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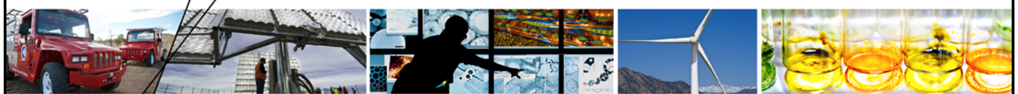
Supply Chain and Blade Manufacturing Considerations in the Global Wind Industry



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With contributions from experts at the U.S. Department of Energy, Sandia National Laboratories, and industry partners

December 12, 2013

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NREL/PR-6A20-60063
Contract No. DE-AC36-08GO28308
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Clean Energy Manufacturing Strategic Analysis

We thank a number of partners, especially Libby Wayman, James Nachbaur, Carla Frisch, and Cash Fitzpatrick from the U.S. Department of Energy (DOE) who supported this work as part of the DOE Clean Energy Manufacturing Initiative. Derek Berry, Ran Fu, Dan Bilello, and Jason Cotrell from NREL and several industry partners also contributed to the development and review of the analysis.

CLEAN ENERGY
MANUFACTURING INITIATIVE
U.S. DEPARTMENT OF ENERGY

Objectives:

- **To increase U.S. competitiveness in the production of clean energy products** by strategically investing in technologies that leverage American competitive advantages and overcome competitive disadvantages.
- **To advance U.S. manufacturing competitiveness across the board by increasing energy productivity** through strategic investments in technologies and the development of best practices.

More information about the U.S. Department of Energy's Clean Energy Manufacturing Initiative is available online:
http://www1.eere.energy.gov/energymanufacturing/index.html

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Executive Summary

- Over the past decade, significant wind manufacturing capacity has been built in the United States in response to an increasingly large domestic market.
- Recent U.S. manufacturing production levels exceed anticipated near-term domestic demand for select parts of the supply chain, in part due to policy uncertainty, and this is resulting in some restructuring in the industry.
- Factory location decisions are influenced by a combination of quantitative and qualitative factors; proximity to end-markets is often a key consideration, especially for manufacturers of large wind turbine components.
- Technology advancements in the wind sector are continuing, and larger blade designs are being pursued in the market, which may increase U.S.-based manufacturing opportunities.

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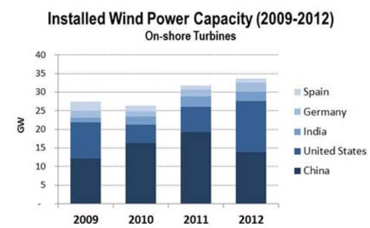
Market Overview

Wind Markets and Manufacturing Growth Continued in 2012

- Wind markets saw strong demand with about 45 GW installed worldwide.
  - Record-breaking U.S. installations accounted for nearly 30% of global demand.
- U.S. manufacturing production exceeded previous years.
  - The U.S. installed a record-setting 13.1 GW of wind power in 2012, and domestic content of installed turbines grew by nearly 10%.
- Imports to the United States exceeded exports to help fulfill domestic demand.
- Transportation costs for major components (blades, towers, nacelles) remain relatively high due to dimensional load considerations.
- Technology advancements and product differentiation are driving competitive advantages in some parts of the global supply chain.



Sources: AWEA U.S. Industry Annual Market Report (2013). U.S. Department of Energy 2012 Wind Energy Market Report (August 2013). Bloomberg New Energy Finance 3Q 2013 Wind Market Outlook (September, 2013).

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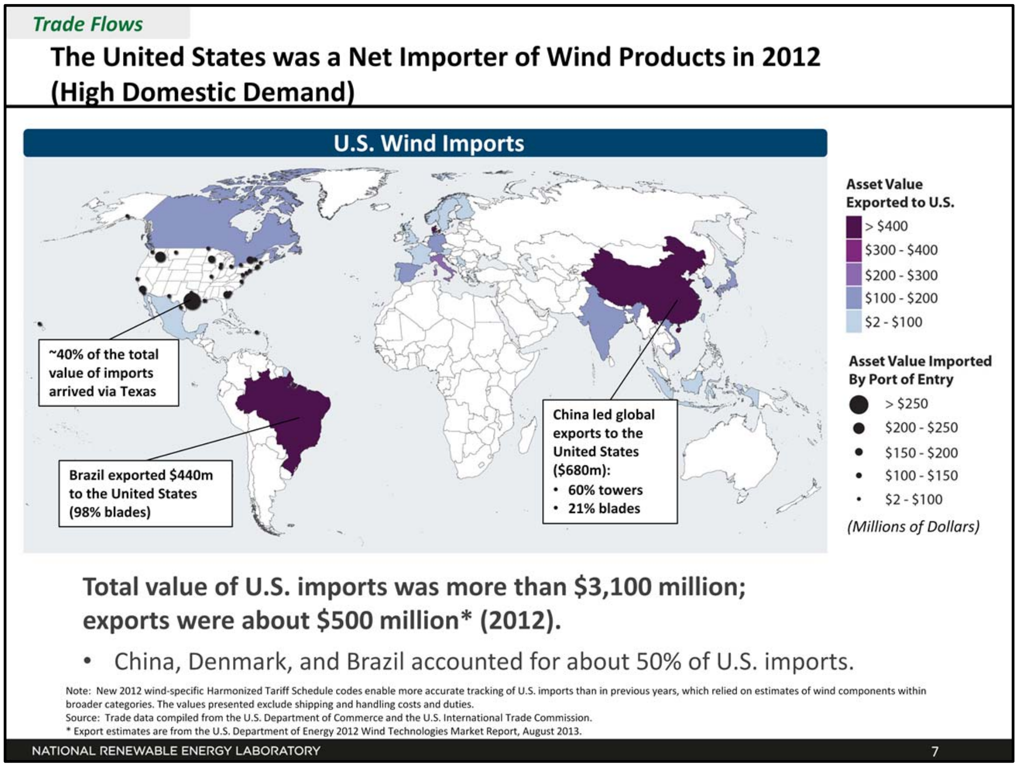
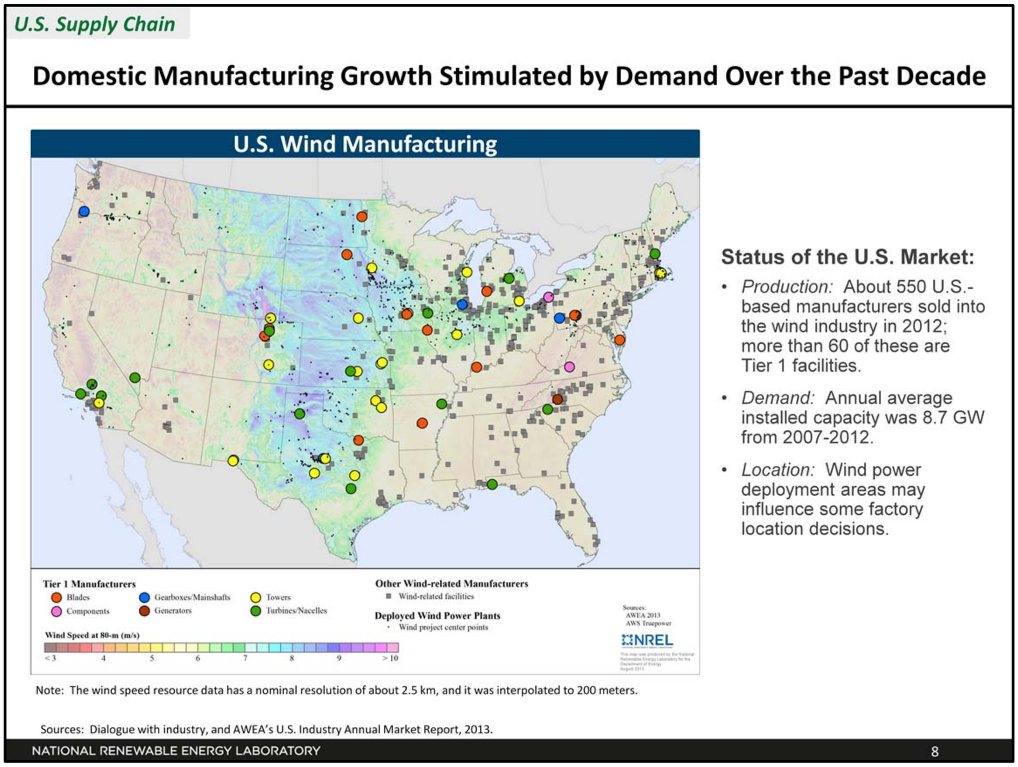
Global manufacturing capacity for wind turbines has doubled since 2008, and worldwide installations of wind power reached new highs in 2012, adding more than 46 GW of capacity to electric grids (BNEF 2013). While wind power is the lowest cost energy source in some locations, demand is still driven by policy support in many markets and the magnitude of deployment opportunities can fluctuate significantly in response to incentives and regulatory changes (IPCC 2011). The United States experienced record-breaking deployment in 2012 (13.1 GW), in part due to the anticipated expiration of the federal production tax credit (PTC) (AWEA 2013). Manufacturers in the United States were mostly able to respond to domestic demand, yet imports did contribute to the U.S. market despite the relatively high transportation costs associated with large wind equipment.

