existing programs may include tax credits, debt mechanisms like LPO financing (see Chapter 2), or economic development projects such as pre-development of coastal infrastructure (e.g., remediation and civil upgrades) to unlock new sites for coastal manufacturing facilities. In early discussions, some Tribes have also voiced interest in investing in the port and manufacturing infrastructure needed to build out the supply chain.

New manufacturing facilities require confidence in four key areas to secure investment and ramp production, all of which can by catalyzed by state, tribal, and federal action:

- A suitable site, with manageable site development needs (e.g., civil reinforcements, environmental remediation, quayside upgrades, etc.)
- A clear long-term business case and capital stack (typically $50-500m+ in up-front funding required)
- Revenue certainty and stability through consistent demand (often led by an anchor customer plus long-term business case)
- Specialized workforce (both drawn from established industries, and new training centers)

Coastal manufacturing facilities, especially early movers, face particular challenges due to complex site pre-development needs. Due to the size and transportation needs for OSW equipment (e.g., WTGs, foundations, subsea cables), manufacturing facilities require site locations alongside major waterways and with sufficient acreage, load-bearing capacity, and quayside access. This presents both a challenge and an opportunity to revitalize and reinvest in industrial coastal infrastructure, but as a result, sites often require substantial upgrades before construction can even begin on an OSW port or manufacturing facility. Many announced supply chain facilities have faced schedule and funding challenges due to these needs. Targeted investments can unlock more site locations for coastal manufacturing facilities and enable a robust U.S. offshore wind supply chain.

Challenge #3: Industry lacks long-term market visibility to make long-term plans and investment cases, especially for supply chain.

Challenge	Solutions Underway
1. Tranche 2 offtake cancellations	
2. Current market structures	
3. Industry lacks market visibility to plan long-term investment cases, especially for supply chain needs.	• Clear procurement schedules that provide demand visibility and consistency • Collaboration to support supply chain and transmission buildout on a regional level • Industry consensus on technology specifications and standards for supply chain buildout
4. Transmission	

Long-term state targets anchor demand certainty today, but a lack of set and synchronized procurement schedules risks inefficient project development, stop-and-start build cycles, and inconsistent demand for the supply chain.

Demand consistency and transparency is key for supply chain buildout and efficient project design. Private-sector investments in the U.S. OSW supply chain are predicated on both an anchor first customer and longer-term demand certainty to ensure stable revenues over the life of the asset. While manufacturers recognize there will be significant demand in the medium- and long-term U.S. market, many supply chain companies have shown limited appetite to take first mover risk given recent uncertainty of near-term pipeline and revenue consistency. Global OSW supply chain players expect immense global demand growth and have seen investing in U.S. supply chain expansion as higher risk than international expansion projects. This picture will change as projects move forward this decade and the industry continues to demonstrate long-term consistent demand and deployment.

Procurement frameworks and supporting programs were largely isolated by state historically, which can narrow the potential business cases for supply chain planning. In addition to the pre-FID funding gaps and co-development risks articulated in Challenge 2, this procurement framework risks incentivizing supply chain buildout that is inefficient for wider regional needs (with assets optimized to specific offtake commitments rather than for a broader, efficient market).

In addition, technology uncertainties, particularly from rapid increases in turbine size complicate supply chain business cases. Suppliers and vessel owners worry that investments with long-term payback periods (often 10+ years) may become obsolete soon after they come online. Further, many in the industry increasingly believe that rapidly increasing turbine sizes no longer present the LCOE savings observed historically, in part due to the downstream expenses required to up-scale supply chain assets.

Solution: Clear procurement schedules that provide demand visibility and consistency

Setting clear procurement schedules offers the industry long-term visibility into timelines (solicitation dates) and procurement sizes (MW). This is put forward as a recommended action by the Federal-State Offshore Wind Implementation Partnership, and states like New Jersey already have a long-term procurements schedule in place.

Clear procurement schedules allow the industry to optimize project timelines and project sizes to create smooth demand pipeline for supply chain investment. Continued cross-state collaboration can leverage multiple states' offshore wind deployment targets to ensure steady annual buildout, reduce costs, and foster a healthy supply chain ecosystem. Synchronizing across states to set synergistic procurement schedules, and even in some cases coordinated procurements (e.g., in New England), can further multiply these efforts to ensure consistent demand for suppliers and steady buildout by developers.

New resources made available through the Bipartisan Infrastructure Law and the Inflation Reduction Act provide the industry with long-term visibility into policy support mechanisms, fostering private sector business investment cases.

