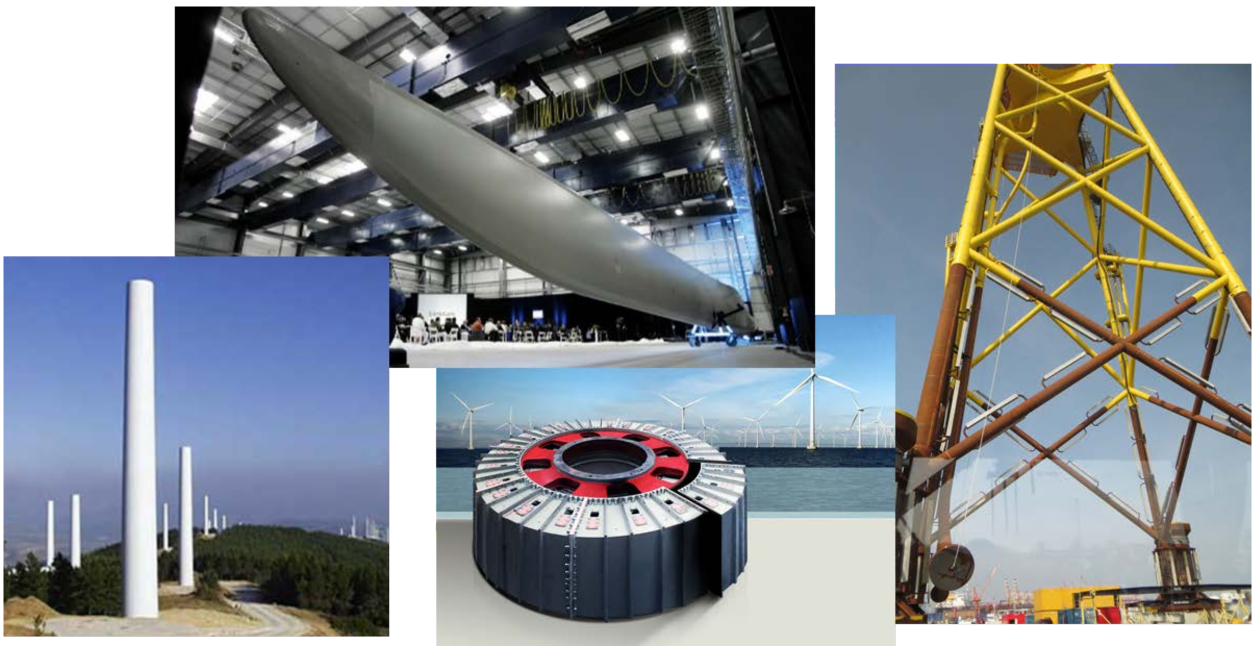
U.S. Wind Energy Manufacturing and Supply Chain: A Competitiveness Analysis



Prepared for:
U.S. Department of Energy

GLWN, Global Wind Network
4855 W. 130th St.
Cleveland, OH 44135
216-588-1440
www.glwn.org

June 15, 2014

This page intentionally left blank

U.S. Wind Energy Manufacturing and Supply Chain: A Competitiveness Analysis

Document DE-EE-0006102
June 15, 2014

Prepared by:

GLWN, Global Wind Network
Patrick H. Fullenkamp, Principal Investigator
Diane S. Holody

Key Collaborators
Dept. of Energy, Office of EERE, Wind and Water Program
Dept. of Commerce, Manufacturing Extension Program
National Renewable Energy Laboratory
Ohio University's Voinovich School of Leadership and Public Affairs
Sandia National Laboratories
Wind Technology Testing Center

**GLWN is a non-profit international wind energy advisory group and supply chain network whose mission is to increase the domestic content of North America's wind turbines and to localize new business opportunities in the industry. Launched in 2007, GLWN is an initiative of WIRE-Net, the Westside Industrial Retention and Expansion Network, 4855 W. 130th St., Cleveland, OH 44135*

Acknowledgements

The authors acknowledge and thank the entire U.S. Department of Energy (DOE) Wind & Water Power Program Team and in particular Cash Fitzpatrick, Gary Norton, Michael Hahn, and Michael Carella for their support throughout this project.

Thank you to the Project Team:

Cash Fitzpatrick, DOE; Gary Norton, DOE, Michael Hahn, DOE; Michael Carella, DOE; Melissa Jacobi, DOE; Richard Tusing, DOE; Sean Xun, DOE; Jason Cotrell, NREL; Rick Damiani, NREL; Derek Berry, NREL; Katherine Dykes, NREL; Kathleen Hallett, NREL; Aaron Smith, NREL; Ted James, NREL; Maureen Hand, NREL; Christopher Monet, NREL; Brian Naughton, Sandia; Brian Ressor, Sandia; Doug Griffin, Sandia; Josh Paquette, Sandia; John Colm, WIRE-Net; Renee Anderson, WIRE-Net; Ed Weston, GLWN; Mathew Bramson, GLWN; Linda Ferguson, GLWN; Dee Holody, GLWN; Patrick Fullenkamp, GLWN.

GLWN would like to thank the following individuals for their contributions to this report:

Lorry Wagner, LEEDCo; Dave Karpinski, LEEDCo; Matthew Morrissey, New Bedford Economic Development Council; Bill White, MassCEC; Alla Weinstein, Principal Power; Jens Eckhoff, German Offshore Wind Federation; Bruce Hamilton, Navigant; James Buddelmeyer, Gamesa; Dileep Thatte, NIST-MEP; Thomas Angelino, Lincoln Electric; Larry Viterna, Nautica Windpower; Sandy Butterfield, Boulder Windpower.

GLWN would also like to thank the following organizations and industry associates for their participation and contributions for this project:

Manufacturing Extension Partnership, Northern California, Corporation for Manufacturing Excellence
Manufacturing Extension Partnership, Florida
Manufacturing Extension Partnership, Georgia
Manufacturing Extension Partnership, Massachusetts
Manufacturing Extension Partnership, Enterprise Minnesota
Manufacturing Extension Partnership, North Carolina, Industrial Extension Services
Manufacturing Extensions program, New Jersey
Manufacturing Extension Program, Oregon
Corpus Christi Texas Economic Development Council
Brownsville Texas Economic Development Council
Maine Wind Industry Association, Portland ME
Southeast Coastal Wind Coalition, Raleigh, NC
Glass Manufacturing Industry Council, Westerville OH
Forging Industry Association, Cleveland OH
Integrated Global Supply Chain Management, Michael Graska

GLWN would like to offer a special note of thanks to the 22 manufacturers that welcomed our project team into their facilities, and graciously shared wind industry knowledge and experience. Without their participation and support, this project would not have been possible.

TABLE OF CONTENTS

TABLE OF FIGURES

Project Overview and Executive Summary Figures

SECTION 1 – Global Competitiveness Analysis Figures

1.1 TOWERS

1.2 BLADES

PROJECT OVERVIEW

This project report was produced on behalf of the Wind and Water Power Technologies Office within the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE) under award DE-EE-0006102 entitled U.S. Wind Energy Manufacturing and Supply Chain: A Competitiveness Analysis.

- Identification of Team, Duration, Goal
  - The project awardee was Global Wind Network (GLWN) (Patrick Fullenkamp PI, Dee Holody, Mathew Bramson, Renee Anderson) The work was carried out in close collaboration with DOE EERE (Gary Norton, Cash Fitzpatrick, Sean Xun); DOE Golden Office (Michael Hahn, Michael Carella, Melissa Jacobi); National Renewable Energy Laboratory (NREL) (Rick Damiani, Jason Cotrell, Aaron Smith, Maureen Hand, Ted James, Chris Mone); Sandia National Labs (SNL) (Brian Naughton, Brian Resor, Josh Paquette, Doug Griffin); Mass CEC Blade Technology Center (Derek Berry); Ohio University Voinovich School of Leadership and Public Affairs, and independent contractor Bowen Liu. We also benefited from the involvement of Department of Commerce Manufacturing Extension Partnership (MEP) agencies, economic development agencies, and manufacturing industry associations.
  - The project duration was from Jan 1, 2013 to June 30, 2014
  - The goal of the project was to develop a greater understanding of the key factors determining wind energy component manufacturing costs and pricing on a global basis in order to enhance the competitiveness of U.S. manufacturers, and to reduce installed systems cost. Multiple stakeholders including DOE, turbine OEMs, and large component manufactures will all benefit by better understanding the factors determining domestic competitiveness in the emerging offshore and next generation land-based wind industries.
- Major objectives of this project were to:
  - Carry out global cost and process comparisons for 5MW jacket foundations, blades, towers, and permanent magnet generators;
  - Assess U.S. manufacturers' competitiveness and potential for cost reduction;
  - Facilitate informed decision-making on investments in U.S. manufacturing;
  - Develop an industry scorecard representing the readiness of the U.S. manufacturers' to produce components for the next generations of wind turbines, nominally 3MW land-based and 5MW offshore;
  - Disseminate results through the GLWN Wind Supply Chain GIS Map, a free website that is the most comprehensive public database of U.S. wind energy suppliers;
  - Identify areas and develop recommendations to DOE on potential R&D areas to target for increasing domestic manufacturing competitiveness, per DOE's Clean Energy Manufacturing Initiative (CEMI).

- Lists of Deliverables
  1. Cost Breakdown Competitive Analyses of four product categories: tower, jacket foundation, blade, and permanent magnet (PM) generator. The cost breakdown for each component includes a complete Bill of Materials with net weights; general process steps for labor; and burden adjusted by each manufacturer for their process categories of SGA (sales general and administrative), engineering, logistics cost to a common U.S. port, and profit.
  2. Value Stream Map Competitiveness Analysis: A tool that illustrates both information and material flow from the point of getting a customer order at the manufacturing plant; to the orders being forwarded by the manufacturing plant to the material suppliers; to the material being received at the manufacturing plant and processed through the system; to the final product being shipped to the Customer.
  3. Competitiveness Scorecard: GLWN developed a Wind Industry Supply Chain Scorecard that reflects U.S. component manufacturers' readiness to supply the next generation wind turbines, 3MW and 5MW, for land-based and offshore applications.
  4. Wind Supply Chain Database & Map: Expand the current GLWN GIS Wind Supply Chain Map to include offshore elements. This is an on-line, free access, wind supply chain map that provides a platform for identifying active and emerging suppliers for the land-based and offshore wind industry, including turbine component manufacturers and wind farm construction service suppliers.
- Logistics and Transportation Considerations

  For purposes of comparing total applicable costs between suppliers in different global regions, the Port of New Bedford, Massachusetts was selected as a common destination for calculating all transportation costs from point of manufacture. The New Bedford port, currently under renovation, is considered to be the first marine commerce terminal built to service the U.S. offshore wind industry and is the planned staging site for the Cape Wind project. The New Bedford port will have the capability of handling the four components in this study.

EXECUTIVE SUMMARY

I. Objectives and Methodology

U.S. policymakers, state & local economic development groups and wind industry participants require a greater understanding of the key factors determining wind energy component manufacturing costs and pricing on a global basis in order to enhance the competitiveness of U.S. manufacturers, and reduce installed systems cost. This report provides actual first-of-a-kind data on 3 - 5MW component designs quoted from global manufacturers in three regions: U.S., Asia, and Europe.

This project carried out detailed manufacturing comparisons on four large wind turbine and balance-of-plant components in order to determine the global cost leaders, best current manufacturing processes, key factors determining competitiveness, and potential means of cost reduction. The four major components studied were towers, blades, permanent magnet generators and offshore jacket foundations. GLWN has also developed a wind industry scorecard assessing U.S. manufacturer's readiness to supply the next generation of turbines and key balance-of-plant components for land-based and offshore wind energy plants.

Technical Approach:
Standardized component specifications and detailed drawings were developed with industry and government labs (National Renewable Energy Lab [NREL] and Sandia National Lab [SNL]) to enable an apples-to-apples comparison between global manufacturers active in the industry on a large scale. NREL's 5MW "reference turbine" was used as a representative configuration. GLWN developed the detailed design for manufacturing drawings for the tower and jacket foundation. NREL developed the detailed drawings for the 5MW Blade.

GLWN visited and collected **manufacturing cost and process data** from 22 suppliers in U.S., Europe, and Asia for towers, blades, foundations, and permanent magnet generators, representative of next-generation wind turbines (3MW and 5MW) for both land-based and offshore applications. The project scope called for 12 site visits, and an additional 10 were completed to improve data reliability. **Cost Breakdown Analysis and Value Stream Mapping** tools were used to understand the cost and manufacturing process.

COMPONENT	USA	CHINA	Europe
TOWERS	2	2	1
JACKET FOUNDATIONS	3	2	1
BLADES	3	2	2
PM GENERATORS	1	2	1

A **U.S. Wind Industry Scorecard** was developed for 13 key wind turbine and balance-of-plant components: tower, blade, generator, gearbox, forge ring, forge shaft, cast hub, cast support base, fabricated support base, composite housing, monopile foundation, jacket foundation, and subsea cable. Over 280 potential suppliers have been identified able to produce one or more of these large components. A majority of the suppliers are in coastal states. This information is available via a public access, web-enabled Wind Supply Chain Map at www.glwn.org. The map includes a wind industry search feature.

For the manufacturing selection and data gathering process, we identified and contacted current active land-based turbine suppliers in the U.S.A. and active land-based and offshore suppliers in Germany and China. Suppliers were sent letters of introduction from GLWN and DOE explaining the scope of the project and propose level of engagement on their part. Requests for quotes with detailed manufacturing drawings and detailed cost breakdown sheets with full Bills of Materials were sent to those interested. Plant visits were scheduled and included meetings with the management teams, project presentation by the GLWN principal investigator, host plant presentations, review of hosting plants process flow, review of cost data, and walking the process on the manufacturing floor from start to finished product which enabled development of the value stream map.

Cost Breakdown Analysis is a means of understanding the quoted cost in cost accounting categories. For this report the aggregated cost breakdown has been summarized in Bar Charts as shown in Figures 2 – 13. The most significant regional cost Breakdown Charts will be shown in the Executive Summary.

A specific cost breakdown analysis form was developed for each of the four product categories. it included a complete bill of materials with net weights, general process steps for labor and burden that was adjusted by each manufacturer to their process, categories of SGA (sales general and administrative), engineering, logistics cost to the Port of New Bedford, MA, and profit. Quoted data was consolidated into a spread sheet and aggregated for this final report out.

Value Stream Mapping (VSM) is an important tool that characterizes both information and material flow from the point of getting a customer order at the manufacturing plant, through the orders forwarded by the manufacturing plant to the material suppliers, the material being received at the manufacturing plant and processed through the system, to the final product ready to be shipped to the customer (reference Figure 1). VSM's were generated for each manufacturer from data gathered during the plant visit and cost breakdown sheets. This tool enables the identification of areas of waste (value added and non-value added) and improvement opportunities for domestic suppliers with a look across all global suppliers. Six Sigma and Lean can be applied to improve the process.

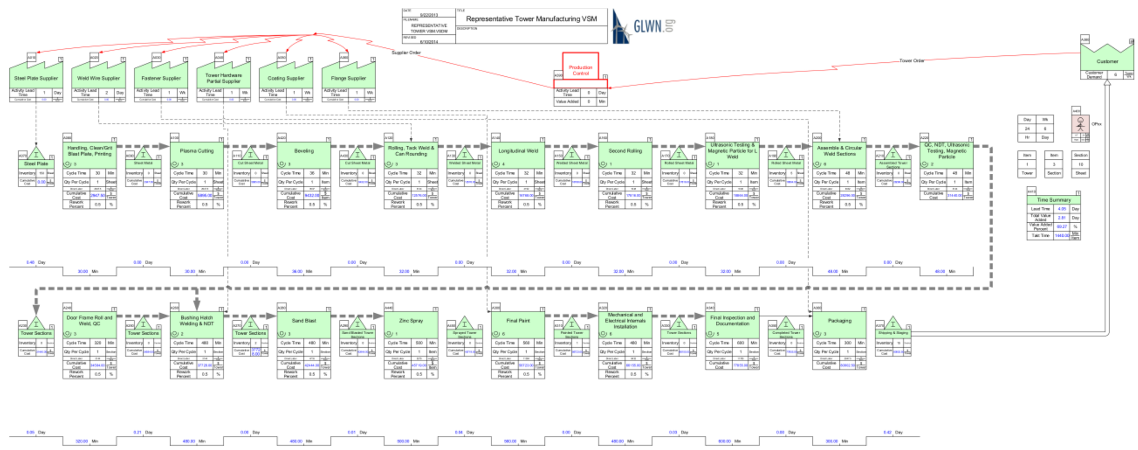


Fig. 1 – Representative Value Stream Map of Tower Manufacturing Process

It must be considered in this study, as in any commercial quotation activity, that some suppliers will be aggressive with quoted prices while others will be conservative. Overall, it was found that the cost data in a given region was consistent, which supports the use of the aggregated numbers reported in this project.

The following listings are the consolidated "biographies" of the companies visited during this study to provide the reader with a perspective on the scale of these manufacturers' operations. Taken as a group, the participants were significant global industry "players" active in both land-based and offshore system component manufacture.

	Annual Tower Sales 2012 (Combined)	**Annual Tower Capacity as of 2013 (Combined)**	**Towers built to date**
USA (2)	$200M	600	2200
China (2)	$320M	1000	6100
Germany (1)	$90M	250	1200

	Annual Blade Sales 2012 (Combined)	**Annual Blade Capacity as of 2013 (Combined)**	**Blades built to date**
USA (3)	$2,030M	2,400	12,500
China (2)	$5,100M	5,700	32,000
Germany (2)	$720M	900	3,300

	Annual Generator Sales	**Annual Generator Capacity**	**Generators built to date**
USA (1)	$7M	300	150
China (2)	$390M	8,900	22,100
Europe (1)	$50M	1000	4,500

	Annual Main Lattice Sales 2012 (Combined)	**Annual Main Capacity as of 2013 (Combined)**	**Main Lattice built to date**
USA (3)	$0M	50	(~20 Oil & Gas)
China (2)	$8M	80	4
Germany (1)	~$38M	100	30 (130 jackets total)

II. Global Competitiveness Analysis

Towers

Towers contribute the highest percentage cost of all the major wind turbine components at 25-30%. Towers provide the height to capture the power of the wind and the structure to support the weight and wind forces on the nacelle and rotor assembly. Currently, the U.S. land-based market maintains a viable supply chain for towers for the 1-3MW turbines. These same manufacturers would have the ability to scale up to 5MW towers, but most will require further investment in their facilities to handle these large components, e.g. material handling upgrades, paint booth expansion, laydown yard considerations. With the primary market for 5MW or greater being offshore, coastal manufacturing would be most cost effective with the logistics being a significant cost contributor of up to $140,000 for shipping cost from China to Port of New Bedford, MA. China has a 15% cost advantage without logistics cost and the applicable tariff.

U.S. Tower Manufacturers are competitive if produced in region of use and not incurring the international logistics shipping cost.

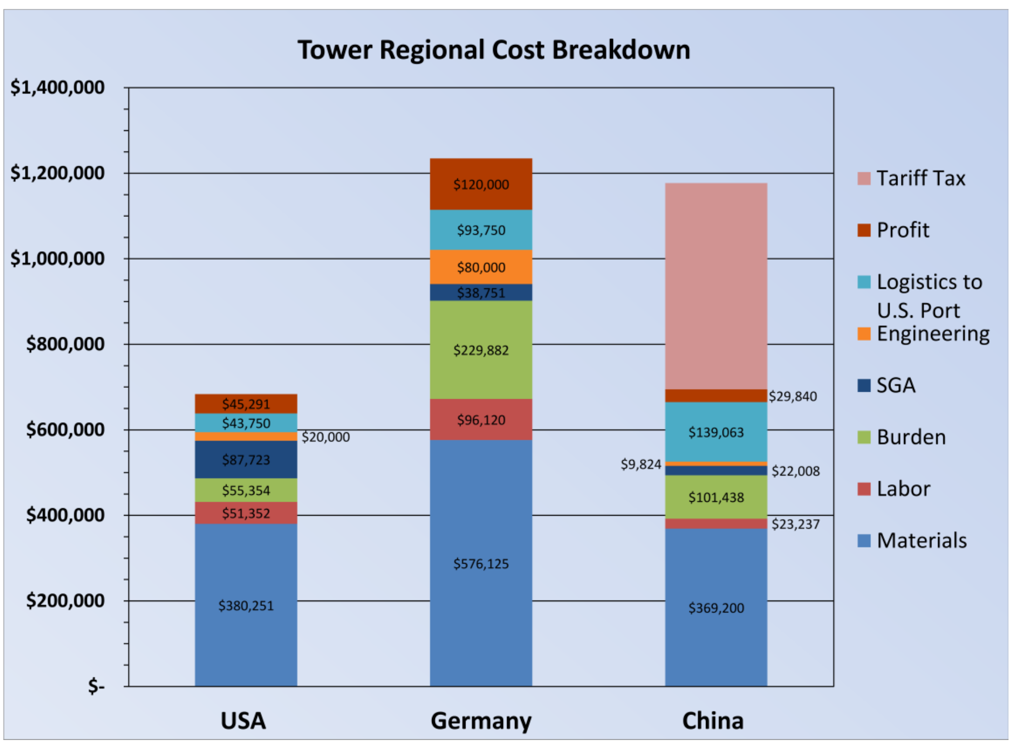


Fig. 2 – 5MW Tower Regional Cost Breakdown by major category

Figure 2 shows the aggregated regional cost breakdown of a 5MW Tower by major cost categories of material, labor, burden, SGA, engineering, logistics to the Port of New Bedford MA, profit, and Tariff in the case of Chinese towers. Chinese suppliers had the additional cost category of a tariff which took effect in 2013. This shut down most imports from China and Vietnam to the U.S. and boosted U.S. production. Although other Asian regions were not subject to the tariff and are importing towers to the U.S. today. The U.S. manufacturers need to continue to reduce cost to be competitive in the long run.

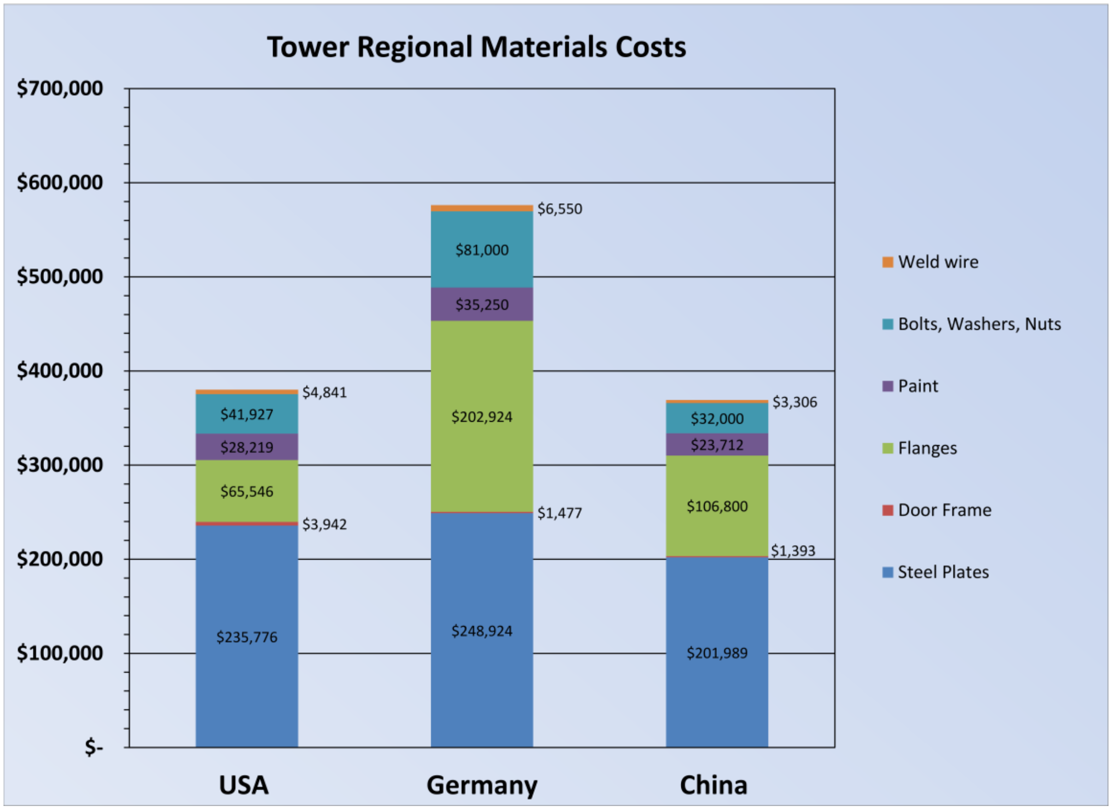


Fig. 3 – 5MW Tower Material Cost Breakdown by major category in three regions

Figure 3 shows the aggregated regional material cost breakdown by major cost categories of steel plates, door frames, flanges, paint, bolts-washers-nuts, and weld wire. Steel plates and flanges are the largest cost drivers at approximately 78% of the total material. China had a 15% cost advantage on steel plate which contributed to approximately 8% lower cost as reported.

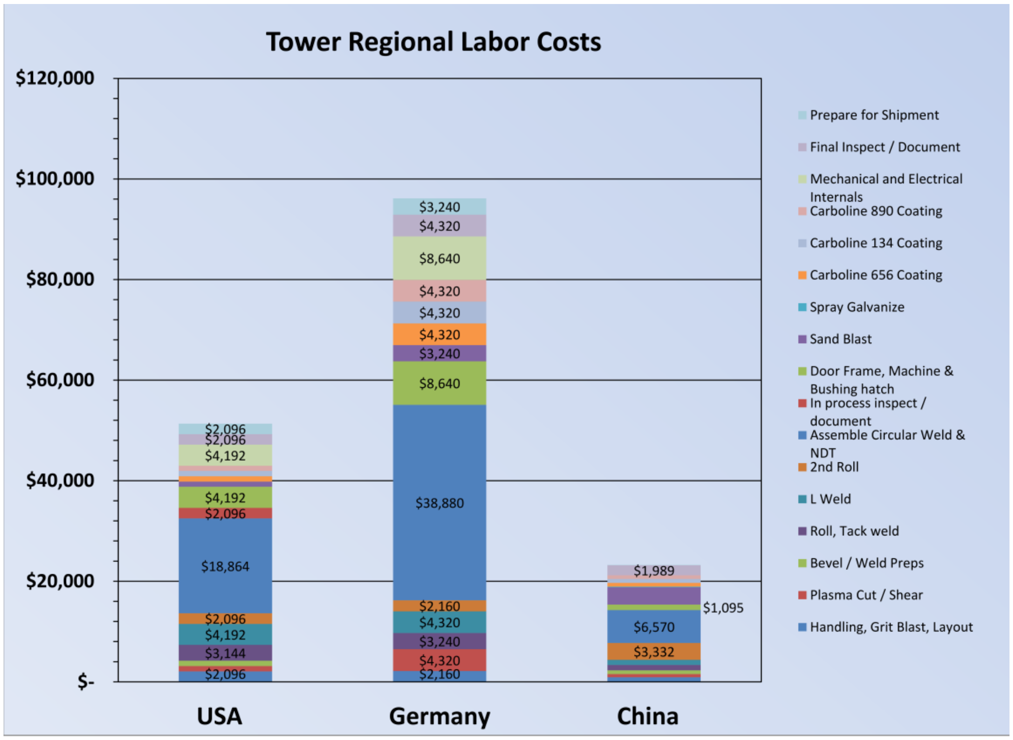


Fig. 4 – 5MW Tower Labor Cost Breakdown by major process category in three regions

Figure 4 shows the Regional Labor Cost Breakdown by the 17 process steps. The burden chart shows a similar trend with the burden cost up to 2X the labor cost level. The burden cost would be the associated indirect labor cost by process step and fixed plant cost.

Tower Cost Summary

Towers are the largest cost contributor at +/-27% of the wind turbine, and based on the regional cost breakdown chart, material is over 50% of the cost of the Tower. Breaking that down further in Figure 3, steel plate accounts for 62%. A valuable R&D (Research and Development) project would be to optimize the steel material and plate size, the larger the better, to reduce mill cost and manufacturing process weld time. Another potential R&D project would look at the weld wire size and delivery system to maximize the speed of the welding. Tower weld rework was seen on most of the towers going through the process in China with up to 3 sections at a time being re-worked. Although rework was not seen during the U.S. and German plant visits, the PI's 30 years in automotive component manufacturing led him to conclude that opportunity exists to reduce labor and burden cost up to 30-50% with improved process flow, design, and quick changeover. New investment in facilities and equipment will be required for new 5MW steel towers >5m in diameter in the coastal regions with deep water quayside access. Adequate facilities are currently located in the Great Lakes and Gulf Coast, but new equipment will be required to handle the larger diameter parts.

Blades

One three-blade set comprises the 2nd highest percentage cost of major wind turbine components at 15-26%. Blades capture the energy of the wind in the swept area and convert the force of the wind into the torque needed to generate useful electrical power. All major global manufacturers have the ability to produce the specified 61m blade, although most of the current production facilities in the U.S. would have to have facility upgrades to make >55m blades. One potential U.S. facility in place today is portside, but the company has not been in serial production of blades at this site.

This study showed that U.S. blade manufactures are globally competitive with an advantage in materials and a 4 to 1 disadvantage in labor and burden. The size of the 5MW or greater blade will require investment in a U.S. coastal manufacturing facility.