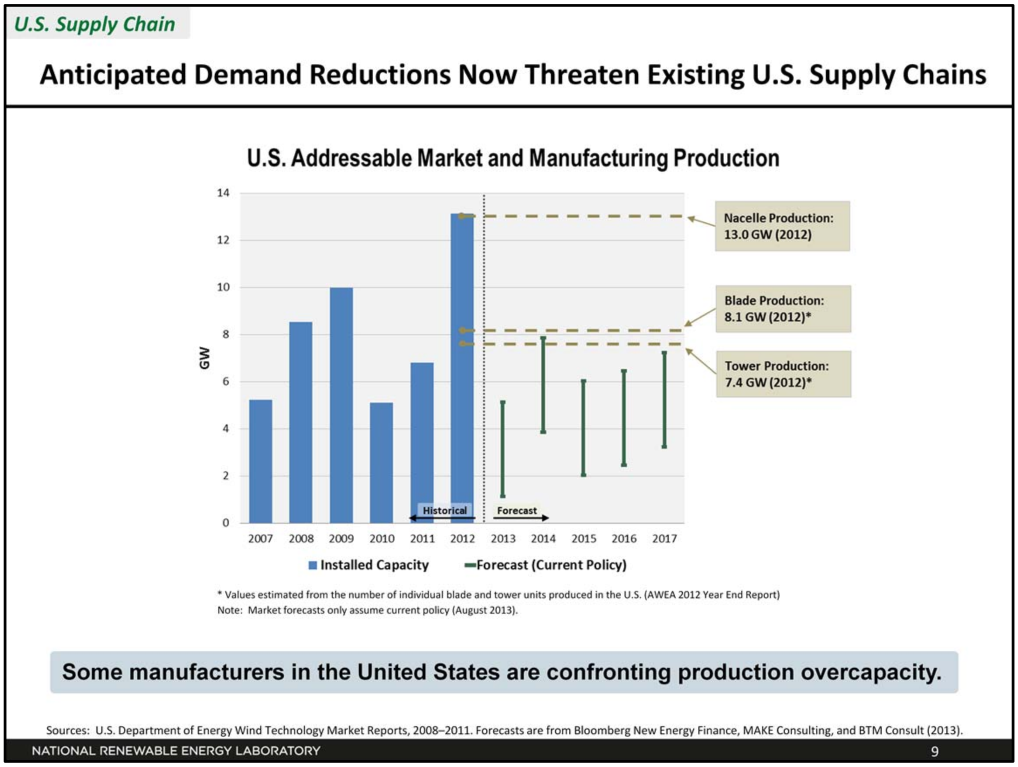


It is unlikely that U.S.-based wind manufacturers could completely satisfy U.S. demand in 2012 based on our analysis of domestic manufacturing production and the record level of wind installations (see slide 9). This contributed to a $2.6 billion trade imbalance of higher equipment imports than exports in the U.S. wind sector in 2012. A total of about $25 billion was invested in wind power project installations in the United States in 2012, and the trade imbalance, while significant, is relatively small by comparison (U.S. Department of Energy Wind Technology Market Report 2013). U.S. equipment exports have likely grown during the period from 2007 to 2012, though U.S. wind service firms appear to have a small share global wind service exports (U.S. International Trade Commission 2013). The ultimate drivers of equipment imports are challenging to identify for any particular year due to time lag considerations (i.e., the time between manufacturing goods, receiving imports, and deploying capacity), inventory holdings, and data inconsistencies. In other words, the magnitude of trade flows in 2012 was likely influenced by some contracts from prior years, as well as some planned deployments for 2013. Among the imports, the largest amount (40% of the total value) arrived via ports in Houston-Galveston, Texas. Compared to ports on the East and West coasts of the United States, the Houston-Galveston area is often the lowest cost location for importing and exporting wind products on account of low fees, relatively low labor costs, and the availability of transport equipment to handle dimensional shipments. Texas installed more wind capacity than any other state during seven of the past eight years (U.S. Department of Energy Wind Technology Market Report 2013), and port operators in the region have significant experience handling wind products. The costs of transporting these goods through major ports has declined in some other U.S. regions that have experienced higher volumes of shipments.

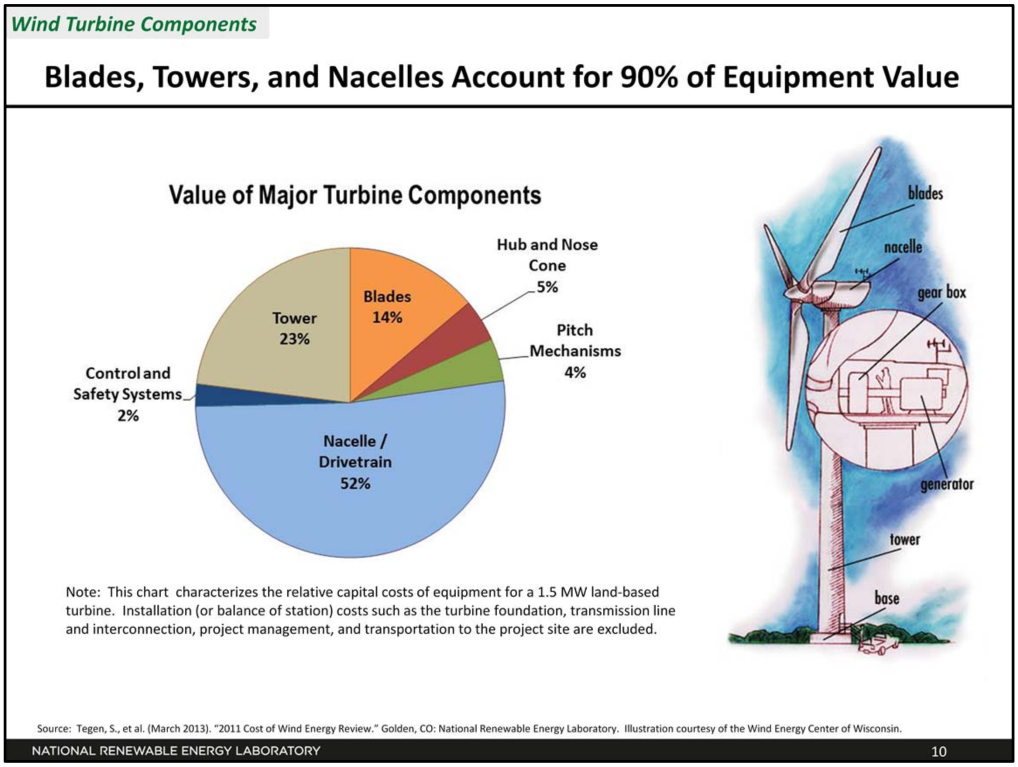


More than 60 U.S.-based "pure play" or Tier 1 manufacturers sold into the wind sector in 2012. These facilities, represented by colored dots on this map, produced goods that were sold exclusively to the wind industry. The facilities illustrated by grey squares contributed goods to the wind sector in addition to other industrial sectors. Examples of products made by these so-called wind-related facilities include: sensors, bolts, clamps, lubricants, paints, coatings, bearings, composite parts, plastics, aluminum extrusions, balsa core, sealants, adhesives, cables, and wiring (AWEA Data Services 2013).