Solution: Collaboration to support supply chain and transmission buildout on a regional level

Incentivizing and supporting supply chain assets on a regional level broadens the demand pool for supply chain assets, unlocks private investment, and fosters more efficient regional buildout of supply chain and transmission needs. (See Challenge 4 for detail on transmission.) For supply chain, regionalization also reduces project execution risk and costs, by widening the pool of potential suppliers and fostering competitive procurement. It may also offer projects additional flexibility to mitigate downstream risks if facing a bottleneck within a particular state. Fostering regional supply chains supports both supply chain companies and OSW deployment. Efforts are underway today, beginning with regional supply chain working groups to establish planning and procurement mechanisms to incentivize supply chain buildout across states. Offtake mechanisms can also serve as a powerful tool to catalyze supply chain investment and regionalization, by valuing economic and social benefits from regional content across state borders.

See additional detail in the Federal-State MOU on East Coast OSW Supply Chain Collaboration, a model that can be replicated and expanded upon for other OSW regions across the U.S.

Potentially Catalytic Solution

The industry has also highlighted the potential value of public or private support to back-stop supply chain order books in the event of exogenous market interruptions, which may be particularly impactful for new-built construction vessels which require long-term consistent charter demands to unlock investment. No such programs exist today.

Solution: Industry consensus on technology specifications and standards for supply chain buildout

Standardizing infrastructure and development plans will enable the supply chain to ensure assets do not become obsolete before their payback period. Future-proofing facilities to the extent possible to allow expansions will ultimately enable further up-scaling long-term. In addition to WTG sizes, clarity on the best foundation types and designs for different U.S. regions, transmission specifications, and construction techniques all support private investment cases.

Larger turbine sizes have historically offered significant scale savings to drive down the LCOEs of offshore wind—via both cost savings and improved capacity factors. However, expectations of rapid continued WTG up-scaling presents an investment risk to supply chain assets (ports, manufacturing facilities, and vessels) that may hamper investment in critical U.S. supply chain needs today. After scaling up from ~3 MW machines

15 years ago to ~15 MW machines today, some in the industry believe that the best path forward in the near term is to focus on cost reductions to existing platforms while scaling deployment.[xxvi,xxvii,xxviii] Larger turbines still present opportunities for cost reductions long term, but liftoff can be achieved with announced turbine models for 2020s projects.

Challenge #4: Transmission risks development bottlenecks and grid inefficiencies

Challenge	Solutions Underway
1. Tranche 2 offtake cancellations	
2. Current market structures	
3. Industry lacks long-term market visibility	
4. Transmission risks development bottlenecks and grid inefficiencies via onshore interconnection, offshore project design, and wider network buildout.	• Coordinated POI identification and solicitations for onshore upgrades across multiple OSW projects • OSW project sizes and standards tailored to low-cost offshore transmission and efficient interconnection • Mobilization of interregional transmission planning

Interconnection challenges pose an increasing risk to project deployment—coordinated investment is required to increase grid efficiency and achieve OSW liftoff. Historically, onshore interconnection upgrades and offshore transmission planning has often been siloed by project and by state, which could lead to piecemeal transmission buildout with inefficient outcomes. OSW projects increasingly face execution risk from onshore upgrades due to the long lead times and cost uncertainty of the interconnection queue process. The exogenous risks posed by interconnection processes and cable route siting (particularly from landfall to onshore POI) also impacts OSW offtake bidding behaviors and can negatively impact ratepayers. Long term, upgrades to aging coastal transmission infrastructure are required to inject into the grid the volumes of offshore wind power planned by states.

Solution: Coordinated POI identification and solicitations for onshore upgrades across multiple OSW projects

State or regional solicitations for cross-project grid upgrades will likely lead to more efficient outcomes by bringing together state energy agencies, system operators, and federal stakeholders. Going forward (for projects beyond Tranche 1 and Tranche 2), separate onshore upgrade solicitations will be critical for liftoff and can tap into existing pools of locally experienced onshore transmission developers.

Several states are taking action to build out injection points sized to meet state OSW goals and de-risk deployment. Two specific examples of competitively awarded onshore upgrades to unlock GWs of offshore wind include (with additional solicitations underway):

- New Jersey State Agreement Approach (SAA) in PJM through which they awarded onshore upgrades to unlock 6.4 GW of OSW interconnection in 2022.
- New York's Public Policy Transmission Need (PPTN) process, through which they awarded onshore upgrades to unlock 3 GW of OSW interconnection in Long Island in 2023.