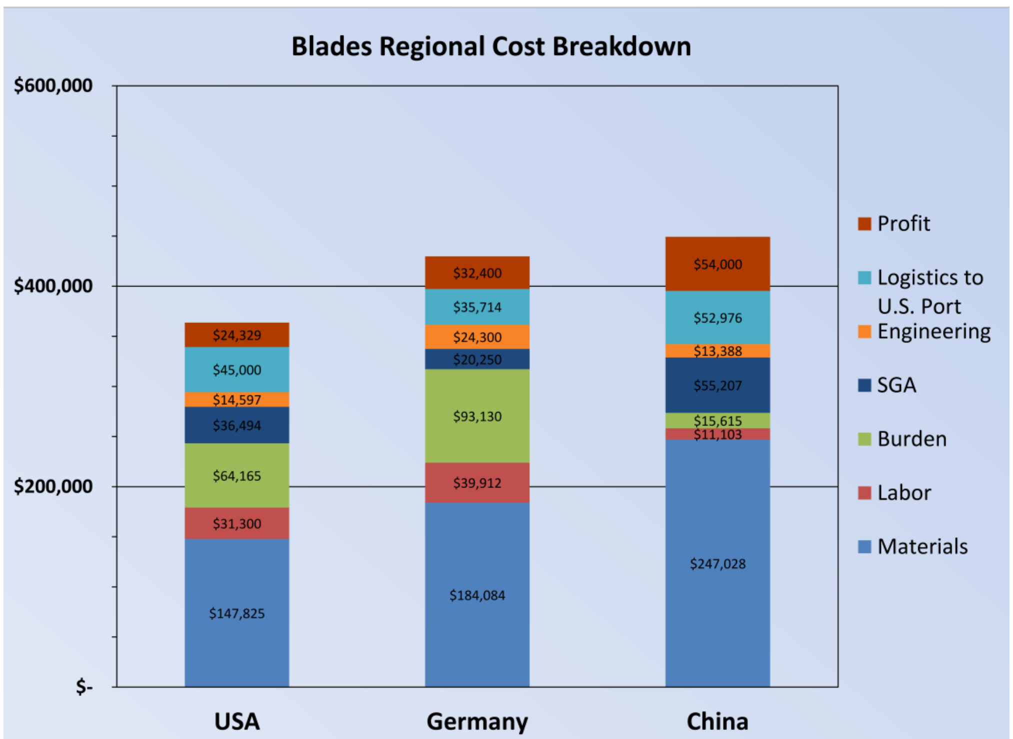


Fig. 5 - 5MW Blades Regional Cost Breakdown by major category

Figure 5 shows the aggregated regional cost breakdown of a 5MW Blade by major cost categories of material, labor, burden, SGA, engineering, logistics to the Port of New Bedford, MA, profit

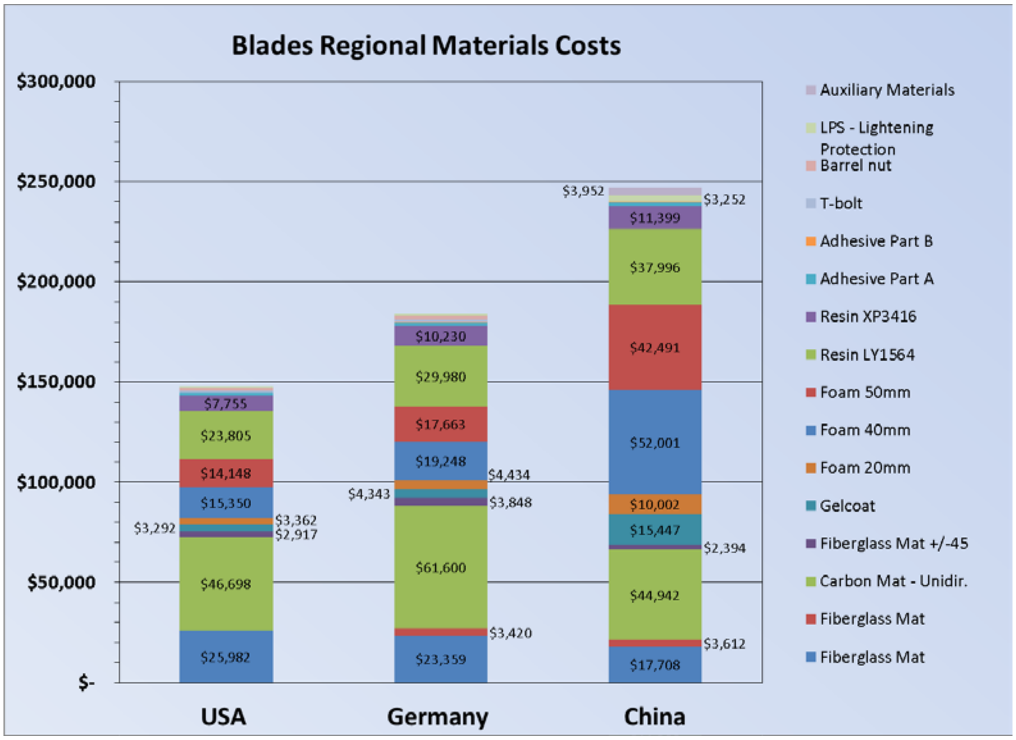


Fig. 6 – 5MW Blade Material Cost Breakdown by major category in three regions

Figure 6 shows the aggregated regional material cost breakdown by major cost categories of fiberglass woven mat, carbon fiber mat, gelcoat, foam, resin, hardener, T-bolts, barrel nuts, lightening protection and auxiliary material. Carbon fiber mat, foam, and fiberglass mat are the largest cost drivers and ones to focus on for material cost reduction.

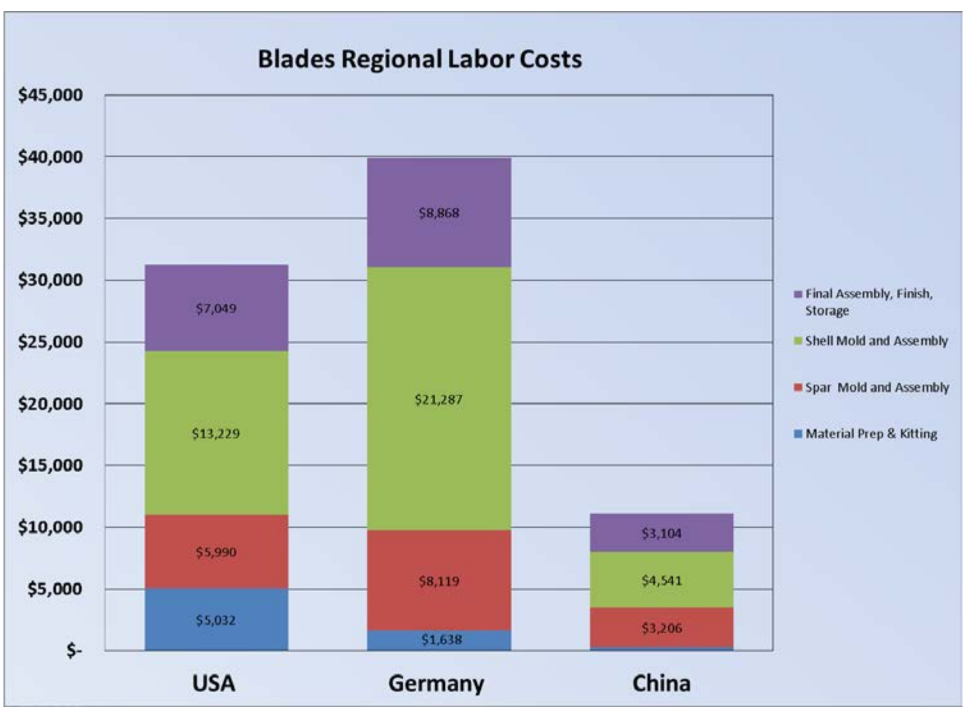


Fig. 7 - 5MW Blade Labor Cost Breakdown by major sub-total category in three regions

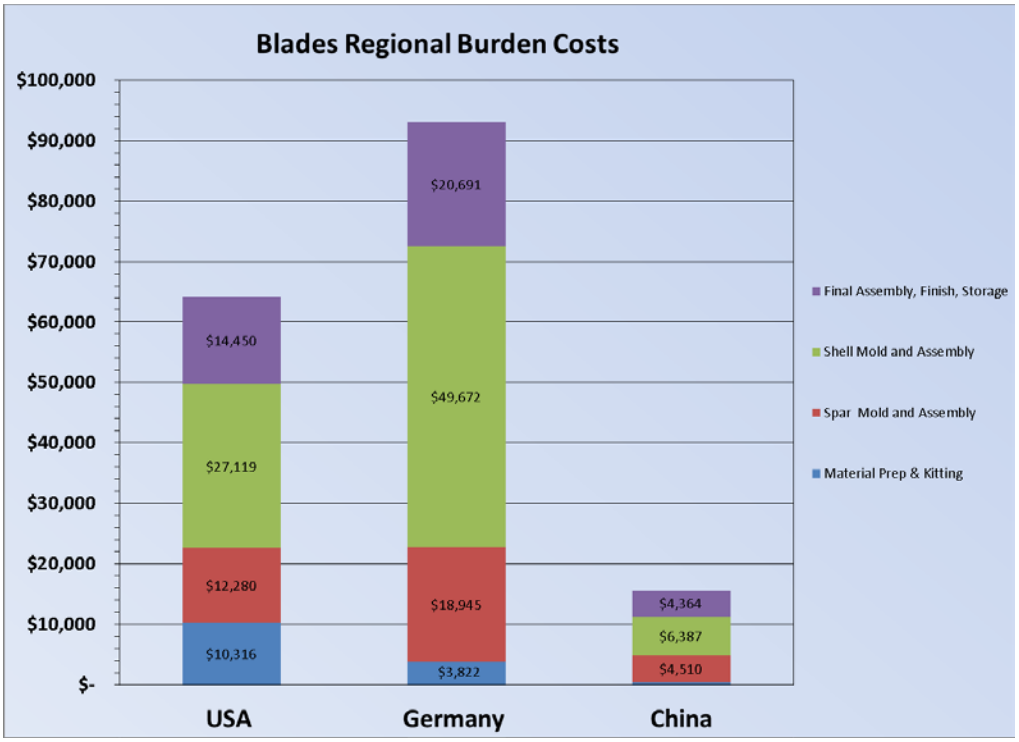


Fig. 8 - 5MW Blade Burden Cost Breakdown by major sub-total category in three regions

Figures 7 & 8 show the Labor & Burden Cost Breakdown by the 4 major sub-totals. The 29 process steps are divided up in the 4 major sub-total categories of material preparation & kitting, spar mold & assembly, shell mold & assembly, and final assembly-finish-storage . The burden is at 2X the labor cost level in the U.S. and Germany. The burden cost is the associated indirect labor cost by process step and fixed plant cost. China has a 4 to 1 advantage in total labor and burden versus the U.S.

Blade Cost Summary

Blades are the 2nd largest cost driver of a wind turbine at +/- 20% of the wind turbine cost. Material is approximately 44% of the cost of the blade of which carbon fiber mat, foam, fiberglass mat, and resin account for 90% of the material. Labor and burden is approximately 27% of the cost of the blade. An R&D initiative to optimize material, process, and design (the three legs of the stool) would be most helpful to enhance blade manufacturing competitiveness. This is a chemical process and needs material and process setting improvements that provide material cost and process time reductions. Incremental improvements can be made by better use of plant assets and focusing manpower resources in the process to eliminate lag times in infusion, molding and downstream processes. The wind turbine blade industry should continue blade design and analysis that maximizes power output and minimizes material usage, while leveraging automotive and aerospace composite knowledge.

Permanent Magnet Generators

Due to the proprietary, turbine-specific nature of multi-megawatt permanent magnet generator designs, we were not able to develop a generic 5MW PMG design that global generator manufacturers were willing to develop detailed quotes for. 5MW generators in production today are design-specific to a given wind turbine model with the intellectual property residing with either the wind turbine manufacturer or the generator manufacturer. Therefore, for purposes of developing global cost comparisons of key generator components, we obtained permission to use a 1MW medium speed PM generator design that could be quoted by various parties.

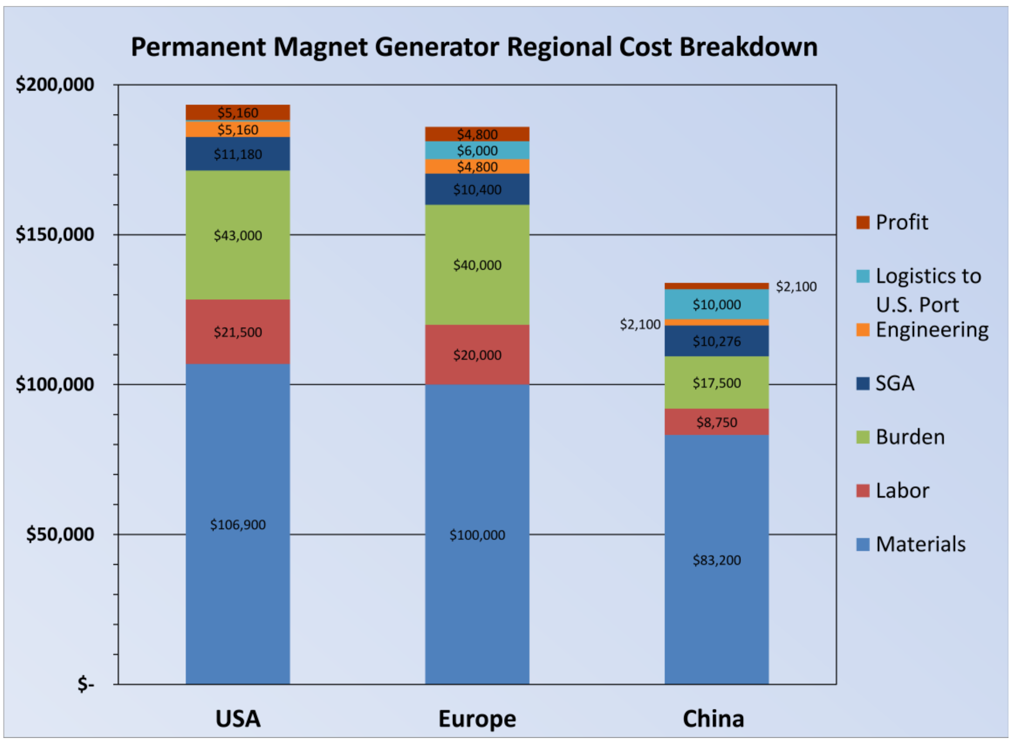


Fig. 9 -1MW PM Generator Regional Cost Breakdown by major category

Figure 9 shows the aggregated regional cost breakdown of a 1MW PM Generator (12,415kg) by major cost categories of material, labor, burden, SGA, engineering, logistics to the Port of New Bedford, MA, profit. For purposes of cost breakdown we had used a current production 1MW medium speed PM Generator. The Value Stream Mapping was based upon a current 2.5MW direct drive PMG in production overseas today.

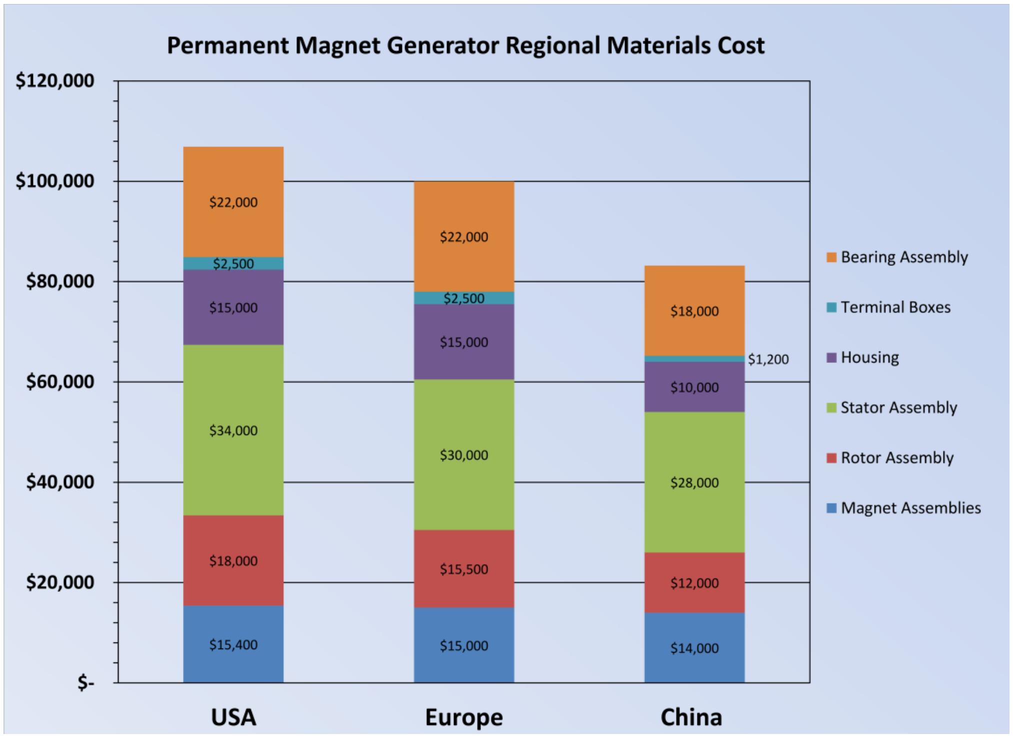


Fig. 10 – 1MW PM Generator Material Cost Breakdown by major category in three regions

Figure 10 shows the aggregated regional material cost breakdown by major cost categories of magnet assemblies, rotor assembly, stator assembly, housing, terminal boxes and bearing assembly. Stator assembly and bearing assembly are the largest cost drivers.

Generators on average are +/- 7% of a wind turbine cost and material is approximately 60% of the cost of a generator. An R&D effort on design for manufacturing should be applied with the evaluation of different material types, shapes, properties and total pieces.
Since we were unable to develop a common 5MW PM generator design to globally quote we used a 1MW design. The following are the general trends noted by the manufactures:

- As you increase generator size from 1MW to 5MW in a common design configuration the weight and cost typically increase proportionately.
- No global region had a unique manufacturing process that provided an advantage. The overall manufacturing process steps were standard.
- China did have lower material and burden cost with their cost accounting.
- The rare earth magnets accounted for 14% of the material cost and 7.5% of the total cost, which is lower than one might have perceived from the rare earth publicity.

Jacket Foundation – Main Lattice

The Jacket Foundation support structure contributes to +/- 15% of the total life cycle cost of an offshore wind turbine system. This compares to +/- 35% for the turbine itself. The main lattice is a main part of the jacket foundation that provides the support for wind turbines in water depths generally ranging from 30m to 60m. The costs shown below are for the main lattice at 258 metric tons, the full jacket foundation structure would also include a transition piece and four piles.

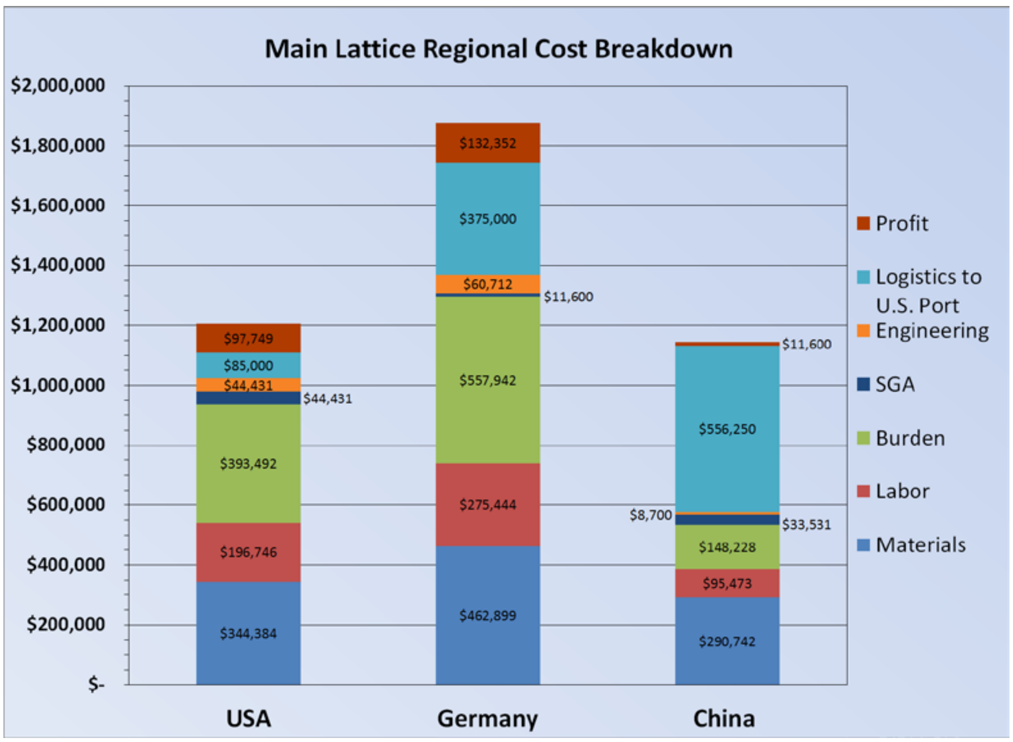


Fig. 11 -5MW Main Lattice Regional Cost Breakdown by major category

Figure 11 shows the aggregated regional cost breakdown of a 5MW Jacket Foundation by major cost categories of material, labor, burden, SGA, engineering, logistics to the Port of New Bedford, MA, and profit.

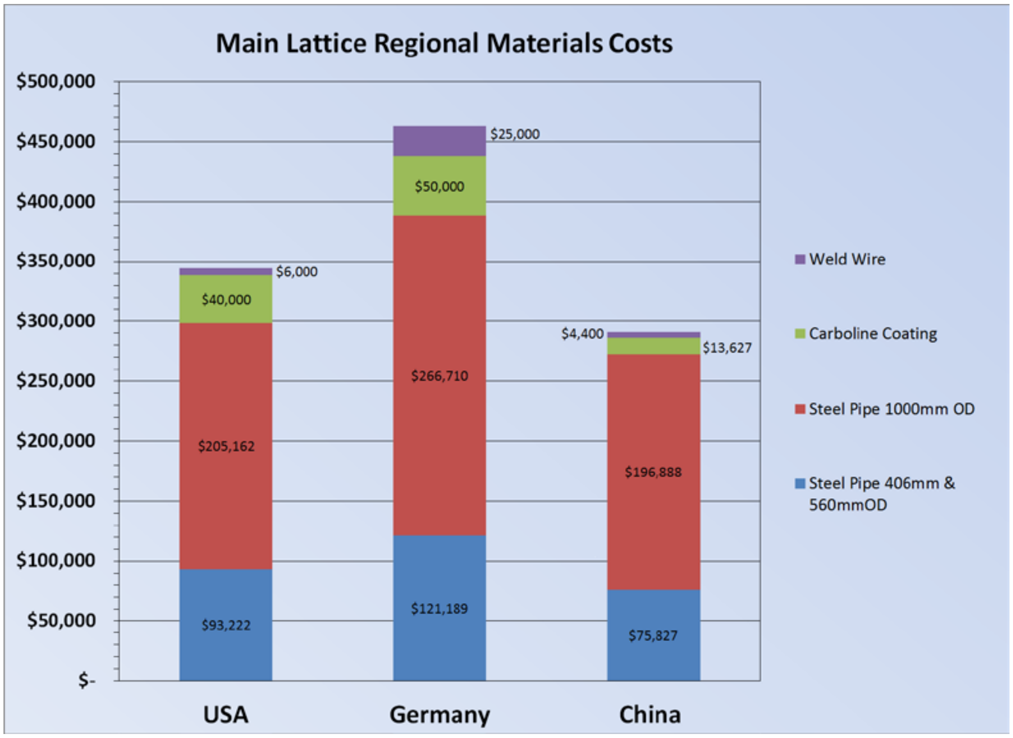


Fig. 12 – 5MW Main Lattice Material Cost Breakdown by major category in 3 regions

Figure 12 shows the aggregated regional material cost breakdown by major cost categories of steel Pipe, carboline coating, and weld wire. Steel pipe is the largest material cost driver at over 80% of the material.

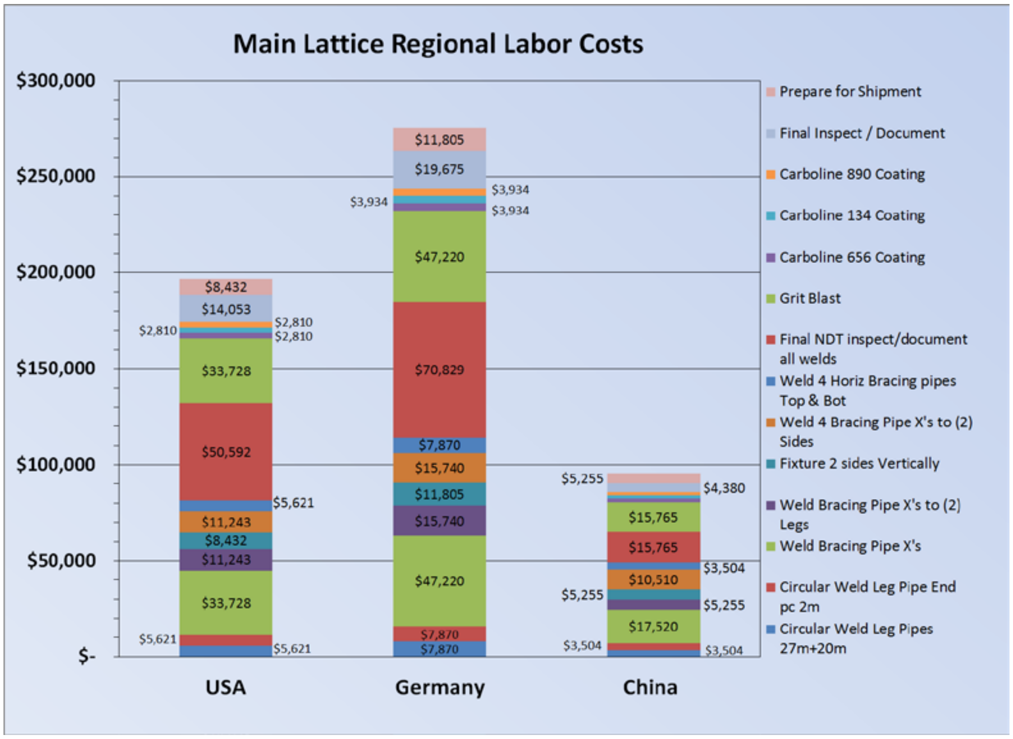


Fig. 13 – 5MW Main Lattice Labor Cost Breakdown by major process category

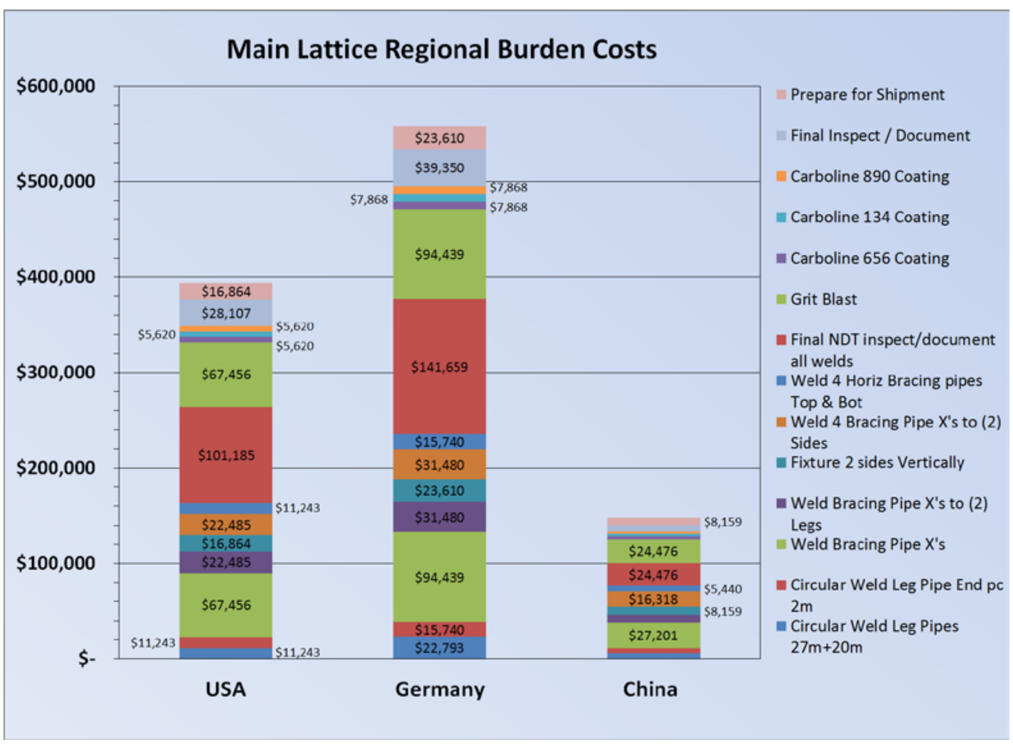


Fig. 14 – 5MW Main Lattice Burden Cost Breakdown by major process category

Figures 13 & 14 show the Labor & Burden Cost Breakdown by the 14 process steps. The burden is at 2X the labor cost level in the U.S. and Germany. The burden cost is the associated indirect labor cost by process step and fixed plant cost. The burden cost in China is lower than U.S. and Germany because they include minimal or no amortization of facilities, equipment and tools in their cost numbers.