Select parts of the domestic wind supply chain locate in areas near the demand for installed wind turbines, mostly on account of high transportation costs and related logistical considerations. To illustrate this dynamic, the map shows the center points of deployed utility-scale wind power plants (black dots), in addition to wind manufacturers. The map also shows the geographic spread of wind resources across the contiguous United States from an analysis of long-term annual average wind speeds at 80 meter heights above the ground (AWS Truepower and NREL 2013). With some exceptions, the most economically viable locations for wind power have been in areas with average wind speeds above 6 meters per second. Thus, the map offers a rough approximation of both historical and potential deployment areas, in addition to information about the locations of existing wind manufacturing facilities. Market structures, access to transmission lines, and local policies also significantly influence the locations of wind plant deployments (U.S. Department of Energy Wind Technology Market Reports 2011 and 2012). Advancements in wind technologies could stimulate more demand for wind power because new turbine designs are enabling economically viable deployments in lower wind speed regions such as the Southeastern United States.



Historically, the demand for wind power in the United States has been strongly influenced by the short-term extensions and expirations of the federal production tax credit (Schwabe, et al. 2009), which has created varied levels of deployment as shown in this figure. In addition to illustrating historical deployment, this chart also highlights the U.S.-based manufacturing production levels for major wind components (nacelles, blades, and towers) in 2012 and near-term demand forecasts under current (2013) policies, which range from less than 2 GW per year to nearly 8 GW per year. Policies assessed in these market forecasts include state renewable portfolio standards (RPSs) and the federal PTC. The survey-based estimates of domestic wind equipment production for 2012 provide a top-down perspective about the overall scale of today's U.S.-based wind manufacturing. While comprehensive data about U.S.-based manufacturing capacity and plant utilization is not available, the production data alone offer important insights about domestic capabilities to respond to demand. For comparison purposes, the production numbers for blades and towers are listed in terms of capacity (GW). These values were derived from actual production data in 2012: 12,500 blades and 3,800 towers (AWEA 2013). The ranges of demand forecasts illustrated in the figure are from the market reports listed. Despite a short-term extension of the federal PTC in January 2013, which is included in these forecasts, it is anticipated that average annual demand through 2017 will be consistently lower than the past five year annual average of 8.7 GW. Expected low natural gas prices and continued stagnant electricity demand contribute to these lower forecasts, and the impacts of these market conditions on wind manufacturers are already apparent; some firms have published information about negative operating margins (resulting from reduced sales, lower margins, and restructurings) and/or announced reduced plant operations. Some closures were also announced in 2012 and early 2013 (e.g., Nordex, Clipper, Nordic, DMI, Trinity, and others).



Wind turbines are composed of more than 8,000 individual components, and about 90% of the value is captured in three main parts: blades, towers, and nacelles (Tegen, et al. 2013). Blades are typically made of fiberglass and epoxy composites, and include some carbon fiber materials. Towers are mainly composed of rolled steel, and in some large-scale designs, the tower base may be made of concrete. Nacelles house the drivetrain/gear box components and the generator, and a range of technologies are available in the market.

Many types of corporate structures exist among today's wind power manufacturers. Some firms, like Vestas, are vertically integrated, producing most parts of turbine systems; other firms, like GE, work with a range of suppliers to acquire individual parts such as blades. Wind turbine parts are not often interchangeable, however. Some components are designed for specific turbine systems, and a breadth of turbine system designs are available today to both serve customer needs and sustain firm-level competitive advantages.

Summary of Global Wind Industry, and U.S. Supply Chain Considerations

- **In 2012, annual installations grew to about 45 GW worldwide.**
    - U.S. installations exceeded previous annual records with 13.1 GW installed.
- **Today, wind manufacturing is often located near areas of deployment for some parts of the supply chain.**
    - About 550 manufacturers in the United States sold into the wind industry in 2012.
    - U.S.-based wind manufacturing in 2012 grew to an estimated 13 GW for nacelles, 8.1 GW for blades, and 7.4 GW for towers.
- **The United States imported about $3.1 billion of wind equipment in 2012, and the majority of this value was shipped from China, Denmark, and Brazil.**
    - U.S. wind equipment exports likely grew over the last several years, and amounted to an estimated $500 million in 2012.
- **Recent U.S. manufacturing production levels exceed near-term domestic demand forecasts, which is resulting in some restructuring in the industry.**
    - Near-term demand for wind power in the United States is expected to decline to an estimated 2 GW/year to 8 GW/year due to policy and market considerations.
- **Nacelles, blades, and towers make up about 90% of the value of a wind turbine.**

II a) Regional Comparisons of Blade Manufacturing Costs

Overview of Blade Manufacturing Considerations

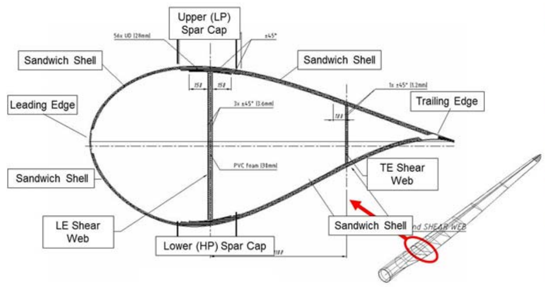
- *Worldwide blade manufacturing in 2012 occurred mostly in regional markets.*
  - More than 70,000 blades were deployed worldwide.
  - 12 facilities in the U.S. produced approximately 12,500 individual blades.
  - 60% to 80% of blades deployed in the U.S. were manufactured within the U.S.
  - The United States imported nearly $900 million of blades and hubs; about 75% of these products were sourced from Brazil, China, and Denmark.
- *Technology differentiation drives some competitive advantages.*
  - Blade sizes have steadily increased over the past 30 years, and designs vary to enable cost-effective harvesting of different wind resources.
- *Transportation costs are relatively high.*
  - Large factories risk diseconomies of scale – factories are located proximal to demand instead of single large plants serving global markets.

The U.S. Department of Energy identified blade manufacturing as a key analysis topic.

Source: NREL estimates based on data from AWEA's U.S. Industry Annual Market Report (2013) and the U.S. Department of Energy 2012 Wind Technologies Market Report (August 2013).

Detailed Regional Cost Analysis

Bottom-Up Modeling of Regional Manufacturing Costs Quantifies Key Competitiveness Considerations

