Potential Impacts of the Inflation Reduction Act on Domestic Manufacturing and Deployment for Land-Based Wind Turbines

Owen Roberts, Paula Pérez, Aubryn Cooperman, and Matt Shields

National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
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List of Acronyms

ACP	American Clean Power
AMPTC	advanced manufacturing production tax credit
CapEx	capital expenditures
DCB	domestic content bonus
DCR	domestic content requirements
GE	General Electric
GW	gigawatt
IRA	Inflation Reduction Act
IRC	Internal Revenue Code
ITC	investment tax credit
kW	kilowatt
kWh	kilowatt-hour
m	meter
MW	megawatt
NPV	net present value
NREL	National Renewable Energy Laboratory
OEM	original equipment manufacturer
PTC	production tax credit
SGRE	Siemens Gamesa Renewable Energy
W	watt

Executive Summary

The land-based wind energy industry in the United States produced 10% of the country's electricity in 2022 with 8.5 gigawatts (GW) of wind capacity additions in the same year, bringing cumulative capacity to 144 GW (Wiser et al. 2023). Increased levels of deployment are expected to be driven by the Biden administration's goal of 100% carbon-free electricity by 2035, as well as by the clean energy tax provisions available under the 2022 Inflation Reduction Act (IRA). Most relevant in the IRA for the wind industry are the extended investment tax credit and production tax credit, which can be augmented by different bonuses, such as the domestic content bonus (DCB) for developers that acquire 40%–55%[1] of qualifying components domestically. In addition, manufacturers can claim the advanced manufacturing production tax credit (AMPTC), which provides a tax credit for every qualifying component on a $/watt basis.

Potential Impacts of the DCB

The demand for domestically produced components will be primarily driven by deployment levels and the value that project developers see in sourcing their components from within the United States. While difficult to quantify, this value could include cost competitiveness; increased jobs and economic benefits; reduced supply chain or geopolitical disruptions; or environmental, social, and governance benefits, such as reduced life cycle emissions. However, the authors assume that most projects would choose to source components domestically if they are cost competitive because of these additional value streams. To focus on the potential impact of the DCB, in this report we assume that all projects in the pipeline will seek to meet the 55% domestic content threshold.

Projects that pursue the DCB may experience an increase in capital expenditures (CapEx) because of increased costs for domestic components, as opposed to cheaper imports. Pursuing the DCB is cost effective for projects only if the CapEx increases are less than its value. A project with $1,600/kilowatt CapEx, receiving a production tax credit (PTC) at $0.026/kilowatt-hour, can incur up to 6.3% in CapEx increases without changing its net present value by offsetting them with the DCB. CapEx increases over 6.3% will result in a higher net present value for a comparable project. If future projects elect the new investment tax credit (ITC) instead, the DCB value will be equal to 10% of the final CapEx, therefore incurring CapEx increases of up to 11.1% of the original CapEx without increasing the net present value.

Qualifying for the DCB requires that projects source their towers and steel or iron rebar in the foundation domestically (Internal Revenue Service [IRS] 2023). In addition, the value of domestically sourced manufactured products (the wind turbine and tower flanges) must be at least 40% of the value of all manufactured products for projects that begin construction in 2024 and earlier, rising to 55% for projects that begin construction in 2027 or later (IRS 2023). Project developers can achieve this minimum threshold via various pathways that correspond to different combinations of U.S.-manufactured products and components. Obtaining a U.S.-built nacelle is likely to be a popular building block because we estimate that it contributes around 50% of the

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[1] Specifically, this amounts to 40% for projects that begin construction in 2024 or earlier, 45% for projects that begin construction in 2025, 50% for projects that begin construction in 2026, and 55% for projects that begin construction in 2027 or later.

value of all qualifying components. Projects could also pursue different percentages of blade supply; for example, developers may choose to buy blades for a subset of their wind turbines domestically and source the rest from lower cost imports, or potentially source all of their blades from the United States.[2] As there are many combinations of domestic and imported components to reach DCB thresholds, we include scenarios that consider a demand for 20% and 100% of all blades to be domestically manufactured to understand the range of potential factory demand. We refer to the former as a "strategic blade distribution" strategy, which could enable a project to import some blades from lower-cost countries while also qualifying for the DCB.

Potential Impacts of the AMPTC on Overall Demand and Supply

The AMPTC gives domestic manufacturers the opportunity to be cost competitive with imported products by providing a per-unit subsidy that could offset the costs of blades, towers, and nacelles. The lowest cost of imported components in 2022 was 20% below domestic blades, 6% below domestic nacelles, and 2% below domestic towers (Liu 2023a). The AMPTC is greater than that difference for all three components, representing around 33% of domestic blade costs, 15% for nacelles, and 22% for towers. Manufacturers may use the AMPTC in various ways that are influenced by factors such as their urgency to improve profitability, commitments to customers to help them qualify for the DCB, or competitiveness compared to imports. For purposes of analysis, we define the following three approaches manufacturers may take (also shown in Figure ES-1):

- Manufacturers keep the tax credit and sell components at current domestic prices
- Manufacturers reduce the sales price of the component by the full amount of the credit (which could reduce component costs for developers below imported prices)
- Manufacturers reduce the sales price of components by an amount less than the full credit to allow the manufacturer to capture some of the credit but is sufficient enough to make the price of a domestic component equal to the equivalent import. The price reduction to match import prices would be equivalent to 20% of blade costs, 6% of nacelle costs, and 2% of tower costs.

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[2] The difference between these choices could be partially driven by the developer's choice of tax incentives for the project. A project pursuing the ITC qualifies at the overall project level, and therefore may comprise some wind turbines with U.S.-built blades and some with imported blades if the overall percentage of domestic content reaches the IRS threshold. A project pursuing the PTC qualifies at the individual wind turbine level, which indicates that each wind turbine would have to meet its own domestic content thresholds and may make it more likely that all of the project's blades would be U.S.-built.

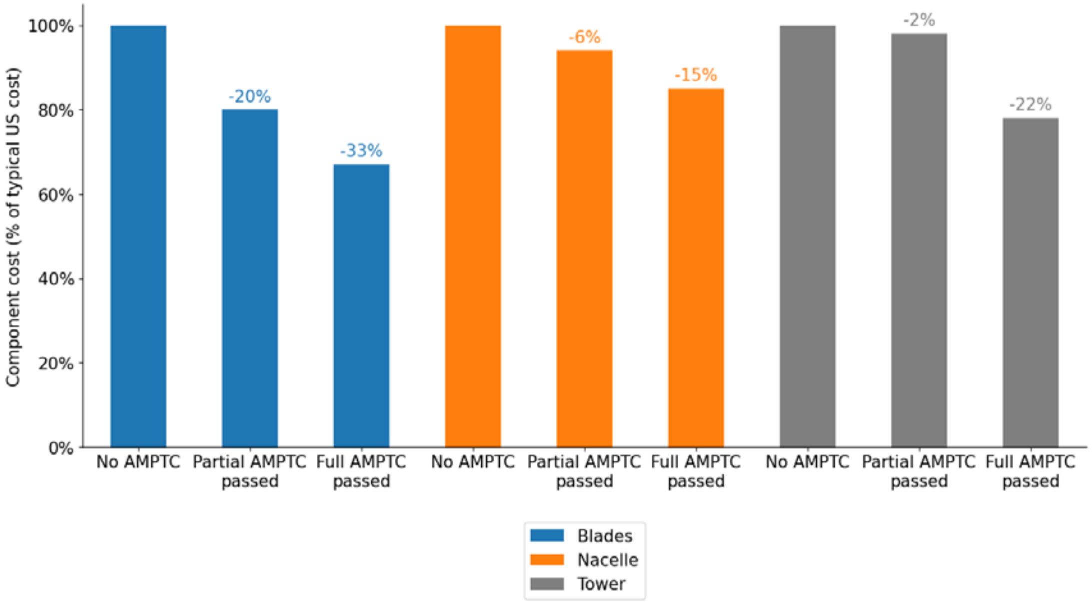

Figure ES-1. Domestic component cost for different AMPTC distributions based on original equipment manufacturers' decisions to keep or share the credit (as a percentage of typical U.S. component costs)

The AMPTC could make domestic components significantly more competitive with imports if original equipment manufacturers (OEMs) use the credit to make their prices more attractive. Additional benefits to developers include reducing risks from global supply chain bottlenecks and reduced transportation costs for projects because of domestic manufacturing.

We evaluated various deployment scenarios to identify the gaps between component demand and existing domestic supply that would need to be met by new U.S. factories, as incentivized by the domestic content needed for the 55% DCB target. We include alternate scenarios where either 20% or 100% of blades are manufactured in the United States to bracket the potential demand from individual developer decisions to balance the overall project cost and available tax incentives.[3] We define scenarios for baseline (reaching an average installed capacity of 21 GW/year from 2030 to 2035), low (15 GW/year), high (36 GW/year), and very high (45 GW/year) deployment.

In the baseline deployment scenario, most of the resulting demand for components (assuming only 20% of blades are domestic) can be met with existing manufacturing capacity (Figure ES-2), except for tower demand, which will require two additional factories. Meeting 100% of blade demand would need to be met with four new facilities.

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[3] Again, this refers to the project developer's decision to either pursue the ITC (where some blades could be imported) or the PTC (where there is more likely to be a demand for 100% U.S.-manufactured blades).

The high and very high deployment scenarios, 24 and 45 GW per year, respectively, that could enable decarbonization goals[4] while meeting the DCB requirements for most projects would need to be met with 1–2 new nacelle factories and 12–17 tower factories, which is more than twice the existing tower capacity (Figure ES-2). Additional blade facilities would be required if projects source more than an average of 20% of blades domestically (one factory for every 2.5 GW of blade production capacity, or 10–14 factories to meet the maximum 45 GW/year of projected demand).

With existing and announced manufacturing capacity, the baseline scenario would enable 91% of projects to qualify for the DCB if they all elect the ITC and implement a "strategic blade distribution" of only 20% domestic blades, whereas the high and very high deployment scenarios would only see a maximum of 63% and 56% of projects qualifying, respectively, because of insufficient domestic manufacturing to meet deployment. If projects use 20% domestic blades, manufacturers could receive AMPTCs for a total of over $12.5 billion in the baseline scenario (over the lifetime of the IRA), and over $16 billion for the high and very high deployment scenarios.

Ultimately, whether the supply gap is met by domestic manufacturing or imports depends on the extent to which OEMs keep the AMPTC or pass it on as savings to developers. OEMs have been struggling with low margins (Lico 2022), which could motivate OEMs to keep prices as high as possible while retaining existing customers. However, they can also benefit from the increased business if they can capture more domestic demand. This trade-off and the OEMs decisions will be key drivers of domestic manufacturing.

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[4] Recent National Renewable Energy Laboratory studies estimate at least an average 24 GW/year of land-based wind energy is needed to reach 100% decarbonization goals for the electric sector by 2035, with peak deployment levels reaching 45 GW/year (Steinberg et al. 2023, Gagnon et al. 2022).

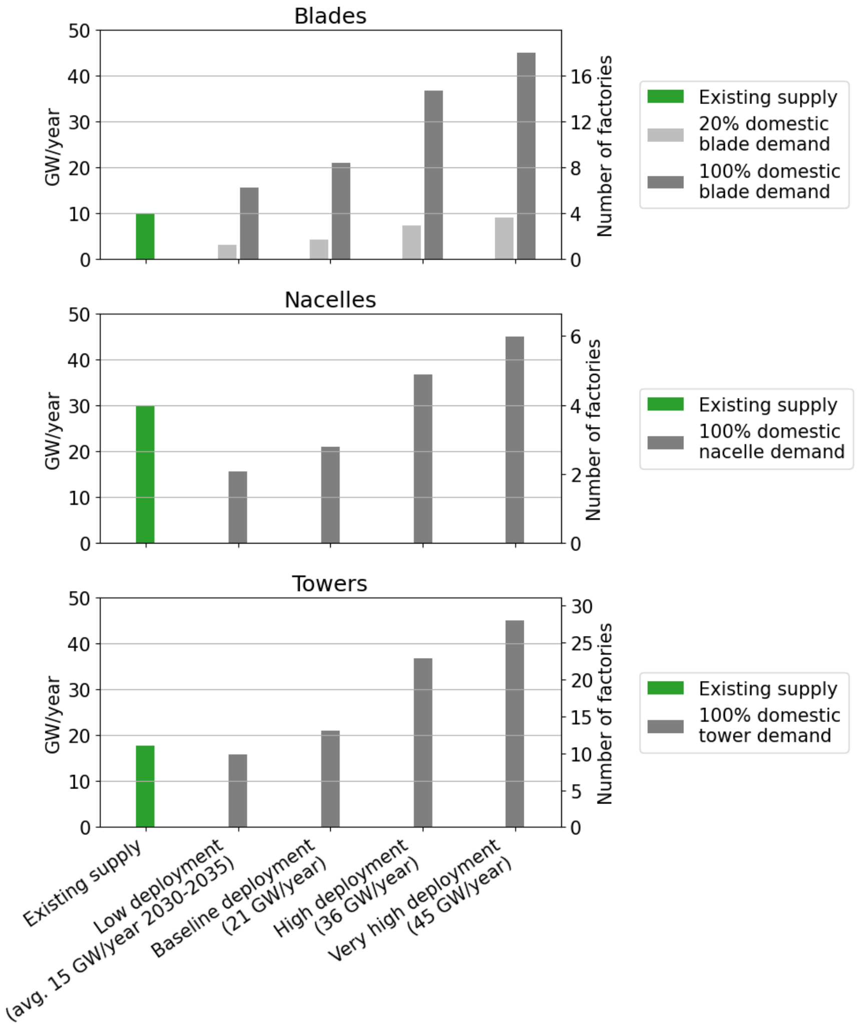

Figure ES-2. Average 2030–2035 component supply and demand across all deployment scenarios.

Challenges in Expanding the Domestic Supply Chain

Expanding the domestic supply chain may result in the following challenges:

- **Component costs**. The extent to which developers elect domestic components is uncertain, as it depends on project-specific cost distributions, external component cost variations, and manufacturers' willingness to pass on savings from the AMPTC, all of which may determine whether pursuing the DCB is cost effective.
- **Wind turbine size and transportation**. Sourcing and distributing components is affected by increased wind turbine sizes and transportation constraints. As platforms grow in size larger components will be more difficult and expensive to transport, especially to the East and West coasts, where infrastructure or geography could increase the risk of delays or prohibitive transport costs to around 8% of the current announced wind energy development, even if there is sufficient domestic manufacturing.

- **Factory costs and risks**. The extent to which new factories are constructed depends on how much manufacturers can capitalize on the AMPTC or the advanced energy project credit given construction and credit phaseout timelines.
- **Repowering**. There is uncertainty regarding how components used to repower projects will qualify for IRA provisions, which may significantly impact the demand for components and the profitability of pursuing the DCB for developers, as well as potentially encourage domestic demand further. However, increased component transportation may limit new deployment as it competes with repowering.

Key Takeaways

Key takeaways from this study include the following:

- The AMPTC allows for domestic components to be cost competitive with imports, although not all manufacturers may pass on savings to customers. If customers receive the full value of the AMPTC, domestic component costs would be reduced by an estimated 15%–33%. We estimate that less than the full value of the AMPTC would need to be passed on to match the cheapest import prices. The AMPTC has already spurred investments from OEMs with announcements of manufacturing facilities reopening or expanding from each of the three major OEMs and component suppliers.
- Pursuing the DCB will not be cost-effective for projects if domestic component costs increase CapEx beyond the bonus value. Qualifying for the DCB requires projects to source 100% of towers and foundation rebar domestically. We consider scenarios where projects source 100% of nacelles and 20%–100% of blades domestically to meet the 55% domestic content requirement. The range of domestic blades is intended to bound the actual demand by either assuming that all projects in the United States would claim the ITC (and therefore could use both domestic or imported blades) or the PTC (and would be more likely to use all imported blade to maximize the value of the DCB). The resulting demand for components can be met for most projects with existing capacity in the baseline scenario, although around four new blade factories would be needed to meet 100% of blade demand.
- The IRA is expected to increase wind energy deployment to 21 to 25 GW/year by 2030. Consistent, elevated deployment levels provide manufacturers with more confidence in future demand. High or very high deployment levels (peak deployment of 36–45 GW/year) that are needed to meet decarbonization goals will result in significant supply gaps, requiring 1–2 new nacelle factories and 12–17 tower factories. In addition, 20% of blade demand can be met with existing capacity (including recent announcements), although 10–14 factories would be needed to meet 100% of demand.

Additional factors may limit deployment and domestic manufacturing, including component cost uncertainty, transportation constraints (mostly impacting project on the East and West coasts), factory investment risks, and repowering demand.