Jacket Foundation Main Lattice Cost Summary

Foundations are on average +/- 15% of the offshore turbine system capital cost compared to the turbine itself at +/- 35%. In the case of the jacket foundation main lattice, labor and burden account for 50% with material average at 30%. The foundation main lattice is, in general, a prime candidate for a "design for assembly and manufacturing" exercise. For instance, one current design incorporates cast steel nodes for connection points, decreasing corrosion at weld points, and allowing use of standard pipe. The complex weld angles and curvatures require manual cutting and welding. Minimizing welding length, using circular cuts, and applying simple automation could have a significant impact on labor and cost. In addition, a higher volume series production manufacturing process needs to be developed and optimized to achieve lowest LCOE.

Overall all global manufacturers were very positive on the offshore wind industry and the new larger components that would be required. The German manufacturers explained the significant process adjustments required for the larger 3 – 5 MW components versus the 1 – 2 MW land – based components. The German's recommended a joint venture or partnership with U.S. manufacturers to take advantage of the German lessons learned and minimize the U.S. start-up time and cost. The Chinese manufacturers expressed the desire for volume production to achieve the lowest cost. Most Chinese facilities were located for water transport. Some of the Chinese manufacturers were interested in closed U.S. manufacturing facilities and shipyards for U.S. component production. The U.S. manufacturers acknowledged the facility upgrades required for the larger components and the need for water transport access. Investigation of coastal facilities especially along the Atlantic has started; although a book of business would be required to make a business case. Most of the U.S. manufacturers who participated in this study are taking the next steps of evaluating lean process improvements to lower their current costs.

III. U.S. Wind Supply Chain Scorecard

A Scorecard was generated for the four main components of this study and 9 additional key wind turbine and balance-of-plant components. The Scorecard is a method of rating the ability of current U.S. manufacturers to supply specific components per the Green, Yellow, and Red legend noted in Figure 15. Figure 15 shows the four main components of this study and their respective supply chain ratings.

GLWN was tasked with developing a Wind Industry Supply Chain Scorecard that reflects U.S. manufacturers' readiness to supply the next generation of wind turbines, 3MW and 5MW, for land-based and offshore applications. Ten key wind turbine components and three balance-of-plant components were analyzed, including the four main components of this study: towers, blades, jacket foundations, and generators, as represented in Figure 15. The analysis was conducted on a national level, with particular emphasis on manufacturers located in coastal regions to take into account the emerging need for an offshore wind supply chain. Capabilities data was assimilated from over 280 companies that participated in a GLWN survey, through GLWN research, and from the existing GLWN Wind Supply Chain database which contains data on over 1700 U.S. companies active or interested in the wind industry.

Criteria were established for the Scorecard to "rate" U.S. manufacturers based on the anticipated level of investment necessary to produce the larger size components of 3W and 5MW turbines. The levels of investment took into consideration not only equipment and facility needs, but also a manufacturer's ability to produce to higher volumes in a consistent, serial production environment. GLWN also considered regional and transportation accessibility (or constraints) relative to current land-based OEM production (primarily in the Midwest) and anticipated coastal wind turbine assembly facilities.

The Scorecard provides not only an overall view of the readiness of U.S. manufacturers to supply the wind industry, but also establishes a baseline for discussing current and potential supply chain gaps, i.e. those industry sectors that would benefit from further analysis or investment in order to advance a given sector's competitiveness and ability to participate in the global market.

		LAND-BASED		OFFSHORE	
Component		Investment Required	Major Hurdles	Investment Required	Major Hurdles
Towers	3MW	LOW	Capability Exists	LOW-MODERATE	Logistics: Rail/road challenges to ports. Mfgs located in Midwest.
	5MW	MODERATE-HIGH	Logistics: Rail/road challenges Fac/Equip: Upgrades likely	HIGH	Logistics: Rail/road challenges to ports. No tower mfg port side.
Blades	3MW	LOW	Capability Exists	MODERATE-HIGH	Logistics: Rail/road challenges to ports. Mfgs located in Midwest.
	5MW	MODERATE- HIGH	Logistics: Rail/road challenges. Facility and equipment upgrades likely	HIGH	Logistics: Rail/road challenges to ports. No blade mfg port side.
Generators	3MW	LOW	Capability Exists	LOW	Capability Exists
	5MW	LOW-MODERATE	Fac/Equip: Possible upgrades for crane capacity & finish tanks	LOW-MODERATE	Fac/Equip: Possible upgrades for crane capacity & finish tanks
Jacket Foundations	3MW	n/a		MODERATE-HIGH	Capability exists in Gulf & Pacific region. Investments likely for serial production. Port-side facilities needed for Atlantic and Great Lakes.
	5MW	n/a		MODERATE-HIGH	

LEGEND:

Low	Can manufacture the component today or a similar product (No real capital investment required)
Moderate	Requires some capital investment (Minor facilities upgrades and/or operations expenses)
High	Major capital investment required (New location/facility, major technology and equipment upgrades)

Fig. 15 –U.S. Industry Scorecard for Towers, Blades, Generators, and Jacket Foundations

Tower Scorecard Summary: GLWN evaluated 16 fabricators, current and potential tower manufacturers capable of supplying wind turbine tower sections. Currently, the U.S. land-based market maintains a viable supply chain for towers for 1-2.5MW turbines. These current and potential suppliers demonstrate the capabilities to produce 3MW towers with little or no additional investment. Further, these same manufacturers have the ability to scale up to 5MW towers, but most will require further investment in their facilities to handle these large components, i.e. material handling upgrades, paint booth expansion, and larger laydown yards.

The offshore market could potentially be supplied by existing U.S. facilities as the capability currently exists for producing towers for 3MW units, with the ability to scale up to production for 5MW and larger. With offshore, logistics must be considered as most tower manufacturers are not located in coastal regions. Manufacturers can produce the towers, but can they transport them to the coastal port, and remain competitive in the global market? Offshore wind farms will most likely be designed using larger turbines, 5MW and greater. Of the 16 manufacturers reviewed, only six are in close proximity to a U.S. coastal market, of which, three are located in the Great Lakes region. Insufficient suppliers exist along the Atlantic, Gulf, and Pacific coasts, most likely requiring future investment in new facilities capable of manufacturing towers for a 5WM and larger unit, located portside, or with minimal rail/road transport to an offshore wind port.

Figure 16 Regional considerations: Current dedicated tower manufacturers (red icons) are primarily concentrated in the Midwest. These wind tower manufacturing facilities are, for the most part, newly constructed within the last 7 years, built to service the land-based wind industry. Manufacturers with the capabilities to manufacture towers for 3MW-5MW turbines, but who also produce for other industrial markets (i.e., NOT dedicated tower manufacturers) present opportunities to supply both the land-based and offshore industry but would most likely require upgrades to technology and facilities (blue icons).

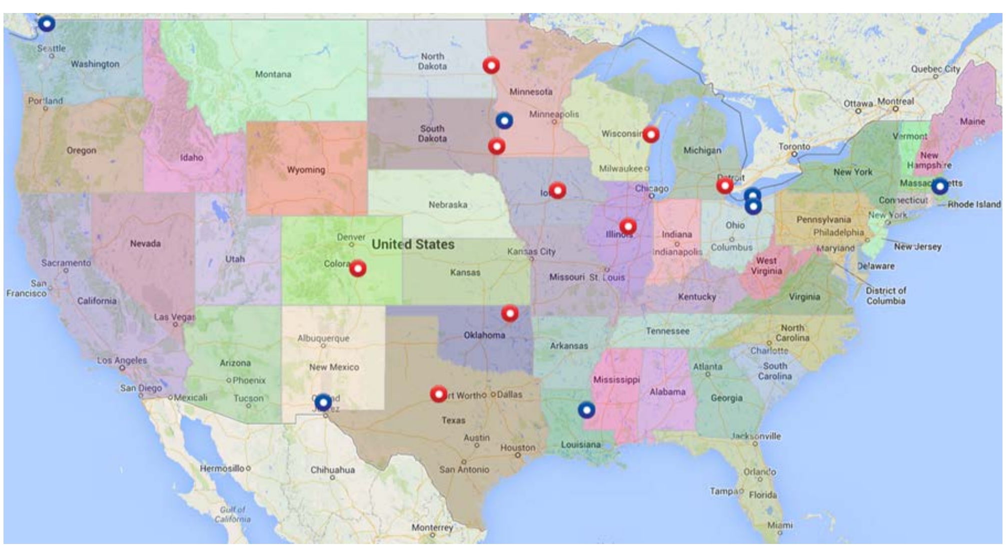


Fig. 16 – U.S. Tower Manufacturers Locations

Blade Scorecard Summary: All of the current U.S. blade manufacturers have capabilities to produce blades up to 50 meters, but with most limited to no more than 53-55 meters, without further investment. Typical limitations at several U.S. blade production facilities include facility physical size, plant location restrictions (limited land for expansion or additional storage area), and process equipment (need for larger paint booths, heavier cranes, etc.). Two of the 11 blade facilities reviewed will most likely require major capital investment to bring the facilities back into production. One facility is portside so logistically is well positioned to supply the Atlantic offshore market but the company has to-date, not been producing blades at this site so equipment and facilities investment is likely to be needed. The second facility has the capability to produce blades that are 50m and larger but could need investment to scale up to a serial production (larger, consistent volumes).

Figure 17 Regional Considerations: The large-scale land-based wind industry began in the Midwest, and the manufacturers accordingly established production facilities in that region. Today's current blade manufacturers are well positioned, both with technology and location, to service a majority of the land-based wind industry that is east of the Rocky Mountain range. Transport capabilities to move blades west from any of the Midwest manufacturers will only increase with difficulty as the blades reach lengths greater than 50 meters. For the offshore industry, of the 11 blade plants reviewed, only three are located near a coast, with only one currently having direct port access. Rail and road limitations to coastal regions will necessitate investment in coastal and/or portside manufacturing facilities to support the offshore industry. Although capable of manufacturing blades for a 3MW or 5MW turbine, the location of U.S. blade manufacturing facilities will prevent cost effective shipments to the coastal port regions. Insufficient suppliers exist along the Atlantic, Gulf, and Pacific coast lines. New blade facilities located at offshore wind port areas are needed.

Fig. 17 – U.S. Blade Manufacturers Locations

Jacket Foundation Scorecard Summary: GLWN reviewed 11 companies considered capable of manufacturing jacket foundations for offshore wind. Two are located in the North Atlantic, five on the Gulf coast, three in the North Pacific, and one on the Great Lakes. More than half have experience producing jacket type structures (but only one-off production) for the offshore oil and gas industry, primarily those located in the Gulf and northern Pacific region. Only one company, Signal Corporation, in Orange Texas, maintains a modern facility, 450,000 sq. ft. under roof, that is capable of producing multiple jackets simultaneously, supporting serial production, and with direct load to barges.

Keppel AmFELS in Brownsville, Texas, is the fabricator in line to produce “hurricane resistant” jacket foundations that will support 6MW direct-drive wind turbines for the proposed Baryonyx project to be developed off the coast of Port Isabella, Texas. Energy Management Inc. has announced that the Cape Wind offshore substation, including support structure will be produced by Cianbro at their Brewer, Maine facility.

Even for fabricators experienced in producing jacket structures for the oil and gas industry, GLWN suggests that investments will be required for these facilities to support wind farm order volumes and serial production of turbine foundations. For heavy fabricators without direct experience in jacket structures, we anticipate there will be cost associated with the learning curve for this new product, possible capital investment in facilities equipment necessary for handling structures of this size, and again, investments to support serial production.

Figure 18 Regional Considerations: A mature fabrication industry exists throughout the U.S. Large heavy fabricators can be found along most of the coastal regions. Further research would most likely identify additional capable U.S. manufacturers well positioned to serve the industry, with the understanding that moderate-to-high investments are likely to be needed to meet production and capacity requirements, or to bring production facilities directly to ports.

Fig. 18 – U.S. Potential Jacket Manufacturers Locations

Permanent Magnet Generator Scorecard Summary: Five U.S. generator manufacturers were reviewed by GLWN. Three are currently supplying the wind industry and capable of providing generators for a 3MW wind turbine, with little or no additional facility or capital investment. One company, not a current supplier to the wind industry, does have the capabilities but would likely require major investment to produce generators for 3MW and larger turbines. The fifth U.S. company, capable of supplying generators for 3MW and 5MW turbines, has a strong global presence in supplying the wind industry but maintains generator production only in Europe. Major investment would be necessary to build a U.S. based generator production facility.

As the land-based and offshore markets develop, and since generator technology is transferrable, GLWN believes that more companies would invest in expanding their capabilities, or in new facilities, for the production of wind turbine generators.

Figure 19 Regional Considerations: Generators for 3MW and 5MW turbines can be shipped via truck or rail but will face some constraints for any long haul transport. For rail, the diameters of 15 ft. and 21.5 ft. respectively, will have issues of tunnel and overpass clearance. For truck transport, the weight will be the deciding factor with a 3MW unit weighing in the area of 40 tons and the 5MW at approximately 68 tons. Both units are considered oversize and overweight loads. Shipment by barge or vessel is also a consideration for these large parts. Of the current U.S. generator manufacturers, three are located in the Midwest [Ingeteam/Indar, Swiger Coil, and Hyundai Ideal Electric] and one in Texas [Teco Westinghouse]. (The fifth company, ABB in West Virginia, does not produce generators in the U.S. at this time)

The U.S. Wind industry will be best served with new facilities being built in the coastal regions, especially for the offshore market which is expected to quickly move to a norm of turbines larger than 3MW.

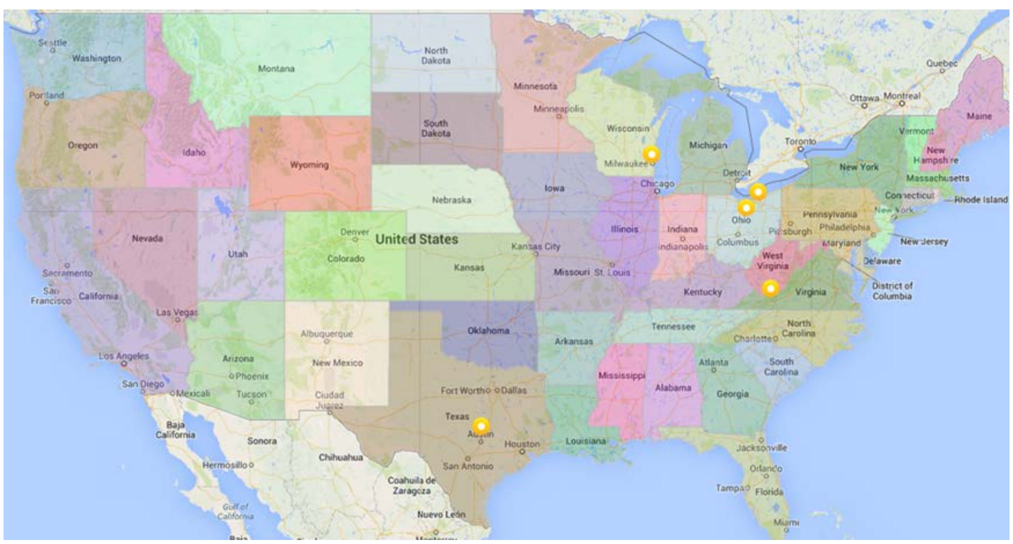


Fig. 19 – U.S. Generator Manufacturers Locations

Wind Industry Supply Chain Scorecard and Conclusions: The Scorecard provides not only an overall view of the readiness of U.S. manufacturers to supply the wind industry, but also establishes a baseline for discussing current and potential supply chain gaps, i.e. those industry sectors that may require further analysis or investment to advance competitiveness in a global market. Of particular concern are U.S. foundry and forge sectors, as reflected in Figure 20.

		LAND-BASED		OFFSHORE	
Component		Investment Required	Major Hurdles	Investment Required	Major Hurdles
Cast Hubs	3MW	HIGH	Capability does not exist for larger than 2.5MW.	HIGH	Capability does not exist for larger than 2.5MW. Facilities concentrated in Midwest. Coastal region casting plant needed.
	5MW	HIGH	Capability does not exist for larger than 2.5MW.	HIGH	
Cast Support Bases	3MW	HIGH	Capability does not exist for larger than 2.5MW.	HIGH	Capability does not exist for larger than 2.5MW. Facilities concentrated in Midwest. Coastal region casting plant needed.
	5MW	HIGH	Capability does not exist for larger than 2.5MW.	HIGH	
Forged Rings	3MW	MODERATE-HIGH	Capability exists. Some concerns with rail and road transport for rings larger than 4.5m diameter.	MODERATE-HIGH	Capability exists. Some concerns with rail and road transport for rings larger than 4.5m diameter.
	5MW	MODERATE-HIGH		MODERATE-HIGH	
Forged Shafts	3MW	MODERATE-HIGH	Capability exists. Concern: U.S. mfgs are NOT supplying the wind market. They are not competitive.	MODERATE-HIGH	Capability exists. Some transport limitations for 5MW depending on shaft design and diameter.
	5MW	MODERATE-HIGH		MODERATE-HIGH	

Fig. 20 – U.S. Castings and Forgings Scorecard

U.S. foundries, although capable of manufacturing a quality product, continue to be challenged to compete globally in the current wind industry, and this problem will only be accentuated for the cast products required for the next generation of turbines. GLWN reviewed several forge companies capable of manufacturing rings and shafts, but again, these companies have not been competitive in supplying the current land-based wind industry.

With castings and forgings estimated to be 23% of a turbine cost, GLWN recommends that a detailed competitiveness analysis be conducted on these four key components, cast hubs, cast support bases, forged rings, and forged shafts, to develop cost matrices and identify opportunities for improvement.

Figure 21 shows the overall scorecard for the 13 components in the 3MW and 5MW capacity, land-based and offshore. The low risk products are shown in green (can manufacture today, no real capital investment required), the moderate risk parts in yellow (minor facilities upgrades and/or operations expenses) and high risk parts in red (new facilities or location needed, or major investment required). Some parts are also designated in transition Low-Moderate and Moderate-High.

	LAND-BASED - Turbine Components									
	Towers	Blades	Generators	Gearboxes	Composite Housings	Fabricated Support Bases	Forged Rings	Forged Shafts	Cast Hubs	Cast Support Bases
3MW	LOW	LOW	LOW	LOW	LOW	LOW	MODERATE-HIGH	MODERATE-HIGH	HIGH	HIGH
5MW	MODERATE-HIGH	MODERATE- HIGH	LOW-MODERATE	LOW-MODERATE	LOW-MODERATE	LOW-MODERATE	MODERATE-HIGH	MODERATE-HIGH	HIGH	HIGH

	OFFSHORE - Turbine Components									
	Towers	Blades	Generators	Gearboxes	Composite Housings	Fabricated Support Bases	Forged Rings	Forged Shafts	Cast Hubs	Cast Support Bases
3MW	LOW-MODERATE	MODERATE-HIGH	LOW	LOW	LOW-MODERATE	LOW	MODERATE-HIGH	MODERATE-HIGH	HIGH	HIGH
5MW	HIGH	HIGH	LOW-MODERATE	LOW-MODERATE	MODERATE	LOW-MODERATE	MODERATE-HIGH	MODERATE-HIGH	HIGH	HIGH

	OFFSHORE - Key Balance-of-Plant		
	Jacket Foundations	Monopile Foundations	Subsea Cabling
3MW	MODERATE-HIGH	MODERATE-HIGH	HIGH
5MW	MODERATE-HIGH	HIGH	HIGH

Fig. 21 – U.S. Wind Industry Scorecard Summary of Key Components

GLWN's overall score of U.S. manufacturers' readiness to supply the next generation wind industry key components for both land-based and offshore applications can be summarized to the following:

- Capabilities exist in the U.S. to manufacture key components for next generation 3MW wind turbines, particularly for towers, blades, generators, gearboxes, composite housings, and fabricated support bases.

- Forgings and castings together make up 23% of wind turbines cost. U.S. manufacturers of forged rings, forged shafts, cast hubs, and cast support bases, although capable, are not competitive in the global supply chain for wind. Investments in casting and forge industry sectors will be necessary if the U.S. wants to recapture these markets for both land-based and offshore applications. *Further detailed analysis of the forge and casting industry is recommended to determine the root cause of this loss of market and non-competitive position.*

- Investment in facilities and equipment is likely within all of the industry sectors for scaling up to the 5MW requirements. Current tower and blade manufacturers in particular will require moderate-to-high investments in equipment and facility upgrades to support 3MW and larger turbines for land-based applications. For 5MW and larger offshore applications, the investment needed will be substantial (HIGH) assuming a new facility, located port side, is the most desirable for the larger components.

- The U.S. wind industry and supply chain is concentrated in the central and midwest United States. Location of the suppliers, current and potential, was taken into account when considering a manufacturers ability to supply the offshore industry. For several of these key components, the manufacturers' current distance from the coastal regions, would likely render them non-competitive, and that is if the component could even be transported given current road and rail infrastructure constraints. For the offshore industry, investment in new facilities is needed in coastal regions, preferably located at major ports equipped to support the offshore wind industry.

- Offshore wind will bring new market opportunities with jacket and monopole foundations. Capabilities exist with U.S. heavy fabricators but moderate-to-high investments will still be necessary to address this new product line, serial production for higher volumes required by wind farms , and potentially new coastal facilities.

- Subsea cable manufacturing, sufficient for offshore utility wind farm applications (continuous line cable) does not exist in the U.S. New portside facilities will be needed.

IV. Wind Supply Chain Database and Map

The fourth project deliverable was to expand the current GLWN Wind Supply Chain Map to include offshore elements. GLWN has been developing this on-line, free access, wind supply chain map over the past five years, creating a platform for identifying active and emerging suppliers for the land-based wind industry, including turbine component manufacturers and wind farm construction service suppliers. The map supports several search features as seen in Figure 22. As part of this Competitiveness Study, GLWN has expanded the Map to include filtering for offshore vs land-based component suppliers, added offshore balance-of-plant component searches to the Construction Supply Chain, and Offshore Wind Farm locations (planned and permitted) and general farm data. ***GLWN's Wind Supply Chain map will continue to be a valuable supply chain search and information tool for manufacturers and OEMs alike, as land-based wind continues to grow and offshore wind emerges. Available at www.glwn.org***

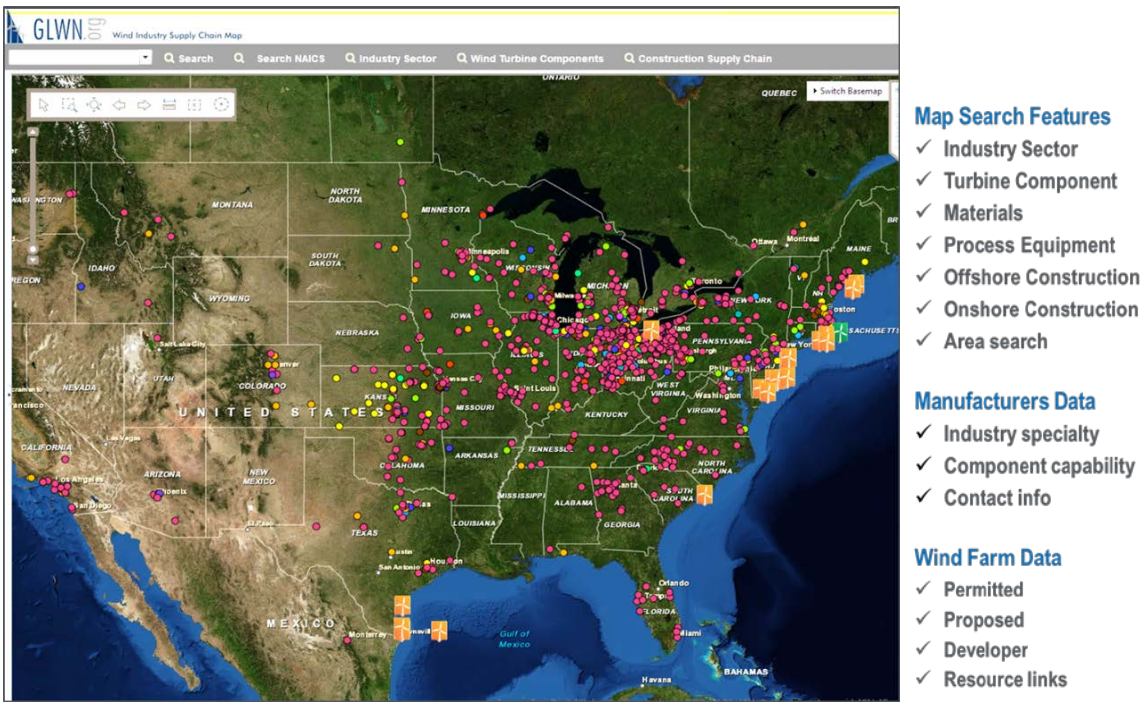


Fig. 22 – GLWN Wind Supply Chain Map

V. Conclusions and General Observations

Conclusions:

As noted earlier, the comparisons presented in this competiveness analysis reflect unique "snapshots" of cost breakdowns and manufacturing processes from a representative sampling of major global suppliers based on standardized sets of design drawings. However, they should not be construed to provide definitive conclusions with respect to regional manufacturing capabilities and market pricing. Additionally, GLWN utilized a common U.S. port to calculate all transportation costs from point of manufacture in the respective countries studied. These relative costs will vary with other offshore wind project locations.

1. **Determine Global Cost Leaders**: China is the lowest cost manufacturer in 3 of the 4 product categories (towers, foundations, generators). U.S. manufacturers had the lowest cost on blades and second lowest on towers & foundations, and highest on generators. Germany was the high cost manufacturer in 2 of 4 categories although they have supplied the majority of the manufactured content in their North Sea offshore projects.
   a. Tower – $555,545 China price without tariff of $482,728 and logistics of $139,063 vs $639,971 U.S. price. Adding logistics cost to China makes the U.S. the lowest.
   b. Jacket Foundation - $588,274 China price without Logistics of $556,250 versus $1,121,233 U.S. price.
   c. Blade - $318,710 U.S. Price versus $394,076 Germany and $396,341 China without logistics of $52,976.
   d. Generator - $123,926 China price vs $180,000 Europe price vs $192,900 U.S. price

2. **Determine Best Current Manufacturing Process:** In general, the US had the most efficient processes on towers, blades and generators based upon the lowest number of total man hours, the highest value added to non-value added ratio, and the highest rate of return. Germany was the most efficient on foundations. China had the highest rework and non-value added process times.
   a. Tower – 1,175 hours U.S. vs 1,216 hours Germany vs 2,641 hours China.
   b. Jacket Foundation – 9,155 hours U.S. vs Germany 10,400 hours vs China 13,080.
   c. Blade – 493 hours U.S. vs 585 hours Germany vs 650 hours China.
   d. Generator – No direct hour comparison available only Value Stream Map with U.S having highest value added to non-value added ratio.

3. **Key Factors that Determine Competitiveness:** China's advantage lies in the lowest material, labor, and burden cost in all product categories except blades. China's focus is on volume production. Chinese manufacturers will buy the latest process technology and component

designs as needed. Examples include a generator coil winding machines purchased from Germany, and roll mills which are purchased from elsewhere in Europe.

4. **Potential Means for U.S. Cost Reduction:** U.S manufacturers are within reach of "Best Overall" which they could achieve through: focus on purchased material that meets Customer product specifications and is cost effective for all, focus on product & process design for lean serial production (even flowing process with waste eliminated), and investment in facilities able to produce large parts for marine transport to coastal or offshore wind farms.

General Observations

This competitiveness analysis generated a large quantity of first-of-a-kind, hard-quoted cost data and manufacturing process detail from 22 manufacturers in four product categories. This study provides a greater understanding of the key factors that determine wind energy component manufacturing costs and pricing on a global scale, and establishes a benchmark to facilitate the improvement of U.S. manufacturers' competitiveness, and reduce the overall installed systems cost. The resulting data and trends can also be utilized by U.S. wind industry leaders and state/local economic development agencies to better understand the challenges of working towards LCOE while advocating for the engagement of their regional manufacturers in the wind supply chains. Additionally, this study provides valuable information for continued analysis by U.S. government agencies and national laboratories for future model comparison and wind technology considerations. Areas with the greatest opportunities for improvement have been identified and recommendations formulated for future R&D projects to drive reductions in component costs.

Utilizing detailed drawings and common bills of materials, and soliciting detailed quotes, GLWN developed and implemented a productive and efficient process for capturing and comparing reliable detailed cost data from the key global regions, Germany, China, and the U.S. GLWN recommends that future global comparative analysis projects of this type should also require detailed "design for manufacturing" drawings and common bills of materials in order to achieve meaningful apples-to-apples results, and a successful analysis.

All suppliers visited during this study were positive about the trend toward larger wind turbines and offshore applications. They were interested in the outlook for commercial offshore wind farms in the U.S. and the Department of Energy's Offshore Technology Demonstration Program. Manufacturers in Germany and China currently supply large components to the offshore wind industry. Those producing components for the 5MW and larger turbines stated that they experienced multiple manufacturing learning phases in scaling up production to manufacture these larger parts. All were producing components for land-based projects so were able to determine what steps were critical to making these larger, high quality components at a serial production rate. New manufacturing methods and procedures were developed as current processes applicable to smaller parts did not necessarily work effectively with larger parts. Fixture designs (devices for holding parts in certain positions during welding) and welding processes needed updated to support these new component product lines. International joint ventures or technical partnerships could help minimize these adaptation risks in the U.S.