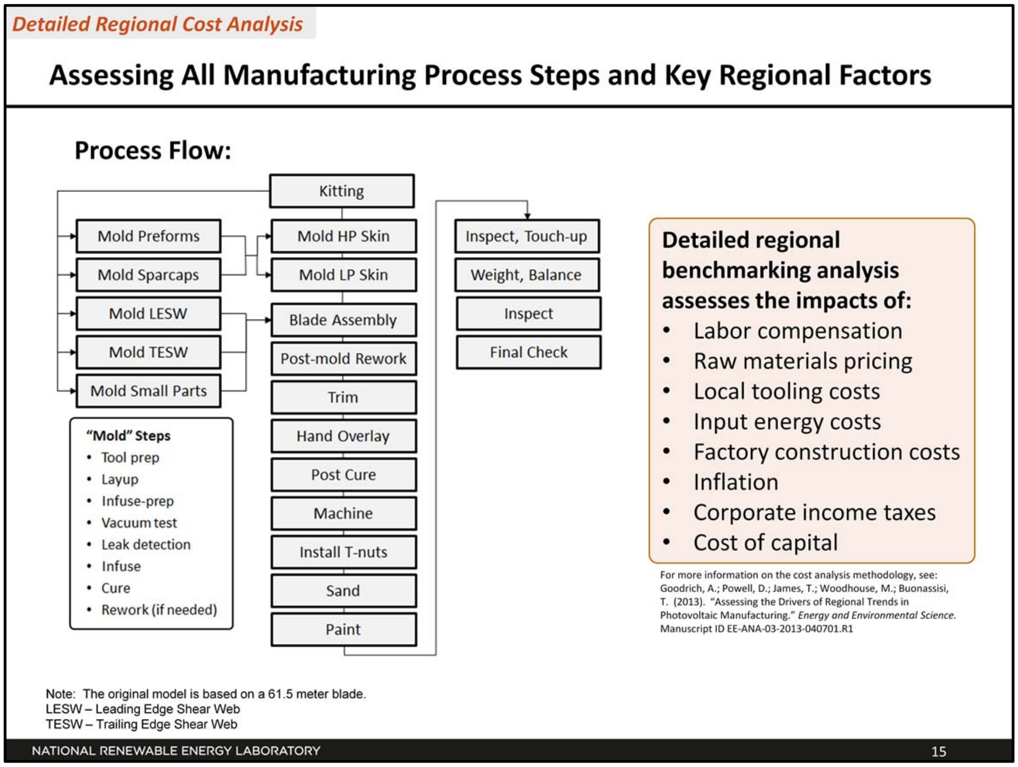


About the NREL Model:

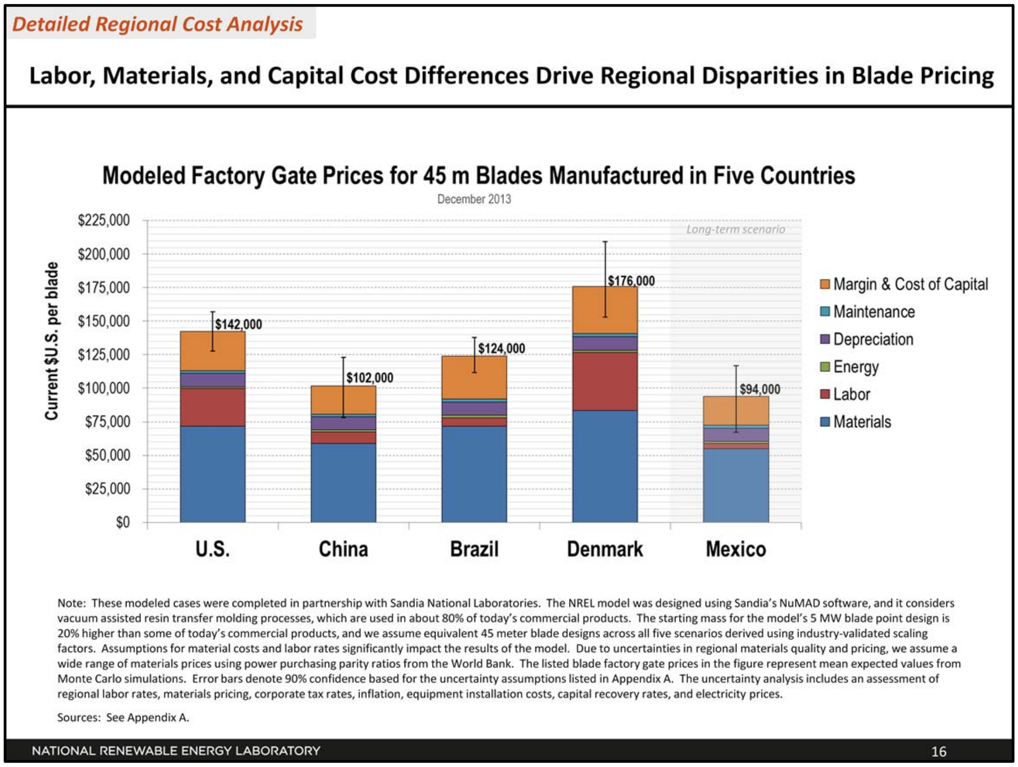
- Bottom-up, spreadsheet-based tool using industry-relevant data.
- Scaling factors provide insights about a range of blade sizes.
- Assumes a vacuum-assisted resin transfer molding process.
  - This process is used to manufacture about 80% of today's blades.

Note: The original model is based on a 61.5 meter blade.
Source: Left image courtesy of Stephen Nolet, TPI Composites, Inc. (2011); Right image from NREL/16002.

NREL's blade cost model was developed in collaboration with experts from Sandia National Laboratories. The tools and analysis developed by Sandia estimate the bill of materials for a 61.5 meter blade design (Johanns and Griffith 2013). While the inputs have been validated by industry, it should be noted that the results do not necessarily represent the costs for all manufacturers and blade designs. The NREL cost model also incorporates insights from past DOE-funded programs like the Wind Partnerships for Advanced Component Technology (Berry, et al. 2003), in addition to more recent National Laboratory-led efforts such as the Advanced Manufacturing Initiative (AMI) and other collaborative work with industry (Griffith and Johanns 2013).

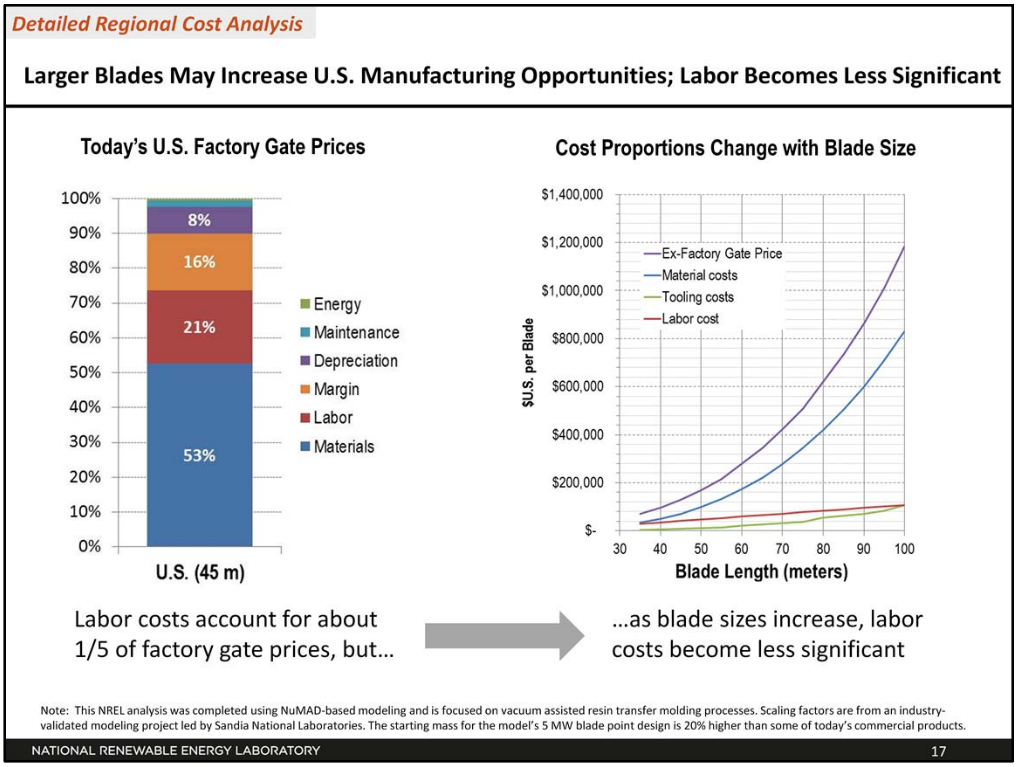


The NREL blade model includes every step of the manufacturing process–from kitting to hand overlays to painting and final check-off–for the vacuum-assisted resin transfer molding process (VARTM). The model is adaptable and structured to use a range of wage rates for skilled and unskilled laborers, materials pricing, tooling costs, electricity costs, and financing considerations. This methodology includes the capability to estimate the minimum sustainable price (i.e., the price that provides investors with a return that overcomes capital costs) for manufacturers based in each region using industry-accepted discounted free cash flow methods. The weighted average cost of capital (i.e., the discount rate) is calculated from a combination of representative corporate leverage, the cost of debt, and the cost of equity. The cost of equity, which companies do not report, is calculated from an equity market risk premium and risk free rate with the risk premium being adjusted for sector-specific factors. More information on the methodology behind the financing assumptions is available in Goodrich, et al. 2013.