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1 Introduction

The land-based wind energy industry in the United States has matured over the past several decades, representing 10% of the country's total electricity generation in 2022. It has experienced periods of rapid growth and decline in recent years, in large part because of supply chain disruptions at a global and domestic level. With the recent passing of the 2022 Inflation Reduction Act (IRA), the industry faces unprecedented opportunities to strengthen domestic manufacturing and enable greater deployment over the next decade. To better understand the opportunities and challenges, the authors explore the value of relevant IRA provisions and provide a set of scenarios evaluating impacts on domestic component demand and manufacturing.

Section 1 provides context on the current state of the industry and the IRA. Section 2 details the methods used for the analysis. Section 3 focuses on the calculated value of relevant IRA tax credits and Section 4 discusses the domestic demand and manufacturing scenarios developed. We used key takeaways from industry conversations to inform the analysis assumptions, which are explained where relevant. Finally, Section 5 summarizes key findings and considerations to further encourage the domestic supply chain.

1.1 Current State of U.S. Land-Based Wind Energy

In 2022, land-based wind energy in the United States saw capacity additions of 8.5 gigawatts (GW), amounting to $12 billion in total investment and bringing the cumulative capacity to 144 GW (Wiser and Bolinger 2023). This influx raises the land-based wind penetration of the total electric-power generation to 10%. This was a significant decline from record-setting wind energy deployment in 2020 of 16.8 GW (a $24.6-billion investment) and 13.4 GW in 2021 (a $20-billion investment). A significant factor influencing deployment is the increasingly longer interconnection timelines, with almost 200 GW of land-based wind in interconnection queues as of 2022 (Lawrence Berkeley National Laboratory 2023).

An additional 1.7 GW of existing wind turbines were repowered, or retrofitted with new blades, hubs, and drivetrain components, in 2022, increasing corresponding energy production capacity to 1.8 GW, extending project lifetime, and increasing access to tax credits (Wiser and Bolinger 2023). The annual repowering capacity ranged from 1.6 GW to 3 GW between 2017 and 2022.

On the supply side, domestic manufacturing capacity for wind turbine blades, towers, and nacelles saw steady growth consistent with component demand up until 2019 (see Figure 1). In 2020, with deployment surpassing 16 GW, blade and tower production capacity became insufficient to meet domestic demand, remaining at approximately 10 GW of capacity each, whereas nacelle capacity remained at 15 GW. With the COVID-19 pandemic of 2020, global and domestic supply chains were severely disrupted, primarily impacting domestic blade production, which fell to less than 5 GW of production capacity by 2022.

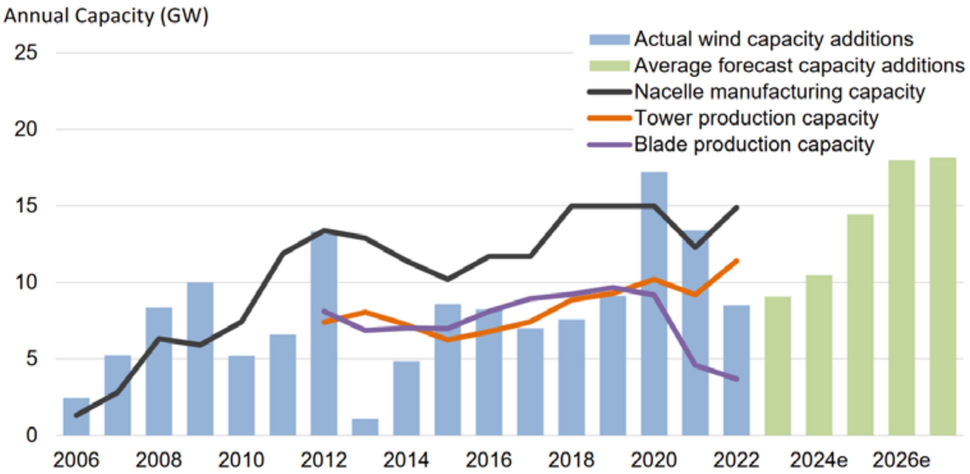

Figure 1. Domestic wind manufacturing capability[5] vs. U.S. wind power capacity installations (Wiser and Bolinger 2023)

Figure 2 displays the value of wind component imports up to 2022. Reliance on imports (equivalent to import value normalized by annual wind-turbine-level costs) has been increasing gradually since before the pandemic, from 20% of components installed[6] in 2015 to more than 35% in 2022. Of the $2.2 billion value of components imported in 2022, the largest share corresponds to blades and hubs, representing 56% of total imports and primarily brought in from Mexico.

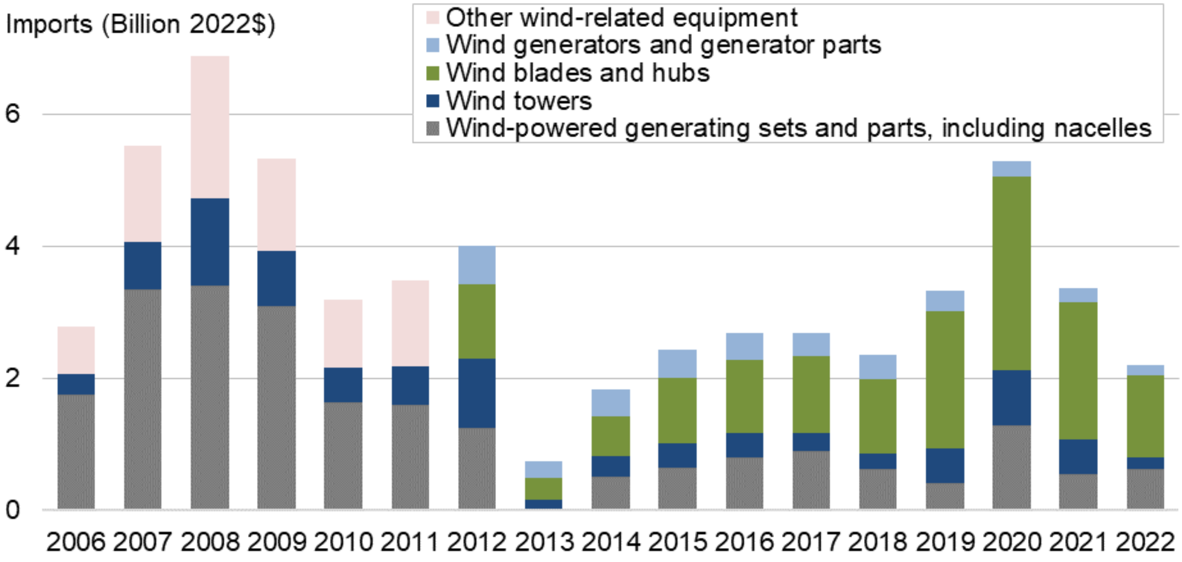

Figure 2. Imports of wind-related equipment (Wiser and Bolinger 2023)

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[5] Actual nacelle assembly, tower production, and blades production would be expected to be below maximum production capacity.

[6] Only includes generators, blades, hubs, towers, and nacelles (including nacelle parts), which are traceable imports via trade codes.

1.2 The Inflation Reduction Act of 2022

The Biden administration passed the IRA in 2022 with the intent of strengthening the clean energy economy and slowing down climate change while lowering consumer costs, creating well-paying jobs, and fostering domestic manufacturing (The White House 2023). The IRA includes several tax provisions to lower energy bill costs and support the deployment of clean energy and energy efficiency technologies, as well as encourage clean manufacturing. A recent National Renewable Energy Laboratory (NREL) report (Steinberg et al. 2023) calculates that the additional land-based wind energy generated by the IRA can result in an average 24 GW/year of wind additions by 2030, representing an additional 171 GW of wind deployment relative to an equivalent scenario without the IRA. Eleven wind manufacturing facilities were also recently announced to be newly constructed, reopened, or expanded in response to the IRA (Wiser and Bolinger 2023).

To support a just and equitable energy transition, many of the provisions also incorporate prevailing wage and apprenticeship requirements. For example, there are bonuses for projects established in low-income or historically disadvantaged communities, or communities negatively impacted by the clean energy transition, as well as for projects meeting domestic content requirements.

Only some of the most relevant tax provisions to land-based wind energy deployment and domestic component supply are explored in this study and explained in the following sections. These include:

- The advanced manufacturing production tax credit (AMPTC), which provides a tax credit for every qualifying component produced domestically on a dollar ($)/watt (W) basis
- The extension and modification of the investment tax credit (ITC) and production tax credit (PTC), which support the deployment of clean energy projects
- The domestic content bonus (DCB), which can augment the ITC by 10 percentage points or the PTC by 10% if domestic content requirements are met.

Other relevant tax provisions that were not included in this study include[7]:

- The energy community bonus credit, which can augment the ITC or PTC if projects are established in an “energy community” that is negatively impacted by the clean energy transition
- The advanced energy project credit (Internal Revenue Code [IRC] §48C, also known as the advanced manufacturing investment tax credit), which provides a tax credit for capital investments in re-equipped, expanded, or newly established clean energy component manufacturing facilities or other clean energy manufacturing investments. This tax credit cannot be claimed in conjunction with the AMPTC.

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[7] More information on all IRA provisions can be found in the White House’s Inflation Reduction Act Guidebook at www.whitehouse.gov/cleanenergy/inflation-reduction-act-guidebook/.

1.2.1 The Advanced Manufacturing Production Tax Credit

The AMPTC (IRC §45X) is a new type of tax credit made available by the IRA for clean energy component manufacturers. The full value of the credit (on a $/W basis for different components) is available from 2023 to 2029 and phases out from 2030 to 2032. The credit amounts are reduced to 75% in 2030, 50% in 2031, and 25% in 2032 (Internal Revenue Service [IRS] 2022).

For land-based wind energy, the full credit per component is as follows:

- $0.02/W per individual blade
- $0.05/W per nacelle
- $0.03/W per complete tower.

1.2.2 The ITC and PTC

One of the most important tax provisions in the IRA for land-based wind is the extension and modification of the ITC (IRC §48) and PTC (IRC §45), followed by their replacement starting in 2025 by the technology-agnostic clean electricity ITC (IRC §48E) and clean electricity PTC (IRC §45Y) (The White House 2023). While the ITC serves as a tax credit as a percentage of qualifying energy generation capital investments, the PTC is a tax credit for electricity production on a $/kilowatt-hour (kWh) basis.

Before the IRA, the ITC applied primarily to solar generation projects and offered a full 30% tax credit for qualifying investments up until the end of 2019, after which it phased out gradually until it reached a maximum tax credit of 10% in 2024 and later years (IRS 2018). The PTC applied primarily to wind generation projects for a period of 10 years and expired by the end of 2021 (Wind Energy Tecnologies Office). The tax credit had a rate of 1.5 cents per kilowatt-hour produced subject to a 1992 inflation adjustment (2.75 cents per kilowatt-hour in 2023 (IRS 2023), with a phaseout to zero based on the construction start date.

Under the IRA, the ITC and PTC return to their full tax credit amount (30% of investment or 1.5 cents per kilowatt-hour before inflation adjustment, respectively) for projects that begin construction before the end of 2024. This depends on meeting prevailing wage and apprenticeship requirements, otherwise projects are only eligible for one-fifth of the amount. Both provisions are replaced by the technology-agnostic clean electricity ITC and PTC starting in 2025.

The new clean electricity ITC and PTC apply to projects placed in service after 2024. They also start phaseouts either in 2032 or when U.S. greenhouse gas emissions from electricity fall to 25% or less of 2022 emissions, whichever happens later (The White House 2023). They also depend on prevailing wage and apprenticeship requirements. Additionally, they can be augmented by an energy community bonus and/or domestic content bonus. Each bonus is equivalent to an additional 10 percentage points for the ITC or 10% of the credit value for the PTC, if prevailing wage and apprenticeship requirements are met. Otherwise, the bonus value decreases to one-fifth of the amount. The DCB and energy community bonus phase out on the same schedule as the ITC and PTC.

1.2.3 Domestic Content Bonus

The DCB included in the IRA can be applied to both versions of the ITC and PTC. The United States Department of the Treasury released Notice 2023-38 (IRS 2023) with additional guidance for the DCB, which defines the two requirements to be met to qualify for the bonus as follows:

- The steel or iron requirement:
  - A project meets the requirement if 100% of steel and iron manufacturing processes happen in the United States, except for refinement of steel additives
  - The requirement only applies to steel or iron used in construction materials and structural in function (for land-based wind, this includes tower sections and steel/iron in foundations), and excludes steel or iron used in manufactured product components or their subcomponents (e.g., nuts, bolts, cabinets).

- The manufactured product requirement:
  - A project fulfills the requirement if it meets the adjusted percentage rule, which is met when the domestic content percentage equals or exceeds the adjusted percentage, where:

$$Domestic\ Content\ Percentage\ = \frac{\begin{array}{c}Domestic\ Manufactured\ Products\\ and\ Components\ Cost\end{array}}{Total\ Manufactured\ Products\ Costs}$$

  - Manufactured products are manufactured items incorporated directly into a project (for land-based wind, this includes wind turbines and tower flanges). They are deemed to be domestic when 1) all manufacturing processes take place in the United States, and 2) all manufactured product components are of U.S. origin.
  - Manufactured product components are manufactured items incorporated directly into manufactured products (for land-based wind, this includes blades, nacelles, rotor hubs, and power converters). They are deemed to be domestic when they are manufactured or produced in the United States regardless of the origin of the subcomponents.
  - The adjusted percentage is defined as follows for land-based wind energy:
    - 40% for projects that begin construction in 2024 or earlier
    - 45% for projects that begin construction in 2025
    - 50% for projects that begin construction in 2026
    - 55% for projects that begin construction in 2027 or later.

2 Value of Inflation Reduction Act Credits

The value of the DCB and AMPTC to developers and manufacturers determines whether they are cost-effective to pursue. In this work, we modeled the value of the DCB for a standard, illustrative project, as well as the value of the AMPTC for the components in a standard wind turbine platform. In this report, we include model assumptions and emphasize that findings should not be taken as representative values nor fiscal guidance. Tax credit values will vary considerably depending on component and subcomponent costs, as well as other costs specific to projects or manufacturing facilities.

2.1 Advanced Manufacturing Production Tax Credits

We estimate the value of the AMPTC[8] for a representative industry wind turbine using 2020 component costs, developed with wind turbine original equipment manufacturers (OEMs), shown in Table 1. This calculation assumes that 100% of the wind turbine blade, nacelle, and tower costs qualify toward the AMPTC, and does not include increases in cost as a result of U.S. steel requirements for towers.

Table 1. AMPTC Value for a Representative Industry Wind Turbine

Component	2020 Baseline Cost ($/kilowatt (kW))	AMPTC Value ($/kW)	AMPTC Value as a Fraction of Component cost[9] (%)
Blades (3)	$184	$60	32.6%
Nacelle	$334	$50	15.0%
Tower	$176	$30	21.8%
Other turbine components	$42	Not applicable	Not applicable
Turbine total	**$736**	**$140**	**19.0%**

We estimate domestic blades to be 20% costlier than their foreign-produced blade, a difference that could be offset by the AMPTC. However, as component costs increase, the AMPTC value as a fraction of total cost decreases. Turbine prices for the second quarter of 2023 are 40%–50% higher than in 2020.[10] Taking an average 45% increase in total turbine cost results in an AMPTC value of 13.1% (out of total turbine cost), showing a reduction in benefit to manufacturers.

While the AMPTC provides the opportunity for domestic manufacturers to be cost competitive with imported products by offsetting the costs of blades, towers, and nacelles, manufacturers may use the AMPTC in different ways (also illustrated in Figure 3), for example:

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[8] These costs include $0.02/watt (W) per individual blade, $0.05/W per nacelle, and $0.03/W per complete tower.

[9] Comparable to Wood Mackenzie calculations of 34% for blades, 20% for nacelles, and 20% for towers (Liu 2023a).

[10] The average 2020 wind turbine cost was $810/kilowatt (kW), and the average 2023 cost was $1,150/kW. Costs include delivery and a 2-year warranty (Wood Mackenzie 2023c).

- Manufacturers could keep the full tax credit and sell components at typical domestic prices, which would not affect the cost of components for developers
- Manufacturers could reduce the sales price of the component by the full amount of the credit, which would reduce component costs for developers below imported prices. The tax credit is equivalent to around 33% of blade costs, 15% of nacelle costs, and 22% of tower costs.
- Manufacturers could reduce the sales price of components by an amount less than the full credit, which would reduce component costs for developers enough to be cost competitive with imports and allow the manufacturer to keep some of the tax benefits. The price reduction to match import prices would be equivalent to 20% of blade costs, 6% of nacelle costs, and 2% of tower costs (Liu 2023a).