As the parts increase in size, workforce training needs to adjust accordingly to ensure the continued production of high quality parts. The tolerances in wind turbine component fabrications are in millimeters versus centimeters for shipyard or general steel fabrication. A high percentage of welders in the U.S. today are not certified for wind components with these tighter tolerances. Those welders that are certified are highly sought after and obtain higher wages which does affect total manufacturing costs, but is offset by the return on investment realized from less re-work.

Of the German/European suppliers interviewed, all expressed interest to partner with American suppliers to manufacture components in the U.S. Such joint ventures would enable utilizing existing capital and infrastructure, as well as availability of a qualified workforce for specialty training. This proactive effort would reduce the time and cost to mobilize a U.S. operation once firm orders have been placed. Cross training would occur between the U.S. and European engineering and skilled plant floor workforces. The European OEMs also see less risk working with a European joint venture company that is already making similar parts in Europe. Some Chinese suppliers were interested in partnering and utilizing idle shipyards and facilities in the U.S. We found the same interest with Chinese wind turbine OEMs awarded wind farm supply contracts in the U.S. They concur there is less risk in entering the U.S. market by establishing Chinese – U.S. joint ventures.

This study enabled real global cost numbers to be obtained for a given set of designs and established a basis for further cost and improvement analysis going forward. Current costing models developed by the National Renewable Energy Laboratory (NREL) and Sandia National Labs can now be validated with accuracy by comparing to GLWN's real-time actual cost data. Connections were fostered for future business opportunities and relationships that could result in reducing the LCOE. The four components in this study, blades, towers, jacket foundations, and PM generators, represent over 50% of the total component capital costs of an offshore wind farm (not including installation). In the Scorecard analysis it was identified that castings and forgings, comprising 23% of the system cost, does not have a "ready" manufacturing base to meet potential future U.S. industry needs. These parts are job intensive due to the long value chain for casting or forging which includes machining, coating, and tooling. U.S. foundries, although capable of manufacturing a quality product, continue to be challenged to compete globally in the current wind industry, and this problem will only be accentuated for the cast products required for the next generation of turbines. GLWN reviewed several forge companies capable of manufacturing rings and shafts, but again, these companies have not been competitive in supplying the current land-based wind industry. This industry needs smart innovation and investment to support larger wind turbines.

Today, manufacturing accounts for 61% of the total value added and corresponding jobs growth in the German offshore wind industry. And U.S. manufacturing has that same opportunity to capture and drive job growth in America's next generation land-based and emerging offshore wind industry.

The U.S. must develop a new coastal manufacturing base for serving and supporting the emerging offshore wind market. And because current offshore project development efforts are concentrated along the Atlantic coast, this region is poised to become the center of such new industrial activities. Current wind manufacturers and component suppliers are generally located in the central and midwest U.S. to primarily support current land-based wind farms. In Germany, the supplier base has developed in the coastal regions to support land-based wind farms and increasingly local and European offshore projects. Most Chinese suppliers have located their facilities near or by waterways to support land-based, offshore, and turbine/components export. Challenges will exist for this new U.S. manufacturing base and infrastructure to compete with existing facilities in Asia and Europe. To compete with existing component suppliers in Europe and Asia, U.S. manufacturers will be faced with significant investments for new coastal facilities and improved infrastructure, and therefore, higher amortization costs at start-up. U.S. suppliers will need a solid book of business and consistent larger volumes to offset the increased amortization.

We would like to thank the Wind and Water Power Technologies Office within the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy for supporting this study in raising awareness on the importance and contribution domestic manufacturing plays in developing the next generation land-based and offshore wind industry in the U.S.

SECTION 1 – GLOBAL COMPETITIVENESS ANALYSIS

1.1 Towers Competitiveness Analysis

1.1.1 Introduction

Towers contribute to the highest percentage cost of all the major wind turbine components at 25-30%. These numbers would be similar for land-based and offshore towers. Towers provide the height to capture the power of the wind and the structure to support the weight and wind forces on the nacelle and rotor assembly. The cost breakdown for the tower includes material, labor, burden, SGA (Sales General Administrative), engineering, logistics, and profit.

Fig. 1.1.1 Tower Section after Paint and Installed Towers

The Process of Obtaining a Global Cost Comparison

Design

One design was developed with a common bill of material (BOM) to obtain a global cost comparison. GLWN collaborated with NREL to develop a standard design that could be quoted globally. NREL had a 5MW system design in place that was being used for other analysis and project work. GLWN used this model and developed a detailed design with manufacturing drawings of all tower structural components. Tower internals were not included since they vary between OEMs. A complete set of drawings (10 total) and bill of material was developed that detailed all components, mass, and material specifications. See Fig. 1.1.2 for a schematic of the 5MW tower for this project.

Identification of Global Suppliers

The current major global suppliers were identified in the U.S., China, and Germany. Targeted suppliers were asked to participate. Two suppliers per region were identified to provide an aggregated representation of data except in Germany.

Tower Manufacturers Bio's (primary representation of land-based towers with some offshore)

	Annual Tower Sales 2012 (Combined)	Annual Tower Capacity as of 2013 (Combined)	Towers built to date
USA (2)	$200M	600	2200
China (2)	$320M	1000	6100
Germany (1)	$90M	250	1200

Tower Schematic

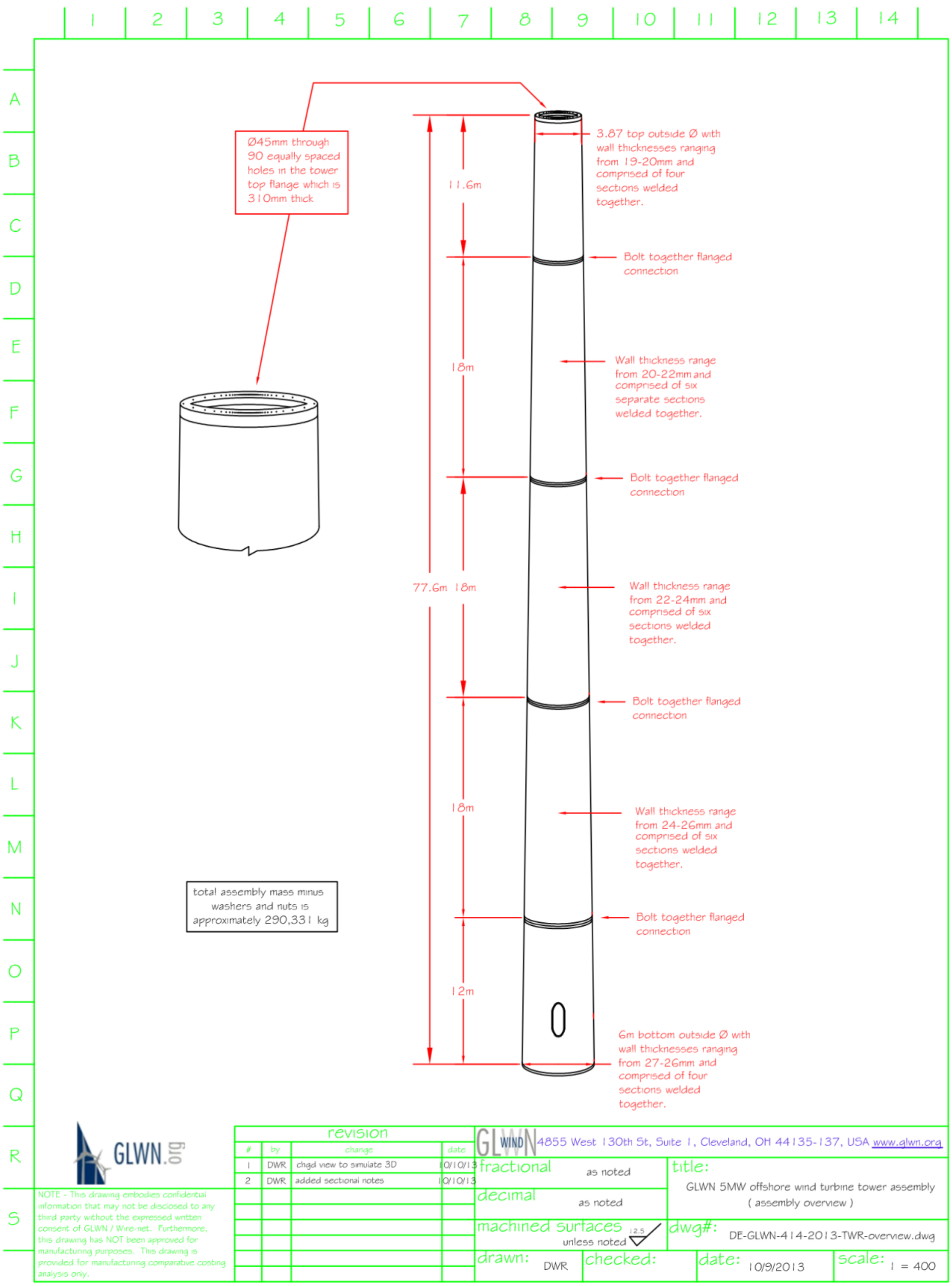


Fig. 1.1.2 Schematic of 5MW Tower used in this study

1.1.2 AGGREGATED Regional Cost Breakdown for Towers

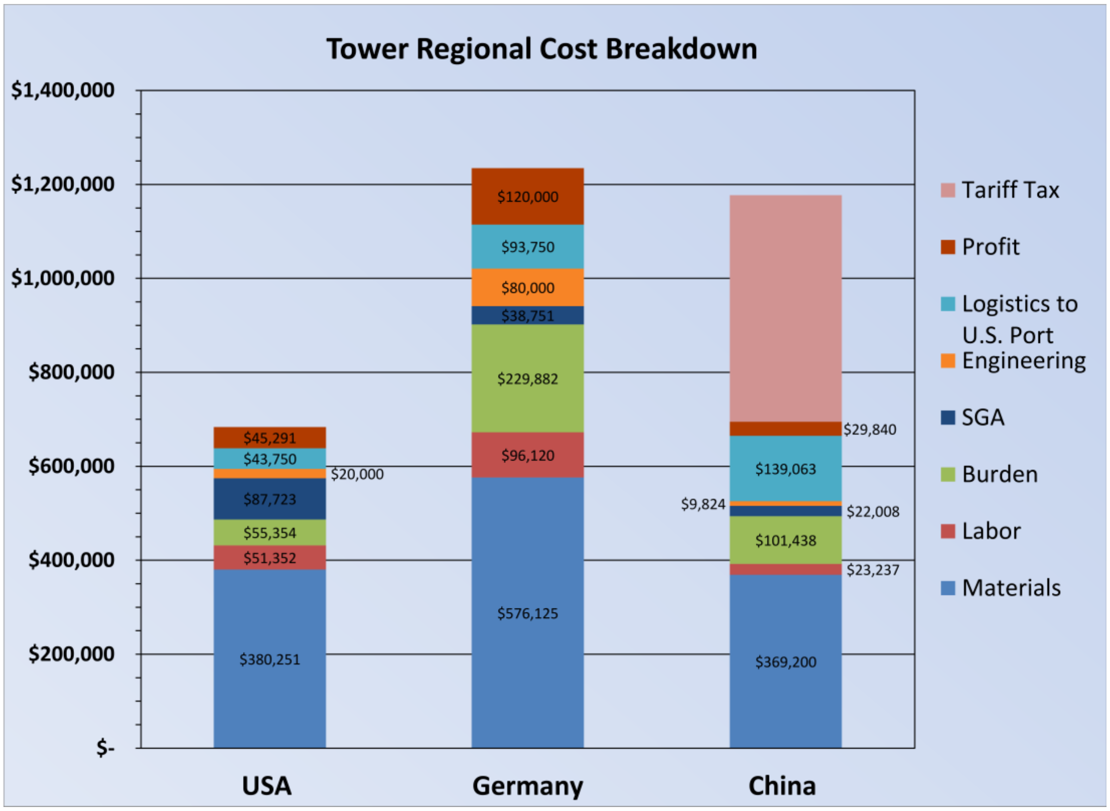


Fig. 1.1.3a Aggregated Regional Cost Breakdown in $

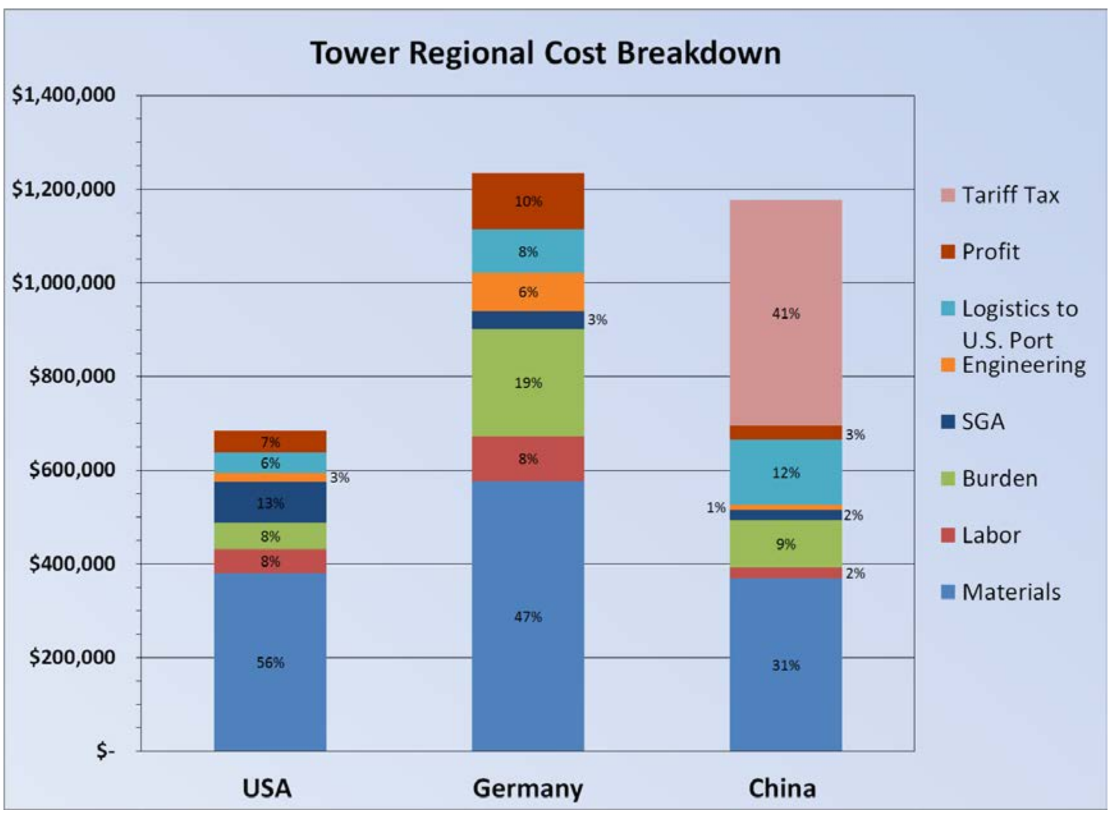


Fig. 1.1.3b Aggregated Regional Cost Breakdown in %

Regional Cost Breakdown - Towers

Description: Regional Cost - the Regional Cost Breakdown in the 8 cost categories is represented in dollars in Figure 1.1.3a and represented in % in Figure 1.1.3b. The % is skewed for China suppliers due to the 92% average Tariff Tax on every tower being sold in the U.S., which close to doubles the tower cost to the buying U.S. OEM.

Findings: Regional Cost

- Material is the largest cost driver in all regions running at 50% or slightly above if the Tariff/Tax is removed from the China Suppliers. The lowest material cost is in China, with the U.S. at +8% and Germany at +63%. The German steel plate and flange quotes are the highest although these specific numbers are felt to be inflated for rough cost estimating purposes. General German market numbers would have it at 20% higher than China.
- Labor & burden combined is the 2nd largest at 16% for the U.S. and 27% for Germany. China is at 17% and 3rd to logistics at 21%
- A major International logistics company provided the shipping cost for a full vessel load. The costs reflected are from closest port from manufacture to common Port of New Bedford, MA[1]. The highest cost is from China at 21%, Germany at 8% and U.S. from the Great Lakes Region at 6%
- SGA for the U.S. is 13%, Germany and China are at 3%
- Engineering in Germany is 6%, U.S. is 2%, and China is 1.5%
- Profit in Germany is 10%, U.S. is 7%, China is 4%
- Tariff/Tax only applies to China and it is 92% average for the two China suppliers in this study. This tariff has impeded the supply of towers to the U.S.
- Overall the R&D focus should be on Material and Labor & Burden. The Logistics cost can be reduced to 0% from a high of 12% by making towers at a coastal manufacturing facility.

[1] For purposes of comparing total applicable costs between suppliers in different global regions, the Port of New Bedford, Massachusetts was selected as a common destination for calculating all transportation costs from point of manufacture. The New Bedford port, currently under renovation, is considered to be the first marine commerce terminal built to service the U.S. offshore wind industry and is the planned staging site for the Cape Wind project. The New Bedford port will have the capability of handling the four components in this study.

1.1.3 MATERIALS – Regional Cost Breakdown for Towers

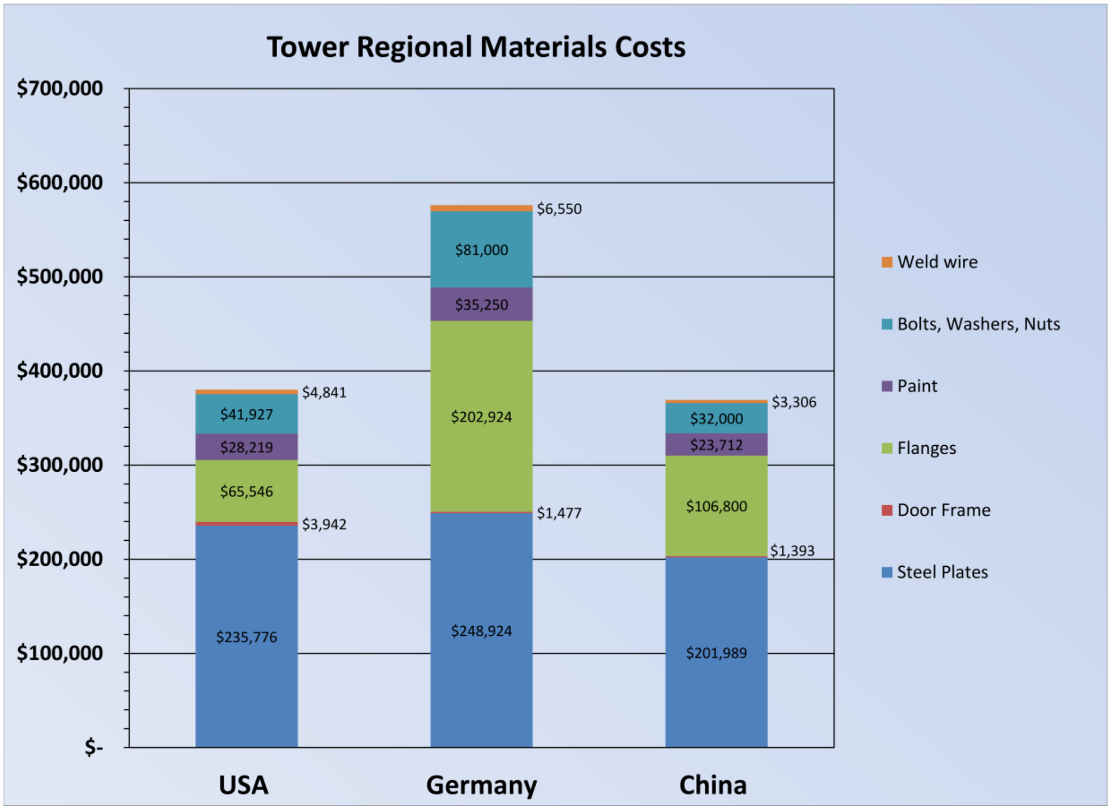


Fig. 1.1.4a Materials Regional Cost Breakdown in $

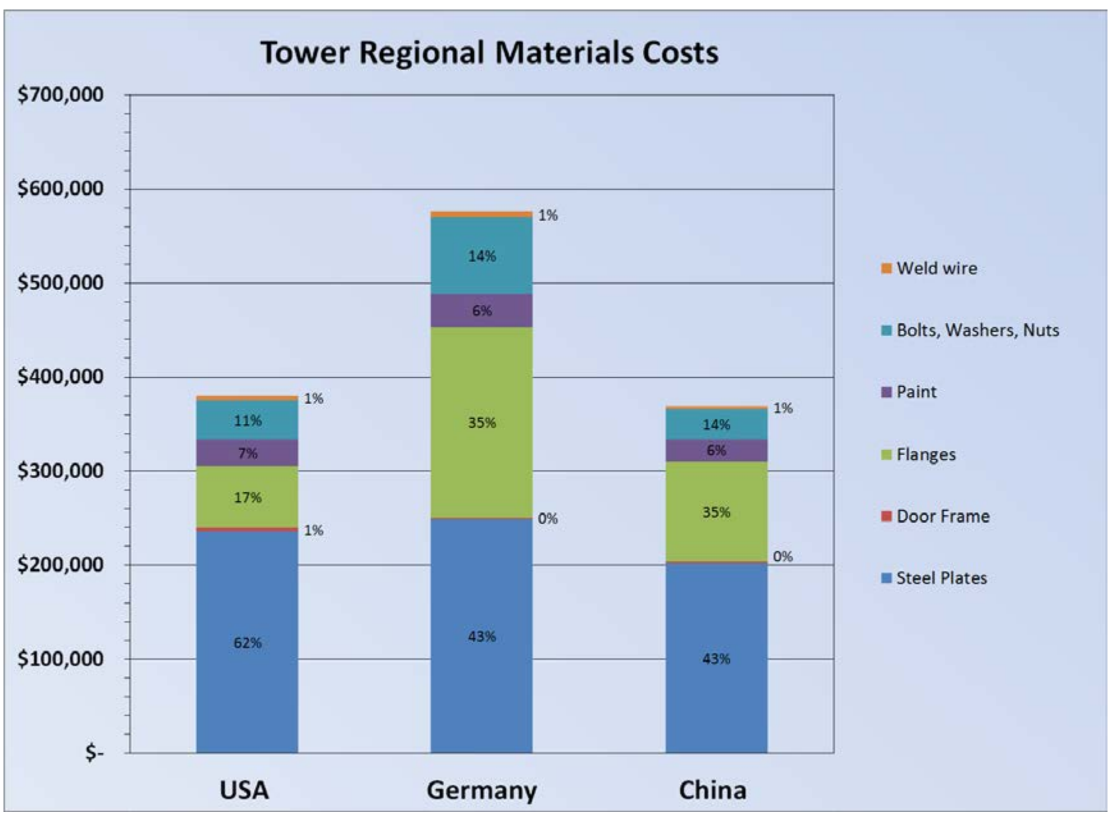


Fig. 1.1.4b Materials Regional Cost Breakdown in %

Materials Cost Breakdown - Towers

Description: Materials - there are 6 Components in the Material Category as represented in Figure 1.1.4a by dollars and 1.1.4b by percentage:

- Steel Plate
- Door Frame
- Forged Ring Flanges
- Paint
- Bolts-Washers-Nuts
- Weld Wire

Findings: Materials

- Material is the biggest cost driver at a little over 50% of the cost of a tower. Manufacturers need to work with steel mills to optimize the material and size of the plate to reduce mill cost and tower manufacturing process cost.
- Steel plate accounts for 62% in the U.S., 57% in China, 43% in Germany, but Germany has the highest total plate cost.
- Forged ring flanges are the second biggest cost driver with 17% in the U.S., 30% in China, and 35% in Germany. The flange cost numbers from Germany and China suppliers have been stated to be conservative and could be improved with additional quotes. The quickest way to reduce cost is to minimize the number of flanges used in a design. Going from 5 sections to 3 sections per tower would reduce the need for 4 of 10 flanges for a 40% flange material reduction and 2 less circular welds per tower resulting in approximately $40,000 total reduction.
- Paint: The U.S. and China paint cost are comparable around $28,000 and Germany 25% higher at $35,000.
- Weld wire is 1% or less for all. Although weld wire, weld cavity and welding process play a larger role in the overall welding cost. R&D work in weld wire size-material and process that increases linear weld length per minute could reduce cost substantially.