Based on our analysis of manufacturing costs, as calculated at the factory gate, we conclude that materials and labor are the most significant factors that differentiate blade costs among regions. The cost of capital, which is reflected in the margin requirements, also influences disparities in factory gate prices, but to a lesser extent than materials and labor. In the U.S. case analyzed, materials and labor costs account for 53% and 21% of the factory gate price, respectively (see slide 17). Due to uncertainties associated with materials pricing differences, we used power purchasing parity ratios to inform the input ranges of the uncertainty analysis. Factors affecting regional materials prices may include manufacturers' economies of scale, buyers' leverage over suppliers, brand recognition, and quality considerations. The values listed in the figure represent the mean expected values from an uncertainty analysis using Monte Carlo simulations, and the error bars denote 90% confidence for the selected model inputs (see Appendices for more information).

Due to its proximity to the United States and lower labor costs than many other regions, we included a Mexico scenario in this analysis. Unlike the other regions analyzed, however, we are not aware of significant blade manufacturing in Mexico at this time – in 2012, for example, the United States imported less than $5 million of blades and hubs from Mexico compared to approximately $145 million, $430 million, and $105 million from China, Brazil, and Denmark, respectively. In this context, our analysis of Mexico is differentiated from the other regional scenarios, and we consider it to be a longer-term case. Our finding of possible low cost blade manufacturing opportunities in Mexico aligns with other analyses about cost competitive manufacturing in Mexico for a number of industries (BCG 2012). The limited availability of infrastructure, skilled workers, and suppliers supporting the production of blades, in addition to concerns about the ease of doing business (e.g., safety concerns), however, may limit Mexico's ability to rapidly scale-up wind turbine blade manufacturing in the near-term.



Using the scaling factors that Sandia National Laboratories developed in partnership with industry, our modeling indicates that as blade sizes increase, labor costs become less significant. As shown in the figure on the right, labor costs become a substantially lower share of factory gate prices as blade sizes increase from 35 meters to 100 meters – thereby decreasing overseas manufacturing advantages, and introducing potential U.S. manufacturing opportunities. It is possible that step functions in these costs may occur, particularly for materials, as advancements in larger blades are developed, but the general relationships illustrated in the figure on the right will likely persist. Over the past 30 years, blade sizes have increased 6-fold (see slide 19), and this trend is continuing since turbines with larger blades and higher hub heights are often better designed for cost effective deployment in lower wind speed environments (IMS Research 2013). In addition to increasing U.S.-based manufacturing opportunities, larger blade sizes hold promise to significantly increase downstream domestic market opportunities for wind power since they may more effectively generate power in regions with lower wind speed resources.

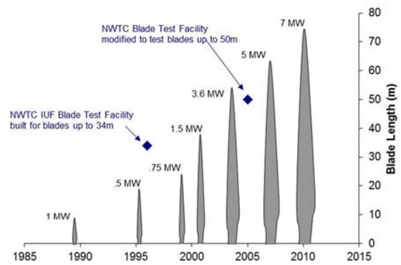
II b) Blade Transportation Cost Assessment

Detailed Regional Cost Analysis

Blade Transportation Considerations and Market Trends

- Moving blades from factories to project sites often requires complex and expensive transport and project logistics.
- Manufacturing facilities generally locate near end-markets to minimize transport costs.

Blade sizes have increased 6-fold since the 1980s



Updated from Cotrell, J., et al. (May 2006). "Necessity and Requirements of a Collaborative Effort to Develop a Large Wind Turbine Blade Test Facility in North America." Golden, CO: National Renewable Energy Laboratory.

Infrastructure constraints in some regions

Transport of a 75 m blade by truck.
Siemens Press Picture (2013). Reprinted with permission.

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Transportation considerations are becoming more important as blade sizes continue to increase. In the 1980s, wind turbine blades were typically between 5–15 meters in length. By 2010, average blade sizes had grown to 40–43.5 meters. And today, some blade lengths are much greater than 45 meters (Caduff, et al. 2012). As blade sizes have grown, so have the challenges for shipping and logistics providers who must navigate the constraints of tunnels, overpasses, and available turning radius areas. For example, today's 43-meter blades require turning radius areas of about 40–46 meters. Trucking companies must sometimes add soil, aggregate, and culverts to expand cornering areas when transporting blades, especially on small rural roads. In some cases, companies must also temporarily remove road signs. Common width and height restrictions on U.S. roadways are about 4 meters and 4.3 meters, respectively (Dvorak 2011). Generally, it can be more difficult to move large dimensional shipments like blades in areas with older infrastructure such as the Northeastern United States.

In addition to infrastructure constraints, logistics companies must carefully synchronize the delivery of wind equipment to deployment sites to effectively manage overall project costs. Logistics experts must assess the trade-offs of using different modes of transport (trucking, rail, barge, and ocean freight), incurring local expenses for permitting and police escorts, and balancing well-coordinated deliveries for all turbine components. Local factors such as wait times for permitting and police escorts, and mechanical issues like truck breakdowns can also affect transport costs and planning.

Detailed Regional Cost Analysis

Transportation Costs Vary by Mode and Blade Technology

Transport decisions are most influenced by:

- *Distance* – companies generally prefer to truck blades less than 500 miles before considering other modes of transport.
- *Managing risk* – through limiting equipment breakdowns, increasing responsiveness to unexpected events, reducing accidents, and diversifying the total value of shipments.
- *Synchronizing logistics* – reducing needs for multiple modes of transport, lowering construction delays and storage fees.

83.5 meter blade in Scotland (offshore prototype)

Reprinted with permission. Fischer, Martin. "World's Largest Blade Begins Journey to Scotland." SSP Technology A/S. July 17, 2013.

Cost summary of blade transport

Mode	$ per mile	Per Blade Costs for 1,100 miles	Per Blade Costs for 300 miles	Per Blade Costs China to WA	Per Blade Costs Brazil to TX	Blade Size
Barge	-	$14,000 to $16,000	-	-	-	45-60 meter
Rail	-	$6,500 to $11,000	-	-	-	40-45 meter
Trucking	$14/mi to $22/mi	-	$5,000 to $7,000	-	-	40-45 meter
Ocean Freight	-	-	-	$28,000 to $42,000	$16,000 to $24,000	40-45 meter

Note: We assume handling costs of $500/blade per transition, and two independent transitions (off-loading and on-loading) between modes.

Source: Experts interviews, and CN. (2009). "The Logistics of Transporting Wind Turbines." White Paper.