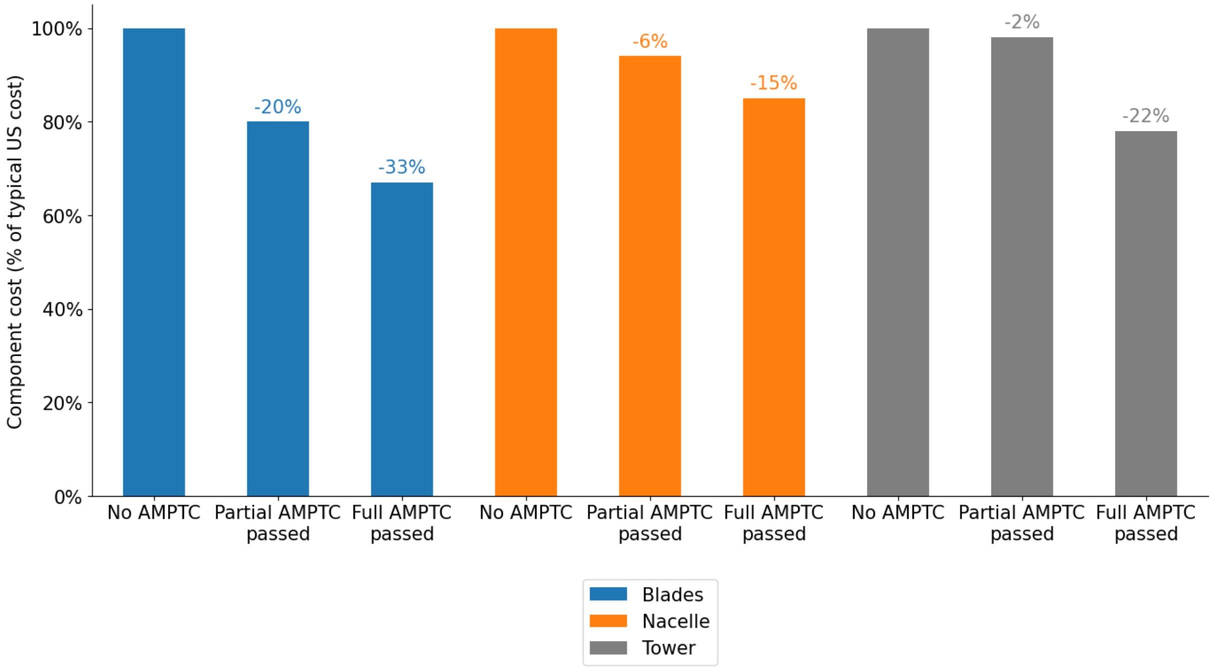

Figure 3. Component cost for different AMPTC distributions based on OEMs' decisions to keep or share the credit (as a percentage of typical U.S. component costs)

While blades receive a larger tax credit as a percentage of component cost, over half of the credit would have to be passed on to customers to lower prices to those of the cheapest imports. On the other hand, nacelles and towers receive a smaller tax credit due to domestic nacelle and tower prices are already competitive with imports and manufacturers would not need to pass on as much of the credit to match import prices.

Overall, the AMPTC could make domestic components significantly competitive with imports if sufficient savings from the credit are passed from OEMs to developers. However, OEMs have been struggling with low margins (Lico 2022) and may still choose to keep the credits, keeping component prices higher and encouraging developers to turn to imports. Nonetheless, OEMs can also benefit from the increased business if they can capture more domestic demand. This trade-off and the OEMs' decisions may be key drivers of domestic manufacturing.

2.2 Domestic Content Bonus

Starting in 2025, land-based wind energy projects can qualify for the new ITC or PTC, so we evaluated the DCB value for both tax provisions because they have different mechanisms. For projects to meet the DCB requirements, they must pay more for domestic components, as shown in Figure 3. Higher costs for domestic components may be offset by the DCB depending on the project ownership and financing methods. Pursuing the DCB may be cost-effective for projects if the CapEx increases are less than the value of the DCB. We calculate the value of the DCB on a net present value (NPV) basis by parameterizing capital expenditures (CapEx) for the reference project both with the base PTC and the base PTC plus the DCB. This approach results in identifying a project with the base PTC with its CapEx value and a project with the DCB with the same NPV. These two projects will have different CapEx values because of the inclusion or exclusion of the DCB, which we express as a percentage of total project CapEx, or the value of the DCB.

To evaluate the value of the DCB, we have modeled a reference project with NREL's System Advisor Model (NREL 2022) using 2022 industry cost and wind resource averages as per the *Land-Based Wind Market Report: 2022 Edition* (Wiser et al. 2022). Assumptions include:

- $1,600/kilowatt (kW) total project installed CapEx
- 7.99 meter-per-second wind speeds at a 100-m (meter) hub height
- 282-megawatt (MW) plant capacity
- 12 rotor-diameter-by-12-rotor-diameter wind turbine spacing
- Turbine model: General Electric 2.82 MW, 127 m rotor diameter, 89 m hub height
- 18.9% losses[11]
- 43.5% net capacity factor
- $32/kW-year operation and maintenance cost
- 2.5% inflation
- $23/megawatt-hour power purchase agreement with 2.5% annual escalation
- 30-year project life
- 1.4 debt-service coverage ratio
- 8% weighted average cost of capital
- 5-year modified accelerated cost recovery system.

2.2.1 DCB Value With the Production Tax Credit

We assume the modeled project qualifies for the 2022 PTC rate of $0.026/kWh (IRS 2022), resulting in a DCB rate of $0.0026/kWh. Based on the site NCF of 43.5%, the modeled project receives a DCB of $100/kW, equivalent to 6.3% of its CapEx. Therefore, the developer can afford to increase project CapEx by up to 6.3% for the same NPV (as shown in Figure 4).

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[11] Averages losses for selected plants included in the Wind Plant Performance Prediction Benchmark Phase 1 Technical Report (Fields et al. 2021).

However, CapEx increases of more than 6.3%[12] will result in a higher NPV (for a comparable project pursuing the PTC). This increase suggests that developers would stand to gain from the DCB if they can keep the cost increases to less than 6.3%, although these results vary depending on other project costs and annual energy production.

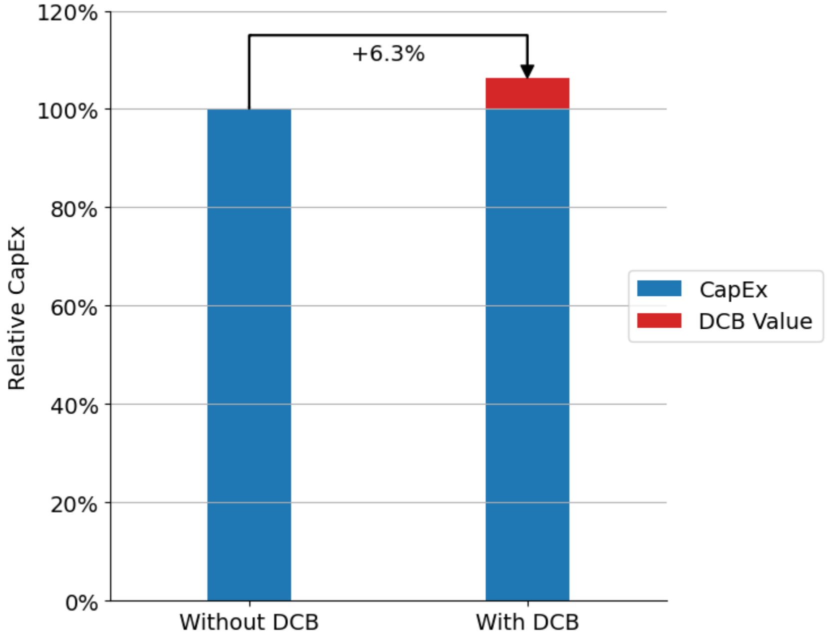

Figure 4. Project CapEx values with and without the DCB, for equal NPV in both cases

Additionally, for the same annual energy production, higher initial project CapEx would result in a lower value of the DCB in $/kW or as a percentage of CapEx, suggesting projects with lower CapEx stand to gain more from the DCB (Figure 5).

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[12] Wood Mackenzie estimates a CapEx increase of 9% to meet DCB requirements (Liu 2023b).

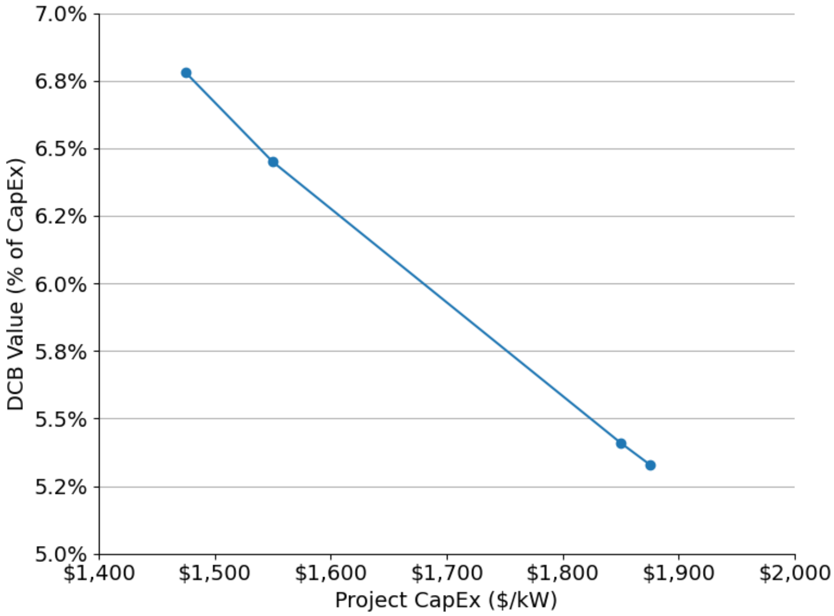

Figure 5. DCB value relative to CapEx decreases as overall project CapEx increases

2.2.2 DCB Value With the Investment Tax Credit

The ITC is calculated as a percentage of qualifying project CapEx (maximum 30%), and a DCB value equal to an additional 10% of CapEx. The same modeled project with original CapEx of $1,600/kW can incur cost increases of up to $178/kW without exceeding the DCB value and maintaining the same NPV. Therefore, the final project CapEx could increase to $1,778/kW and receive a DCB for $178/kW (11.1% of the original CapEx). See Table 2 for a cost breakdown.

As a result, developers would benefit from the DCB if they can keep the increase in cost to less than 11.1% for comparable projects. Cost increases greater than 11.1% of the original CapEx would result in a lower NPV since they would not be entirely offset by the DCB.

Table 2. DCB Value for a Standard Project With the ITC

	Value ($/kW)	Value (% of Original CapEx)
Original CapEx	$1,600	100%
Cost increase	$178	11.1%
Final CapEx	$1,778	111.1%
DCB value (10% of final CapEx)	$178	11.1%

While the value of the DCB relative to CapEx is greater for the ITC (11.1%) versus the PTC (6.3%), whether the ITC or PTC are more cost-effective for a project will depend significantly on specific project costs and characteristics.

2.3 Key Takeaways From Industry Conversations

Conversations with developers and manufacturers also help inform how they perceive the tax credits and how they may approach them. The following key takeaways come from conversations with stakeholders from one of the main OEMs, a project developer, three separate component manufacturers, and the American Clean Power Association (ACP):

- Developers acknowledge that domestic blades may be required to qualify for the DCB. They are interested in and able to source the minimum number of domestic blades needed per project to qualify for the DCB, then import the remainder to reduce costs, depending on domestic blade availability and blade costs. However, they state the DCB is more of an extra perk than a significant driver. The value of the DCB depends on other factors, including guidance on U.S. tower steel qualification.
- The PTC is usually the most attractive incentive for developers but being able to claim the full ITC, DCB, and energy community bonus makes the ITC package preferable for higher-cost and lower-capacity-factor projects.
- Because the AMPTCs are on a $/W basis, they will likely incentivize shorter towers, shorter blades, and higher wind turbine ratings.
- AMPTCs may not significantly change domestic component prices paid by developers. Manufacturers say they are currently unlikely to pass along AMPTC benefits as they compensate for low margins and higher supply chain costs. However, the availability of the credit has already incentivized more domestic manufacturing, and there is a significant opportunity for domestic components to be cost competitive with imports and increase demand for them.

Considering the cost of components is one of the major factors for whether developers pursue the DCB or domestic components in general, manufacturers have a significant influence in this situation, based on their decision to pass (or not) some of the AMPTC savings onto customers. This decision may also be impacted by competition within the U.S. market and how capable different OEMs are in passing on savings versus keeping the credit to improve low margins.

3 Domestic Component Demand and Supply Scenarios

We developed multiple scenarios to better understand the impact of the DCB and AMPTCs on domestic component demand and supply. While the DCB may not be cost-effective for all developers, we assume that they will pursue it to identify the peak demand on the domestic supply chain in each scenario.

3.1 Scenario Development Methodology

While the AMPTCs are set to end in 2032, the ITC and PTC could extend beyond 2032, depending on emission reduction levels. For this reason, the scenarios are based on three key datasets, representing annual values from 2023 to 2035 (explained in more detail in the following sections):

- Deployment projections in GW/year
- Manufacturing capacity by number of components for blades, nacelles, and tower sections
- Technology projections defining average turbine nameplate rating, average blade length, and average tower sections per turbine.

Dividing each scenario's annual deployment (GW/year) by average rating (MW) provides the average number of wind turbines needed to meet a given year's deployment.

We calculated the annual demand for blades, nacelles, and towers from the number of turbines per year (e.g., three blades, one nacelle, one tower per turbine). The annual demand for tower sections is equal to the demand for towers multiplied by the average number of tower sections per turbine.

We include alternate blade demand scenarios to consider how the selection of the PTC or the ITC could drive demand. Projects claiming the PTC that pursue the DCB need to qualify the domestic content of each individual wind turbine; therefore, to maximize the value of the DCB, each wind turbine would likely have all domestic blades.[13] Projects that claim the ITC could supply a subset of their wind turbines with domestic blades (and import the rest from lower-cost countries) and still meet the domestic content threshold at the overall project level. This "strategic blade distribution" concept would reduce the overall demand for U.S. blade manufacturing. The two scenarios assume that either all projects in the U.S. pipeline claim the PTC (resulting in 100% blade demand) or the ITC (resulting in 20% blade demand). The actual development of the U.S. pipeline is likely to be in between these scenarios.

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[13] It is possible that an individual wind turbine could mix domestic and imported blades from different suppliers or factories, provided that the design and tolerances of the blades were identical, and still meet the DCB threshold (e.g., one domestic blade and two cheaper, imported blades). However, this would impose significant logistical and quality control challenges for the project. Therefore, we assume that, under the scenario where all projects in the pipeline claim the PTC, each turbine uses 100% domestic blades.

Annual component demand was compared to manufacturing capacity to determine instances of over- or undersupply of components, and opportunities or challenges for the domestic supply chain.

The four scenario sets in this report are:

1. **Baseline scenario**
    - Employs the baseline deployment projection, which reaches 21 GW/year by 2035.
    - Applies existing manufacturing capacity only without considering future expansions or reductions.
    - Uses a standard technology projection based on the current market distribution of OEMs and turbine models alongside industry projections.
    - Outlines a "strategic blade distribution" option (mix of domestic and imported blades) for developers to meet the DCB and maximize domestic content, dependent on whether they elect the ITC or the PTC.
2. **Low, high or very high deployment scenarios**
    - Evaluates the impact of low, high, and very high deployment based on projections with an average 15.8 GW/year, 36.8 GW/year, and 45 GW/year, respectively, for the period of 2030 through 2035. The very high deployment scenario corresponds to a 100% clean electricity grid by 2035.
    - Maintains the same manufacturing capacity and technology projection assumptions as the baseline scenario.
    - Also explores a "strategic blade distribution" option (mix of domestic and imported blades) for developers to meet the DCB and maximize domestic content.
3. **Increased wind turbine size scenario**
    - Uses the same baseline deployment projection and same existing manufacturing capacity as the baseline scenario
    - Evaluates the impact of overall larger wind turbines used to meet annual deployment. Standard technology projections are modified to only include turbines with ratings equal to or greater than 4.5 MW. This assumption results in a larger average annual rating, blade length, and tower sections per turbine.
4. **Transportation constraints scenario**
    - Because of higher spatial resolution in different deployment projections, this scenario uses a different projection from the baseline: a 2022 NREL Mid-case standard scenario with no decarbonization target by 2035, with an average of 17.8 GW/year by 2035 (Gagnon, Cowiestoll, and Schwarz 2023).
    - Maintains the same manufacturing capacity and technology projection assumptions as the baseline scenario
    - Identifies geographic and logistical barriers for domestic component transportation based on industry conversations.

3.1.1 Deployment Projections

Our scenarios use newly defined deployment projections that are based on reference scenarios from the literature. Compared to those projections, the newly defined projections have less annual variation but capture similar average and maximum deployment trends. Each projection has a constant deployment from 2030 to 2035 due to increased uncertainty beyond 2030 in deployment trends. Considering most IRA tax credits phase out around 2032, but are contingent on emission reductions, we display projections up to 2035 to capture potential component demand and supply trends past 2032 if the IRA takes longer to phase out.