1.1.4 LABOR – Regional Cost Breakdown for Towers

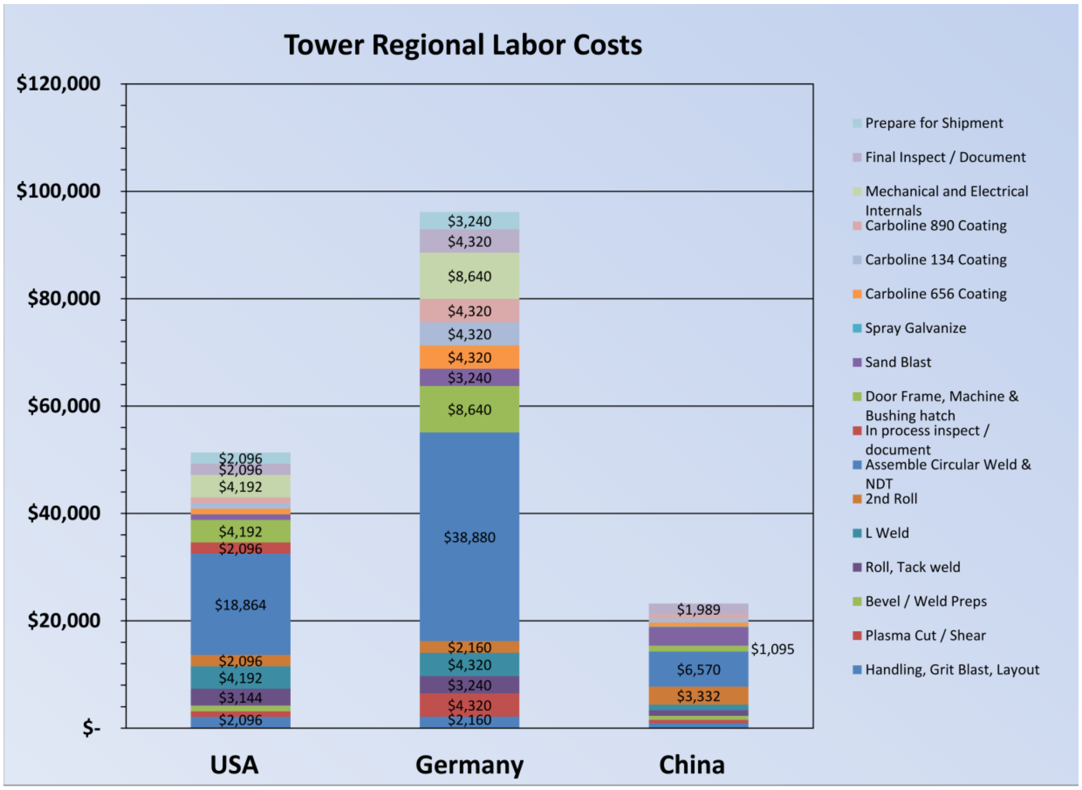


Fig. 1.1.5a Labor Regional Cost Breakdown in $

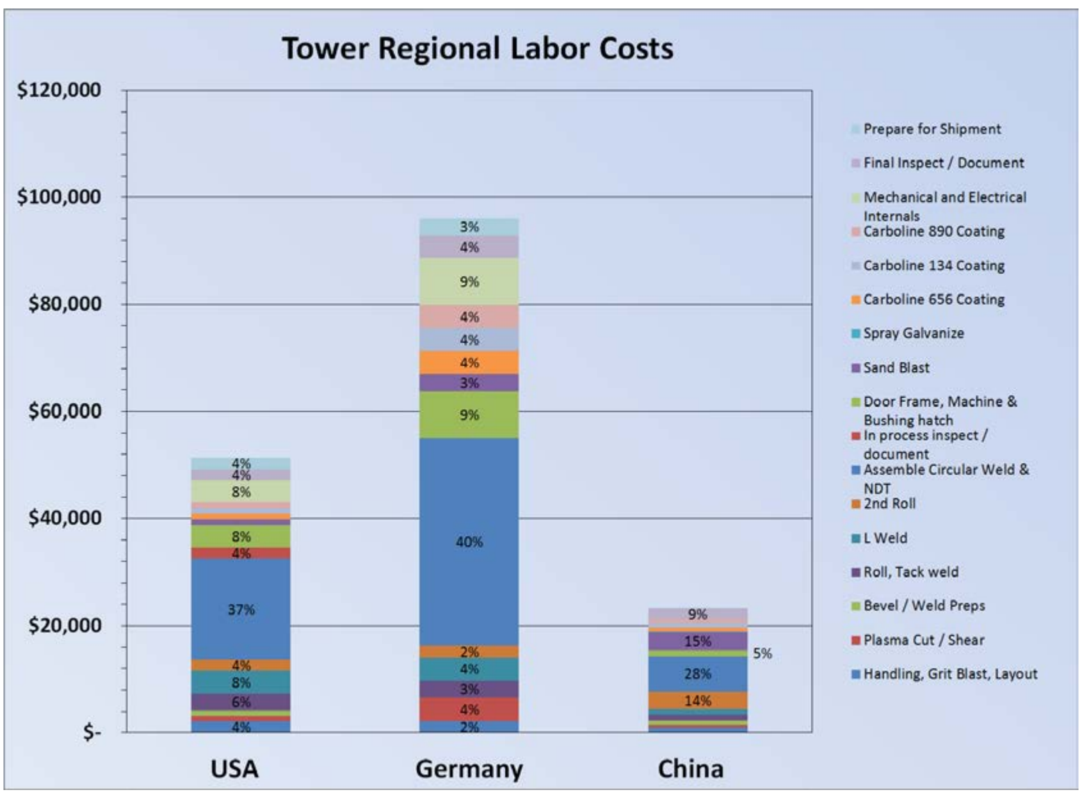


Fig. 1.1.5b Labor Regional Cost Breakdown in %

Value Stream Map - Towers

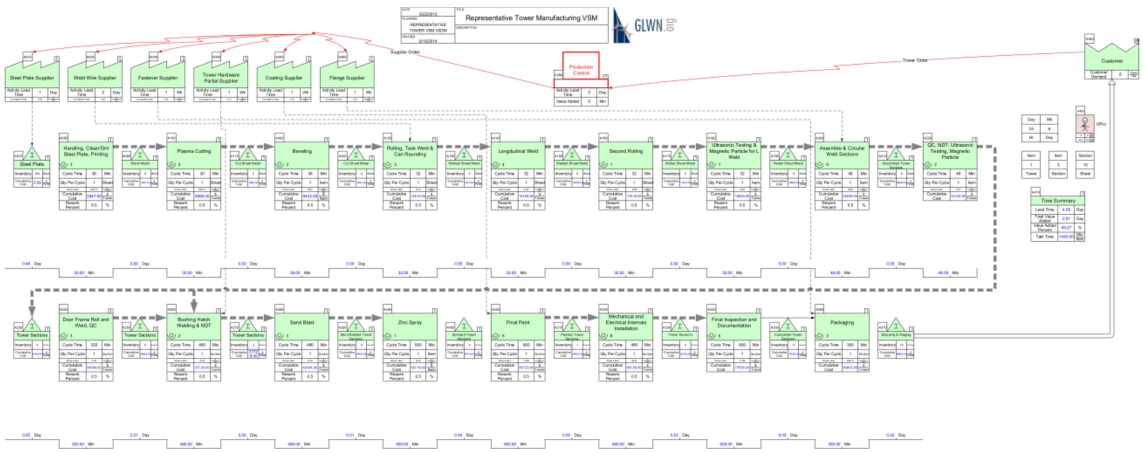


Fig. 1.1.6 Representative Tower Manufacturing Value Stream Map

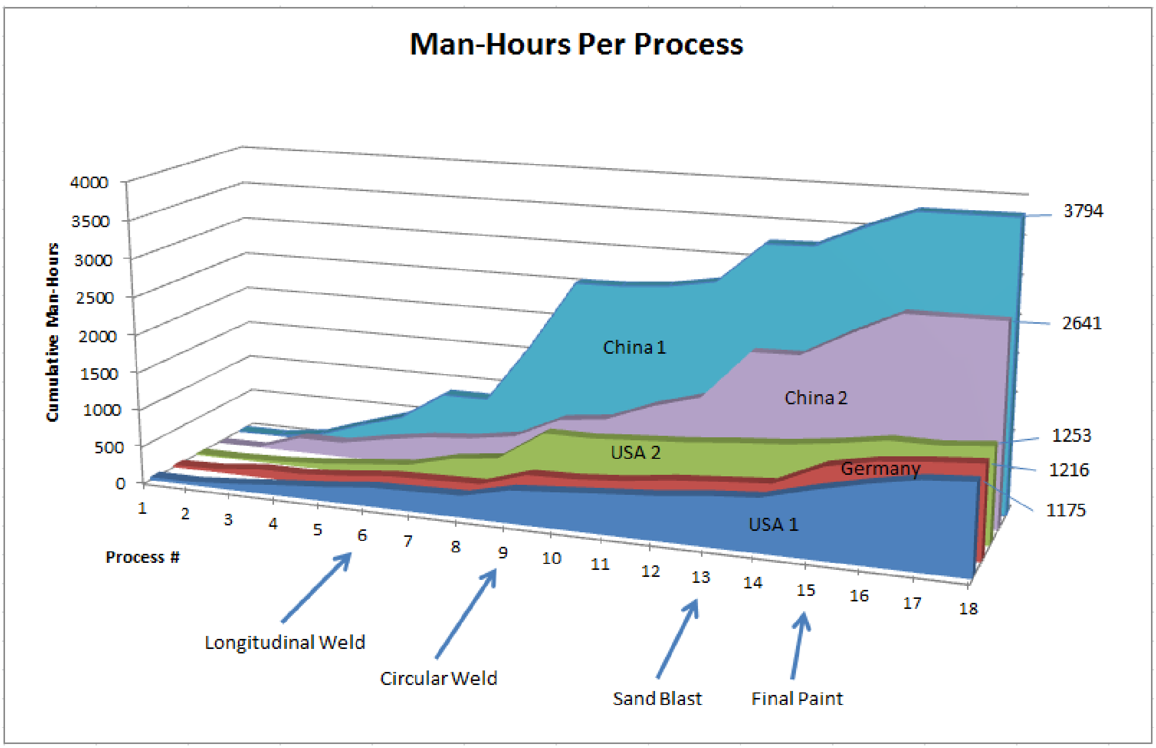


Fig. 1.1.7 Accumulative Labor Man Hours per Process

Description: Labor has 18 Process Steps

1	Handling, Clean/Grit Blast Plate	10	NDT, MP
2	Primer Coat, Printing	11	Door Frame Roll and Weld
3	CNC Cutting (Sometimes Beveling)	12	Bushing Hatch Welding
4	Beveling	13	Sand Blasting
5	Rolling, Tack Weld & Can Rounding	14	Zinc Spraying
6	Longitudinal Weld	15	Final Paint
7	Second Rolling	16	Mechanical and Electrical Internals Installation
8	Flange, Shell, Assembly, QC	17	Final Inspection
9	Circular Weld	18	Packaging

Labor Cost Breakdown - Towers

Description: Labor – Cost is the sum of all direct labor hours to produce a part

- Figure 1.1.5a and 1.1.5b detail the labor cost by the 18 process steps which is driven by process step man-hours.
- Figure 1.1.6 is a representative Value Stream Map for one of the manufacturers visited. A VSM was generated for each of the manufacturers visited. Value stream mapping is a lean management tool used to analyze and design the flow of materials and information required to bring a product to a consumer. It identifies value added and non-value added activity from which you can identify opportunities to eliminate waste and improve the process.
- Figure 1.1.7 shows the accumulative man hours for the 5 plants visited.

Findings: Labor

- Circular welding is the largest process cost driver and the bottleneck in all manufacturing processes visited. This is also the process step that drives rework and weld repair. Weld repair was the most visible in the China plants visited. Three to four partially finished tower sections were set aside and full-time welders were grinding out weld sections and re-welding them. The number of weld section repairs at the time of the visit was around 5 per tower section.
- The current process of rolling steel plate (tack-weld and L-weld), followed by a “can marriage” (joining each new can to the current section) in a “grow line”, using a circular weld, was the common process used at all sites visited. Re-organizing the process to accommodate more welding in the flat state with linear welds could provide improvements.
- Final sand blasting and painting was very labor intensive, unless some automation was used on the exterior diameter. Flexible and portable equipment would be beneficial.
- Plate cutting and edge preparation was a key factor in weld quality and weld rate. This process varied with the different manufacturers.

1.1.5 BURDEN – Regional Cost Breakdown for Towers

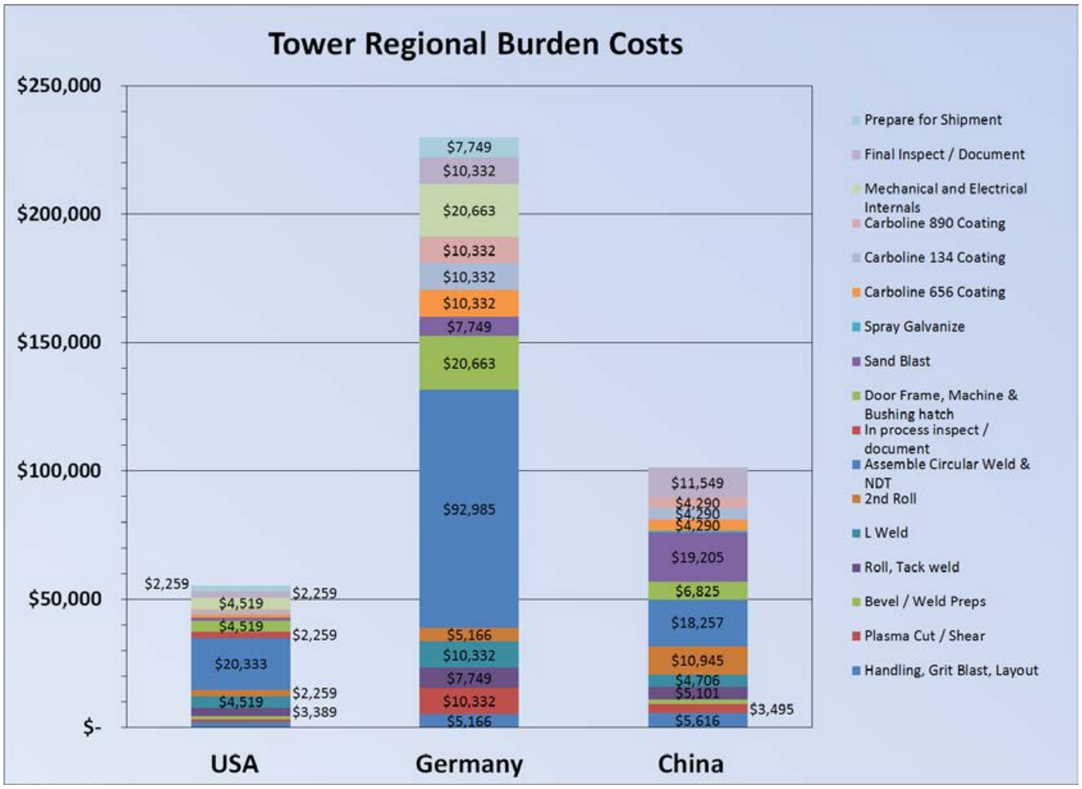


Fig. 1.1.8a Burden Regional Cost Breakdown in $

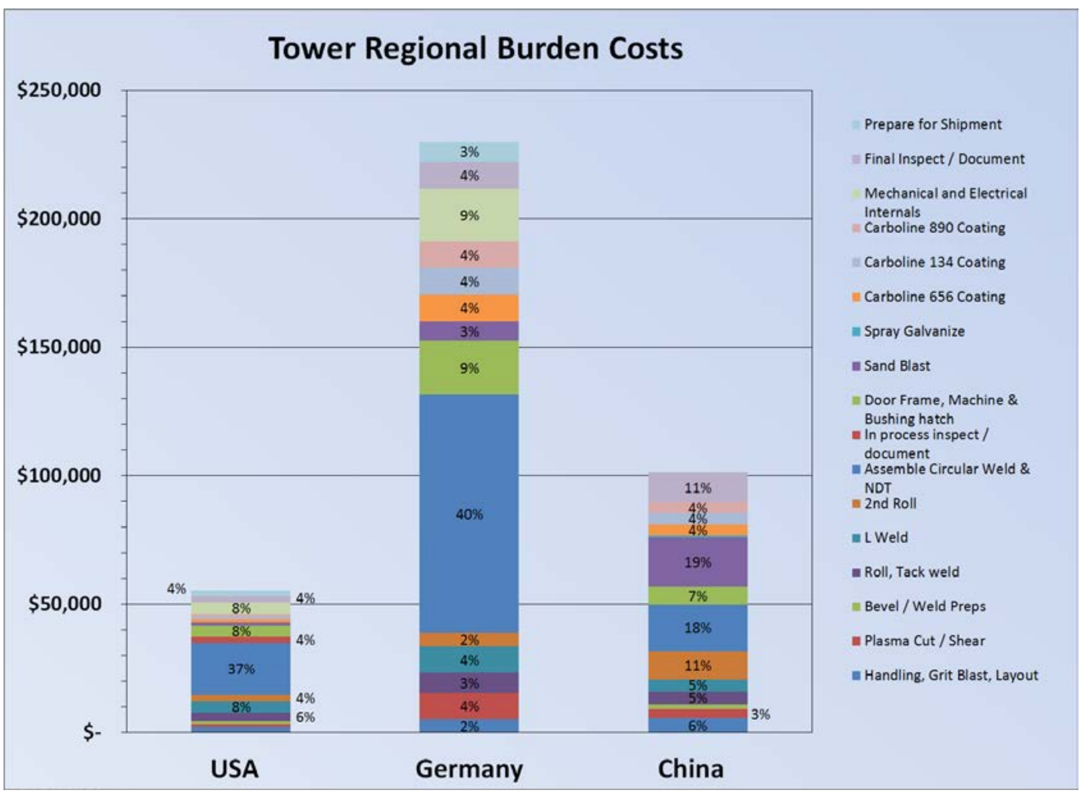


Fig. 1.1.8b Burden Regional Cost Breakdown in %

Burden Cost Breakdown - Towers

Description: Burden - Cost is the sum of the variable cost and plant fixed cost

Findings: Burden

- Burden costs at most of the manufacturers were applied as a % to direct labor and plant fixed cost spread over parts produced**.** Improvements in labor and throughput would reduce burden.
- Burden cost could be reduced in all areas by doing a full ABC cost analysis on all variable and fixed cost drivers. Power usage for each welder and all electric drive units would be a starter.

1.1.6 SGA (Sales, General, Administrative) – Regional Cost Breakdown for Towers

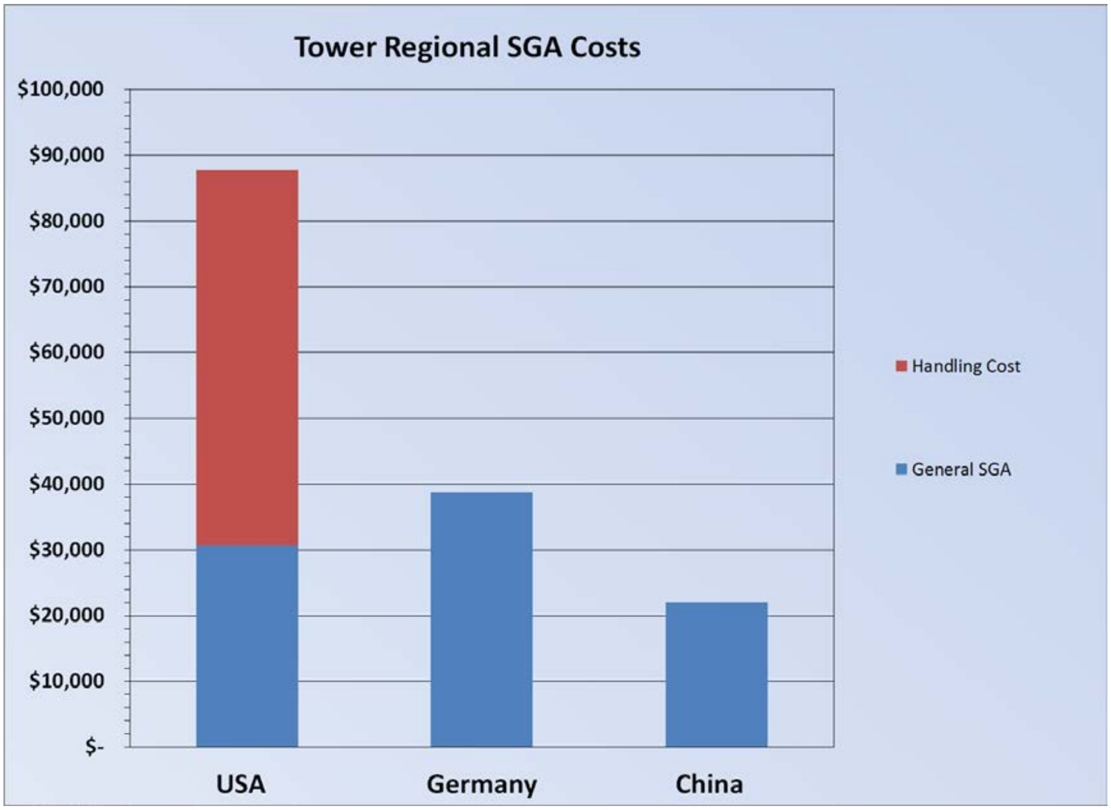


Fig. 1.1.9 SGA Regional Cost Breakdown in $

SGA Cost breakdown - Towers

Description: SGA - Cost of Sales, General, Administrative, Accounting, Executive Salaries, travel, and Special Handling as represented in Figure 1.1.9.

Findings: SGA

- SGA and Handling accounted for 13% of the U.S. cost, 3% of the Germany cost, and 2% of the China cost
- The following was the breakdown by region
  - U.S. $30,678 SGA and $57,045 Handling
  - Germany $38,751 SGA
  - China $22,008 SGA and $25,240 Handling.

1.1.7 ENGINEERING – Regional Cost Breakdown for Towers

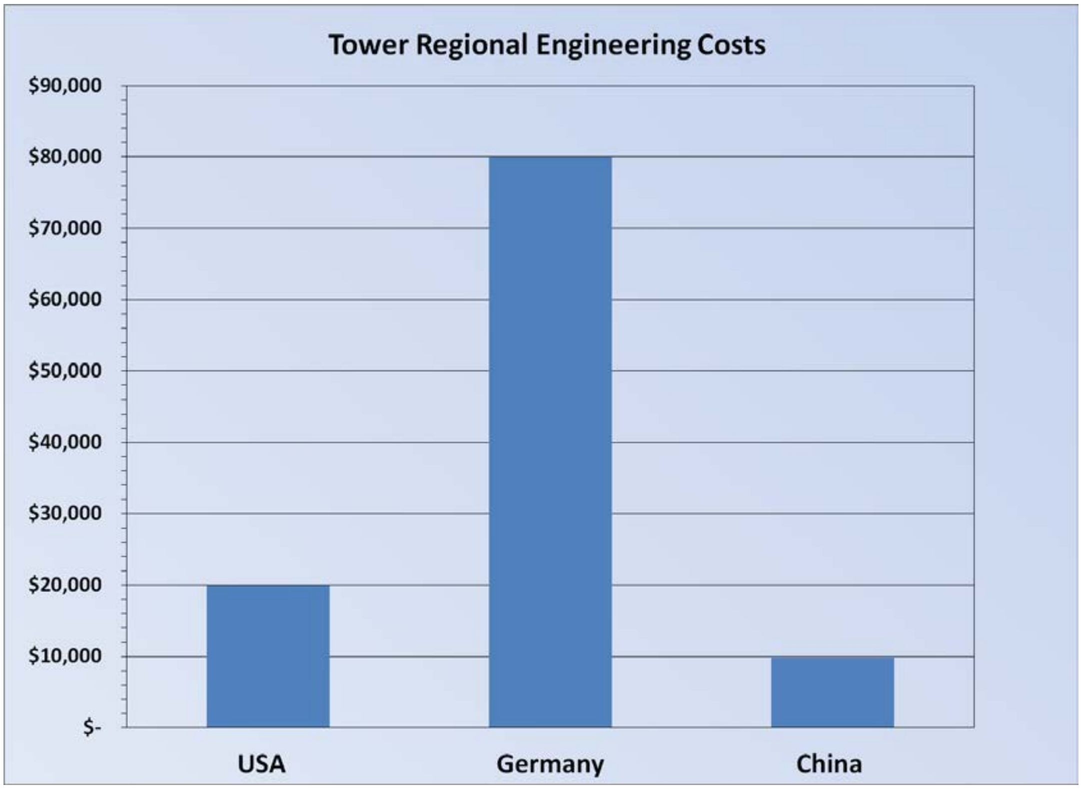


Fig. 1.1.10 Engineering Regional Cost Breakdown in $

Engineering Cost Breakdown - Towers

Description: Engineering - Cost of all Engineering: Product, Development, Manufacturing

Findings: Engineering

- China suppliers spend little money on Engineering. Their preference is to buy the design technology and manufacturing process technology. They stated during the visit they want to focus on volume production.
- Towers are not engineering intensive, although real opportunities exist for U.S. manufacturers to develop improved flow and high efficiency processes.

1.1.8 LOGISTICS – Regional Cost Breakdown for Towers

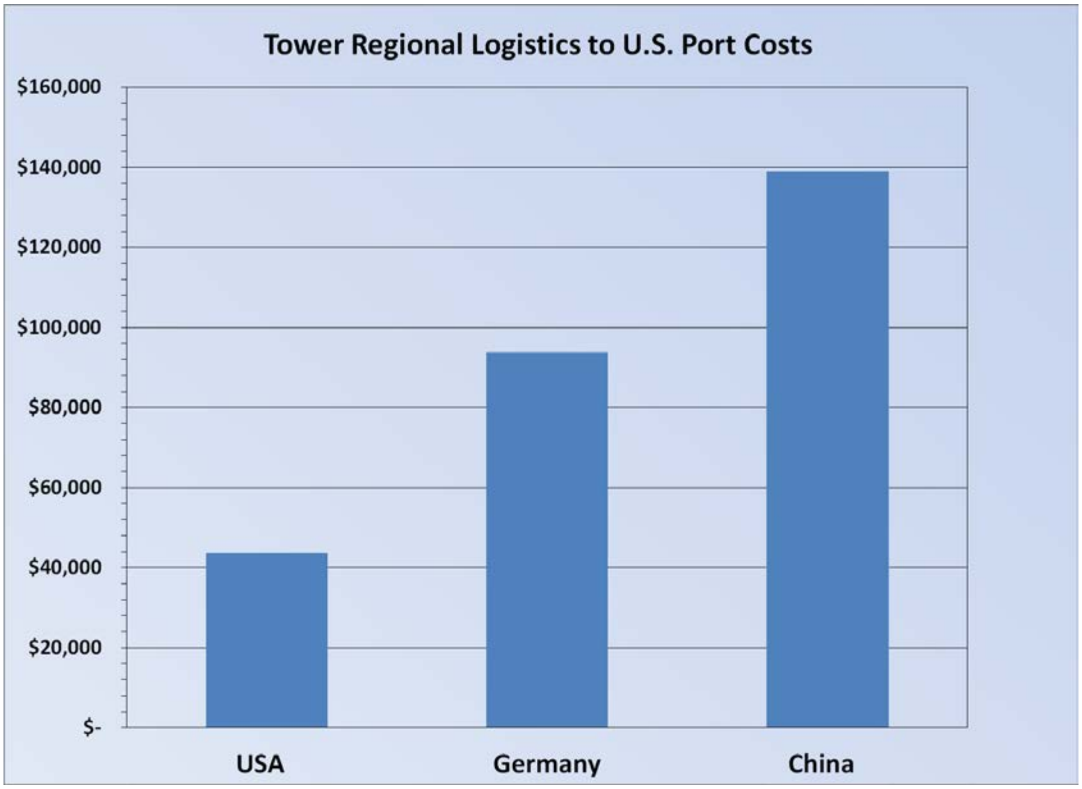


Fig. 1.1.11 Logistics Regional Cost Breakdown in $

Logistics Cost Breakdown - Towers
Description: Logistics - Cost from manufacturer port to the Port of New Bedford, MA.

Findings: Logistics

- With common shipping space requirements, the cost is driven by total transport miles and time. China is the highest followed by Germany and then the U.S. If the U.S. tower manufacturers would have been located near the New Bedford port, the cost would have been minimal. Tower production close to water access and close to the wind farm will have the lowest logistics cost.

1.1.9 PROFIT – Regional Cost Breakdown for Towers

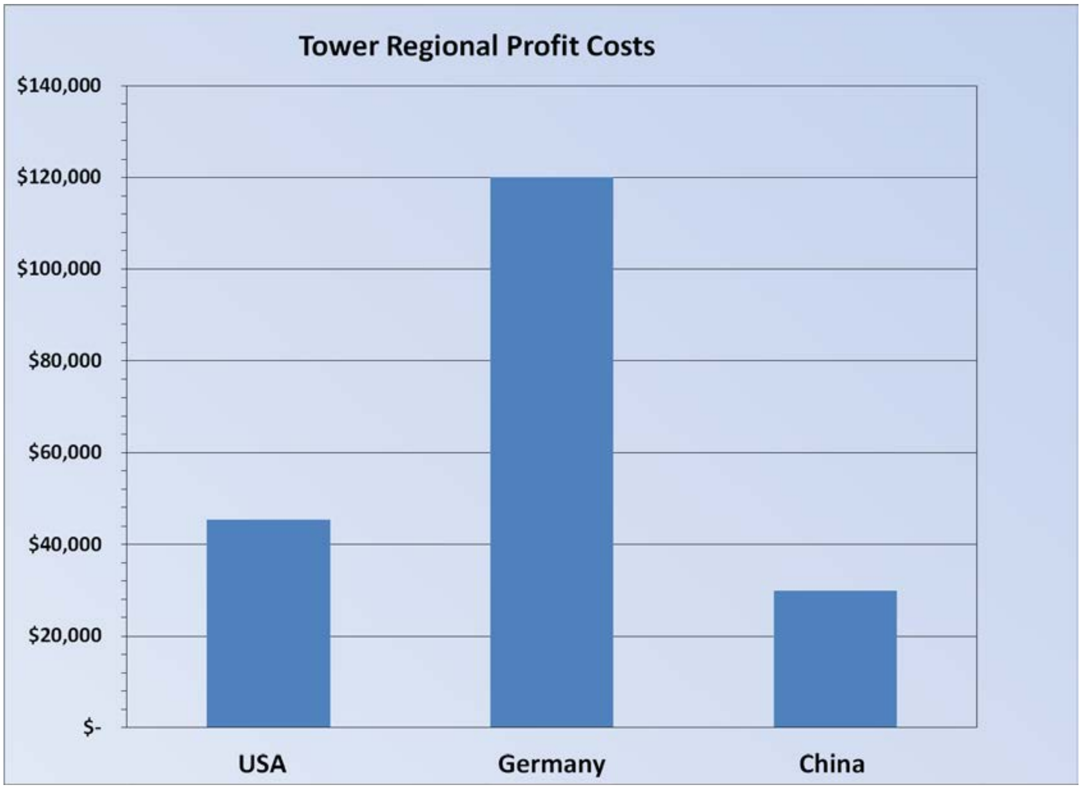


Fig. 1.1.12 Profit Regional Cost Breakdown in $

Profit Cost Breakdown - Towers

Description: Profit - The reported profit portion of the selling price.

Findings: Profit

- The reported profit range is 4-10%. This could be verified with a full on site cost analysis.

.

1.1.10 Overall Tower Observations and Conclusions

U.S. Tower Manufacturers are in a good position today for land-based. Consolidation has occurred in the last few years with some tower manufacturers going out of business and Chinese manufacturers have become non-competitive with the 90% average tower tariff applied in 2013. Most of the existing tower manufacturers have a book of business through 2014 and some into 2015. This position could change within one or two years, and it is recommended that tower manufacturers look at improved lean processing and also work with steel mills to develop the most cost effective steel sheets since they make up 25-30% of the total cost of a finished wind turbine tower.

The following are the key points for future R&D

- Material is the biggest cost driver at a little over 50% of the cost of a tower. Manufacturers need to work with steel mills to optimize the material and size of the plate to reduce mill cost and tower manufacturing process cost. **R&D Project is recommended for Steel Mills, Tower Manufacturer, and Welding Equipment Supplier.**
- Forged ring flanges are the 2nd biggest cost driver with 17% in the U.S., 30% in China, and 35% in Germany. A large part of the U.S. supply comes from Mexico. The numbers in Germany and China are being reported as conservative. The quickest way to reduce cost is to minimize the number of flanges used in a design. Going from 5 sections to 3 sections per tower would reduce the need for 4 of 10 flanges for a 40% material reduction and 2 less circular welds per tower resulting in approximately $40,000 reduction total.
- Weld Wire is 1% or less for all manufacturers. Although weld wire, weld cavity and welding process play a larger role in the overall welding cost. R&D work in weld wire size-material and process could reduce cost. **R&D Project is recommended for Steel Mills, Tower Manufacturer, and Welding Equipment Supplier.**
- Circular welding is the largest process cost driver and the bottle neck in all manufacturing processes visited. This is also the process step that drives rework and weld repair. The current process of rolling plates – tack weld – L weld –followed by can marriage on a grow line and circular weld is the common process used at all international sites visited. A variation of this process by doing more welding in the flat state with linear welds could provide improvements. **R&D Project is recommended for Steel Mills, Tower Manufacturer, and Welding Equipment Supplier.**
- Final sand blasting and painting was very labor intensive, unless some automation was used on the exterior diameter. Flexible and portable equipment would be beneficial**. Small R&D Automation Project is recommended.**
- Tower production close to water access and close to the wind farm will have the lowest logistics cost. The newest facilities visited have been able to utilize some lean principals, although further opportunities are seen. For offshore having a book of business and water transport access and close proximity to the wind farms will provide the lowest LCOE. Portable weld lines exist today that can be rented and transported to a site, utilized to build the required parts, and then moved to another job.

1.2 Blades Competitiveness Analysis

1.2.1 Introduction

One three-blade set comprises the second highest percentage cost of major wind turbine components at 15-26%. These numbers would be similar for land-based and offshore blades. Blades capture the energy of the wind in the swept area and convert the force of the wind into the torque needed to generate useful electrical power. The cost breakdown for the blade includes material, labor, burden, SGA (Sales General Administrative), engineering, logistics, and profit.

Fig. 1.2.1 – Blade after Paint and Blade in Transit

The Process of Obtaining a Global Cost Comparison

Design

One design was developed with a common bill of material (BOM) to obtain a global cost comparison. GLWN collaborated with NREL to develop a standard design that could be quoted globally. NREL had a 5MW system design in place that was being used for other analysis and project work. NREL's blade expert developed a detailed design with manufacturing drawings of all blade structural components. A complete set of drawings (12 total – Laminate LESW, Laminate LP, Laminate TESW, Root HP, Root LP,SC HP, SC LP, TE HP, TE LP, Geometry, BOM Weights) and bill of materials was developed that detailed all components, mass, and material specifications.