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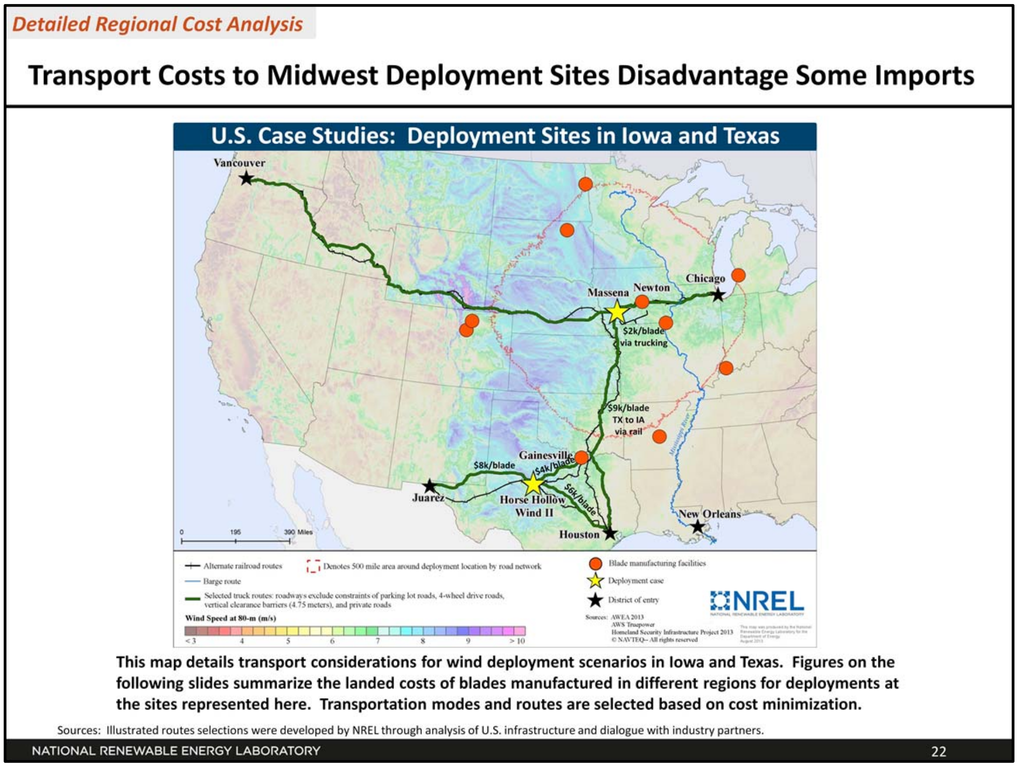
Limited information is published about the transport costs for wind equipment. The price ranges presented in the table are common for transporting today's utility-scale blades designed for land-based turbines in the United States. They do not include high-end prices that occur with market distortions such as demand spikes tied to policy schedules or for addressing unique project characteristics. Because costs for these dimensional shipments vary on account of route selections, blade technologies (i.e., size and weight considerations), and the supply and demand for specialized transport equipment and skilled laborers, logistics providers often generate pricing quotations through individual consultations. Transporting some large blade types, for example, may require temporary road and/or rail lane closures, and ground construction to accommodate loading and intermediary storage. Different modes of transport also have different risk profiles and attributes; for instance, shipping blades long distances via barge is often cheaper than using trucking, but it is slower. When using rail, costs can vary depending on volume (unit trains typically include at least 30 rail cars) and whether a company owns its rail equipment or leases from a railroad company. Overall permitting costs are often lower with rail transport, but infrastructure constraints along specific rail routes can increase costs. For every mode of transportation, fuel prices and distance affect total transport costs. With these considerations in mind, the blade transport costs listed in the table provide approximations of common pricing in the United States.

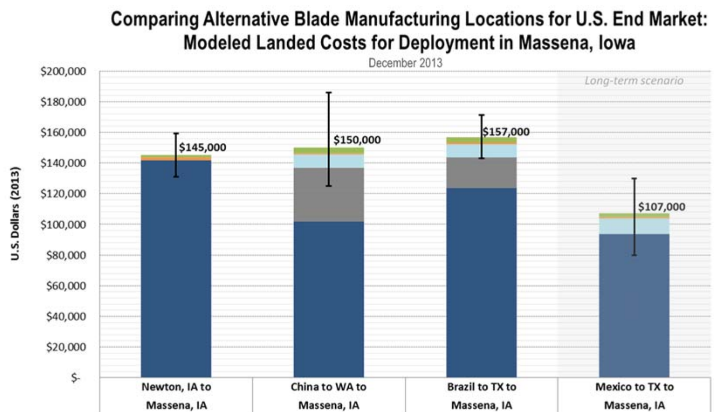
II c) Analysis of Landed Costs for Wind Blades



This map illustrates viable transportation routes for moving wind turbine blades from U.S.-based manufacturers (red dots) and import terminals (black stars) for overseas-based manufacturers for wind power deployments in Texas and Iowa (yellow stars). The largest wind power plant in Iowa is located near the town of Massena, and we use this location for one of our case studies of landed costs–i.e., the cost of blades delivered to project sites–for blades manufactured in various locations. The other end-market scenario we analyze is Horse Hollow, Texas, which is located near the town of Abilene. As noted on slide 20, producers of blades generally prefer trucking to transport blades if manufacturing facilities are within 500 miles of project sites, and the red ring around Massena, Iowa, indicates a 500 mile trucking distance. The shape of the ring is not circular because it is calculated from available road networks, as opposed to Euclidean distances. To determine likely transport routes for each case, we used a database from the U.S. Department of Homeland Security, filtering for infrastructure constraints such as low overpasses, bridges, and tunnels.

Detailed Regional Cost Analysis

For Today's Blades, Shipping Costs Exceed the Benefits of Manufacturing in Lower Cost Labor Regions for Some Midwest Deployment Locations (e.g., Iowa)



	Newton, IA to Massena, IA	China to WA to Massena, IA	Brazil to TX to Massena, IA	Mexico to TX to Massena, IA
Total Handling Costs	$1,500	$3,500	$3,500	$2,500
Trucking	$1,980	$900	$900	$900
Rail	$0	$8,750	$8,750	$10,063
Overseas Shipping	$0	$35,000	$20,000	$0
Ex-factory Gate Price	$142,000	$102,000	$124,000	$94,000
TOTAL (rounded)	$145,000	$150,000	$157,000	$107,000

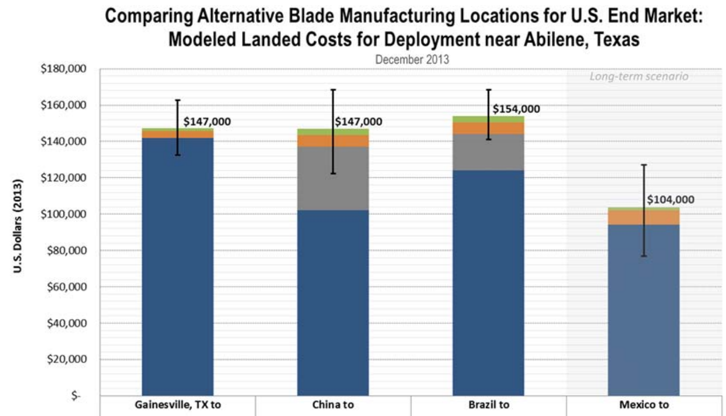
Note: This figure represents example scenarios. Shipping costs for wind blades vary due to a number of factors such as route selection, transport equipment supply and demand dynamics, and local fees and permitting considerations.

Source: NREL modeling and analysis.

Using the route selections mapped on the previous slide, this figure represents the estimated landed costs for blades delivered to Massena, Iowa from manufacturing locations in the United States, China, Brazil, and Mexico. We arrived at these estimates by combining our assessment of transport costs with our analysis of regional factory gate blade prices (see slide 16). Our modeling shows that for turbine deployments in locations like Iowa, the United States is a cost competitive manufacturing location compared to China and Brazil due to shipping costs. The Mexico scenario highlights potential longer-term risks to U.S.-based blade manufacturing opportunities on account of both low cost labor and the proximity to U.S. end-markets. Yet, as described earlier, the costs of the Mexico scenario are less certain due to the lack of existing industry production capacity. Overall, the figure illustrates that while the United States is at a cost disadvantage in terms of factory gate blade prices, blades manufactured in the United States are competitive if deployment occurs near production facilities and far from ports. This detailed analysis aligns with other market reporting that describes the co-location of wind manufacturing in regions with significant deployment, and the general trend of capital flows (i.e., foreign direct investment), as opposed to product flows, in the global wind industry (Kirkegaard 2009). Cost analysis provides insights about this key competitiveness driver, though companies often weigh many other factors when making factory location decisions. Issues such as the ease of doing business, supply-chain relationships, and policy support are among other important considerations, and Slide 26 provides more information about qualitative factors.

Detailed Regional Cost Analysis

Imported Blades are Less Disadvantaged by Transportation Costs at Deployment Locations Near Coastal Areas (e.g., Texas)



	Gainesville, TX to Horse Hollow, TX	China to Horse Hollow, TX	Brazil to Horse Hollow, TX	Mexico to Horse Hollow, TX
Total Handling Costs	$1,500	$3,500	$3,500	$1,500
Trucking	$3,816	$6,300	$6,300	$8,100
Overseas Shipping	$0	$35,000	$20,000	$0
Ex-factory Gate Price	$142,000	$102,000	$124,000	$94,000
TOTAL (rounded)	$147,000	$147,000	$154,000	$104,000

Note: This figure represents example scenarios. Shipping costs for wind blades vary due to a number of factors such as route selection, transport equipment supply and demand dynamics, and local fees and permitting considerations.