We display the baseline, low, high and very high deployment projections in Figure 6, with labels indicating the annual deployment rate. These are projections or estimates of deployment from various literature sources, actual deployment will be a function of many factors such as transmission availability, permitting, appetite for wind energy, and many other factors. Actual deployment values will vary as these are only estimates of future deployment. The industry cannot choose which future projection will be realized. See Appendix A for more details on the reference scenarios. The low and high deployment projections are equivalent to a 25% decrease and 75% increase from the baseline, respectively. The very high deployment projection is based on the baseline trend but reaches 45 GW/year and maintains it for 2030-2035.

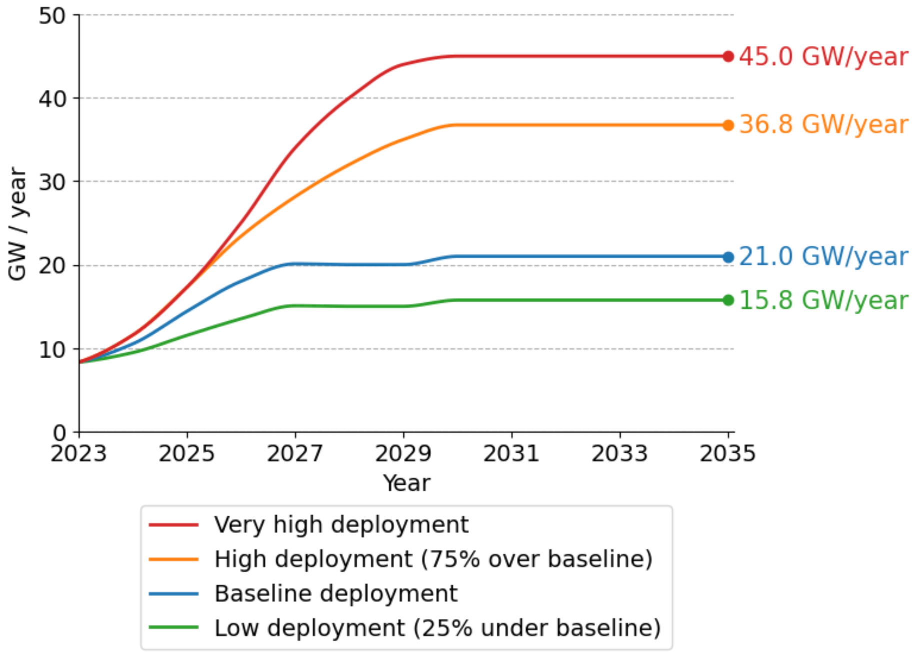

Figure 6. Deployment projections used for scenario analysis

3.1.2 Existing Manufacturing Capacity

Modeled manufacturing capacity for blades, nacelles, and tower sections is based on the facilities that are either operational or announced to be re-opened as of November 2023 (see Appendix A for list of announcements). Blade production per facility is calculated using the estimated floor area and expected production capacity from public factory announcements and state air permits. Nacelle and tower production per facility is based on data from ACP as well as public announcements. Figure 7 illustrates the locations of all facilities included in the study.

One additional nacelle plant was announced close to publication of this report, from GE Vernova in Schenectady, New York (Governor Kathy Hochul's Press Office 2023). It is included in

Figure 7 and considered qualitatively as a solution to potential supply chain gaps, but not included in the nacelle capacity numbers modeled.

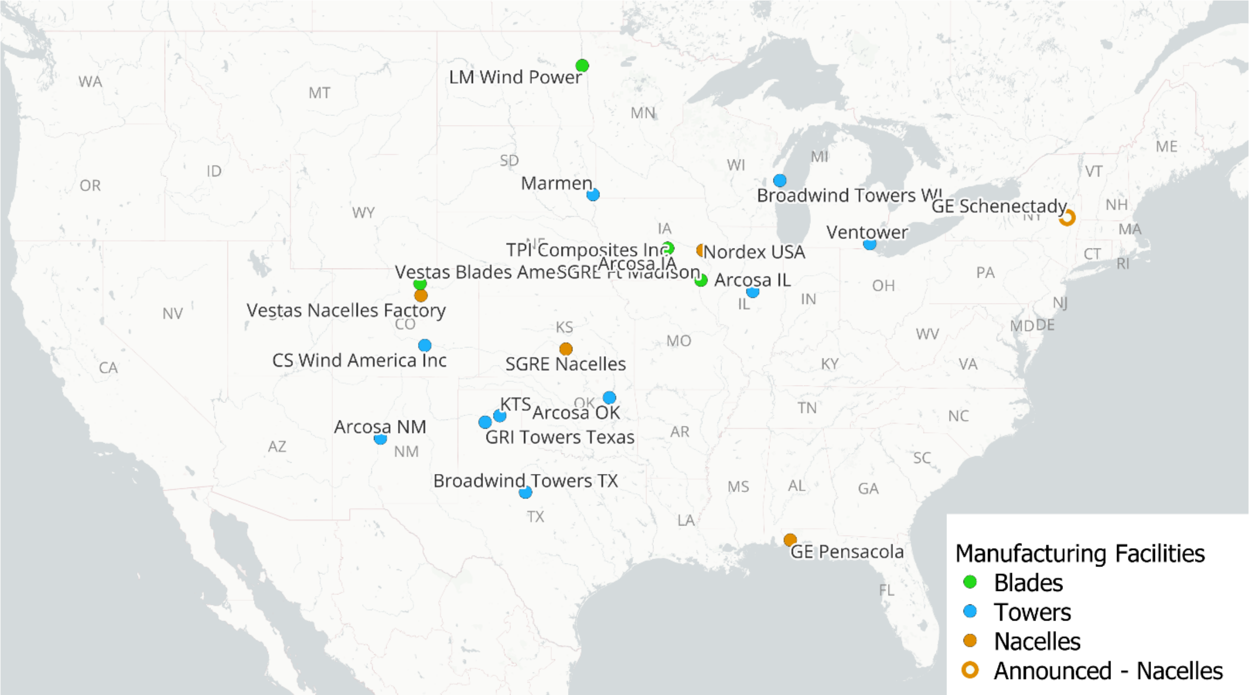

Figure 7. U.S. blade, nacelle, and tower section manufacturing facilities

Existing nacelle capacity (Table 3) and tower section capacity (Table 4) are assumed to be independent of increases in component size or rating, therefore the number of components per facility is kept constant from 2023 to 2035. In contrast, blade length increases are assumed to impact production capacity more significantly, as longer blades require more floor space. Blade capacity is scaled year by year by average blade length, such that the increase in average blade length is proportional to the decrease in annual blade production. Table 5 shows capacity for 2023 and 2035; see Appendix C for all years' figures.

Table 3. Nacelle Manufacturing Facilities and Capacity

	Facility Company	Location	Maximum Number of Nacelles per Year
1	GE	Pensacola, Florida	4,000
2	Vestas	Brighton, Colorado	1,500
3	Siemens Gamesa Renewable Energy (SGRE)	Hutchinson, Kansas	600
4	Nordex	West Branch, Iowa	300
	Total		**6,400**
	Average		**1,600**

Table 4. Tower Section Manufacturing Facilities and Capacity

	Facility Company	Location	Maximum Number of Tower Sections per Year
1	CS Wind (previously Vestas)	Pueblo, Colorado	10,000
2	Keystone Tower Systems	Pampa, Texas	1,000
3	Arcosa	Belen, New Mexico	2,000
4	Arcosa	Newton, Iowa	900
5	Arcosa	Clinton, Illinois	900
6	Arcosa	Tulsa, Oklahoma	600
7	Broadwind Towers	Abilene, Texas	600
8	Broadwind Towers	Manitowoc, Wisconsin	1,050
9	GRI Towers	Amarillo, Texas	900
10	Ventower	Monroe, Minnesota	750
11	Marmen	Brandon, South Dakota	1,050
	Total		**19,750**
	Average		**1,795**

Table 5. Blade Manufacturing Facilities and Scaled Capacity

	Facility Company	Location	Maximum Number of Blades in 2023 (Average 65.7-meter (m) Blade)	Maximum Number of Blades in 2035 (Average 81.8-m Blade)
1	TPI Composites	Newton, Iowa	1,105	887
2	LM Wind Power	Grand Forks, North Dakota	1,282	1,029
3	SGRE	Ft. Madison, Iowa	3,449	2,767
4	Vestas	Windsor, Colorado	1,990	1,596
	Total		**7,826**	**6,279**
	Average		**1,957**	**1,570**

While this study does not offer projections of potential re-openings or expansions, opting instead to focus on existing and announced capacity exclusively, some blade manufacturing stakeholders mentioned in industry conversations believe they could expand their facilities' capacity if needed. This expansion could equal approximately 50% of total existing capacity. Furthermore, this expansion is only considered qualitatively in the subsequent supply chain scenarios.

3.1.3 Technology Projections

The average annual rating, blade length, and number of tower sections per turbine are calculated based on two separate technology projections, which helps model the market share of different wind turbine models year by year and incorporates moderate turbine size increase trends.

The first is a standard technology projection, based on industry input, with a moderate increase in platform sizes over time. This technology projection is used in the baseline scenario; low, high, and very high deployment scenarios, and transportation constraints scenario which is detailed in section 3.5.

While the standard technology projection already models moderate increases in turbine sizes, OEMs have expressed that they expect more companies to move to larger platforms. As such, we analyzed an increased turbine size scenario using a technology projection that only includes turbines with 4.5-MW nameplate rating or higher.

To model this change, we took the same predicted market share per turbine model from the standard technology projection, excluded wind turbines below 4.5 MW, and weighted averages once more with the remaining larger turbines and corresponding market shares. This change still reflects growth in turbine size year by year, with an increased average annual rating, blade length, and number of tower sections per turbine used to model component supply and demand (shown in Figure 8). Tables with annual technology projections are included in Appendix D.

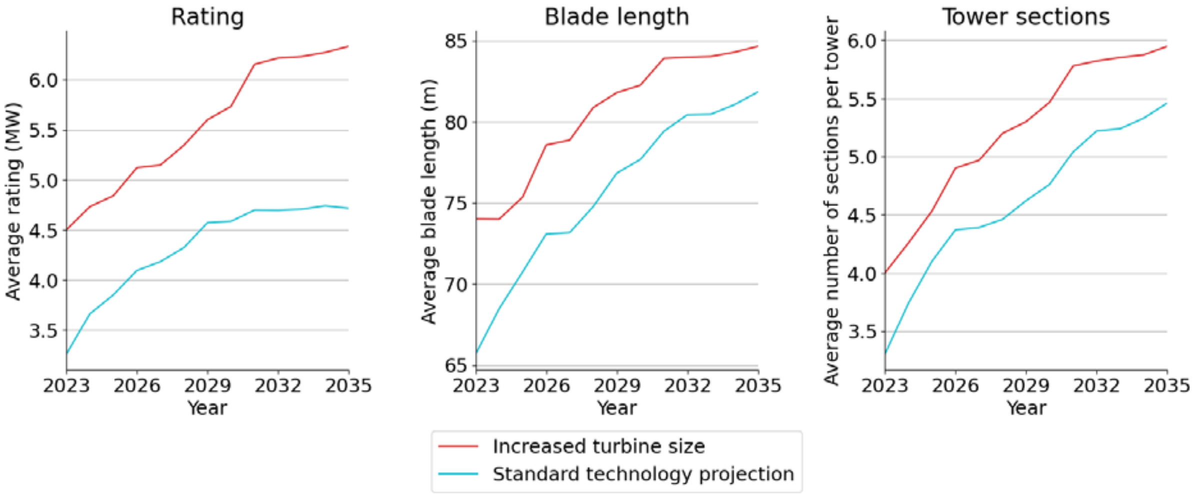

Figure 8. Rating, blade length, and tower section changes across technology projections

3.2 Baseline Deployment Scenario

Based on a standard technology projection (Section 3.1.3), the demand for blades, nacelles, and towers needed to meet the baseline deployment projection is shown year by year in Figure 9. This scenario assumes only existing manufacturing (based on open plants or those announced to reopen, to date) is available to meet demand, as outlined in Section 3.1.2. Component production capacity is sufficient to meet demand for nacelles, but not for blades or towers.

The percentage of domestic blade demand that can be met with existing production capacity declines quickly from 102% in 2023 to 49% in 2027 and remains at approximately 50% until

2035. The percentage of tower demand met with existing capacity remains between 81% and 98% from 2026 to 2035.

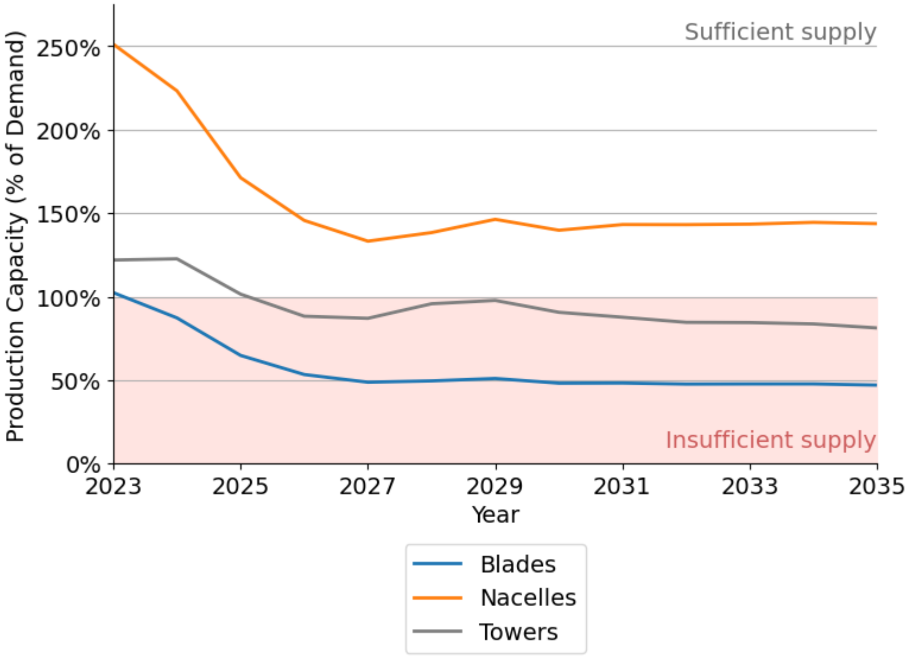

Figure 9. Production capacity in the baseline scenario

The average demand for blades between 2030 and 2035 is 13,372 per year, which is greater than the average production capacity of 6,373 for the same period (see Figure 10 for annual values). Based on existing blade production capacity across four manufacturing facilities, the average facility produces 1,950 blades per year, suggesting approximately another four new facilities (or expansions of similar size) would be needed to meet 100% of domestic blade demand through 2035.

For towers, the 2030-2035 average shortfall in capacity to meet demand is 3,685 tower sections, only a fraction of the existing capacity of 19,750 per year (Figure 10). The average tower factory produces 1,800 sections per year; therefore, two additional tower factories would be required to meet the gap in supply.

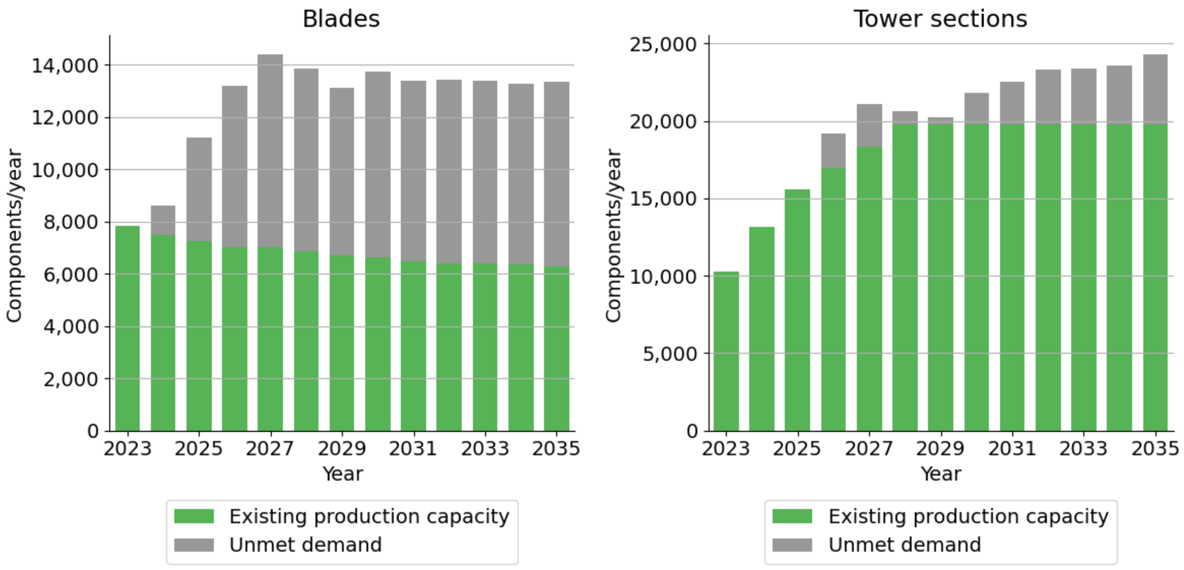

Figure 10. Production capacity and unmet demand in the baseline scenario

Industry stakeholders have noted that blade manufacturing facilities likely have the possibility of expanding their capacity to around 150% of existing capacity. These expansions may meet growing domestic demand, as may be the case with higher deployment, bigger turbine sizes, or increased transportation or supply chain bottlenecks, as explored in latter scenarios.