Identification of Global Suppliers

The current major global suppliers were identified in the U.S., China, Germany. Targeted suppliers were asked to participate. Two suppliers per region were identified to provide an aggregated representation of data. Some suppliers were visited but did not provide full cost breakdowns. Suppliers in Germany and China were building offshore blades.

Blade Manufacturers Bio's (primary representation of land-based blades with some offshore)

	Annual Blade Sales 2012 (Combined)	Annual Blade Capacity as of 2013 (Combined)	Blades built to date
USA (3)	2,030	2,400	12,500
China (2)	5,100	5,700	32,000
Germany (2)	720	900	3,300

Blade Schematic

Blade Total Mass – 21,132 kg

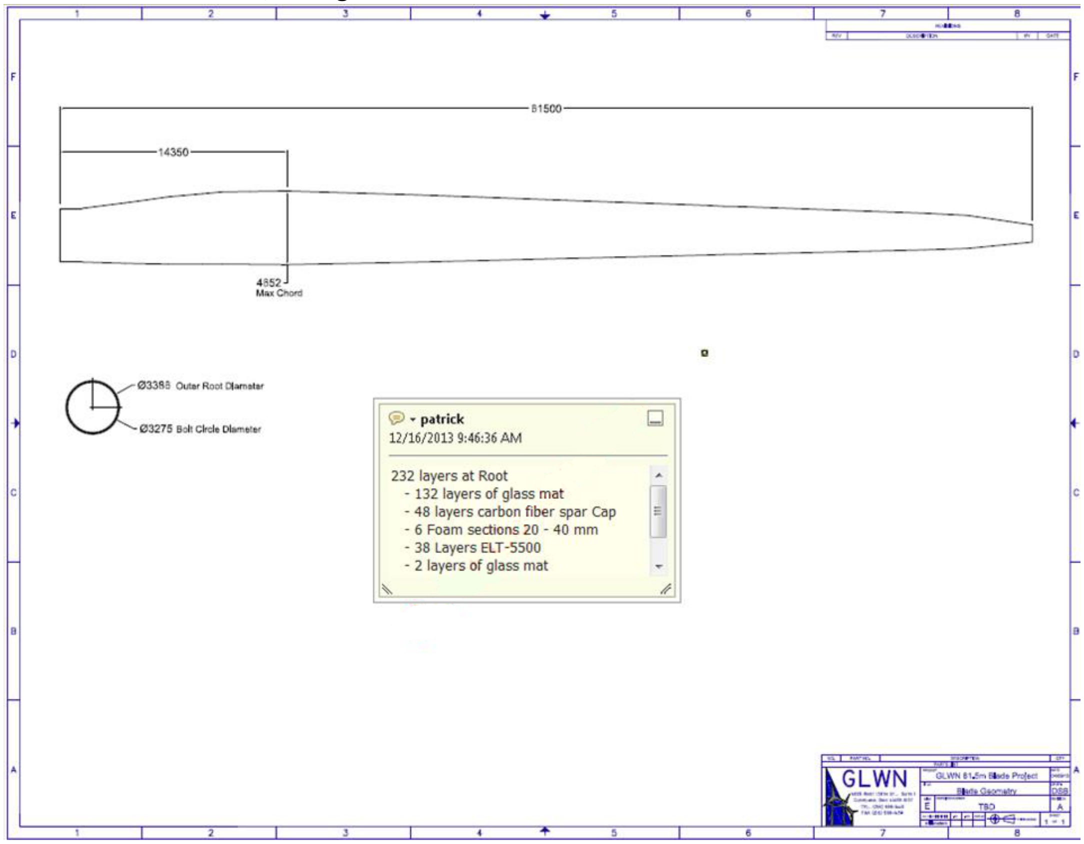


Fig. 1.2.2a Schematic of 5MW Blade used in this study

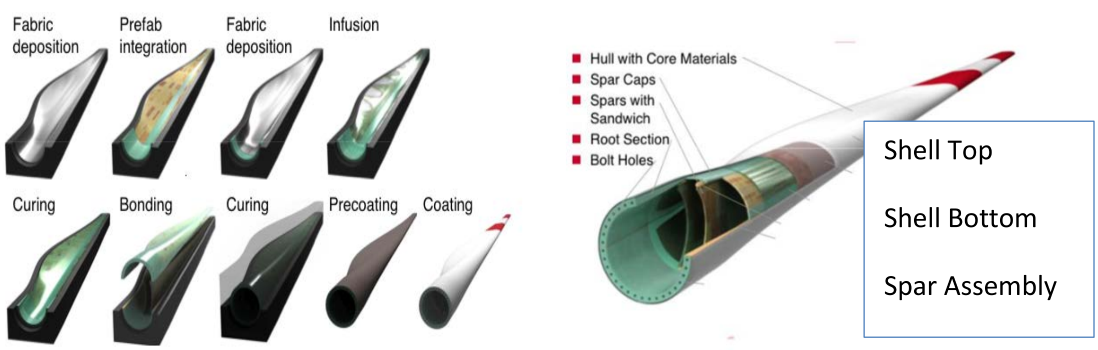


Fig. 1.2.2b Blade Process and Cross-Section – Credit BASF Corporation

1.2.2 AGGREGATED Regional Cost Breakdown for Blades

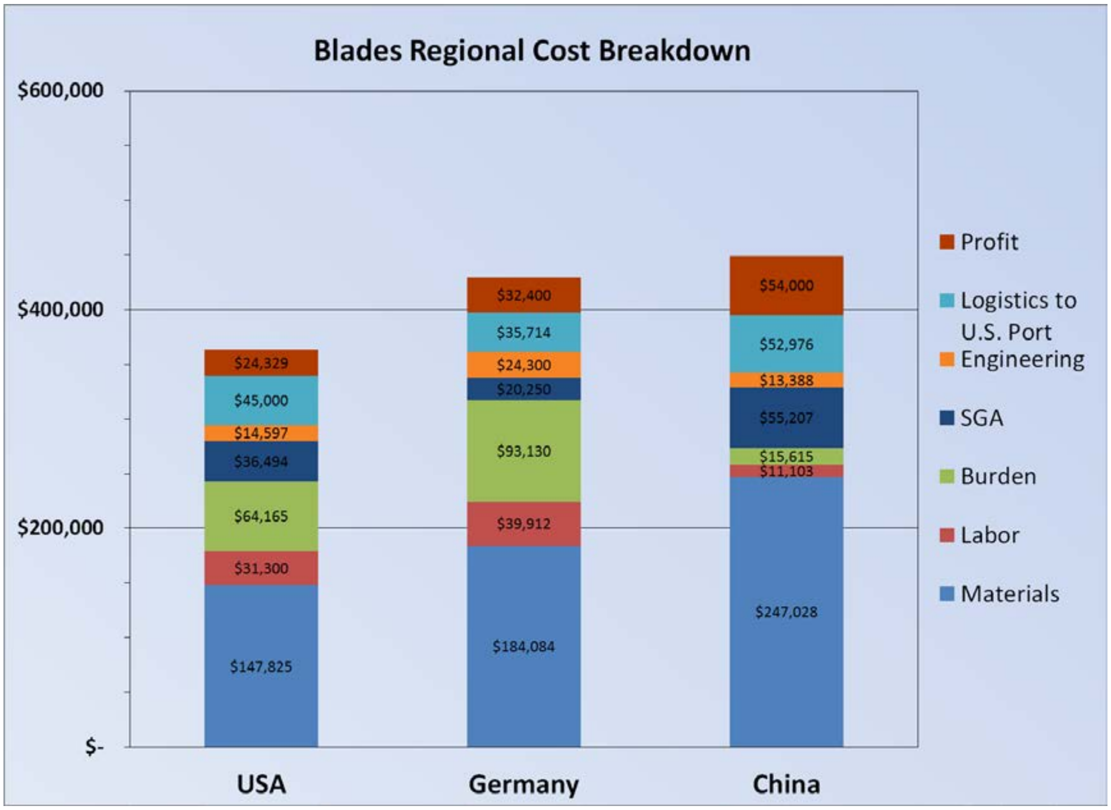


Fig. 1.2.3a Aggregated Regional Cost Breakdown in $

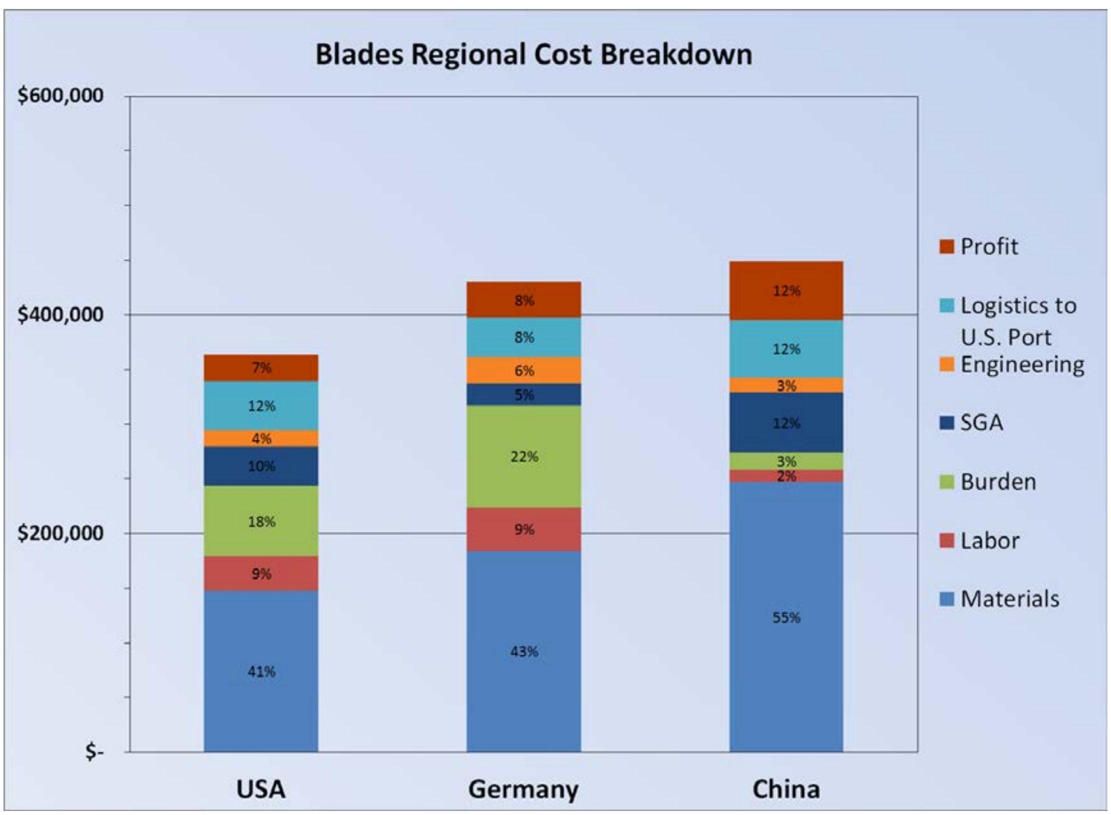


Fig. 1.2.3b Aggregated Regional Cost Breakdown in %

Regional Cost Breakdown - Blades

Description: The Regional Cost Breakdown in the seven cost categories is represented in dollars in Figure 1.2.3a and represented in percentages in Figure 1.2.3b

Findings:

- Material is the largest cost driver in all regions running from 41% to 55%. The lowest material cost is in the U.S., with Germany at +4% and China at +34%. The one China Supplier indicated they are using all U.S. or European material to meet their current customer specifications. Another China supplier that did not provide a full cost breakdown indicated they were using all China produced materials, with the fiberglass coming from a sister plant. All indications were that they had equal or lower cost than U.S. material. Another supplier with global operations in U.S. and China who did not provide a cost breakdown had advised that they buy material from suppliers that provide material for the same price at all global operations. This is a common practice of global material price for global companies. The Chinese company with the higher material cost does not have global blade operations. This was a limited snap shot study and numbers may vary depending on quoting circumstances.
- Labor & Burden combined is the 2nd largest at 27% for the U.S. and 31% for Germany. China is at 5%. The labor rate played a big part in the difference, but also plant fixed amortization cost and other played a role in this number.
- A major international logistics company provided the shipping cost for a full vessel load. The costs reflected are from closest port from manufacturer to a common Port of New Bedford, MA along the Atlantic Coast. The highest cost is from China at 12%, Germany at 8% and U.S. from the Midwest by truck to the Great Lakes and St. Lawrence Seaway to the Atlantic Ocean at 12%. A U.S. west coast delivery would decrease the cost from China and increase cost from central U.S. and Germany FOB points.
- SGA for the U.S. is 10%, Germany at 5% and China at 12%
- Engineering in Germany is 6%, U.S. is 4%, and China is 3%
- Profit in Germany is 8%, U.S. is 7%, China is 12%

1.2.3 MATERIALS – Regional Cost Breakdown for Blades

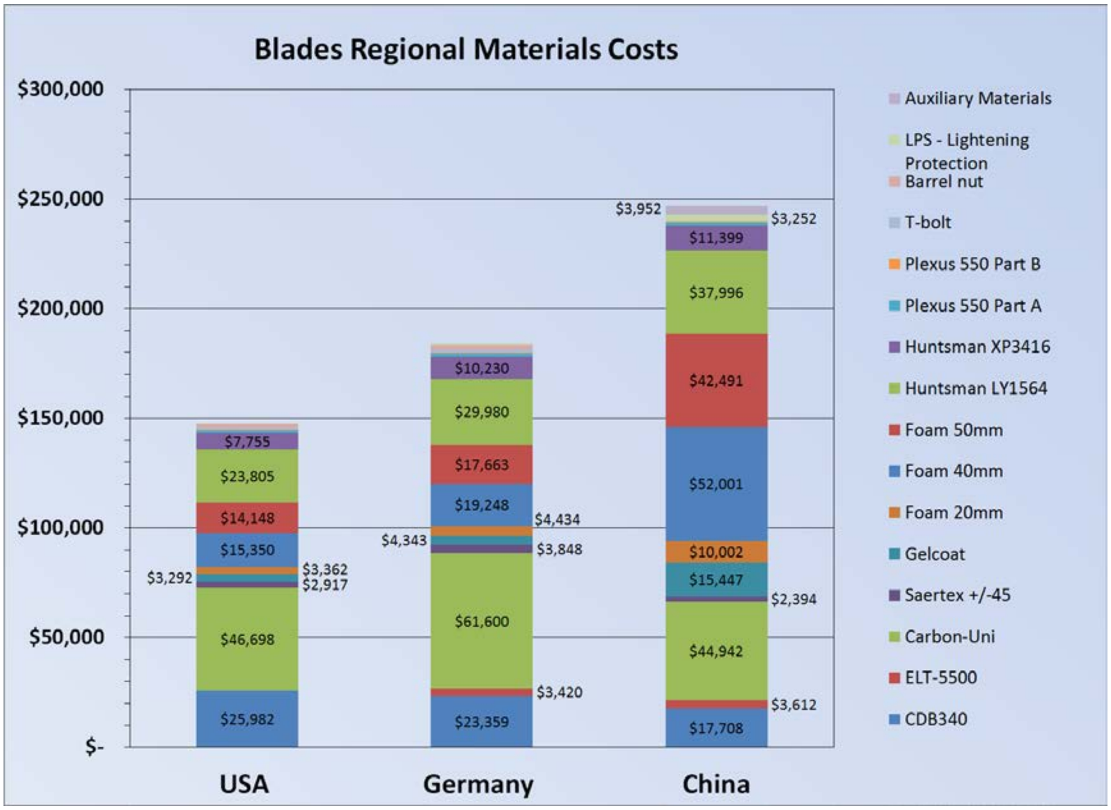


Fig. 1.2.4a Materials Regional Cost Breakdown by Region in $

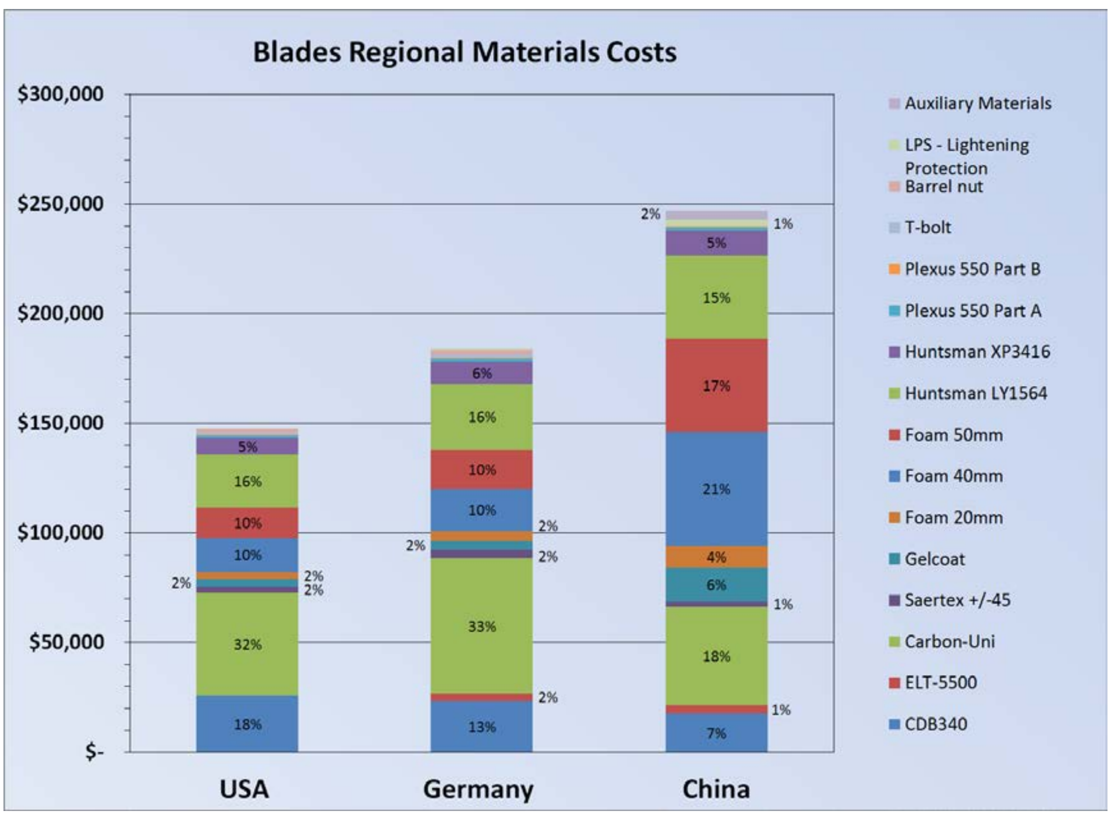


Fig. 1.2.4b Materials Regional Cost Breakdown by Region in %

Materials Cost Breakdown - Blades

Description: Material - There are 16 Components in the Material Category listed in Figure 1.2.4a and Figure 1.2.4b

Findings: Material

- Material is the biggest cost driver in all regions from 41% to 55% of the cost of a blade. The four main component families below make up ~90% of the total material cost
  - Uni-directional Carbon accounts for 32% or $46,698 in the U.S., 18% or $44,943 in China, 33% or $61,600 in Germany
  - Foam combined (50mm, 40mm, 20mm) accounts for 22% or $32,860 in the U.S., 42% or $104,494 in China, 22% or $41,335 in Germany
  - Resin accounts for 21% or $31,560 in the U.S., 20% or $49,395 in China, 22% or $40,210 in Germany
  - Fiberglass Mat accounts for 18% or $25,982 in the U.S., 7% or $17,708 in China, 13% or $23,359 in Germany

1.2.4 LABOR – Regional Cost Breakdown for Blades

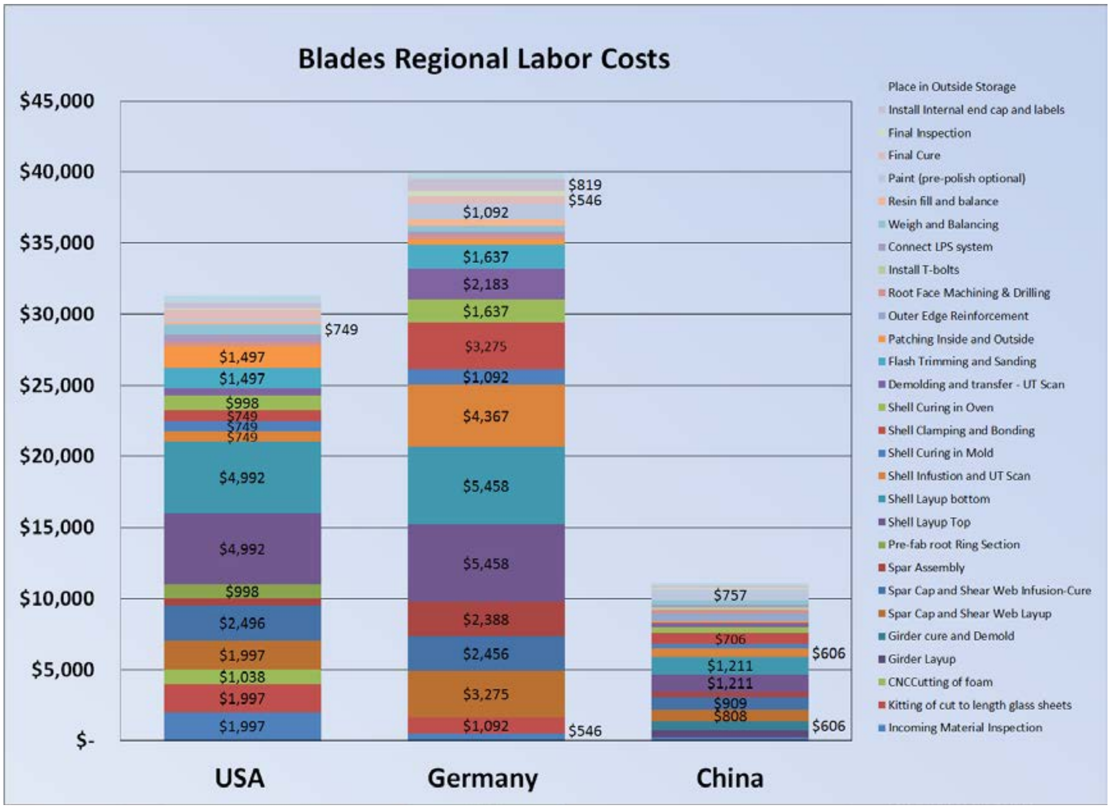


Fig. 1.2.5a – Labor Regional Cost Breakdown in $

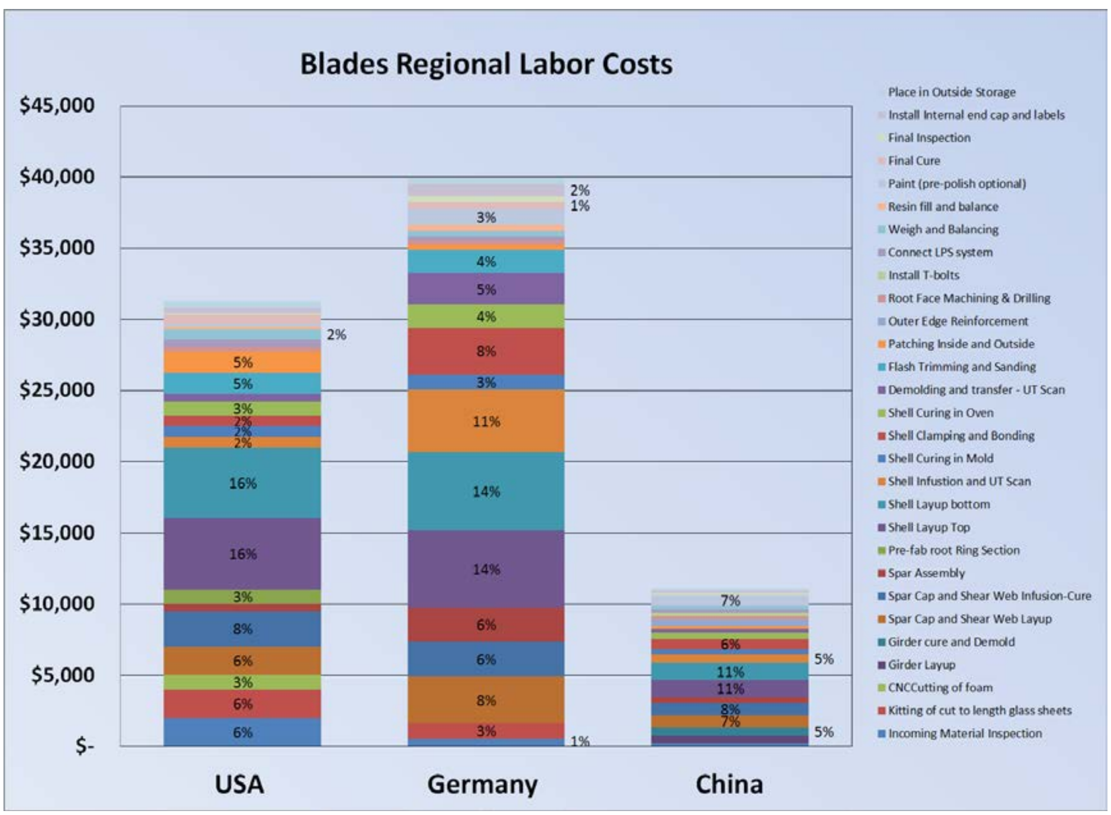


Fig. 1.2.5b – Labor Regional Cost Breakdown in %

Value Stream Map - Blades

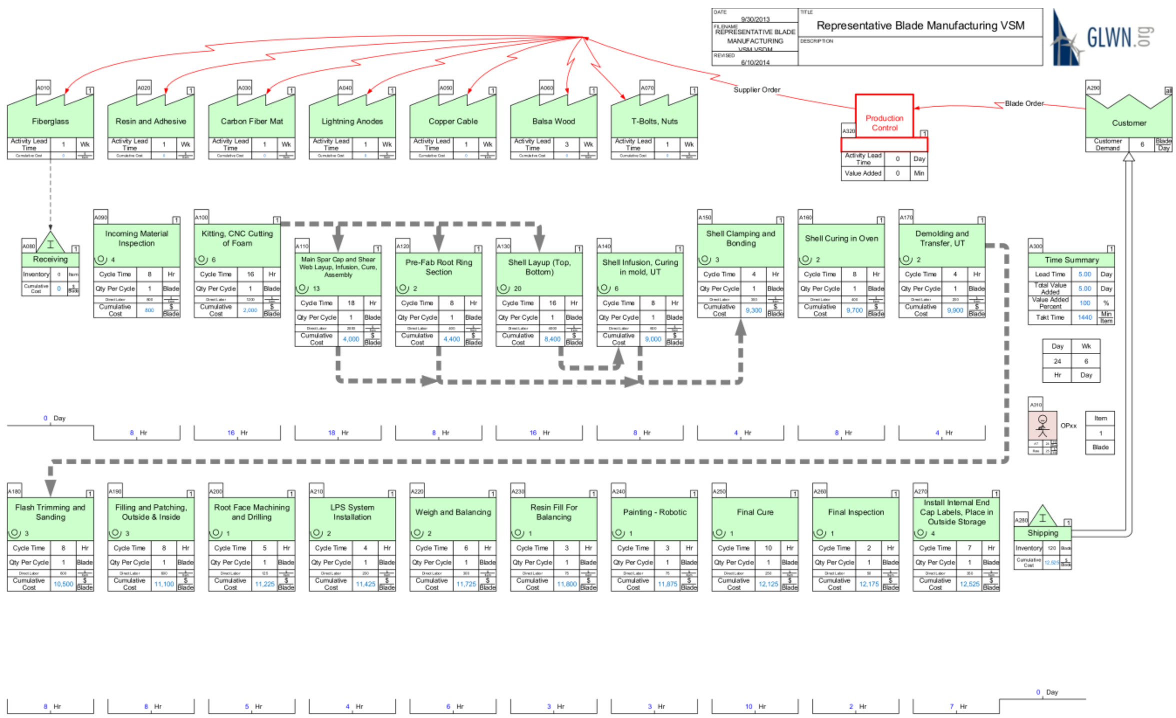


Fig. 1.2.6 Representative Manufacture's Value Stream Map

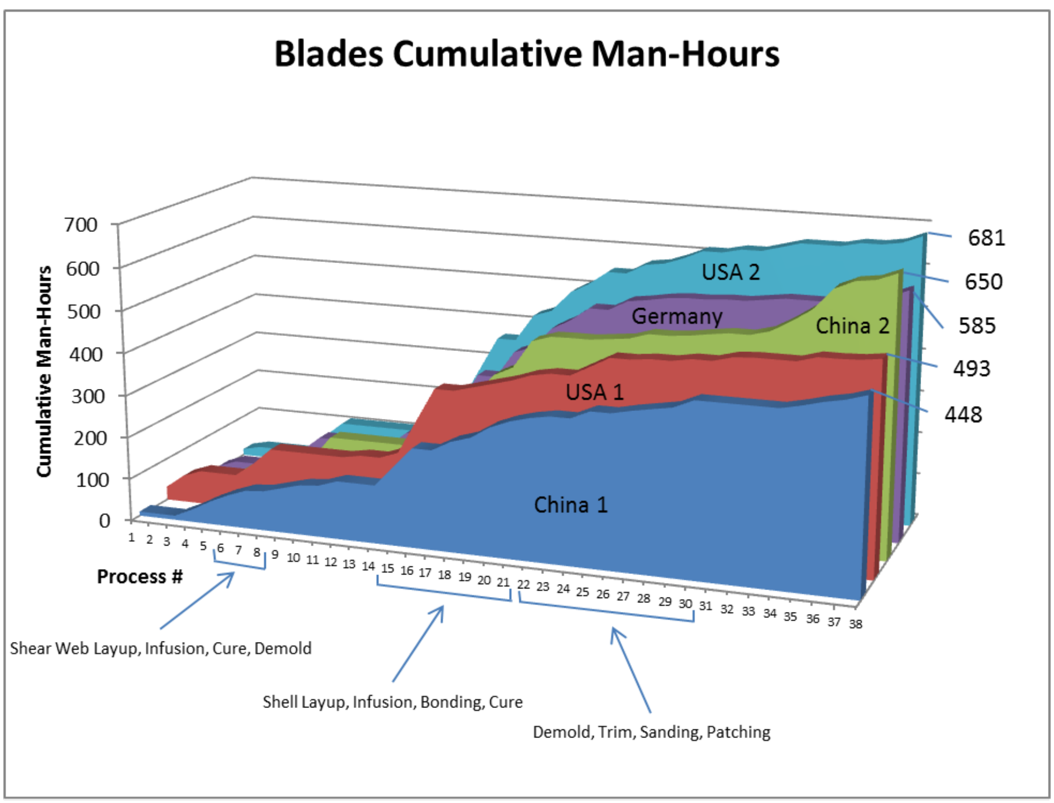


Fig. 1.2.7 Cumulative Labor Man-Hours by Process by Region

Description: Blade labor has 29 Process Steps

1. Incoming Material Inspection
2. Kitting of cut to length glass sheets
3. CNC Cutting of foam
4. Girder Layup
5. Girder cure and De-mold
6. Spar Cap and Shear Web Layup
7. Spar Cap and Shear Web Infusion-Cure
8. Spar Assembly
9. Pre-fab root Ring Section
10. Shell Layup Top
11. Shell Layup bottom
12. Shell Infusion and UT Scan
13. Shell Curing in Mold
14. Shell Clamping and Bonding
15. Shell Curing in Oven
16. De-molding and transfer - UT Scan
17. Flash Trimming and Sanding
18. Patching Inside and Outside
19. Outer Edge Reinforcement
20. Root Face Machining & Drilling
21. Install T-bolts
22. Connect LPS system
23. Weigh and Balancing
24. Resin fill and balance
25. Paint (pre-polish optional)
26. Final Cure
27. Final Inspection
28. Install Internal end cap and labels
29. Place in Outside Storage

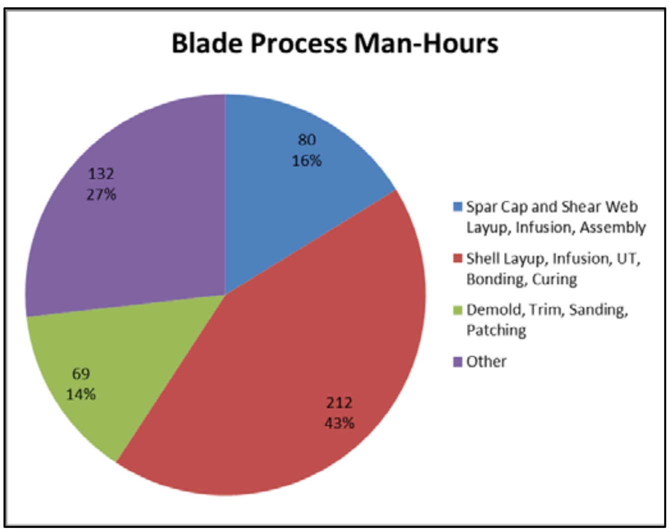


Fig. 1.2.8 Pie Chart U.S.A. Man-Hours

Labor Cost Breakdown - Blades

Description: Labor – Cost is the sum of all direct labor hours to produce a part.