Coordinating onshore upgrades across projects to meet long-term goals is likely to be less expensive for ratepayers, can be incorporated into the rate-base (or project tariffs depending on the approach), and fosters more competitive OSW procurement by leveling the playing field with respect to interconnection.

State-level solicitations represent great progress, but current approaches may not procure the most technically efficient solutions due primarily to (1) lack of a cost allocation framework for interregional planning and solicitation, (2) the need to broaden methods for the evaluation of ratepayer benefits from wider network upgrades.

To ensure these solicitations result in efficient outcomes, procurements can continue to be tailored to standardized cost allocation frameworks and expanded benefit valuation tools. These efforts will bring together states and system operators with federal efforts to address transmission planning and cost allocation (e.g., FERC Docket No. RM21-17-000).[xxix]

There is broad consensus on the need for coordinated onshore network upgrades and better offshore planning. In summer 2023, 10 states formed the Northeast States Collaborative on Interregional Transmission to enhance system reliability, accelerate offshore wind deployment, and transition to a clean energy future more quickly and affordably.[xxx] Efforts will continue to be led by state consortiums and transmission/system operators and fold into wider interconnection queue reform efforts underway (e.g., FERC Order No. 2023).[xxxi]

Solution: OSW project sizes and standards tailored to low-cost offshore transmission and efficient interconnection

Potential inefficiencies in near-term projects' utilization of constrained cable corridors and injection points can be mitigated through the continued tailoring of OSW procurements to match grid needs and constraints. Procurements can ensure the efficient use of constrained onshore locations and to size projects at cost-efficient offshore transmission buildout blocks (especially for HVDC systems). HVAC infrastructure is often most cost efficient at ~400 MW building blocks, and HVDC is often most cost efficient at ~1,300 or ~2,000 MW scale. While HVAC systems are more cost effective at shorter distances, HVDC becomes competitive at transmission distances exceeding ~50 miles for GW-scale projects. The larger the OSW project, and the longer the transmission distance, the more cost effective HVDC becomes. HVDC can also support efficient use of constrained cable corridors because it generally requires fewer cables than HVAC for GW-scale projects.

Solution: Mobilization of interregional transmission planning

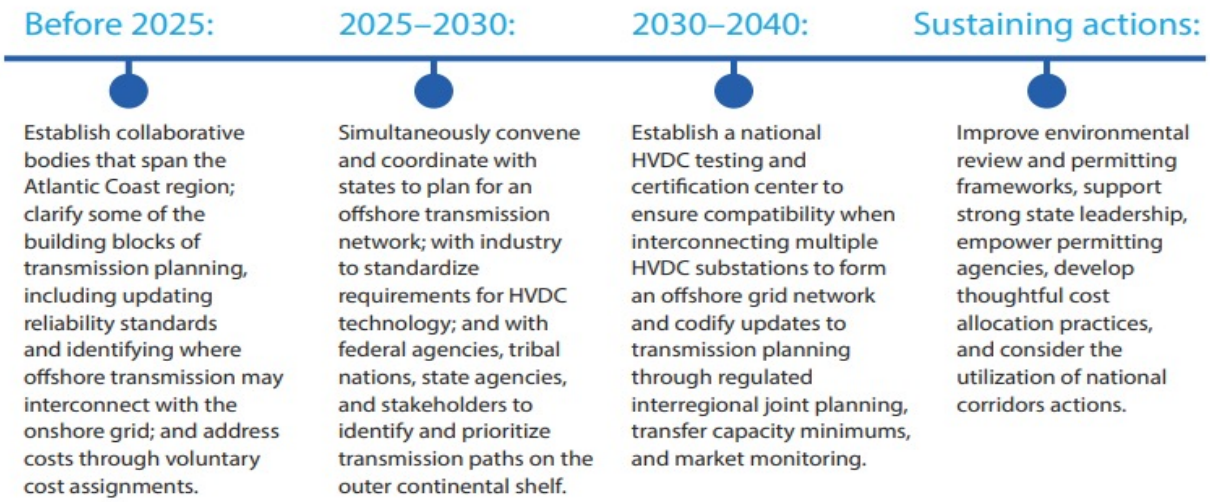
Long term, offshore networked transmission, especially interregional, presents a valuable option to connect new and existing OSW projects (likely ~2035 and beyond). If the status quo is maintained, today's lack of interregional transmission would increase ratepayer costs and exacerbate OSW revenue and curtailment risks. In addition to onshore reinforcements, networked offshore transmission presents billions of dollars in potential ratepayer benefits long term, though it is complex to execute.[xxxii,xxxiii]

Note: Interregional offshore transmission for the East Coast is explored in depth in the Atlantic Offshore Wind Transmission Action Plan, and Atlantic Offshore Wind Transmission Study published in March 2024.