Source: NREL modeling and analysis.

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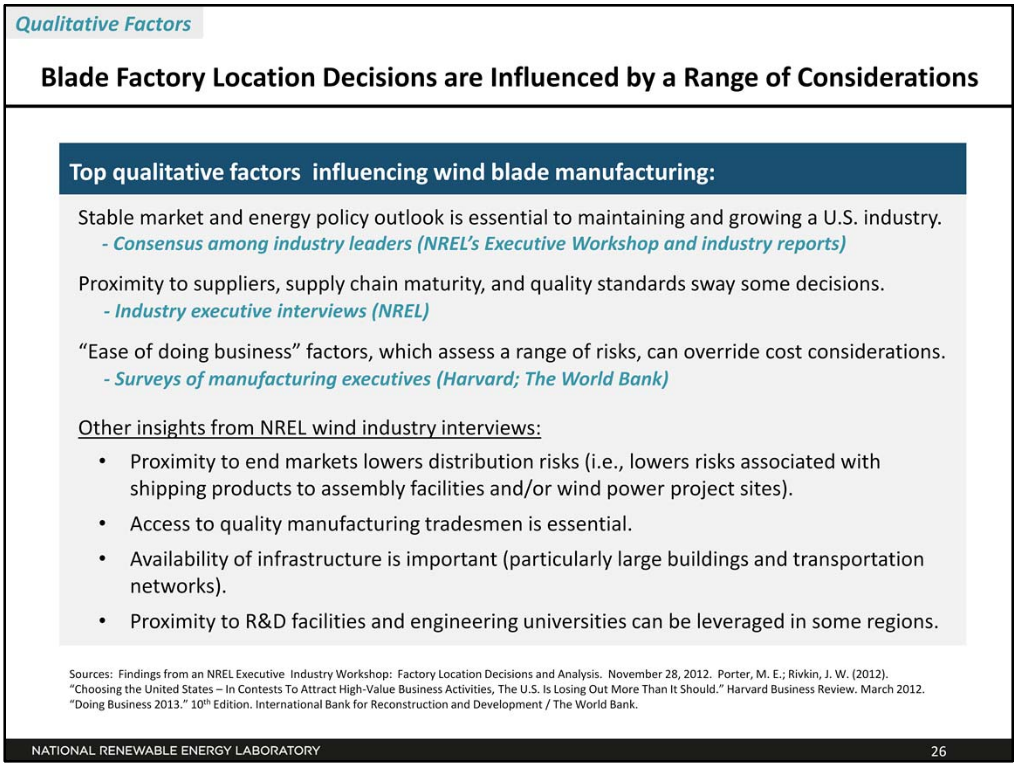
Similar to the previous slide, this figure illustrates the modeled landed costs for blades manufactured in four different regions for turbine deployments in central Texas. Compared to manufacturing facilities in China and Brazil, our analysis shows that U.S.-based manufacturing facilities may be cost competitive if U.S. turbine deployments are occurring near production facilities. This Texas end-market scenario, when compared to the Iowa end-market scenario on Slide 23, also illustrates that U.S. manufacturing opportunities may be more competitive in the middle of the country if deployments are proximal to production facilities. Again, costs of the Mexico case are less certain due to limited industry experience, but we present it for comparison purposes due to its proximity to U.S. end-markets. While our modeling illustrates the potential for cost competitive U.S. manufacturing to serve select markets in Texas, the analysis also identifies Mexico as a possible low cost provider of blades in the longer-term. The figures in Slides 16, 17, 23 and 24 show that materials prices, manufacturing labor costs, and transportation considerations largely drive landed blade costs.

III

Qualitative Factors Influencing Factory Location Decisions



Manufacturing cost and transport considerations significantly influence factory location decisions in the global wind industry; yet, less quantitative factors also drive location decisions. This chart summarizes frequently cited, wind-industry-specific considerations. Wind industry experts have highlighted how a range of qualitative factors influence decision-making, and research into other manufacturing industries indicates that location decisions are not often based on cost factors alone. Issues like political risks can sway decisions, especially when product cost disparities are relatively minor. Processes to assess factory location decisions vary among firms, and heuristics (i.e., rules of thumb), as opposed to rigorous analyses, may even drive some choices (Porter and Rivkin 2013).

IV Strategic Insights

Strategic Insights

Blade Manufacturing Considerations in the Global Wind Industry

- **Domestic demand for wind turbines is an important driver for maintaining and growing wind supply chains.**
  - Relatively high transportation costs for wind products, in addition to growing domestic demand for turbines, helped enable the U.S.'s strong domestic manufacturing capacity, but exports opportunities may be limited due to transport costs.
- **Recent U.S. manufacturing production levels exceed near-term domestic demand forecasts resulting in some restructuring in the industry, and it may affect trade flows.**
  - Manufacturing capacity reductions and some closures are occurring in the wind supply chain.
  - Exports are increasingly important for U.S.-based producers, but global demand growth for turbines is uncertain and exports from the United States may not be cost competitive in some markets.
- **The United States is a competitive location to manufacture wind blades for the domestic market, mostly due to shipping costs, but may face threats from lower cost labor regions like Mexico and Brazil.**
- **Demand for larger blades may increase U.S. manufacturing opportunities.**
  - Labor costs become a smaller proportion of factory gate prices as blade sizes increase, and this reduces a U.S. competitive disadvantage for blade manufacturing.
  - Demand for wind power may increase with larger blade technologies because larger blades are often more economical to deploy in lower wind speed resource areas like the Southeastern United States.
  - Larger blades may increase domestic manufacturing opportunities, but countries like Mexico, which are located near U.S. end markets and have lower cost labor resources, may present longer-term risks to U.S.-based blade manufacturers.
- **The wind industry will continue optimizing global supply chains by leveraging regional strengths.**

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Appendix A: Selected Input Assumptions
Sensitivity Analysis of Modeled Factory Gate Blade Prices

Cost Factors		U.S.			China			Mexico			Brazil			Denmark		
	Units	Low	Input	High	Low	Input	High	Low	Input	High	Low	Input	High	Low	Input	High
Labor Cost - unskilled[1a]	multiplier	0.53	1.00	1.47	0.66	1.00	1.64	0.53	1.00	1.47	0.89	1.00	1.04	0.80	1.00	1.20
Labor Cost - skilled[2a]	multiplier	0.60	1.00	1.65	0.66	1.00	1.64	0.60	1.00	1.65	0.89	1.00	1.04	0.80	1.00	1.20
Corporate tax rate[3a]	effective	12.0%	28.0%	35.0%	5.0%	15.0%	25.0%	10.0%	24.6%	30.0%	10.0%	24.6%	30.0%	15.0%	20.0%	25.0%
Inflation[4a]	core	1.1%	1.8%	4.0%	1.8%	2.7%	10.0%	3.3%	4.1%	7.0%	4.9%	6.2%	10.0%	0.4%	1.6%	4.0%
Capital recovery rate[5b]		9.8%	10.9%	12.0%	11.5%	12.7%	14.0%	13.2%	14.7%	16.1%	16.1%	17.9%	19.7%	11.8%	13.1%	14.4%
Electricity price[6a]	per kWh	$ 0.040	$ 0.066	$ 0.130	$ 0.07	$ 0.09	$ 0.20	$ 0.09	$ 0.12	$ 0.15	$ 0.10	$ 0.13	$ 0.16	$ 0.09	$ 0.12	$ 0.15
Materials discounts[7a]		-10%	0%	10%	-5%	0%	33%	-5%	0%	42%	-10%	0%	10%	-34%	0%	10%
Equipment installation costs[8b]		11.4%	12.0%	12.6%	8.6%	9.0%	9.5%	8.6%	9.0%	9.5%	4.6%	4.8%	5.0%	11.4%	12.0%	12.6%
Shipping Cost 1[9a]		$ 3,040	$ 3,480	$ 3,920	$ 38,700	$ 48,150	$ 57,600	$ 10,747	$ 13,463	$ 16,178	$ 26,700	$ 33,150	$ 39,600	$ -	$ -	$ -
Shipping Cost 2[10a]		$ 4,468	$ 5,316	$ 6,164	$ 42,900	$ 53,550	$ 64,200	$ 7,800	$ 9,600	$ 11,400	$ 30,900	$ 38,550	$ 46,200	$ -	$ -	$ -

Sources:

(1) U.S. Bureau of Labor Statistics, and NREL estimates.