- **Figure 1.2.5a & b** details the cost by process category which is driven by process category man hours.
- **Figure 1.2.6** is a representative Value Stream Map (VSM) which was developed for each manufacture. Value stream mapping is a lean management tool used to analyze and design the flow of materials and information required to bring a product to a consumer. It identifies value added and non-value added activity.
- **Figure 1.2.7** is the cumulative man hours from the VSM by process in the regions studied.

- **Figure 1.2.8** is a Pie Chart of the major process step man-hours.

Findings: Labor

- Labor overall is at 9% in the U.S. and Germany and only 2% in China. In all three regions labor is lower than material, burden, SGA, and logistics
- The following are the highest labor cost processing groups:
  - Shell top & bottom lay-up, Infusion, Bonding, and Curing accounts for 42% or $13,229 in the U.S., 53% or $21,287 in Germany, 41% or $4,541 in China.
  - Spar cap and Shear Web Layup Infusion, Cure, and Assembly accounts for 16% or $4,992 in the U.S., 20% or $8,119 in Germany, 18% or $2095 in China.
  - Demold, Flash Trim & Sand, and Patch accounts for 12% or $3493 in the U.S., 10% or $4,229 in Germany, 4% or $429 in China.

1.2.5 BURDEN – Regional Cost Breakdown for Blades

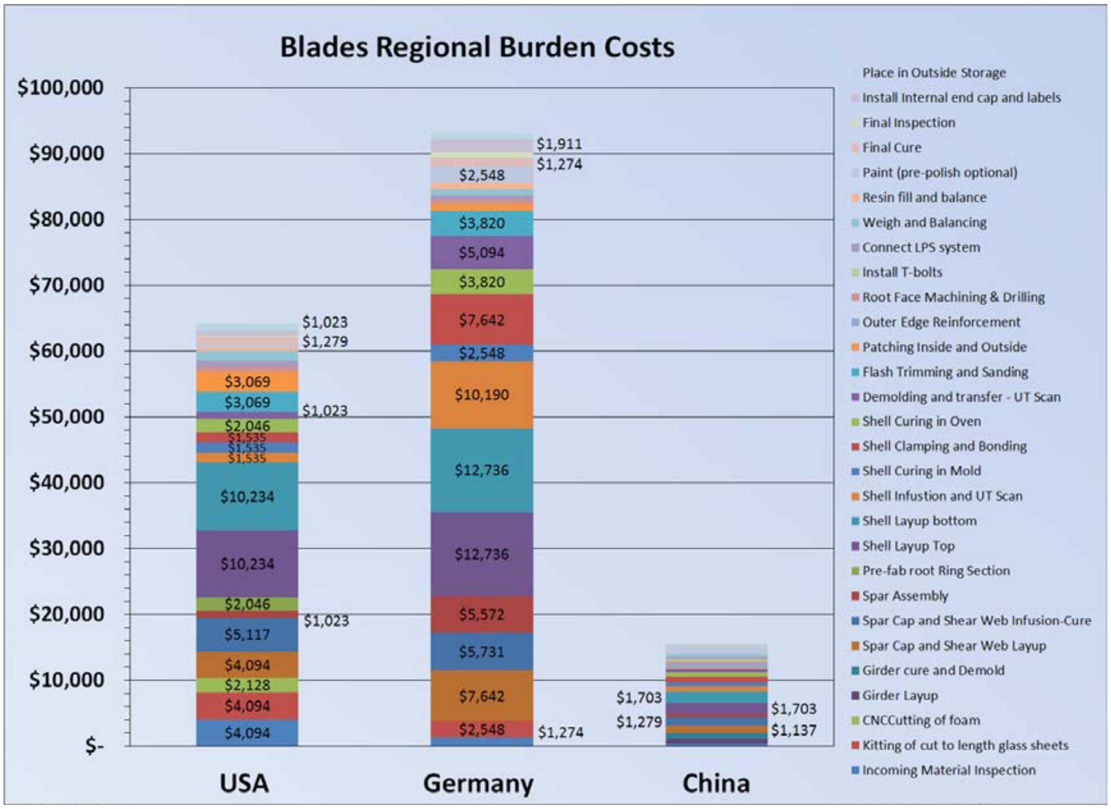


Fig. 1.2.9a Burden Regional Cost Breakdown in $

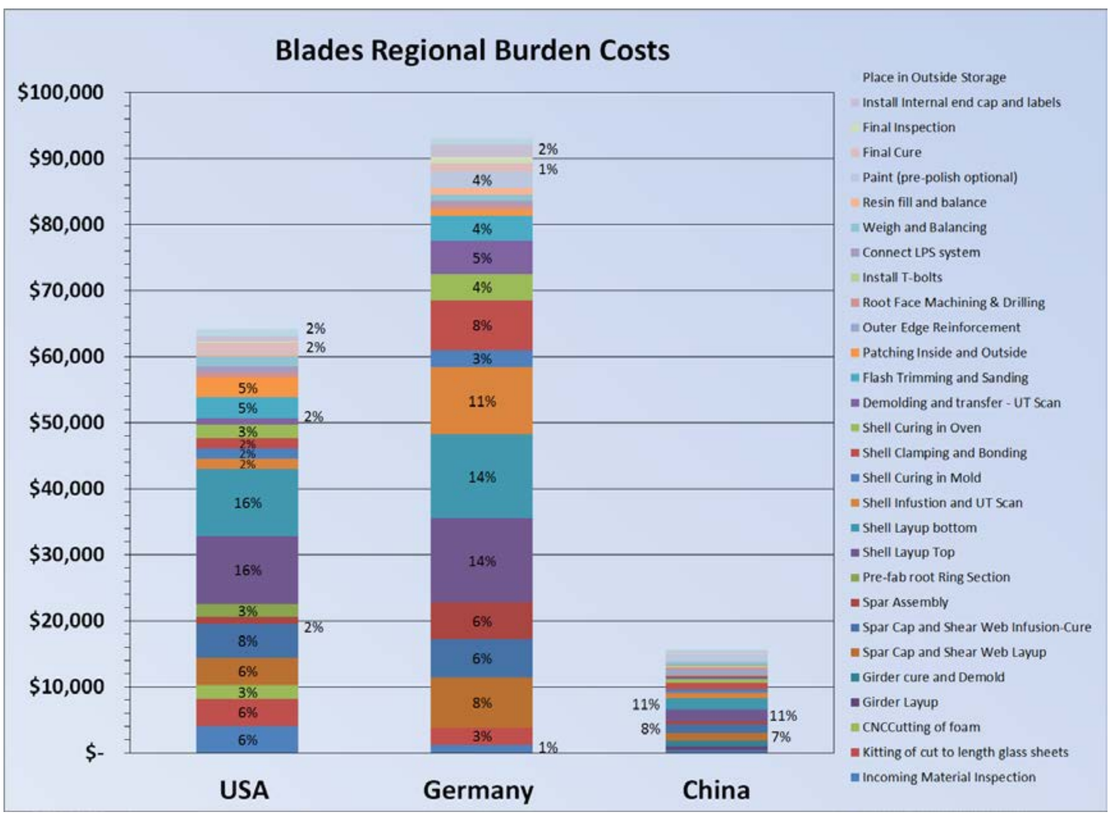


Fig. 1.2.9b Burden Regional Cost Breakdown in %

Burden Cost Breakdown - Blades

Description: Burden - Cost is the sum of the indirect variable labor cost and plant fixed cost as represented in Figure 1.2.9a in dollars, and Figure 1.2.9b in percentage.

Findings: Burden

- Burden costs on blades was the second highest cost contributor in the U.S. and Germany and the fourth highest in China. Burden consists of the indirect variable labor and plant fixed cost. It is 2x the labor in the U.S., 2.4x in Germany, and 1.5x in China.
- The following are the highest burden cost process groups (they follow the labor trend)
  - Shell Top & Bottom Lay-up, Infusion, Bonding, Curing accounts for 42% or $27,119 in the U.S., 53% or $49,672 in Germany, 41% or $6,387 in China
  - Spar Cap and Shear Web Layup Infusion, Cure, and Assembly accounts for 16% or $10,234 in the U.S., 20% or $18,945 in Germany, 18% or $2,948 in China
  - Demold, Flash Trim & Sand, and Patch accounts for 12% or $7,161 in the U.S., 10% or $9,868 in Germany, 4% or $603 in China
- Burden cost could be reduced in all areas by doing a full ABC cost analysis on all variable and fixed cost drivers. Direct labor reduction would also reduce indirect labor / burden.

1.2.6 SGA (Sales, General, Administrative) – Regional Cost Breakdown for Blades

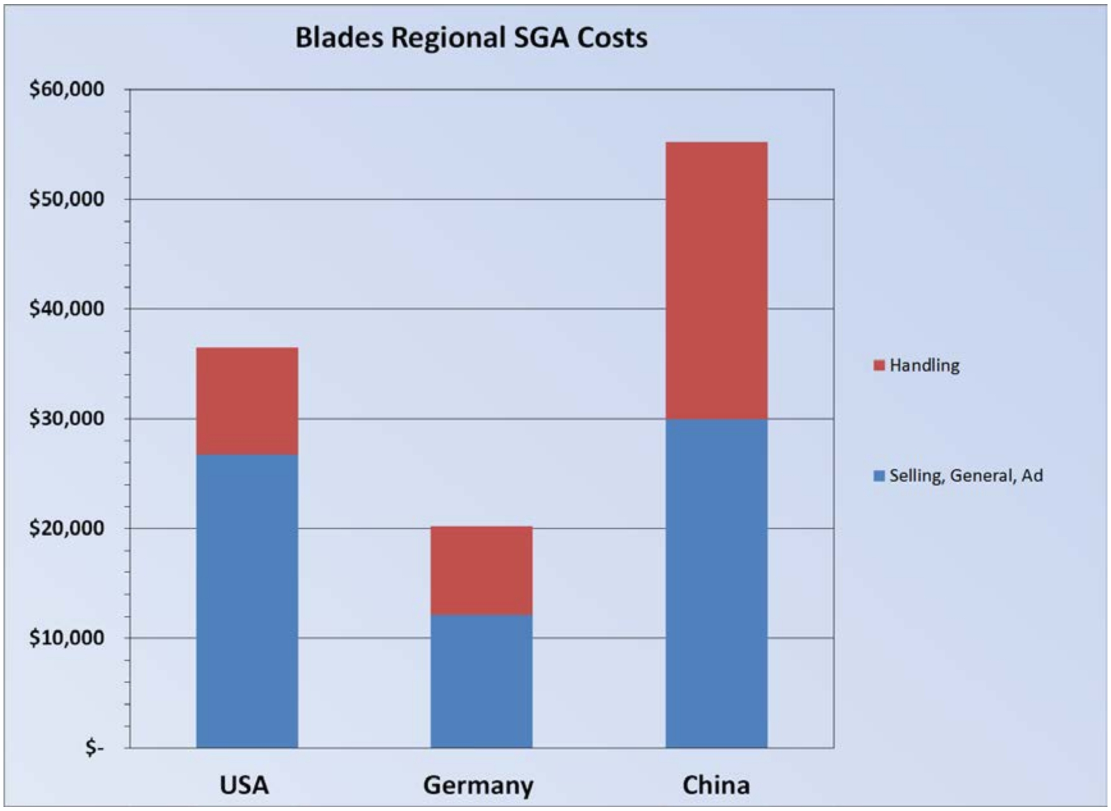


Fig. 1.2.10 SGA Regional Cost Breakdown in $

SGA Cost Breakdown - Blades

Description: SGA - Cost of Sales, General, Administrative, Accounting, Executive Salaries, travel, and special handling as represented in Figure 1.2.10.

Findings: SGA

- SGA and Handling accounted for 10% of the U.S. cost, 5% of the Germany cost, and 12% of the China cost.
- The following was the breakdown by region:
  - U.S. $26,762 SGA and $9,732 Handling
  - Germany $12,150 SGA and $8,100 Handling
  - China $29,967 SGA and $25,240 Handling. China was not doing anything different than other regions. The higher number is more the method of accounting.

1.2.7 ENGINEERING – Regional Cost Breakdown for Blades

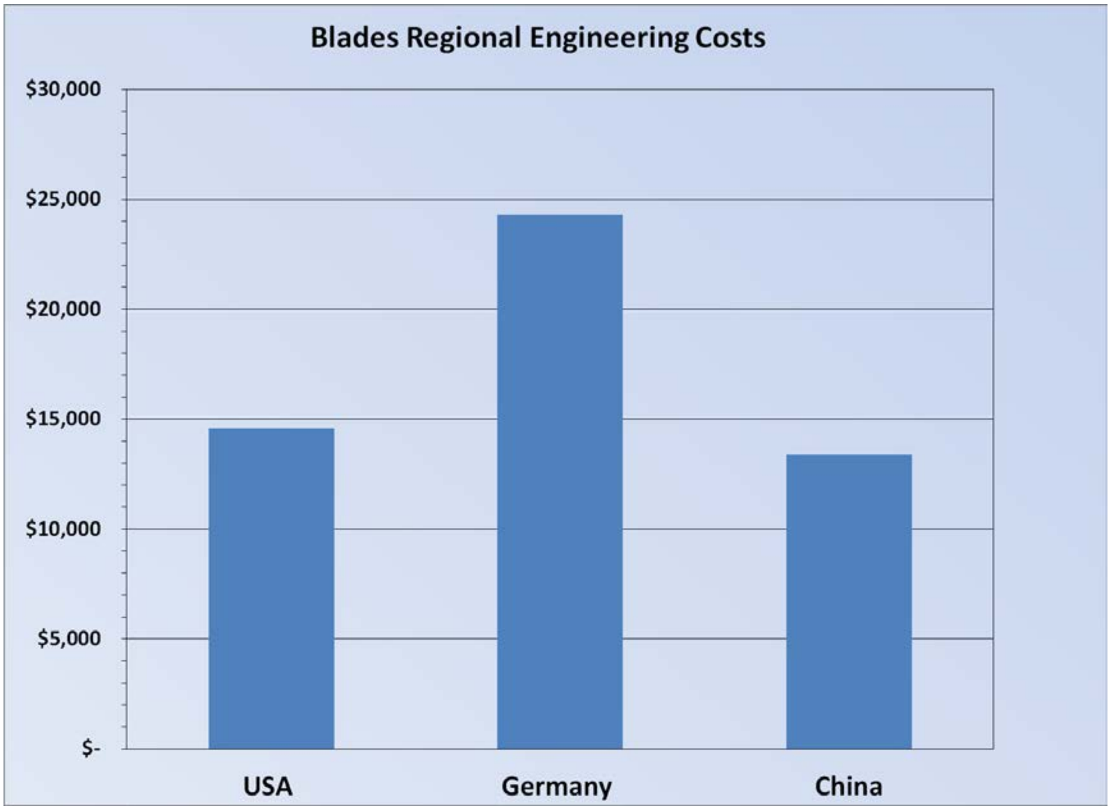


Fig. 1.2.11 Engineering Regional Cost Breakdown in $

Engineering Cost Breakdown - Blades

Description: Engineering - Cost of all Engineering: Product, Development, Manufacturing as represented in Figure 1.2.11.

Findings: Engineering

- Engineering accounted for 4% of cost in the U.S., 6% in Germany, 3% in China
- Overall Blades had more Engineering cost than Towers. It showed across all regions. Blades with chemical processes require more Product and Process Engineering follow up to insure quality of the product.

1.2.8 LOGISTICS – Regional Cost Breakdown for Blades

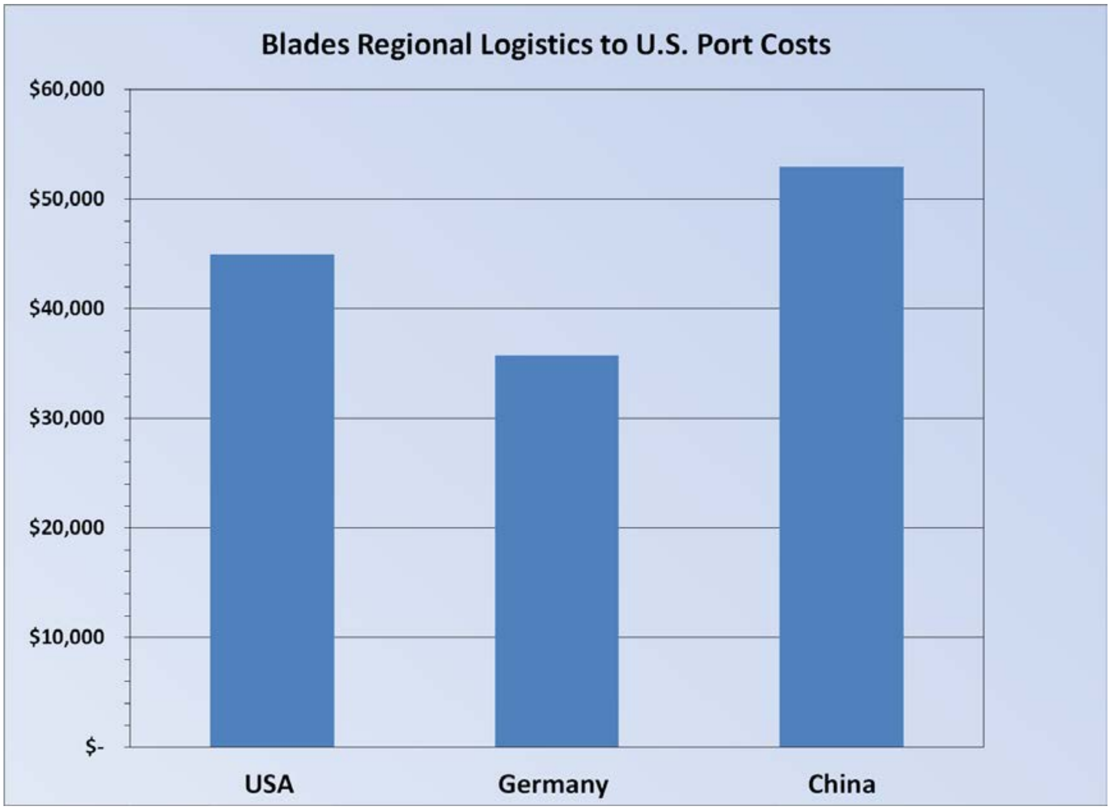


Fig. 1.2.12 Logistics Regional Cost Breakdown to the Port of New Bedford, MA

Logistics Cost breakdown - Blades
Description: Logistics - cost breakdown from manufacturer port to Port of New Bedford, MA

Findings: Logistics

- With common shipping space requirements, the cost is driven by total transport time. China is the highest followed by the U.S. and then Germany. The U.S. cost was based upon manufacture in the Great Plains and transport by truck to the Great Lakes, through the St. Lawrence Seaway and down the Atlantic Coast to the Port of New Bedford, MA. The transportation cost would have been minimal if manufactured along the Atlantic Coast.

1.2.9 PROFIT – Regional Cost Breakdown for Blades

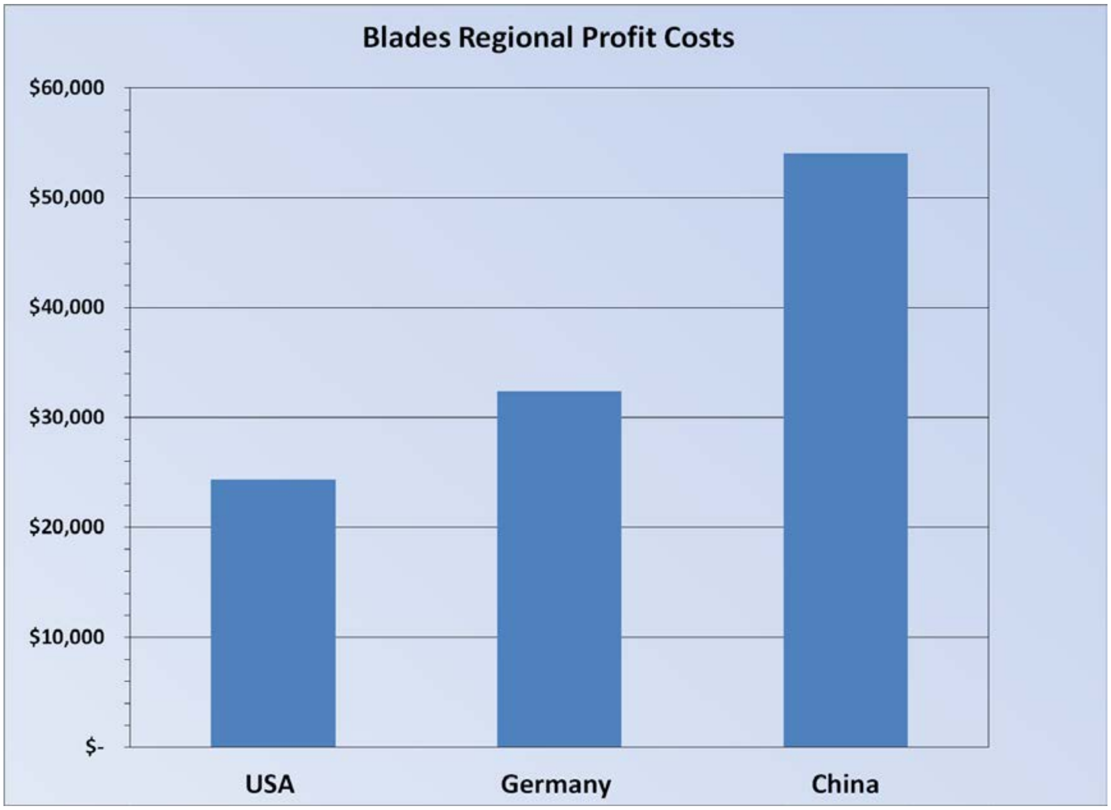


Fig. 1.2.13 Profit Regional Cost Breakdown

Profit Cost breakdown - Blades

Description: Profit - The reported profit portion of the selling price

Findings: Profit

- The reported profit range is 7-12%. This could be verified with a full on site cost analysis.

.

1.2.10 Overall Blade Observations and Conclusions

Blades are the second largest cost driver of a wind turbine at approximately 15-26% of the wind turbine cost. Material is 44% of the cost of the blade of which carbon fiber mat, foam, fiberglass mat, and resin account for 90% of the material. Labor and burden is 27% of the cost of the blade. An R&D project that optimizes the three legs of the stool would be most helpful: Material- Process-Design. This is a chemical process and needs material and process setting improvements that provide material cost and process time reductions. Incremental improvements can be made by better use of plant assets and focusing manpower resources in the processes that eliminate lag times in infusion, molding and downstream processes. Also, continued blade design and analysis that maximizes power output and minimizes material usage, while leveraging automotive and aerospace composite knowledge.

U.S. blade manufacturers are in a good position today for the land-based market. Most blade manufacturers have a book of business that will carry them through 2014 and some into 2015. The design, process and material technology is fairly consistent globally. The U.S. has only one blade manufacturing plant close to the Atlantic coastal areas that will see the first offshore wind farms (Atlantic, Great Lakes and Gulf). The technology, bill of process, and equipment is very portable and could be installed at a central coastal location once farms and turbine suppliers are identified.

The Cost Breakdown data shows the top three cost contributors which we should be focusing on are material, burden, and logistics cost for the larger blades.

To make further cost reductions in blades one would need to focus on all three: Design-Materials-Process. Changes in just one of the three would not have significant effects. It is the integration and optimization of all three that will result in larger reductions.

1.3 Permanent Magnet Generators Competitiveness Analysis

1.3.1 Introduction

Generators contribute on average +/- 7% of the cost of the wind turbine. The permanent magnet (PM) generator is being used more frequently in wind turbine and offshore applications as it reduces the number of total components and operations & maintenance expenses. The PM generators are unique to each application and also a wide variation in cost. The cost breakdown for the generator includes material, labor, burden, SGA (Sales General Administrative), engineering, logistics, and profit.

Fig. 1.3.1 Permanent Magnet Generator Section

The Process of Obtaining a Global Cost Comparison

Design

Between GLWN and NREL we were not able to develop a generic 5MW permanent magnet generator design to be able to quote globally. All the 5MW designs in production today are design specific to a given Wind Turbine nameplate. The IP is either with the wind turbine OEM or generator manufacturer. For purposes of cost breakdown in this study we had used a current production 1MW medium speed PM Generator for global quoting. A 2.5MW PM generator Value Stream Map was developed based upon a current direct drive permanent magnet produced overseas for a non-U.S. application.

Identification of Global Suppliers

The current major global suppliers were identified in the U.S., China, and Germany. Targeted suppliers were asked to participate but most of them did not due to intellectual property concerns. The following is the aggregated representation of the limited data.

Generator Manufacturers Bio's (primary representation of land-based towers with some offshore)

	Annual Generator Sales	Annual Generator Capacity	Generators built to date
USA	$7M	300	150
China	$390M	8,900	22,100
Europe	$50M	1000	4,500

1MW Permanent Magnet Generator Description

Description of Purchased Components for 1MW Permanent Magnet Generator	Size (MM)	Quantity	Mass(kg)	Total Mass (kg)
Magnet Assembly	100X22X18	1100	0.25	275
Rotor Assembly (less Magnets)	ϕ1550X500	1	1800	1800
Stator Assembly	ϕ1900X590	1	5000	5000
Housing	ϕ2050X900	1	3200	3200
Terminal Boxes	600X300X250	2	20	40
Bearing Assembly	ϕ1950X100	1	2100	2100
Total				12415

Cost Breakdown Analysis (CBA) Form

For the Cost Breakdown Analysis we were only able to obtain the detailed material cost breakdown for a 1MW PM Generator by region. A cost percentage breakdown provided by current global manufacturers was used for all the other categories.