To prepare for coordinated offshore transmission, OSW markets require transmission plans that are cost-effective in the near-term and compatible with long-term transmission coordination. In parallel to deploying projects today with established interconnection plans, interregional transmission planning, siting, and standardization must begin now, regardless of the transmission solutions selected.

Ensuring efficiently sized and planned radials will remain a key need for long-term OSW buildout. In the *Atlantic Offshore Wind Transmission Study*, all scenarios found that most OSW will be built with radial lines, especially in the near term (~63-77 GW of an 85 GW scenario for Northeast OSW, according to NREL modelling). The study found that topologies linking power markets inter-regionally offers the best cost-benefit ratio from networked transmission. For this topology, the study's modeling calls for 14 GW of networked transmission for 85 GW of OSW by 2050. The first multi-terminal HVDC deployment is estimated to be built around 2035 in DOE's Atlantic OSW Transmission Action Plan and Transmission Study, with actions pre-2025 necessary for 2035-50 deployment. Inaction in the coming years would risk constraining future transmission solutions by inefficiently utilizing constrained cable corridors.

Figure 23 – Recommended Action Timeline in the Atlantic OSW Transmission Action Plan



Source: DOE Atlantic Offshore Wind Action Plan Fact Sheet

Chapter 5: Metrics and Milestones

Progress towards offshore wind liftoff can be tracked at the state, regional, and national level. Three categories of metrics—outcomes, leading indicators, and lagging indicators— can track the progress and impact of offshore wind sector growth.

Outcome	• Total clean energy capacity & production nationwide and by region (MW & MWh) • Greenhouse gas and air pollution reductions resulting from OSW energy production • Ratepayer prices ($/kWh) • Job creation, workforce development, and stakeholder benefits
Leading Indicators	• State OSW targets (MW) • Planned OSW lease sales (acres of seabed, by region) • Announced OSW offtake awards (MW total and annually) • Pace and volume of OSW project FIDs (MW total and annually) • Supply chain FIDs ($m) • Transmission buildout and procurements of coordinated transmission • OSW capEx costs ($/MW) • OSW offtake prices and terms ($/MWh) • Global floating wind project costs and buildout ($/MW and MW)
Lagging Indicators	• Annual OSW construction rate & operational capacity nationwide & by region (MW) • Operational OSW farms' energy production (MWh, and % of electricity supply) • Operational OSW farms' capacity factors and curtailment losses (%) • Number of states and regions with deployed OSW • Number of operational OSW ports, manufacturing facilities, and vessels

Outcomes track the benefits of OSW to the grid, economy, and communities:

- **Total clean energy capacity and production nationwide and by region (MW and MWh)**
  Updated estimates on total clean energy deployment capacity can help determine whether the nation's grid and individual states are on track to an efficient and decarbonized grid.
- **Greenhouse gas and air pollution reductions resulting from OSW energy production, particularly in coastal energy demand centers.**
  The extent to which OSW displaces fossil fuels will result in reduced greenhouse gas emissions and pollution, as well as indicate progress towards a decarbonized grid.
- **Ratepayer prices ($/kWh)**
  Average ratepayer electricity prices ($/kWh) will track the affordability of energy as clean energy resources scale.
- **Job creation, workforce development and stakeholder benefits**
  As the OSW industry scales, the number of workers entering the industry (either by transitioning from transferable sectors or by training), along with the revitalization of coastal infrastructure and manufacturing, will indicate the economic impact of the growth in this sector. Stakeholder benefits and support demonstrate the equitable and sustainable buildout of the OSW sector.

Leading indicators signal market momentum for OSW deployment and liftoff

- **The number and volume of state OSW targets (no. of states and MW)**
  State OSW targets indicate long-term OSW buildout needs and expectations, especially when secured in legislation (rather than just stated goals). States announcing and expanding offshore wind targets indicates long-term industry growth.

- **Planned OSW lease sales (acres of seabed, by region)**
  Consistent long-term deployment depends on sufficient site locations to meet deployment goals. Current seabed leased to developers translates to roughly 50 GW of capacity, with additional lease areas planned for auction.