(2) U.S. Bureau of Labor Statistics, U.S. International Trade Commission, and NREL estimates.

(3) U.S. Government Accountability Office, and NREL estimates.

(4) TradingEconomics.com, Federal Reserve Bank of St. Louis Economic Data, and NREL estimates.

(5) Industry reports, and NREL estimates.

(6) U.S. Energy Information Agency, International Energy Agency Energy Statistics, Boston Consulting Group, Woodrow Wilson Center, Bloomberg, and NREL estimates.

(7) Power purchasing parity ratios from the World Bank, and NREL estimates.

(8) Industry reports and interviews, and NREL estimates.

(9) Industry interviews, and NREL estimates.

(10) Industry interviews, and NREL estimates.

a – denotes triangular distribution assumptions; b – denotes PERT distribution assumptions.

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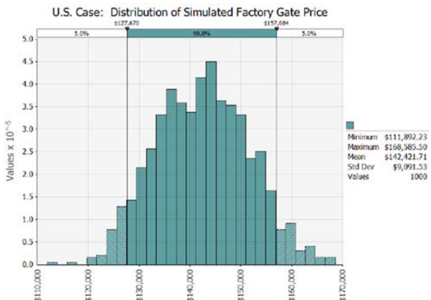
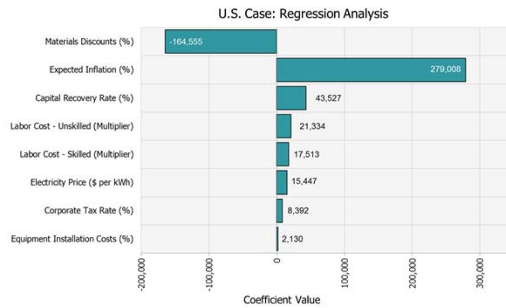
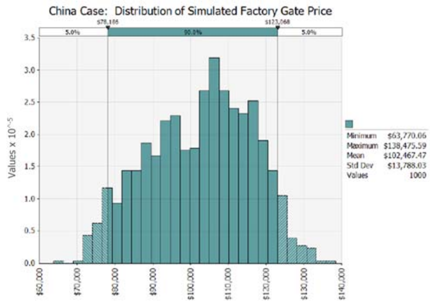
Appendix B: Monte Carlo Simulations
U.S. Modeled Case – Factory Gate Blade Price

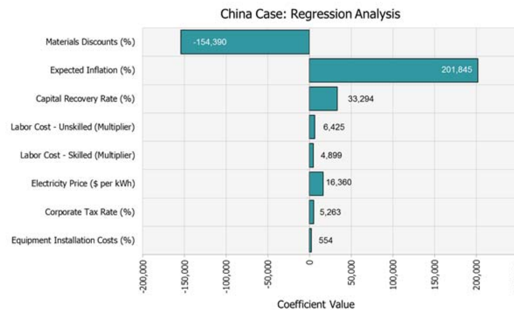




Note: These figures were developed using @Risk 6.1 software. The regression coefficient values identify the factors that are driving the distribution, but they cannot be compared across the modeled regional cases due to differences in the regression equations for each scenario.

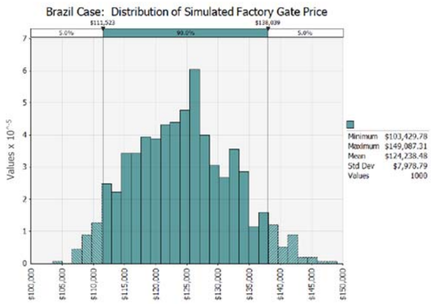
Appendix B: Monte Carlo Simulations
China Modeled Case – Factory Gate Blade Price

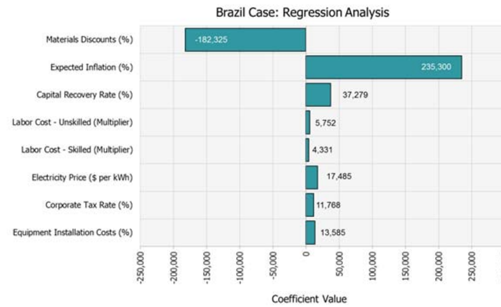




Note: These figures were developed using @Risk 6.1 software. The regression coefficient values identify the factors that are driving the distribution, but they cannot be compared across the modeled regional cases due to differences in the regression equations for each scenario.

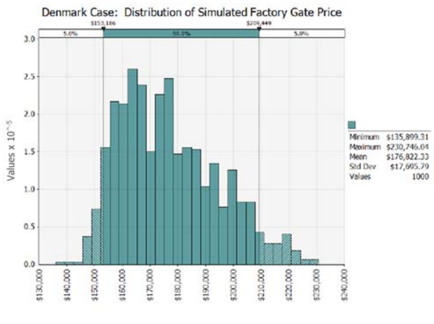
Appendix B: Monte Carlo Simulations
Brazil Modeled Case – Factory Gate Blade Price

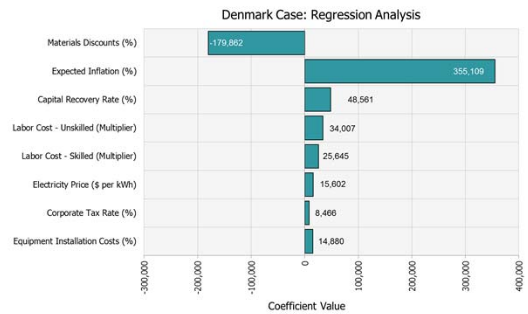




Note: These figures were developed using @Risk 6.1 software. The regression coefficient values identify the factors that are driving the distribution, but they cannot be compared across the modeled regional cases due to differences in the regression equations for each scenario.

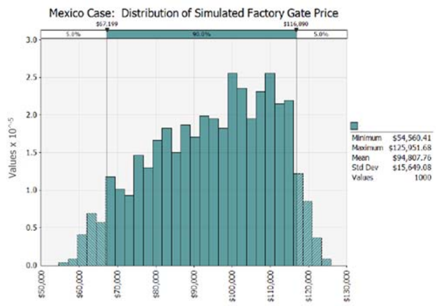
Appendix B: Monte Carlo Simulations
Denmark Modeled Case – Factory Gate Blade Price

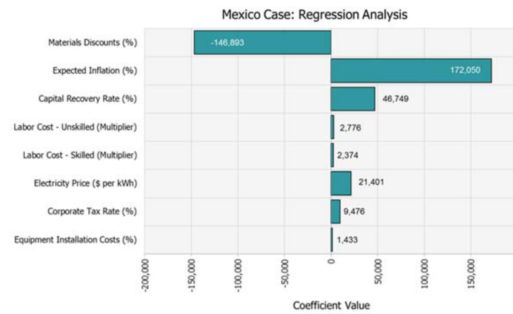




Note: These figures were developed using @Risk 6.1 software. The regression coefficient values identify the factors that are driving the distribution, but they cannot be compared across the modeled regional cases due to differences in the regression equations for each scenario.

Appendix B: Monte Carlo Simulations
Mexico Modeled Case – Factory Gate Blade Price





Note: These figures were developed using @Risk 6.1 software. The regression coefficient values identify the factors that are driving the distribution, but they cannot be compared across the modeled regional cases due to differences in the regression equations for each scenario.