3.2.1 Strategic Blade Distribution To Meet the DCB

Whether projects can source components domestically or not affects their eligibility for the DCB. To meet the requirements, towers must be entirely sourced domestically as part of the steel or iron requirements under the DCB; therefore, the shortfall in tower sections to meet demand poses a barrier for projects to meet the DCB and receive the bonus.

In contrast, blades and nacelles fall under the manufactured product requirement in the DCB, for which the percentage of domestic manufactured product costs out of total eligible manufactured product costs must meet or exceed the stipulated adjusted percentage.[14]

Table 6 shows the average contribution toward the total manufactured product cost (with qualifying components based on the latest guidance, as detailed in Section 1.2.2), calculated over nine typical turbine models ranging from 2.82 to 6.6 MW with the NREL Cost and Scaling Model (Fingersh, Hand, and Laxson 2006).

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[14] This percentage includes 40% for projects that begin construction in 2024 or earlier, 45% for projects that begin construction in 2025, 50% for projects that begin construction in 2026, and 55% for projects that begin construction in 2027 or later.

Table 6. Average Contribution to Total Manufactured Product Cost and Associated Range

Component	Average Contribution (% of Total Manufactured Product Cost)	Range of Contribution (% of Total Manufactured Product Cost)
Nacelle	48.8	47.9–49.9
Blades	30.6	27.2–33.0
Hub and pitch	10.2	9.0–12.0
Tower flanges	1.8	1.4–2.2
Power converter	8.7	7.6–10.0

Nacelles contribute an average of 48.8% toward the total manufactured product cost (Figure 11), which is sufficient to meet the lower 40% and 45% requirements before 2026, but not the 55% requirement after 2026. For projects that elect to pursue the ITC, the remaining ~6% can be met with a “strategic blade distribution,” in which a portion of blades are sourced domestically. Essentially, projects do not need to supply 100% of their blades domestically to meet the DCB thresholds. Based on industry conversations, developers affirm they are already considering sourcing a subset of their blades domestically and importing the remaining portion. To meet the 55% DCB requirement, an average of 20.2% of a project’s total blades would need to be produced domestically, although developers may choose to have a higher percentage of domestic blades for reasons other than the DCB.

Projects that pursue the ITC are able to adopt this “strategic blade distribution” because the ITC guidelines consider an entire wind energy plant as the ‘facility’ under consideration, therefore the 55% domestic content threshold can be met with a varying distribution of domestic versus imported components across the entire plant. In this case, approximately 20% or more wind turbines in a plant would need domestic blades to qualify for DCB. However, projects that pursue the PTC are less likely to adopt a “strategic blade distribution” because the PTC guidelines consider each individual wind turbine to be a ‘facility’ under consideration for the tax credits and bonuses. As such, each individual wind turbine must meet or exceed the 55% domestic content threshold to qualify for the DCB.

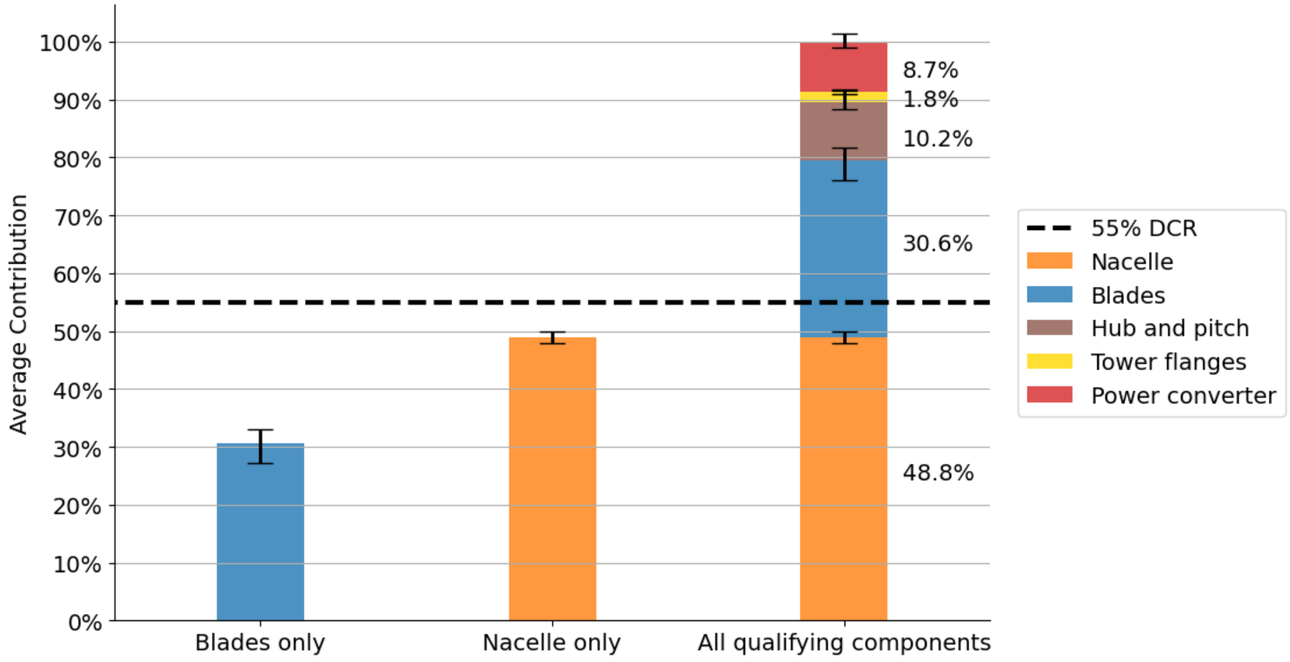

Figure 11. Average contribution to total manufactured product cost by eligible component toward the 55% domestic component requirement (s).

Error bars represent the range of contributions based on cost variations across the nine modeled wind turbine models.

Whether developers pursue the ITC or PTC will impact the extent to which they obtain domestic blades to meet domestic content requirements, and ultimately there may be a mix of both types of projects. In following sections, we consider the blade manufacturing capacity needed to meet a low domestic blade demand of 20%, where most developers choose an ITC with a "strategic blade distribution", and a high domestic blade demand of 100% assuming all blades will need to be domestically produced to qualify for the DCB.

With existing and announced blade manufacturing facilities, there is not enough blade manufacturing capacity to meet 100% of blade demand domestically, although there is enough to meet the minimum 20.2% of blades needed for a "strategic blade distribution" (for projects pursuing the ITC) to meet the 55% DCB adjusted percentage rule (Figure 12). For lower DCB percentages before 2027, there will not be as much reliance on domestic blades to meet the domestic percentage requirement. However, the largest shortfall in blade supply occurs in 2027, the same year the 55% requirement begins, indicating the potential for new domestic blade manufacturing.

On average, blade capacity is around 50% of total demand after 2025, indicating there are other factors encouraging manufacturing, and that suppliers could capture more domestic demand than 20.2%. If most developers pursue a strategic blade distribution, a shortfall in towers becomes the most likely barrier for projects to meet the DCB. Otherwise, the blade shortfall will also be a considerable challenge for developers.

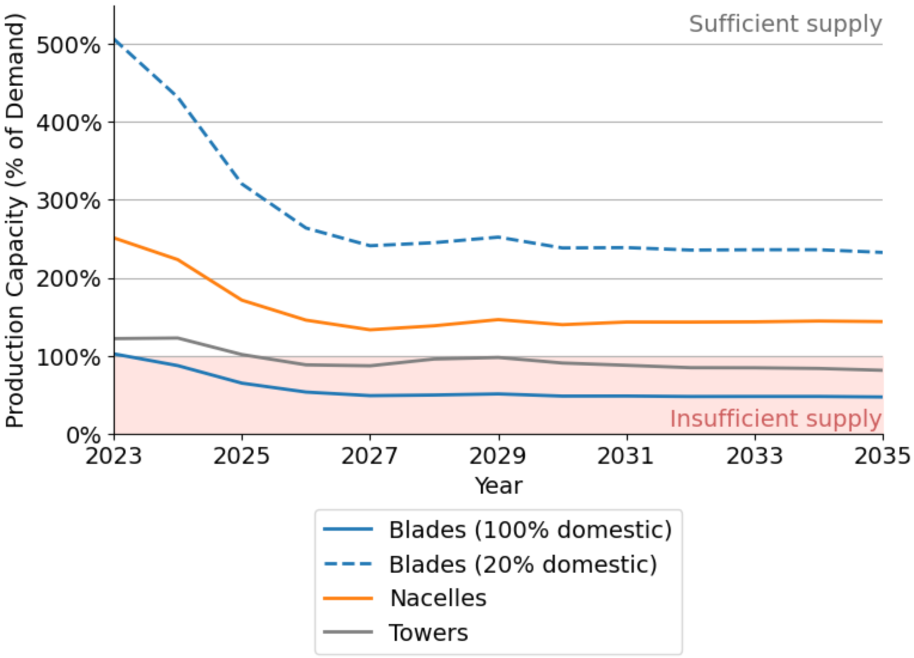

Figure 12. Production capacity with a strategic blade distribution in the baseline scenario

Variation in component costs impact the domestic content percentage calculation, and consequently impact the percentage of domestic blades needed for a “strategic blade distribution” for projects pursuing the ITC. Global logistics and transport costs may increase the value of domestically manufactured components, with global turbine component supply chain stress potentially increasing in future years as U.S. and global deployment rates increase. Even with higher domestic blade costs, the industry may see more value in using a domestic supply chain to reduce future supply risk.

Blade and nacelle cost variations have the greatest impact on the domestic content percentage as they are the largest contributors to the total manufactured product cost under the DCB. Figure 13 shows the maximum and minimum contributions to the total manufactured product cost with cost variations of 25% for blades and nacelles, which is equivalent to some of the largest cost fluctuations in blade costs in recent years (25% blade cost increase from July 2020 to July 2022 (Wood Mackenzie 2022)).

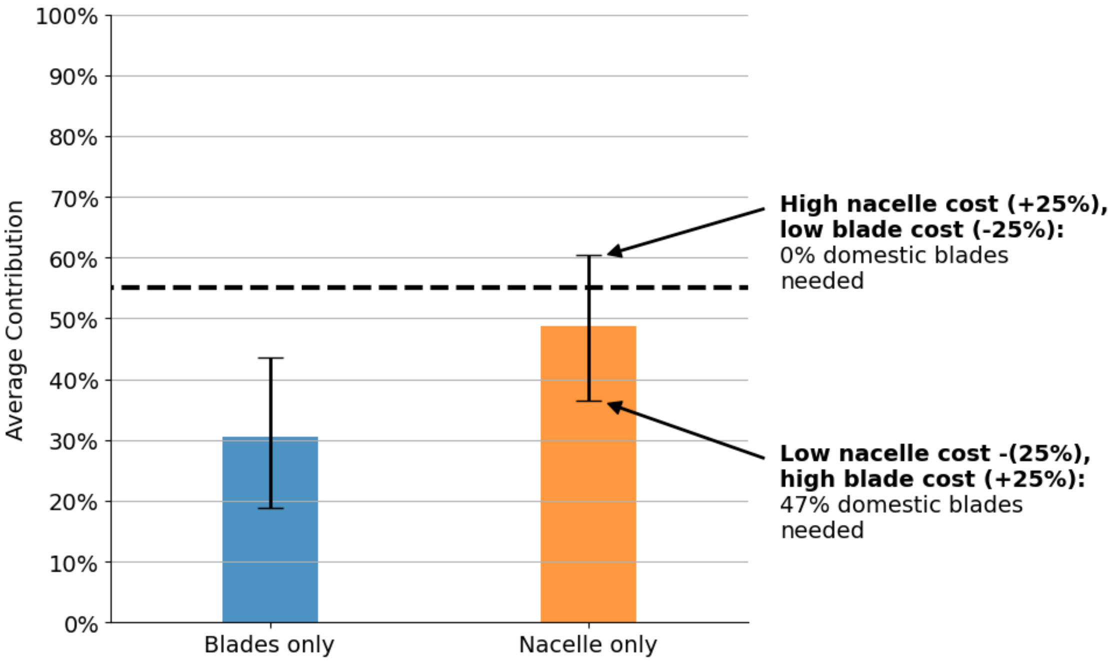

Figure 13. Contribution to total manufactured product cost with blade and nacelle cost variations

Higher nacelle costs alongside lower blade costs may increase the nacelle contribution to the total manufactured product cost above the 55% threshold, such that no blades would need to be sourced domestically to meet the DCB requirements.

In contrast, lower nacelle costs and higher blade costs reduce the nacelle contribution to the total manufactured product cost and require a larger percentage of a project's blades—up to 47%, based on modeled costs—to be produced domestically to meet the requirements. In this case, there could be sufficient blade production to meet this domestic demand because blade production capacity is almost equivalent to domestic demand in 2027 and later (Figure 14), although inefficiencies in blade allocation could still result in shortages.

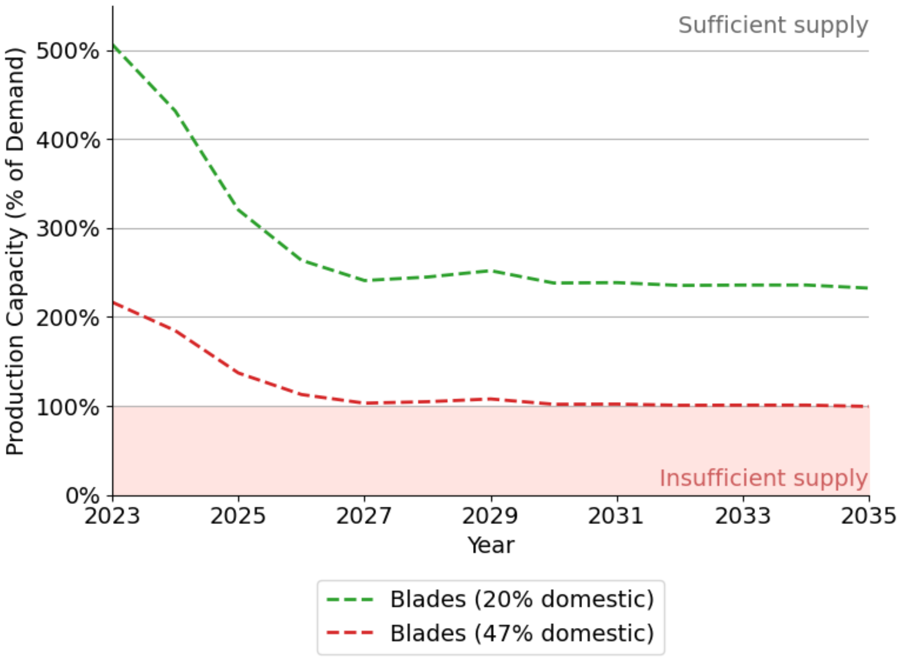

Figure 14. Production capacity with strategic blade distributions

3.2.2 Scenario Takeaways

The following are key scenario takeaways:

- There is sufficient capacity to meet at least 20% domestic blade demand and 100% nacelle demand, and consequently for 100% of projects to meet the domestic manufactured product requirement under the DCB, if they pursue the ITC with a "strategic blade distribution." Specifically:
  - This finding relies on the assumptions that production capacity can be distributed efficiently to projects pursuing a "strategic blade distribution", the full nacelle cost qualifies toward the DCB requirements, and an average of 20% of domestic blades is used per project.
  - Four additional blade factories (or equivalent expansions) would be needed to meet 100% of blade demand.
  - The percentage of domestic blades needed by project varies based on relative component costs, wind turbine model, blade transport constraints, turbine rating (scaling), and specific power (larger blade cost contribution, less nacelle cost contribution).
- Nine percent of projects may not meet the domestic steel/iron construction requirement at the current tower production capacity. Specifically:
  - Existing capacity can only meet 91% of tower demand. Because towers must be 100% domestically produced to qualify for the DCB, the remaining 9% of projects will be unable to source towers domestically or qualify for the DCB.

- The tower section shortfall could be met with the addition (or expansion) of two manufacturing facilities that each produce approximately 1,800 sections per year.

3.3 Low, High, or Very High Deployment Scenarios

As outlined in Section 2.2, the high and low deployment scenarios are scaled from the baseline scenario, such that their respective deployment rates by 2030–2035 are 75% above the baseline (or 36.8 GW/year for high deployment) and 25% under the baseline (or 15.8 GW/year for low deployment). A more ambitious very high deployment scenario is also included to reflect deployment levels needed to meet decarbonization goals (primarily based on the NREL 2022 Mid-case Standard Scenario with a 100% decarbonization target by 2035), reaching 45 GW/year by 2030–2035.