- **Announced OSW offtake awards (MW total and annually)**
  Consistent offtake announcements track progress facilitating steady offshore wind deployment. Offtake awards pre-date project FIDs and so are an early leading indicator of future capacity additions, though with lower certainty than project FIDs.

- **Pace and volume of OSW project FIDs (MW total and annually)**
  Project FIDs generally mark the point at which an OSW development starts construction and therefore is 3-4 years from COD. It is a strong indicator of near-term deployment rate and capacity additions.

- **Supply chain FIDs ($m)**
  Supply chain FIDs are a strong indicator of near-term supply chain buildout and a signal that private capital is flowing into the OSW supply chain.

- **Transmission buildout and procurements of coordinated transmission**
  The rate of transmission buildout and number of available and planned OSW injection points will track the progress of building out infrastructure needed for OSW deployment and an efficient grid.

- **OSW CapEx costs ($/MW)**
  CapEx costs are a strong proxy for OSW cost trends and are more easily compared and interpreted than offtake prices given the lack of financial nuances.

- **OSW offtake prices and terms ($/MWh)**
  OSW offtake prices track ratepayer impacts and progress towards OSW cost declines as the industry scales (comparing prices in normalized real terms).

- **Global floating wind project costs and buildout ($/MW and MW)**
  Global floating wind capacity demonstrates technology maturity and competitiveness as the market scales.

Lagging indicators track observed progress towards offshore wind liftoff:

- **Annual OSW construction rates and operational capacity nationwide and by region (MW)**
  Updated estimates on offshore wind deployment rate and total capacity can help determine whether the nation's grid and individual states are staying on track to OSW liftoff and an efficient and decarbonized grid.
- **Operational OSW farms' energy production (MWh, and percent of electricity supply)**
  The MWh of OSW production and percentage of electricity supply will demonstrate progress towards a decarbonized grid, and the extent to which load serving entities are balancing clean supply and demand for electricity.
- **Operational OSW farm's capacity factors and curtailment losses (%)**
  Average capacity factors will indicate the operational success of constructed OSW farms, and curtailment rates will indicate whether load serving entities are balancing clean supply and demand for electricity.
- **Number of states and regions with deployed OSW**
  The geographical range of OSW deployment will demonstrate the nationwide success of OSW liftoff and will be particularly important to track progress to unlock floating wind markets.
- **Number of operational OSW ports, manufacturing facilities, and vessels**
  The number of maritime and manufacturing assets serving the industry will track the health of the U.S. OSW supply chain and serve as a proxy for local economic development benefits.

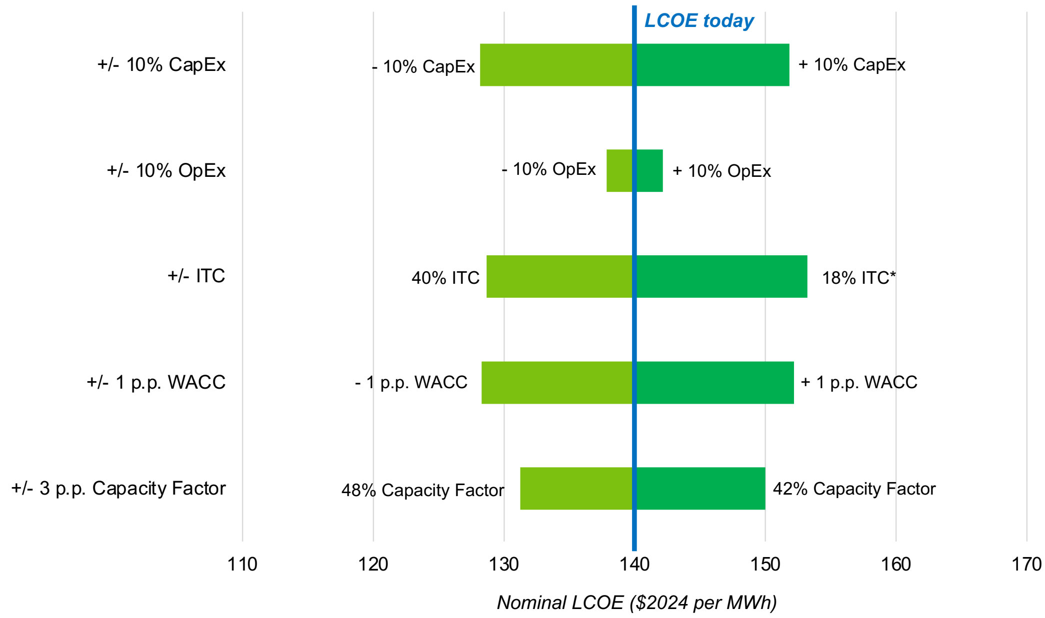
Appendix: Additional Figures

Figure A1 – The parallel paths to unlock floating wind liftoff

	Key considerations on the critical path	*Key actions*
Technical validation	**Foundation design** – should be standardized for serial fabrication, where possible, and a set of designs need to be proven in-situ at scale. Early deployments must navigate IP complexities, and how developers/contractors are often tied to specific designs. **Mooring Design** – approaches need to evolve for commercial-scale; cost/economics of materials and installation methods (e.g. synthetic lines). Mooring design and installation approaches must be tailored and proven by geographic conditions (e.g. depth, soil conditions) **O&M** – prove and optimize O&M models, to ensure reliability and refine approaches to heavy-maintenance work, including automation. **Floating substations & dynamic export cables** for West Coast; risk in adapting existing technologies for floating wind transmission needs. California may be the first market globally to deploy floating substations, given projects abroad are planned for shallower waters. **Dynamic array cables** – models are commercially proven, though potential supply chain issues remain. **Installation regimes** – proving repeatability and predictability at scale, considering geography-specific factors (e.g. water depth). Plant-level **design** – optimize integrated array design (site-specific array layout, etc.), systems engineering & controls co-design, and resource mapping/utilization	**Early-commercial deployment (primarily global)** **Geography-specific technical studies** **Design standardization and certification** **R&D Initiatives**
Enabling infrastructure	**Ports –** floating wind ports are fundamentally different than fixed-bottom, since foundation assembly and turbine installation typically occurs at quayside. Needs vary by foundation type, but early planning is critical (tailored to the most viable foundation designs). Ports can require on the order of $1B, and 10 years to develop, and generally require public investment. Preparing initial ports is a "no-regrets" move. **Supply Chain –** Targeted investments ensure that the floating wind market can serve US demand during construction and operation, leveraging existing O&G and fixed-bottom wind supply chains. One key need is yards for local assembly of floating substructures. **Transmission** – onshore transmission upgrades should be built ahead of project development (esp. CA northern coast, which will likely require 100s miles transmission buildout). Investments should be planned early and allocated separately from wind project development.	**Regional port, transmission, and supply chain planning** **State and Federal funding for early strategic onshore investments**
Demand Certainty	**Signaling demand certainty** – successful policy regimes indicate clear volume and timeline of offtake, even if exact offtake mechanism is not yet defined. Developers need clear timeline milestones in order to structure their development activities. **Clear offtake mechanism** – clear, multi-phase sequence of awards, with long, bankable revenue sources as a part of technology-specific offtake. States could consider multiple offtake rounds with price caps (e.g. as seen in the UK) to signal clear demand as costs lower.	**Enact state offtake frameworks** **Set clear buildout timelines**
Commercial Ecosystem	**Contracting interfaces** – commercial integration for design, project execution, and liability interfaces, made more complex by floating wind **Insurance** – early commercial projects will need to pioneer insurance packages and sector comfort, especially for construction techniques **Bankability / investor comfort –** early commercial projects will need to demonstrate predictable costs and performance to secure debt	**Commercial deployment abroad** **Investor engagement**
Stakeholder & Permitting	**Regulatory** – developers and governments need to adapt existing frameworks and standards for environmental review/permitting **Stakeholder support** – early and thoughtful stakeholder engagement is required to ensure public buy-in and standards for co-use and sharing of development benefits (e.g. justice, community benefits, tribes, etc.)	**Gov. and stakeholder engagement** **Proactively establish regulatory frameworks**

Figure A2 – Drivers of OSW Costs: LCOE sensitivity to key drivers

OSW LCOEs are most sensitive to CapEx, weighted average cost of capital (WACC), ITC, and energy production