Wind turbine component demand is directly proportional with deployment, assuming the same standard technology projections as the baseline scenario. Figure 15 shows there are enough blades for projects to meet a "strategic blade distribution" for projects pursuing the ITC across all scenarios.

However, domestic blade capacity is less than the total demand in all deployment scenarios, which would present a challenge in helping projects qualify for the DCB if there is a demand for 100% domestic blades. After 2027, the average production capacity is 65% of demand for low deployment, 48% for the baseline scenario, 29% for high deployment, and 23% for the very high deployment scenario. Although there is only a 6% difference from the high to the very high deployment scenario, the absolute gap in number of blades supplied versus total demand is larger for this scenario than for the high deployment scenario.

Across the high and very high deployment scenarios, there is a risk of having insufficient domestic blade supply if demand exceeds 29% or 23%, respectively. Considering the high level of competition and bottlenecks across the global supply chain, increasing domestic manufacturing may be necessary to alleviate bottlenecks and avoid gaps in supply.

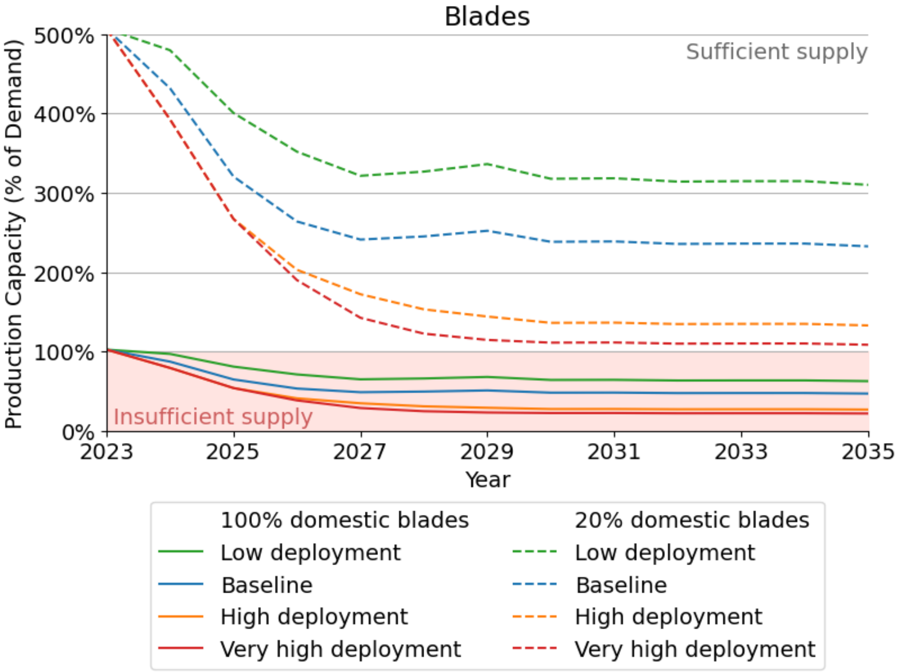

Figure 15. Blade production capacity in the low, high, and very high deployment scenarios

With high deployment, nacelle production capacity becomes insufficient to meet demand (84% on average after 2027), and the tower deficit grows even larger than with baseline deployment (capacity of 52% of demand on average after 2027), as shown in Figure 16. There is an even greater gap in a very high deployment scenario (nacelle capacity meeting 72% demand and tower section capacity meeting 45% demand on average after 2027). With low deployment, there is sufficient capacity for both components, although tower capacity remains close to 100% of demand.

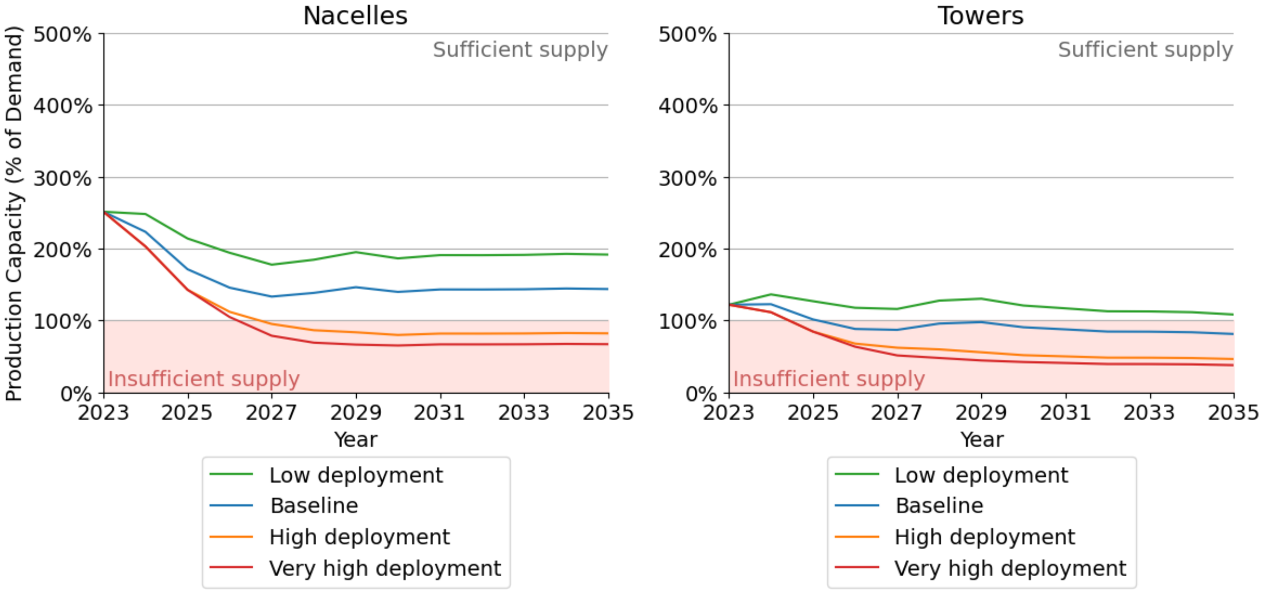

Figure 16. Nacelle and tower capacity in the low, high, and very high deployment scenarios

The gaps in manufacturing capacity provide an estimate of the number of new (or expanded) factories that are needed to meet domestic demand. In the high deployment scenario, the average annual nacelle shortfall is of 1,400 between 2030 and 2035 (Figure 17). Considering an average nacelle manufacturing factory capacity of 1,600 nacelles per year, one additional factory or an expansion of this same size would be necessary. GE Vernova has announced a nacelle facility in Schenectady, New York (Governor Kathy Hochul's Press Office 2023) that may bridge this gap. In the very high deployment scenario, the average annual nacelle shortfall in the same period is 3,151 nacelles, which could be met by a total of two new facilities of average capacity.

Shown in Figure 17, the average annual tower section shortfall is 21,261 between 2030 and 2035 in the high deployment scenario. This would require more than double the existing tower production capacity. With an average manufacturing capacity of about 1,800 sections per year across 11 existing facilities, this is equivalent to almost 12 additional tower factories, or expansions of the same size. A very high deployment scenario reaches an average annual tower section shortfall of 30,468, equivalent to a total of 17 new facilities.

The total amount of steel needed for towers under the high deployment scenario ranges from 191,068 to 601,014 tons per year for 2023–2035. This demand represents 0.23%–0.73% of 2022 U.S. raw steel production based on United States Geological Survey estimates (2023).

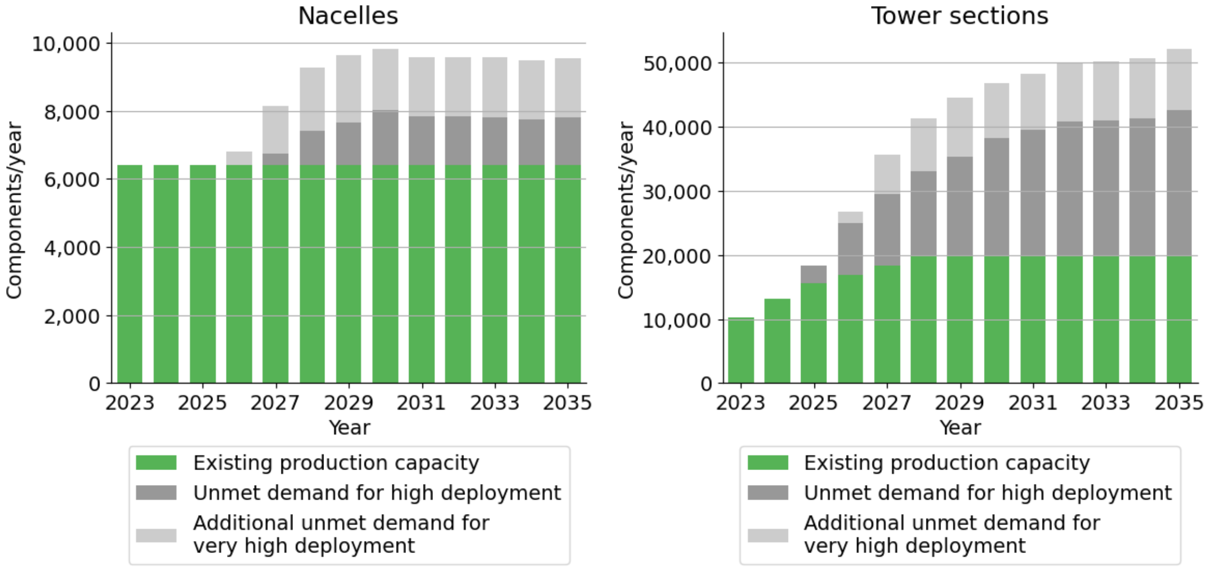

Figure 17. Production capacity and unmet demand in high and very high deployment scenarios

3.3.1 Scenario Takeaways

Scenario takeaways include the following:

- The large shortfall in tower capacity in the high or very high deployment scenario becomes the biggest barrier for developers to meet the DCB requirements and a risk for overall tower section procurement. Tower manufacturing would need to be doubled (or more) to meet 100% domestic demand. Specifically:

    - The high deployment scenario would need 12 new tower factories, and the very high deployment scenario would need 17 new factories, with an average 1,800 sections per year per facility.
    - Developers cannot meet the DCB without 100% domestic towers.
- Nacelle capacity also falls short of meeting 100% of demand in a high or very high deployment scenario. Specifically,
    - A U.S.-made nacelle is crucial for developers to meet the DCB 55% threshold.
    - To meet the demand, capacity would need to be expanded by one facility in a high deployment scenario (around 1,600 nacelles per year), equivalent to approximately 25% of existing capacity, or two facilities for the very high deployment scenario.
- Blade capacity is sufficient for projects with 20% domestic blades to meet the DCB, but only meets 29% of total demand in the high deployment scenario and 23% in the very high deployment scenario. Specifically:
    - Global supply chain bottlenecks may drive up domestic demand, and limited blade capacity would become another barrier to meet both the DCB requirements and blade procurement overall. Bottlenecks are more likely with higher deployment as well.
    - To meet 100% of blade demand, 12–17 new blade factories would be needed.
- The low-deployment scenario results in sufficient nacelle and tower capacity, whereas blade capacity meets an average of 65% of total demand. However, this scenario is far from achieving decarbonization goals.

3.4 Increased Turbine Size Scenario

We evaluated the increased turbine size scenario assuming the baseline deployment projection used in the baseline scenario. However, instead of using the standard technology projection, this scenario only includes turbines with a 4.5-MW nameplate rating or higher (see Section 3.1.3 for details).

An increase in blade and tower sizes (an increase in sections per complete tower as hub height grows) results in larger but fewer components produced to meet the same deployment numbers. Consequently, the percentage of production capacity that can meet demand is close to the baseline, as shown in Figure 18 and detailed here:

- Blade capacity over total demand increases slightly. Specifically:
    - Capacity per facility decreases slightly with larger blades (capacity is scaled by area needed per blade)
    - Demand decreases with a higher rating (fewer blades needed per megawatt)
- Tower capacity over demand increases slightly. Specifically:
    - Capacity to produce tower sections remains constant, but capacity for complete towers decreases with larger turbines (more sections needed per turbine)

    - Demand for complete towers decreases with a higher rating (fewer towers per megawatt) at a faster rate than the increase in demand for sections per tower
    - The result is a bigger decrease in tower section demand than the decrease in production capacity relative to the baseline.
- Nacelle capacity over demand increases. Specifically:
    - Capacity remains constant
    - Demand decreases with higher-rating turbines

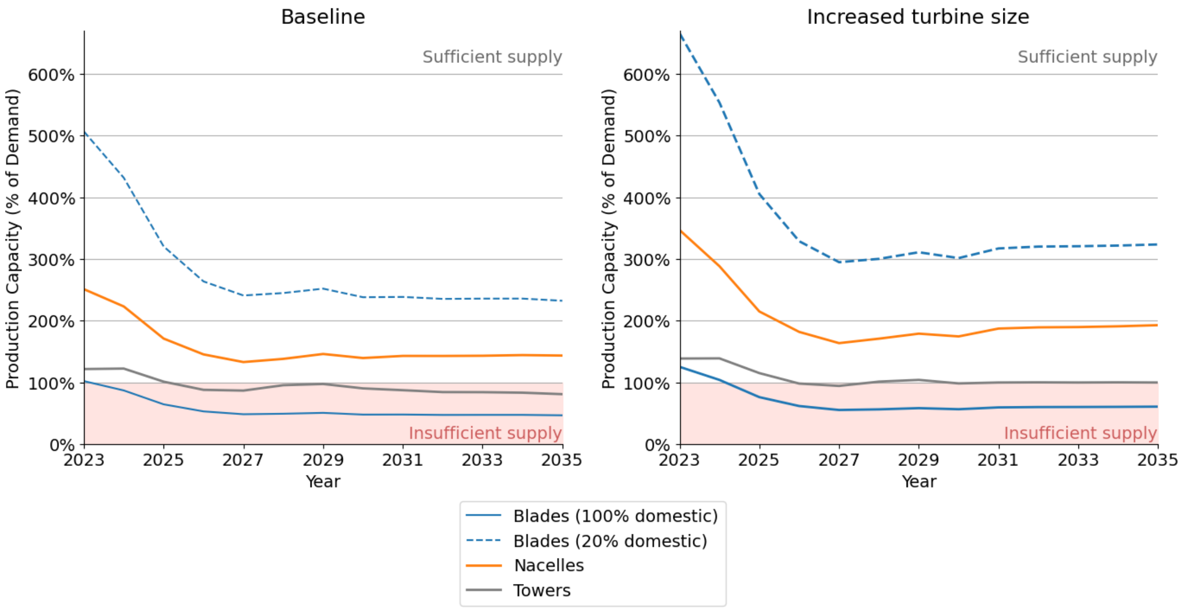

Figure 18. Production capacity over demand in the baseline scenario (left) and increased turbine size scenario (right)

With increased wind turbine sizes, there is less of a gap between production and demand for both blades and tower sections (Figure 19). Blade production capacity is reduced slightly but demand decreases at a faster rate. The largest gap is 5,201 blades in 2027. With an average of 1,950 blades produced per year per facility, three additional facilities of average capacity would be needed to meet the demand.

Tower section capacity remains the same as the baseline scenario. While more sections are needed per turbine, there is less demand for turbines overall, thereby decreasing the gap (or closing it in some years) between tower section capacity and demand.

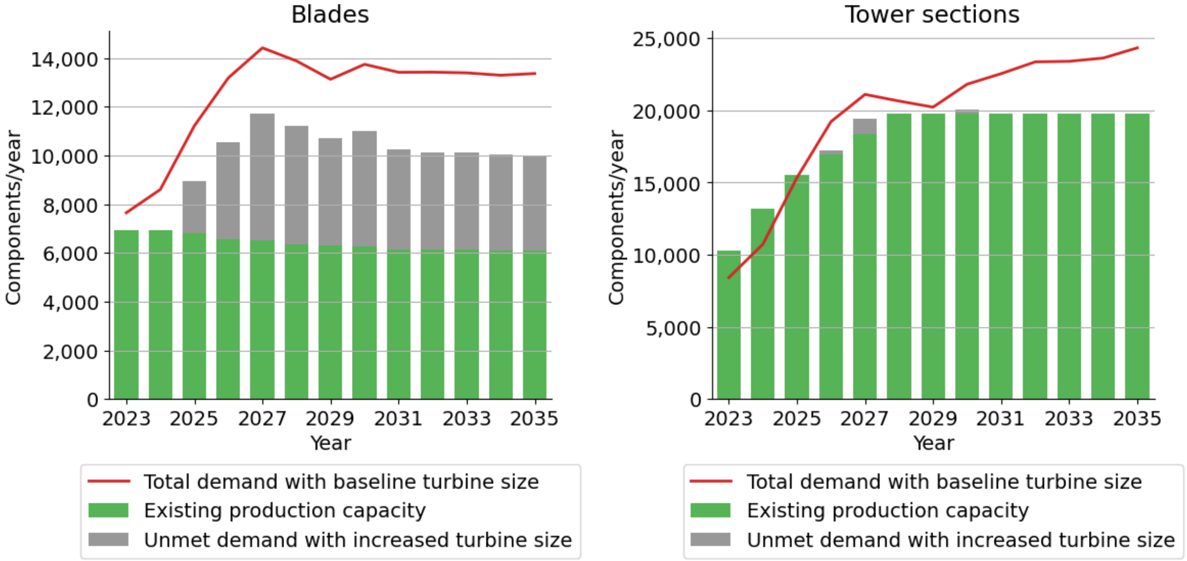

Figure 19. Production capacity and unmet demand in the increased turbine size scenario

3.4.1 Scenario Takeaways

The key takeaways for the increased turbine size scenario including the following:

- Component capacity for the increased turbine size scenario is comparable to the baseline scenario (in terms of % of demand met) because of counteracting effects, where manufacturing capacity on a per-unit basis is reduced for larger turbines but fewer turbines overall are needed for the same deployment levels. Specifically:
    - Existing blade capacity can meet around 60% of demand, with more than sufficient capacity to qualify for the DCB if most projects adopt a "strategic blade distribution" with a minimum of 20% domestic blades, but not enough for 100% of domestic blade demand
    - Tower capacity nears meeting 100% of demand; additional investment in tower capacity may ensure sufficient supply of towers for all projects
    - Nacelle capacity exceeds 100% of demand.
- While production capacity for increased turbine sizes appears sufficient, reconfiguring facilities may still require investment. Specifically:
    - The production capacity levels modeled do not account for investments in larger molds, training, transportation barriers, or other costs of scaling up to larger technologies.