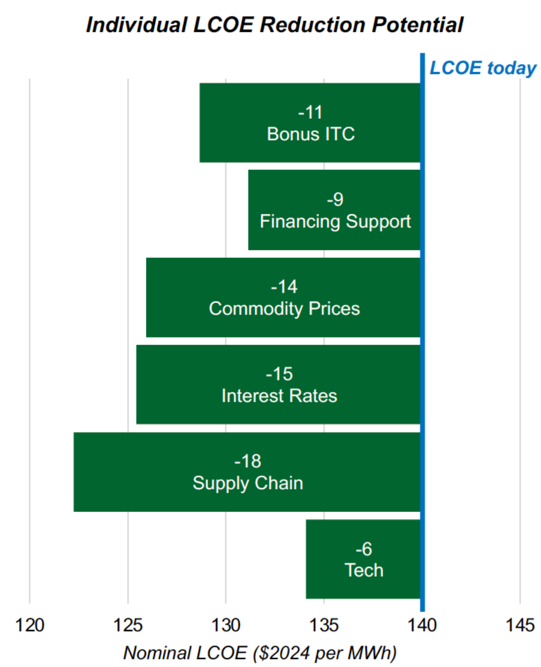


Source: DOE Analysis

Note: "LCOE Today" Baseline of $140 assumes a 30% ITC and 45% capacity factor
** 18% ITC reflects the assumption of some OSW projects pre-2021, before the Consolidated Appropriations Act, 2021 which provided a 30% ITC for offshore wind. This change was a relevant support for some projects that committed to offtake pricing in pre-2021.*

Figure A3 – Key opportunities for OSW LCOE reductions

Key levers to reduce costs	***Driven by***	***Impact through FID 2030***
Bonus ITC – 10% bonus ITC for qualifying projects (primarily Energy Communities)*	Policy (available for qualifying projects)	High – Many projects could qualify
Financing Support– such as LPO financing for eligible projects (potential to lower cost of debt by 75 to 150+ bps)**	Policy (available for qualifying projects)	Moderate – reduction in cost of capital for projects and supply chain
Commodity price reversion – Reduction in raw materials prices from 2022-2023 peaks	Macroeconomic conditions	High – Partial savings realized today, though lag between indices and supplier quotes
Interest rate / WACC reduction – Potential decrease in WACC from a 2% reduction in SOFR rates	Macroeconomic conditions	High – Many projects expected to benefit as rates might decline 2024-onwards
Supply chain buildout – Fewer cost overruns, delays, infrastructure upgrades, and inefficiencies	Policy, investments, US deployment & strong demand signals	High – Many projects expected to benefit (but first movers bear the cost of initial buildout)
Technology improvements – Innovation in design and construction	Investments & global deployment	Low – Limited benefit for near-term projects, with greater opportunities long term