3.5 Transportation Constraints Scenario

All three previous scenarios look at aggregate capacity and demand across the entire United States, yet transportation of domestic components faces geographical and logistical barriers in different regions that may impact deployment.

With most blade, tower, and nacelle manufacturers based in the Midwest (see Figure 20), transportation to coastal sites is more challenging and costly. As expressed in conversations with component transportation stakeholders, the main geographic barriers are the Rocky Mountains toward the West Coast, along which large components (namely blades and tower sections but increasingly nacelles as they grow in size) are very difficult to transport. East of the Mississippi River, infrastructure limits like lower bridge clearances and smaller curves across the East Coast also limit transporting large components.

If domestic components cannot be delivered to the east and west coasts, related projects face two main risks: not being able to qualify for the DCB, and being forced to rely on imported components, which may also face transportation barriers or supply chain bottlenecks. Stakeholders also point out that some near-term deployment, such as upcoming coastal GE projects, will nonetheless have a lower domestic content threshold than longer-term deployment as transportation constraints will take time to address.

Using deployment projections with higher spatial resolutions provides a measure of what percentage of national installed capacity may be impacted by the above transportation barriers. Figure 20 is based on the 2022 NREL Mid-case Standard Scenario with no decarbonization target (Gagnon, Cowiestoll, and Schwarz 2023), with a total installed capacity of 370.9 GW by 2035 (average 18.2 GW/year for 2023–2035). This is comparable to the baseline scenario, which has 381.3 GW of total installed capacity by 2035 (average 18.3 GW/year for 2023–2035).

The total capacity at risk due to transportation constraints amounts to 31.3 GW by 2035, or 8.4% of the total across the 48 contiguous states (18.6 GW west of the Rockies and 12.7 GW east of the Mississippi River).

Analyses of other deployment scenarios (like the 2022 NREL Mid-case Standard Scenario with a 100% decarbonization target by 2035), as well as data on planned projects from the Federal Aviation Administration (U.S. Fish & Wildlife Service 2023) and ACP (2023) result in a range of 6.3% to 15.5% of future capacity impacted by transportation limitations.

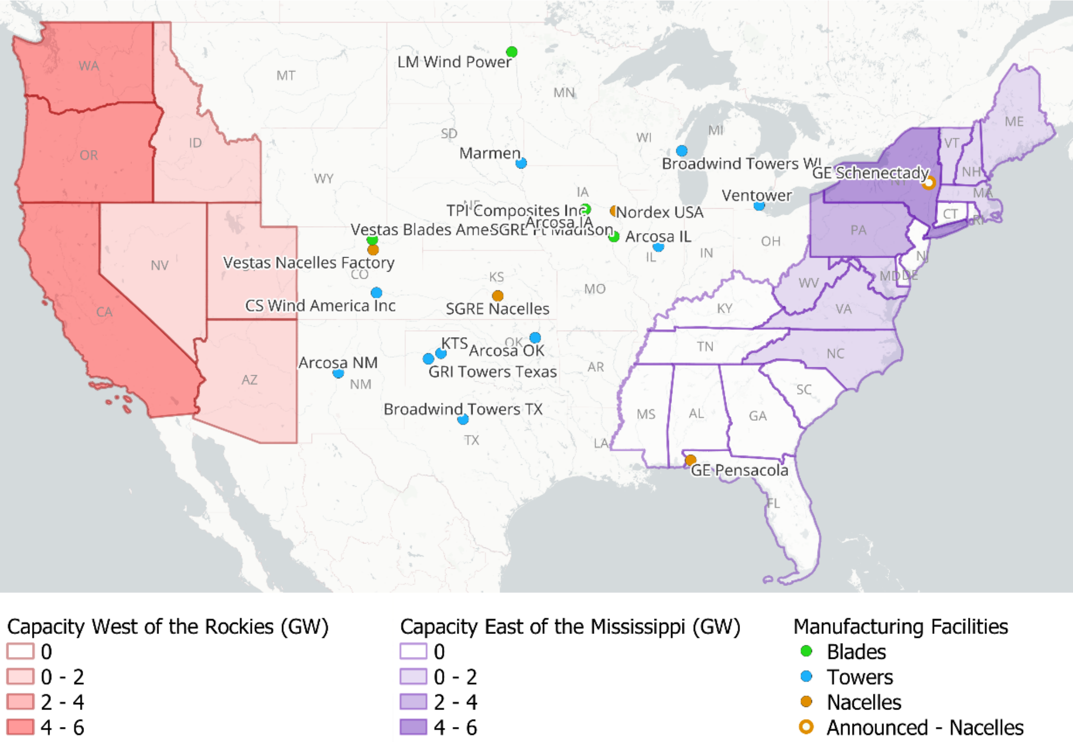

Figure 20. Map of projected capacity with transport constraints by 2035

Other future deployment considerations with larger turbine components may exacerbate bottlenecks. Primarily, as blade length increases, new trailers will be required. Vestas and Siemens Gamesa Renewable Energy have both announced wind turbines around 4.5 MW with monolithic blades around 81 m in length to be manufactured in Colorado and Kansas, respectively, for the U.S. market (Vestas 2023; Nehls 2023). Blades with a maximum chord length over 4.3 m or root diameter over 3 m require a Schnabel trailer as opposed to conventional trailers, further increasing overall truck and trailer length, as well as travel time. The average travel times rise as blade length increases because of travel restrictions and size limits depending on specific routes, resulting in higher transportation costs.

While the number of turbines installed decreases with larger turbines for the same deployment levels, the number of components shipped per turbine increases, causing greater shipping complexity (see Table 7 for an example comparison). To maintain the same rate per day of wind turbine component delivery, as typically demanded by developers to keep up with construction schedules, the number of trucks on a project basis must be increased.

Peak historical capacity addition was 16.8 GW in 2020 (Wiser and Bolinger 2023) whereas peak capacity additions in the baseline deployment projections under the baseline scenario were 21 GW/year. These amounts represent a 26% increase in peak annual deployment that must be met with expansions in transportation capabilities, vehicles, and efficiency.

Table 7. Component Transport Comparison

Wind Turbine	Representative 2.8-MW Turbine	Representative 5.3-MW Turbine
Rating	2.8	5.3
Number of large components and truck trips/turbine[15]	8	12
Blade length (m)	62.2	77.4
Components per megawatt	2.9	2.3
Turbines/year at 21 GW/year	7,500	3,962
Components/year at 21 GW/year	60,000	47,547

Additionally, the Infrastructure Investment and Jobs Act (also known as the Bipartisan Infrastructure Law) is increasing the number of interstate projects, many of which require wind turbine component transport to find alternate routes. Turbine component transportation companies also express having difficulties coordinating among multiple state authorities throughout their routes, resulting in higher travel times and costs.

The 8.4% of deployment identified as being at risk because of geographic or infrastructure barriers for component delivery does not include additional barriers presented by larger components or logistical difficulties. These limitations may put a larger portion of deployment at risk.

3.5.1 Scenario Takeaways

The key takeaways from the transportation constraints scenario include the following:

- It will be increasingly more difficult to deliver larger wind turbine components to projects west of the Rockies and east of the Mississippi River. Specifically:
    - As a result, 8.4% of deployment by 2035 is at risk (or a range from 6.3% to 15.5% based on different projections)
    - Without access to domestic components, projects in coastal states may not qualify for the DCB or may be forced to rely on imports, even if there is sufficient domestic production capacity.
- Additional logistical barriers identified by transportation companies may add risk to projects. Specifically:
    - The need to acquire new and larger trucks and trailers for larger components, as well as additional complexity and costs in delivering larger components at the same rate to developers

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[15] Based on GE transport documents for each platform

- The increased travel time due to construction projects on highways where turbine component trucks expect to travel through (exacerbated by the Bipartisan Infrastructure Law), as well as difficulties coordinating among different state authorities.

3.6 Domestic Content Bonus Qualification and Credits Across Scenarios

Across the different scenarios presented, there is manufacturing capacity to meet significant domestic demand and allow most projects with a "strategic blade distribution" to qualify for the DCB. However, considerably less projects will be able to qualify for the DCB if they require 100% domestic blades, as may be the case under the PTC.

One key assumption is that the total number of components manufactured can be distributed efficiently and evenly across projects. This assumption fails if component transportation or distribution is significantly inefficient, or if a significant number of developers are selective about who they source their components from, which could lead to supply fluctuations from specific OEMs.

Figure 21 shows the maximum number of projects that could qualify for the DCB across scenarios with and without a "strategic blade distribution" (using either 20% or 100% domestic blades across projects). With a "strategic blade distribution, the baseline scenario would enable 91% of projects to qualify for the DCB, whereas the high and very high deployment scenarios would only see a maximum of 63% and 56% of projects, respectively, qualifying because of insufficient domestic manufacturing to meet deployment. Without a "strategic blade distribution", 57% of projects would be able to qualify for the DCB in the baseline scenario, 72% in the low scenario, 41% in the high scenario, and 37% in the very high scenario. These findings highlight the need for additional domestic manufacturing not just to enable higher deployment levels to meet decarbonization goals, but also to unlock IRA benefits for more projects to enable further deployment.

Increased turbine sizes would reduce the number of blades needed per MW but also reduce the number of blades that can be manufactured at existing facilities. The overall effect is slightly higher than the baseline as 99% and 70% of projects could qualify for the DCB with and without a "strategic blade distribution", respectively. However, this scenario does not account for transportation constraints, which may reduce qualifying projects closer to 84.5% as in the transportation constraints scenario.

The land constraints scenario only considers the effects of transportation barriers, where the upper end of the range of projects at risk is 15.5% of total deployment. As such, 84.5% of all projects may be able to transport domestic components to their site, but may still be impacted by additional supply chain constraints seen in other scenarios.

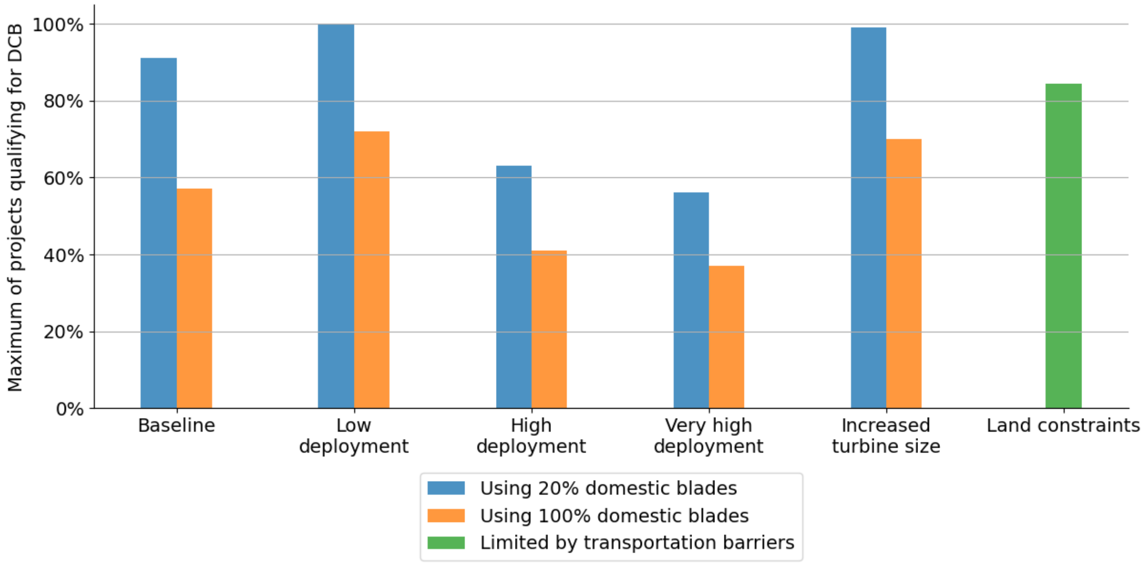

Figure 21. Maximum percentage of projects qualifying for the DCB across scenarios

The extent to which manufacturing meets demand determines the amount of AMPTCs that manufacturers receive. Figure 22 shows the maximum amount of AMPTCs they could receive from all qualifying components if developers purchase as many blades as are manufactured domestically (in blue), or if developers only purchase 20% domestic blades per project (in orange). The gap between the two cases ranges from $2.4 to $4 billion, highlighting the significant opportunity manufacturers have to claim more of the AMPTCs. Expanding blade capacity could further increase the tax credits claimed because existing capacity is still under 100% of domestic demand for most scenarios.

The high deployment scenario comes close to maximizing the AMPTCs (based on existing production capacity) because demand begins to exceed domestic supply for most components, which results in a minimal increase in the more ambitious very high deployment scenario. Additional investment in manufacturing facilities would allow manufacturers to capture more demand in both scenarios.

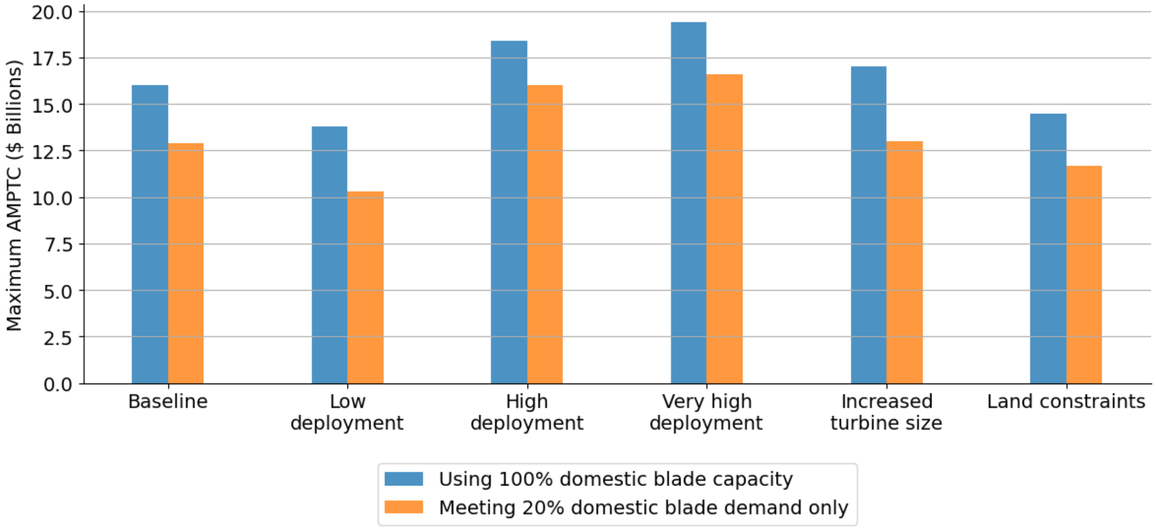

Figure 22. Maximum AMPTCs received by manufacturers across scenarios

Overall, higher deployment levels are the most likely factor that may stress the U.S. manufacturing sector, yet at the same time these higher levels are necessary to achieve ambitious decarbonization goals (such as 100% decarbonization of the grid by 2035). Increased wind turbine sizes or expansion into new or geographically challenging areas could present additional challenges for deployment because of the required investments and distribution challenges. A limited supply chain results in a reduced proportion of projects being able to source components domestically and meet the DCB, but perhaps more critically, may make it difficult for projects to procure components considering an already-constrained global supply chain.