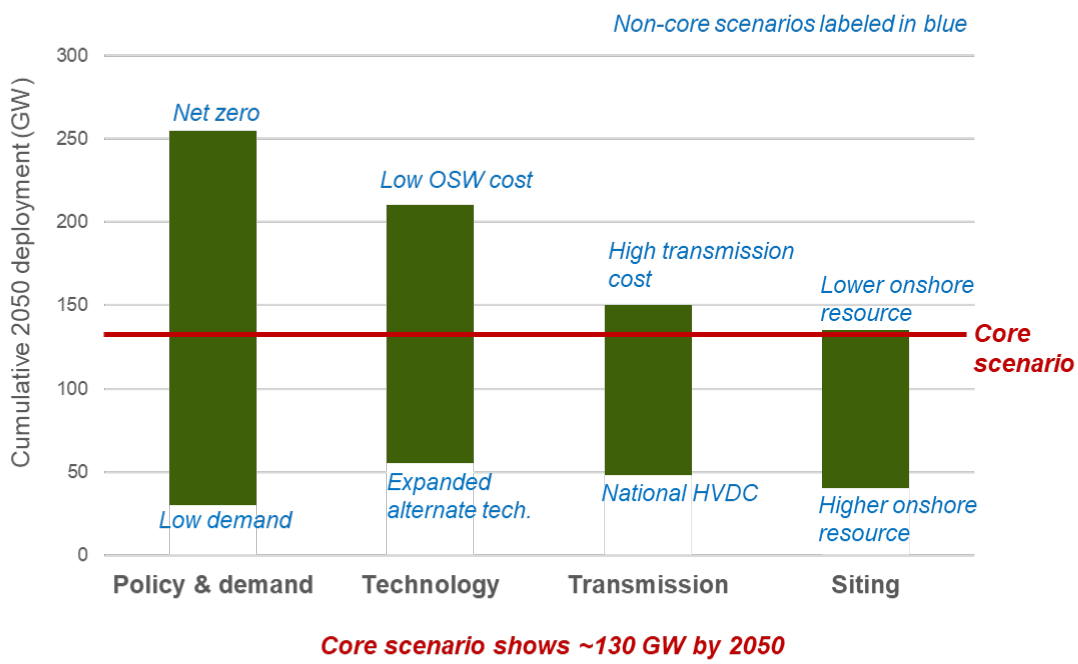


Source: DOE Analysis

** Industry expects additional 10% bonus ITC for Domestic Content may be realized for selected projects by late 2020s, but with value primarily captured by the supply chain (limited impact on project LCOEs).*
*** This $9 reduction assesses a 130 bps reduction in cost of debt alone. Additional benefits may include potential higher leverage and better terms (e.g., recourse), which may add substantial added value (weighed against potential added compliance costs and slower financing processes).*

When the cost reduction levers described above are applied individually to a project with a $140 LCOE (as shown above), the LCOE impact is greater than when they are realized together. This is because cost reductions are generally realized as a percentage reduction in project cost (i.e., a reduction in relative cost of capex rather than absolute dollars). When all cost reduction measures are realized in concert, the relative contribution of each is lessened, as shown in Chapter 2.

Figure A4 – Offshore Wind Capacity Expansion Modeling Sensitivities



Data Source: [Beiter, P. et al. (2023)]

For full analysis, see [Expanded modelling scenarios to understand the role of offshore wind in decarbonizing the United States] by Beiter et al. (2023). 133 GW deployed in "core" scenario, which assumes 6.7 TWh annual electricity demand by 2050, 95% power sector decarbonization by 2050, NREL ATB "moderate" costs for renewable energy technologies, transmission expansion within 12 planning regions, and moderate siting constraints; the "net zero" scenario has the same assumptions, but with 100% decarbonization by 2050. In lower-deployment scenarios (e.g., lower electricity demand, or fewer siting constraints affecting onshore renewables build), modeling estimated roughly 50 GW offshore wind buildout.

Offtake Models for OSW farms

The goal of an OSW offtake mechanism is to provide projects with a bankable and stable revenue stream, maximizing ratepayer benefits while ensuring project delivery. Globally, governments have tested many policy mechanisms to support OSW. In the U.S., two primary models exist today:

1. Competitive auctions, where independent power producers present bids to a state entity and winning bidders then build the OSW asset and sell the energy.
2. "Self-builds," whereby the incumbent utilities seek approval from state regulators to build an offshore wind facility and, once built, the asset becomes part of the utility's "rate base" with the returns on the asset is regulated by the state. In both cases, state legislatures are instrumental in specifying demand for OSW.

Competitive offtake is expected to remain the norm, but the advantages of rate-based projects provide valuable lessons for potential reforms to competitive offtake mechanisms. See the table below for a comparison of the advantages and disadvantages to each approach.

Table A1: Offtake Models for OSW Projects

	Competitive Offtake	Rate-Base
Developer / Owner	Non-utility Independent Power Producer	Incumbent electric utility
Revenue Mechanism	**Price based** IPP recoups costs through long-term power purchase agreement at a set price per MWh determined through competitive auction. (unregulated return on equity)	**Cost Based** Costs recovered through addition of the capital costs of the asset to the utility's Rate Base. (regulated return on equity)
Advantages	• Competition among developers can yield lower per-unit costs • Typically provides greater price certainty for ratepayers, and IPPs have long-term visibility into revenues per unit generated • Ratepayers pay only for power delivered (developer takes risk of under-production or construction cost overruns)	• Developer returns are transparent and backed by regulatory oversight. • Better able to cope with market changes as revenues scale to match investment need (with ratepayer protections) • Potential reduced financing costs if utility is permitted (in state statute) to collect revenue associated with new asset before COD
Disadvantages	• Competitive auctions tend to reward optimistic bids (price, timeline, local content) and therefore ambitious projects. • Historically, revenues were set years before costs are finalized, without indexation, leaving developers exposed to market conditions • Reliant on states administering and soliciting competitive auctions	• With regulated returns, ratepayers are typically more exposed to cost overruns and project under-performance • If recovering costs in real time, ratepayers bear costs upfront, before project is online • Reliant on an incumbent local utility willing to rate-base an OSW development • Incentives don't always align with lowest cost (grow rate-base, O&M pass-through, etc.)
Takeaway	Global standard, but reforms needed on sequencing and risk allocation	Valuable for transmission upgrades, and for OSW projects in select markets that permit utilities to own generation assets.

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