4 Discussion and Conclusions

4.1 Potential Impacts of the Inflation Reduction Act

The IRA is expected to increase deployment to 21–25 GW/year by 2030 and enable domestic manufacturing, as evidenced by recent factory reopening or new construction announcements. Meeting decarbonization goals by 2035 will require even higher deployment levels on the scale of 36–45 GW/year. Such deployment levels will be the primary driver of demand for domestically produced components, as well as the value that project developers see in sourcing their components from within the United States. This value could come from the IRA provisions, including increased amounts and availability of tax credits, as well as tax credit extensions and clear timelines past 2030. Additional value comes from component cost competitiveness; increased jobs and economic benefits; reduced supply chain or geopolitical disruptions; or environmental, social, and governance benefits, such as reduced life cycle emissions.

For developers, pursuing the DCB may not be cost-effective for all projects, and as such there is uncertainty as to whether it will drive domestic component demand. Qualifying for the DCB is expected to result in CapEx increases for developers from buying domestic components versus imports, making the DCB valuable only if it exceeds the increase in CapEx. For a standard project with $1,600/kW all-in CapEx, developers may be able to offset 6.3%–11.1% of CapEx increases with the DCB. However, this highly depends on specific project costs and characteristics, as well as on whether the ITC or the PTC is selected. For projects that do pursue the ITC, a "strategic blade distribution" (with at least 20% domestic and the remaining imported) will allow more projects to meet the 55% DCB threshold based on limited domestic supply while keeping costs low and qualifying the full U.S.-made nacelle cost. Conversely, projects pursuing the PTC may need to source up to 100% of their blades domestically to meet the PTC. Which option is pursued by different developers depends on other factors like specific project costs and domestic component availability.

The estimated demand for components with 55% domestic content shows a range of supply gaps that can be met with additional domestic manufacturing, including:

- The demand in a baseline deployment scenario (2030-2035 average 21 GW/year) can mostly be met with existing manufacturing capacity, including four blade factories (to meet 20% of demand), four nacelle factories, and 11 tower factories. An additional two tower factories would be needed to meet the entire domestic tower demand. Existing capacity can meet approximately 50% of blade demand, therefore there is an opportunity for manufacturers to expand blade capacity (up to four additional factories to meet all demand) if developers find domestic blades more cost-effective than imports.
- The high deployment scenario (2030–2035 average 36.8 GW/year) would require an additional 12 tower factories and one nacelle factory. Existing blade capacity would only meet 29% of demand, suggesting expansions or new factories would likely be needed if more projects pursue the PTC instead of a "strategic blade distribution". An additional 10 blade factories could meet 100% of demand.
- The very high deployment scenario (2030–2035 average 45 GW/year) reaches deployment levels that are ambitious but likely necessary to meet decarbonization targets. Manufacturing would need to be greatly expanded to meet demand and ensure projects

can source all their components while decreasing the risk from global supply chain bottlenecks. This scenario would require an additional 17 tower factories and two nacelle factories. Blade capacity comes close to meeting 20% domestic demand, whereas 100% of demand could be met with an additional 14 factories.

The AMPTC provides a significant opportunity for manufacturers to bridge supply gaps by being cost competitive with imports if they pass on some of the credit to developers in the form of cost savings. This decision presents a trade-off for manufacturers on whether to keep most or all of the credit to improve their low margins while keeping prices high, or to lower prices to capture more domestic demand while keeping less of the tax credit. The full value of the AMPTC is estimated to reduce domestic component costs by 15%–33% to below the cheapest imported component price. To match the price of the cheapest imports, manufacturers would need to pass on approximately two-thirds of the tax credit for blades, and less than one-third of the credit for nacelles and towers. The growth of domestic manufacturing will be influenced considerably by how manufacturers incorporate the AMPTC.

4.2 Challenges and Opportunities

4.2.1 Component Cost Uncertainty

The extent to which developers elect domestic components is uncertain, as it depends on factors that may determine whether paying higher costs for domestic components is justified in comparison to the DCB value. Main factors include:

- Project-specific costs that determine relative contributions per component to total component cost
- External/market component cost variations, which are sensitive to ongoing global supply chain bottlenecks
- The willingness of manufacturers to pass on savings from the AMPTC and lower prices.

Variations of 25% in nacelle and blade costs could significantly affect the number of blades needed for developers to meet DCB requirements, and consequently domestic blade demand. High nacelle costs and low blade costs could result in a domestic content contribution from nacelles of 59%, which is sufficient to meet the DCB without domestic blades. Conversely, low nacelle and high blade costs could result in a nacelle domestic content contribution as low as 36%, requiring approximately 47% of a project's blades to be sourced domestically to qualify under a "strategic blade distribution".

4.2.2 Transportation Coordination and Investment

The ability to source and distribute components is largely affected by increased wind turbine sizes and transportation constraints. Larger components (as turbine platforms grow) do not have a significant impact on how well manufacturing capacity can keep up with demand (less components manufactured but also fewer are needed for the same deployment level). However, factories may need to invest in new tooling, molds, or training to manufacture these components.

Additionally, larger components will be harder to transport. This is especially true for East and West Coast projects where infrastructure or geography may limit component delivery, accounting for 8.4% of total capacity by 2035. New blade trailers will be required for blades that are 75 meters long and up, adding cost and length to transport.

Other logistical challenges like construction closures (intensified by the Bipartisan Infrastructure Law) force transportation companies to modify their routes, increasing time and cost. Inefficient coordination across state lines will also require better strategies of manufacturers, transportation companies, and states to maintain component key transport routes.

4.2.3 New Factory Feasibility

While several manufacturers have announced reopened or expanded factories after the IRA was passed, there is considerable risk in constructing new factories because of limited profits in the past several years and uncertainty in the near- and long-term deployment of new wind energy projects.

The extent to which additional factories are built also depends on the component type. While the gap between supply and demand is greatest for blades, domestic nacelles and towers are competitive against imports even without the AMPTC, which may prove to be easier and more profitable for manufacturers to pursue.

An additional consideration is that the AMPTCs expire at the end of 2032 but new factories or expansions may take several years to reach production, reducing the time needed to take advantage of the tax credits. The construction of new factories depends on whether a new factory can still be profitable within that time frame and which tax credit benefits it most.

4.2.4 Repowering Demand

Aside from component demand expected from new deployment, many developers plan to repower projects after 10 years to requalify for the PTC. The current policy for partial repowering requires an 80/20 distribution of replaced versus original equipment, which typically includes blades, hub, and drivetrain replacements. Future repowering demand in the United States is estimated to contribute 1−4 GW/year between 2023 and 2032 with an average of 2.3 GW/year (Wood Mackenzie 2023c).

The increased blade and drivetrain component demand may encourage expansion of domestic blade manufacturing, especially if repowering components can also qualify for the AMPTC. If blades for repowering turbines qualify for the AMPTC demand for domestically produced blades may further increase blade demand. The magnitude of this demand for blades for repowering is unknown and further analysis and industry engagement is recommended. Additionally, nacelle production capacity is higher than demand in most analyzed scenarios, which could be an opportunity to produce drivetrains for partial repowering. However, in conjunction with transportation constraints, an increase in domestic component delivery may result in bottlenecks for new deployment without adequate investment in trucks and trailers, as well as improved coordination.

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Appendix A. Reference Deployment Scenarios

Figure A-1 displays the reference projections that served as the baseline for the deployment projections defined and used within this report's scenarios. The reference projections include the following:

- Wood Mackenzie market outlook projections from the first and second quarter of 2023 (the second quarter projection reduces the expected impact of the Inflation Reduction Act [IRA}) (Wood Mackenzie 2023a, Wood Mackenzie 2023b)
- BloombergNEF (BNEF) projections for a moderate and an economics-only case (excludes interconnection bottlenecks) (BNEF 2022)
- The 2022 National Renewable Energy Laboratory (NREL) Mid-case Standard Scenario with current policy (Gagnon, Cowiestoll, and Schwarz 2023)
- The NREL Standard Scenario detailed analysis of the IRA's impact on deployment (Steinberg et al. 2023)
- The NREL 100% Clean Electricity by 2035 study, low-renewable-energy-cost scenario (Denholm et al. 2022).

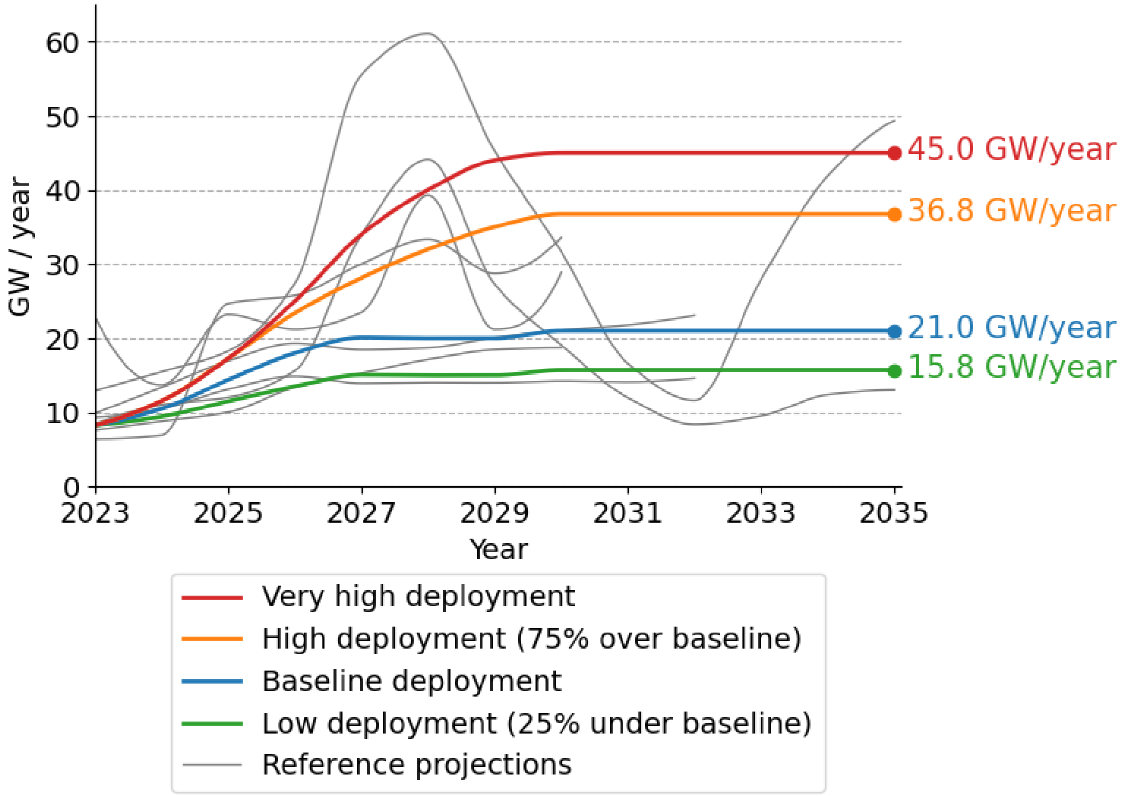

Figure A-1. Deployment projections used for analysis alongside reference projections

Appendix B. Manufacturing Announcements

This appendix contains public announcements of reopened and new blade, tower, and nacelle manufacturing facilities as of the end of November, 2023.

Blades

Recent announcements regarding manufacturing wind turbine blades include the following:

- General Electric (GE) and TPI sign an agreement for a 10-year extension for the TPI Newton, Iowa, plant (2024 through 2033). "This agreement is possible in part due to the support provided by the Inflation Reduction Act of 2022 for critical American industries serving the domestic renewable energy sector," said TPI President and Chief Executive Officer Bill Siwek (TPI Composites Inc 2022). GE and TPI also extended their supply agreements through 2025 (TPI Composites Inc 2023a).
- GE and TPI sign an agreement to produce wind turbine blades in Juarez, Mexico, thereby adding four new production lines, with an initial term through 2025 (TPI Composites Inc 2023b).
- Siemens Gamesa re-opens a blade plant in Fort Madison, Iowa (Kessler 2023).
- Vestas announces expansion of its Windsor, Colorado, blade plant as part of its recent $40-million investment. It will manufacture blades for their newest wind turbine in the U.S. market, the V163-4.5 MW (Vestas 2023).

Nacelles

Recent announcements regarding manufacturing nacelles include the following:

- GE announces production expansion of their Pensacola, Florida, nacelle plant as part of its $20-million investment (GE 2023).
- GE announces $50-million investment in new nacelle plant in Schenectady, New York, (Governor Kathy Hochul's Press Office 2023). The new facility will produce components for the company's 6-megawatt (MW) platform (Ferry 2023).
- Siemens Gamesa announces reopening of nacelle plant in Hutchinson, Kansas (Kessler 2023).
- Vestas announces expansion of Brighton, Colorado, nacelle plant as part of its recent $40-million investment. The facility will manufacture nacelles for the V163-4.5 MW turbine (Vestas 2023).
- Nordex deliberates on reopening their mothballed nacelle plant in West Branch, Iowa. "The question for us is not if, it's going to be when," said Nordex Chief Executive Officer Jose Luis Blanco (Steitz 2023).

Towers

Recent announcements regarding manufacturing towers include the following:

- CS Wind announces expansion of its tower plant in Pueblo, Colorado, reportedly making it the world's largest wind energy manufacturing site (Seward 2023; Van Dyne 2023).

- Marmen Energy announces expansion of its Brandon, South Dakota, tower plant (Marmen Energy 2023).
- Broadwind Heavy Fabrications announces a $3-million investment in their Abilene, Texas, tower plant to improve productivity, train and retain their workforce, and expand their weld lab area (Development Corporation of Abilene 2022).
- Arcosa announces a new tower plant in Belen, New Mexico, as a result of a high number of orders in the Southwest. "The $750 million of new orders are expected to be eligible for the Advanced Manufacturing Production tax credit included in the Inflation Reduction Act" (Arcosa, Inc 2023).
- Keystone Tower Systems began commercial production of spiral-welded towers at its new tower plant in Pampa, Texas, in 2022 (Richard 2022).

Other Components

Recent announcements regarding manufacturing other components include the following:

- Flender Corporation announces expansion of its manufacturing facility in Elgin, Illinois, where it produces mechanical gears, including gearboxes for wind turbines (State of Illinois 2023).
- Prolec GE USA announces an investment of up to $28.5 million in their Shreveport, Louisiana, plant to manufacture transformers to be used in wind plants and other renewable energy applications (Office of Governor John Bel Edwards 2023).

Appendix C. Annual Blade Manufacturing Capacity

Table C-1 outlines the blade manufacturing capacity numbers used in the modeled scenarios, which are calculated as a function of annual average blade length and facility area. Refer to Section 3.1 for details.

Table C-1. Blade Manufacturing Facilities and Estimated Scaled Capacity for All Years 2030–2035

Year	Average Blade Length	Maximum Number of Blades Produced per Facility			
		TPI Composites	LM Wind Power	Siemens Gamesa Renewable Energy	Vestas
2023	65.7	1,105	1,282	3,449	1,990
2024	68.5	1,060	1,230	3,307	1,908
2025	70.7	1,026	1,190	3,201	1,847
2026	73.1	993	1,152	3,099	1,788
2027	73.2	992	1,151	3,095	1,786
2028	74.8	971	1,126	3,029	1,747
2029	76.8	945	1,096	2,948	1,701
2030	77.7	935	1,084	2,916	1,682
2031	79.4	914	1,060	2,852	1,645
2032	80.4	902	1,047	2,815	1,624
2033	80.5	902	1,046	2,814	1,624
2034	81.0	895	1,039	2,794	1,612
2035	81.8	887	1,029	2,767	1,596

Appendix D. Technology Projections

Technology projections used across scenarios are based on estimated original equipment manufacturer market share and technology trends. Table D-1 presents the standard technology projection, whereas Table D-2 presents the increased turbine size projection, which only includes turbines rated at 4.5 megawatts or higher.

Table D-1. Weighted Average Wind Turbine Specifications for the Standard Technology Projection

Year	Turbine Rating (megawatts [MW])	Number of Tower Sections	Blade Length (meters [m])
2023	3.3	3.3	65.7
2024	3.7	3.7	68.5
2025	3.9	4.1	70.7
2026	4.1	4.4	73.1
2027	4.2	4.4	73.2
2028	4.3	4.5	74.8
2029	4.6	4.6	76.8
2030	4.6	4.8	77.7
2031	4.7	5.0	79.4
2032	4.7	5.2	80.4
2033	4.7	5.2	80.5
2034	4.7	5.3	81.0
2035	4.7	5.5	81.8

Table D-2. Weighted Average Turbine Specifications for the Increased Turbine Size Technology Projection

Year	Turbine Rating (MW)	Number of Tower Sections	Blade Length (m)
2023	4.5	4.0	74.0
2024	4.7	4.3	74.0
2025	4.8	4.5	75.3
2026	5.1	4.9	78.6
2027	5.1	5.0	78.9
2028	5.3	5.2	80.9
2029	5.6	5.3	81.8
2030	5.7	5.5	82.2
2031	6.2	5.8	83.9
2032	6.2	5.8	84.0

Year	Turbine Rating (MW)	Number of Tower Sections	Blade Length (m)
2033	6.2	5.9	84.0
2034	6.3	5.9	84.3
2035	6.3	5.9	84.6