- Material – 6 material categories in actual quote
- Labor – Total cost was based upon a percentage
- Burden – Total cost was based upon a percentage
- SGA (Sales General Administrative) – Total cost was based upon a percentage
- Engineering – Total cost was based upon a percentage
- Logistics – Quoted cost to transport from manufacturer to Port of New Bedford, MA (Atlantic Coast)
- Profit – Total cost was based upon a percentage

Plant Visits

All plants were visited by the Principle Investigator. The Principle Investigator provided a project overview and the host plant provided a plant overview. A detailed plant tour was provided that walked the process flow. Process flow diagrams were also reviewed.

A Value Stream Map (VSM) was generated which mapped out the process steps in the PM Generator value stream. Value added and non-value added time was derived

1.3.2 AGGREGATED Regional Cost Breakdown for PM Generators

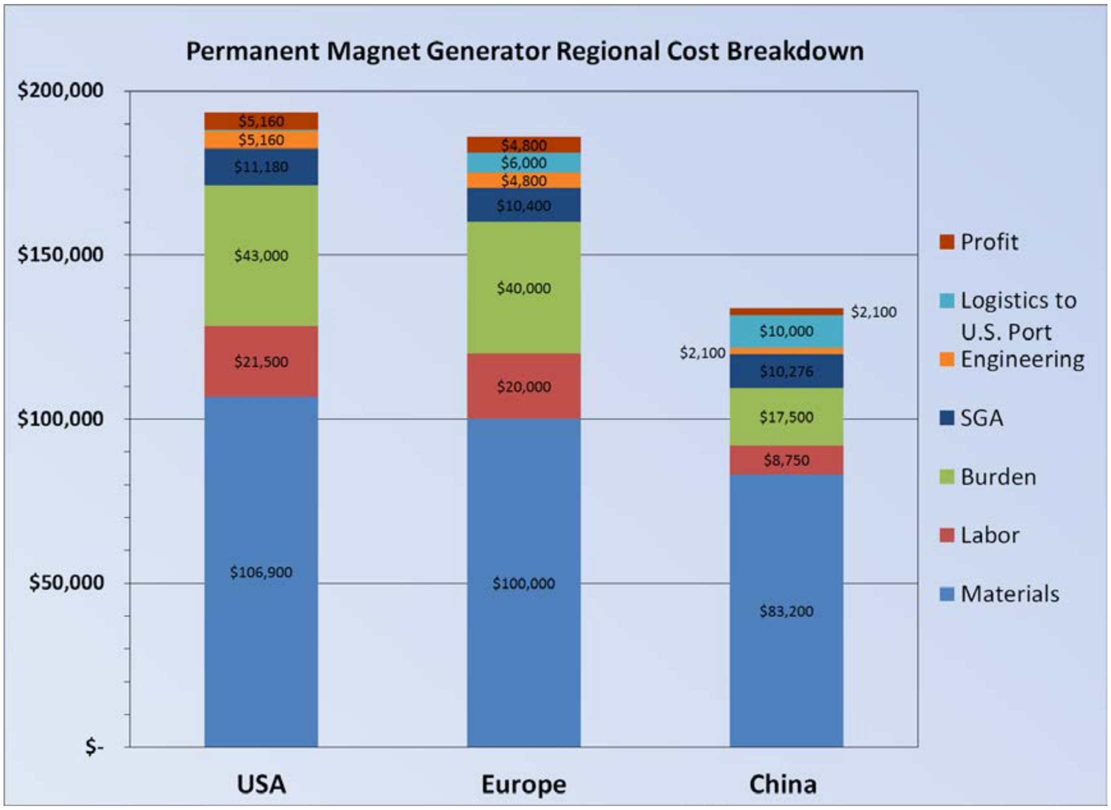


Fig. 1.3.2a Aggregated Regional Cost Breakdown in $ (1MW PM Generator)

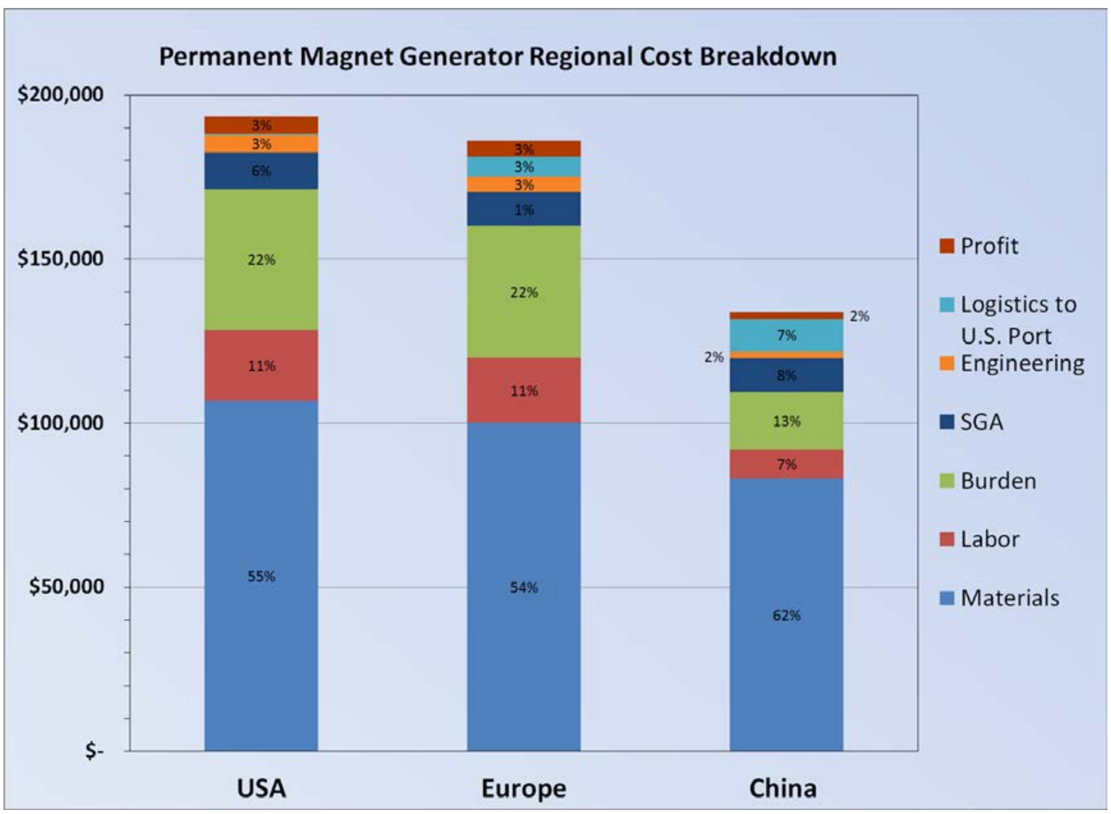


Fig. 1.3.2b Aggregated Regional Cost Breakdown in % (1MW PM Generator)

Regional Cost Breakdown – PM Generators

Description: PM Generators - The Regional Cost Breakdown in the seven cost categories is represented in dollars in Figure 1.3.2a and represented in percentages in Figure 1.3.2b.

Findings: PM Generators

- Material is the largest cost driver in all regions running at 54- 62%. The lowest material cost is in China, with the U.S. at +29% and Europe at +20%
- Labor and burden combined is the second largest cost driver at 33% for the U.S., 33% for Europe, and China at 20%.
- Logistics to a common New Bedford, MA port is highest from China at 7%, Europe at 3% and U.S. at <1%
- SGA for the U.S. and Europe is 6%, and China at 8%
- Engineering in Europe and U.S. is 3%, and China is 2%
- Profit in Europe is 3%, U.S. is 3%, China is 2%

1.3.3 MATERIALS – Regional Cost Breakdown for PM Generator

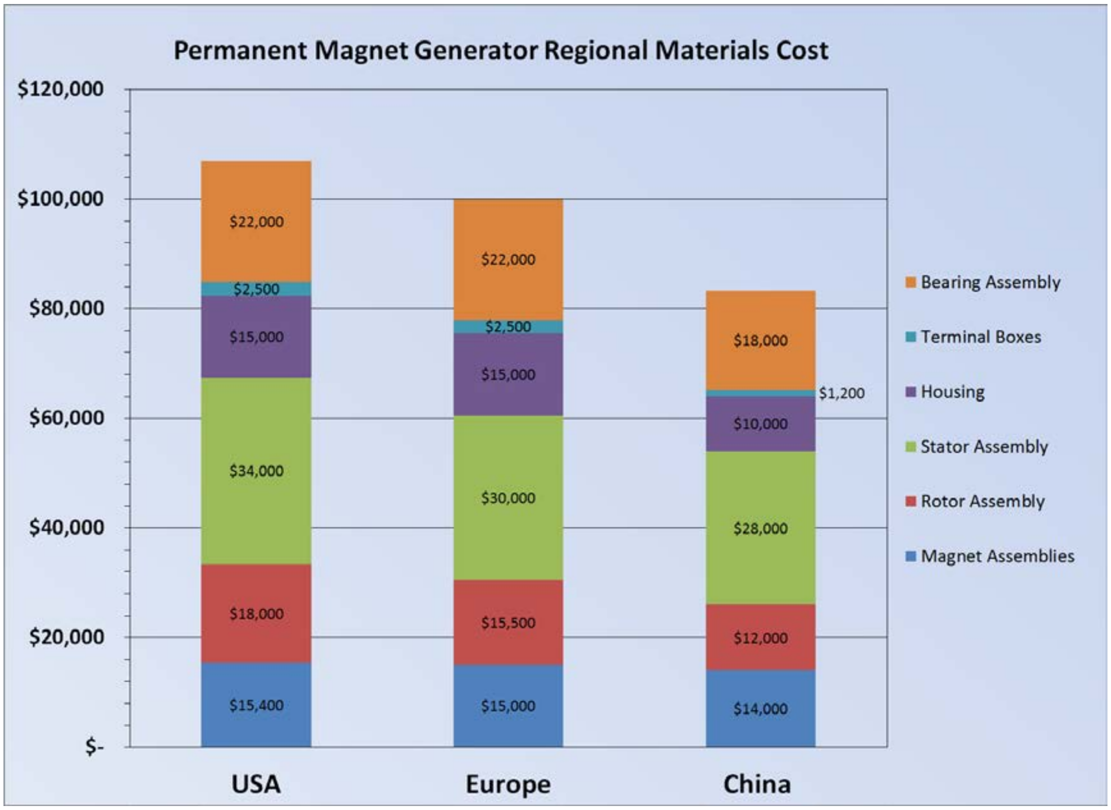


Fig. 1.3.3a Materials Regional Cost Breakdown in $ (1MW PM Generator)

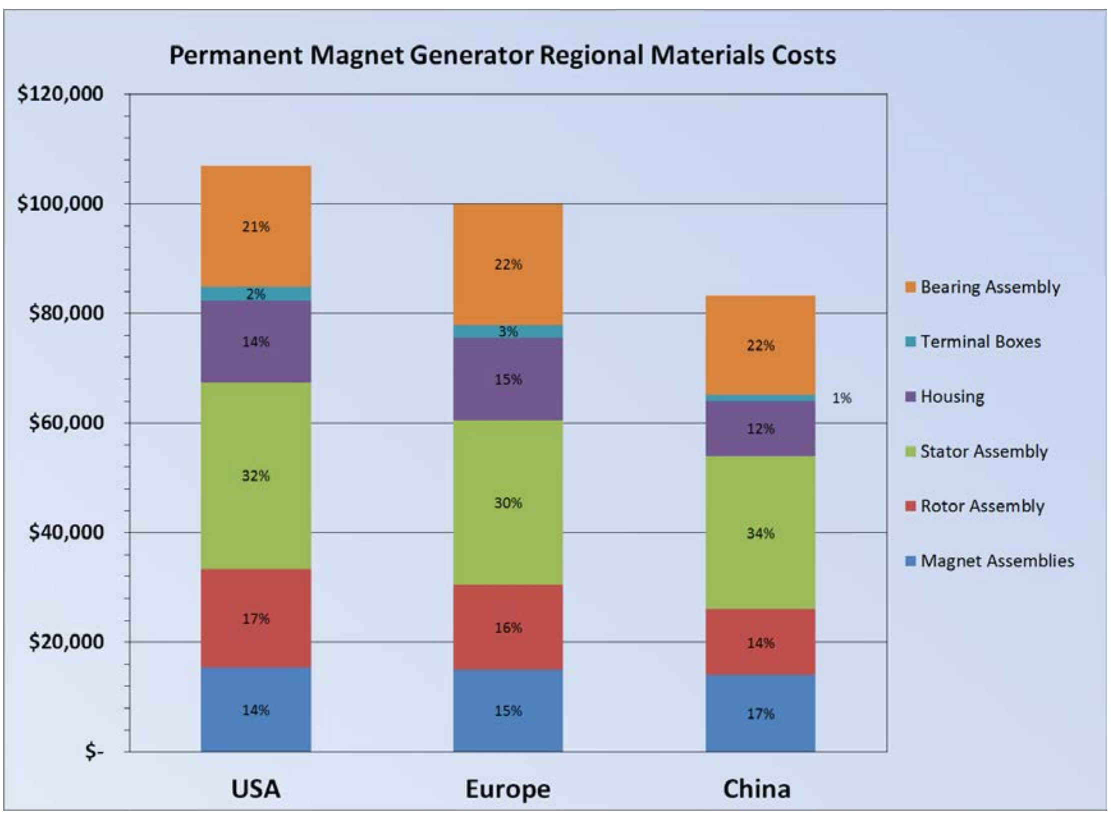


Fig. 1.3.3b Materials Regional Cost Breakdown in % (1MW PM Generator)

Materials Cost Breakdown – PM Generators

Description: Material - there are 6 Components in the Material Category represented in Figure 1.3.3a by dollars, and Figure 1.3.3b by percentage: Magnet Assemblies, Rotor Assembly, Stator Assembly, Housing, Terminal Boxes, Bearing Assembly (NOTE: This is unique to the 1MW and may vary with different designs)

Findings: Materials

- Material is the biggest cost driver at 54-62% of the cost of a PM Generator
- Stator Assembly is the largest material cost driver at 32% in the U.S., 34% in China, 30% in Europe
- Bearing Assembly is the 2nd largest cost driver with 21% in the U.S., 22% in China, and 22% in Germany
- Rotor Assembly is the 3rd largest cost driver with 17% in the U.S., 16% Europe and 14% in China.
- Magnet Assemblies (including the rare earth magnet) is the 4th largest driver running 14 to 17 % in all regions. In this cost estimate all magnet assemblies came from China with a 10% premium for U.S. and China

1.3.4 LABOR – Regional Cost Breakdown for PM Generator

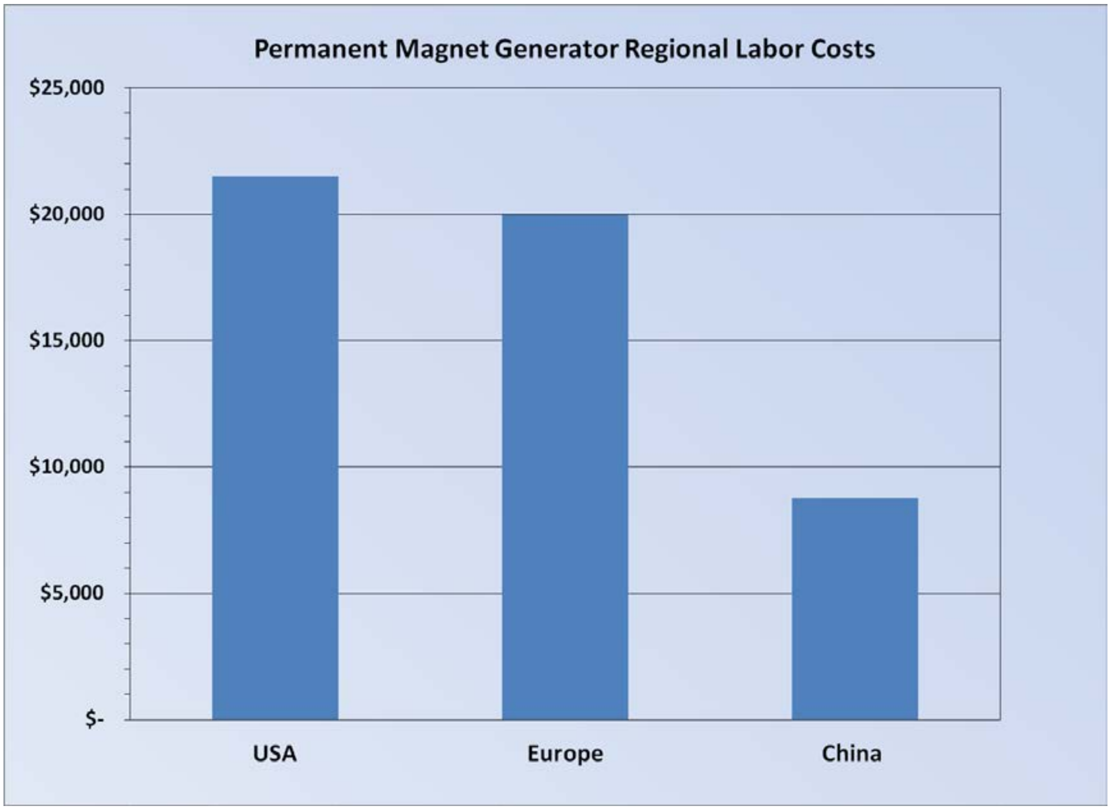


Fig. 1.3.4 Labor Regional Cost Breakdown in $ (1MW PM Generator)

Value Stream Map – Generator Rotor Frames

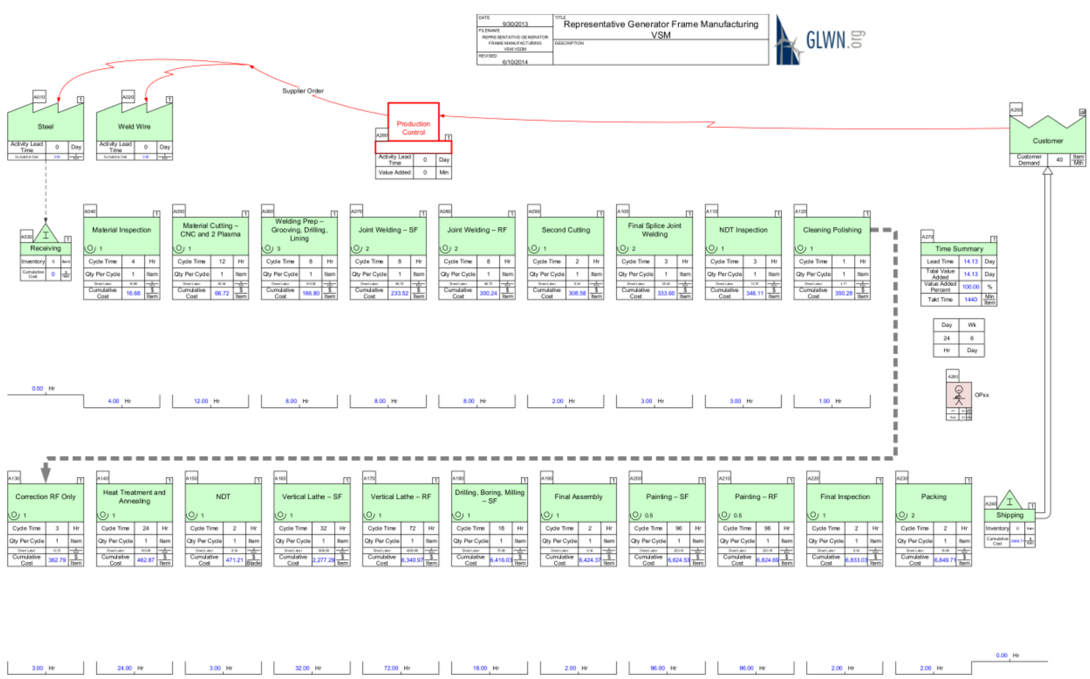


Fig. 1.3.5 VSM for Stator and Rotor Frames (2.5MW PM Generator)

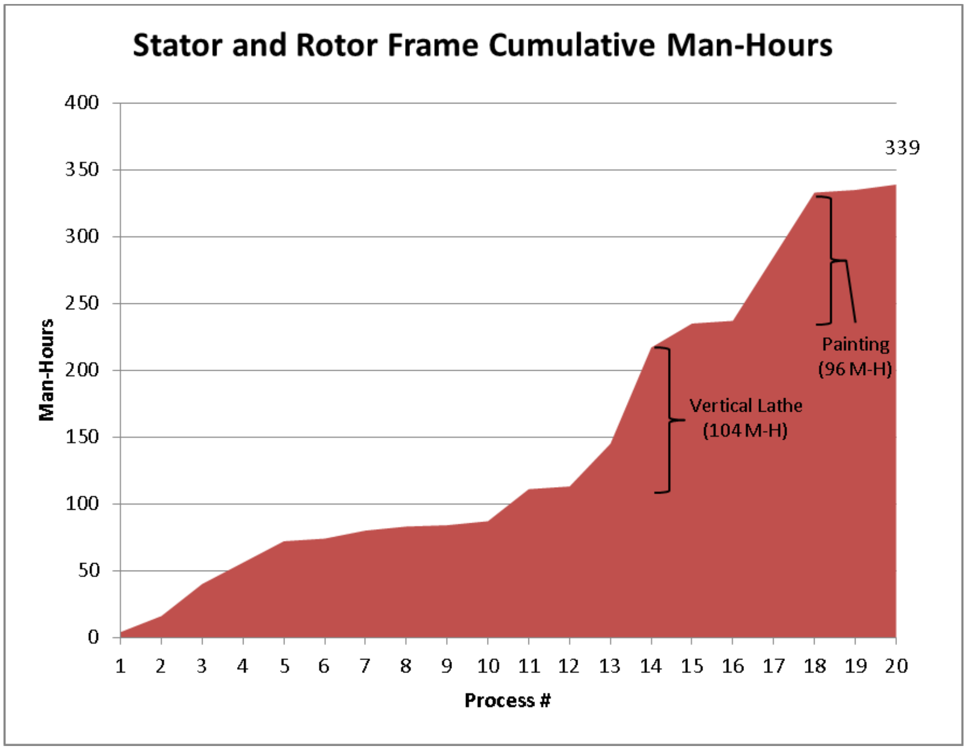


Fig. 1.3.6 Stator and Rotor Frame Cumulative Man-Hours (2.5MW PM Generator)

Value Stream Map - Generator Rotor Assembly

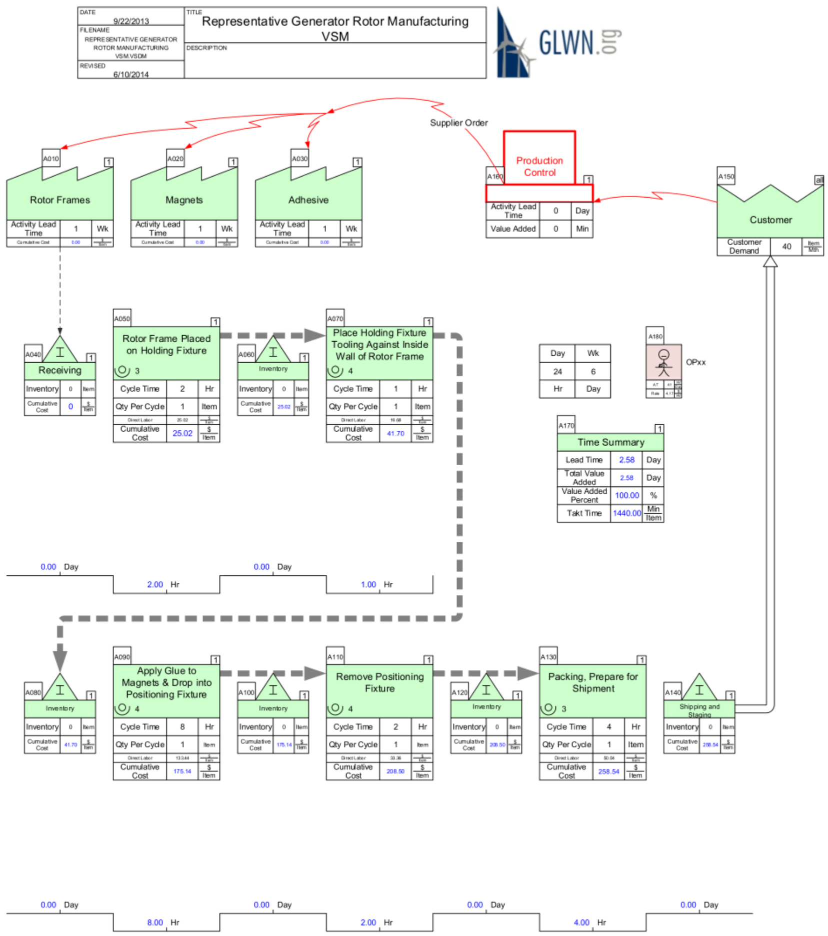


Fig. 1.3.7 VSM for Rotor Assembly (2.5MW PM Generator)

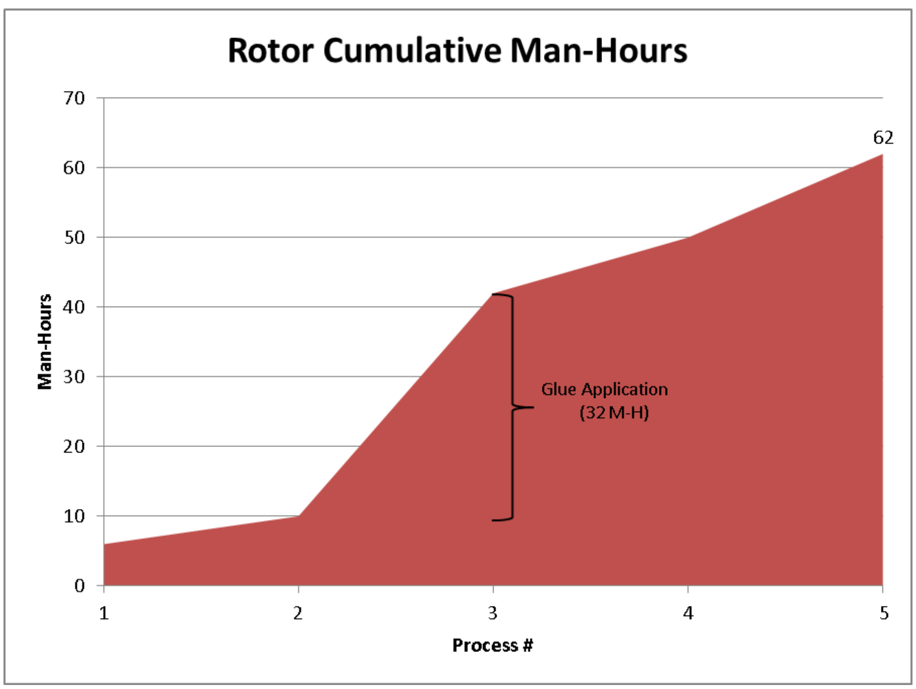


Fig. 1.3.8 Rotor Assembly Cumulative Man-hours (2.5MW PM Generator)

Value Stream Map - Generator Stator Assembly

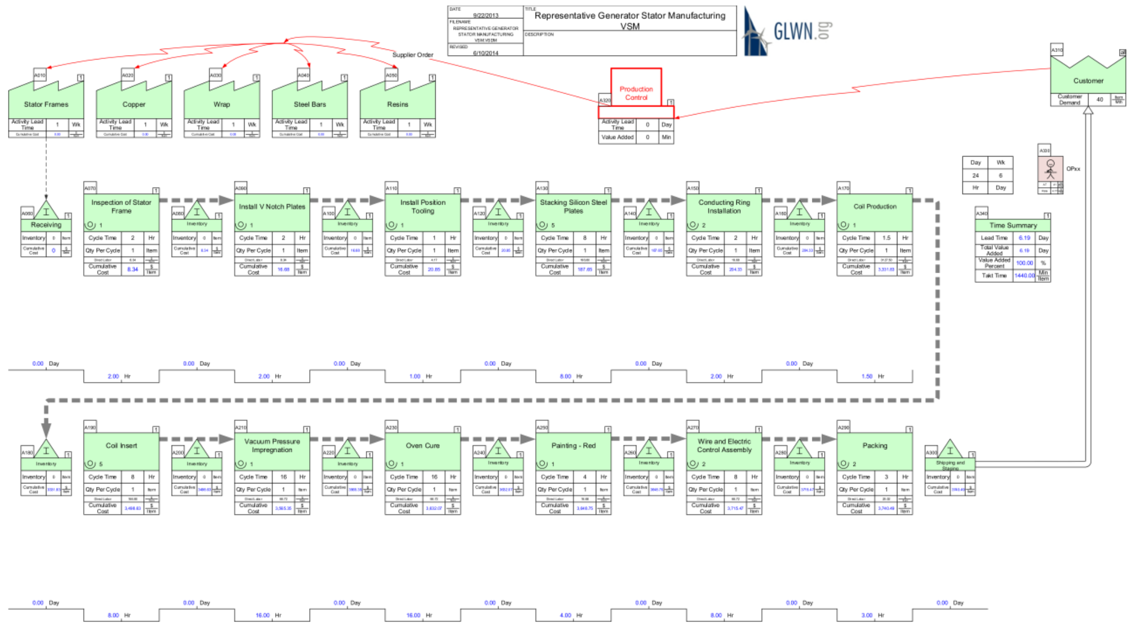


Fig. 1.3.9 Stator Assembly VSM (2.5MW PM Generator)

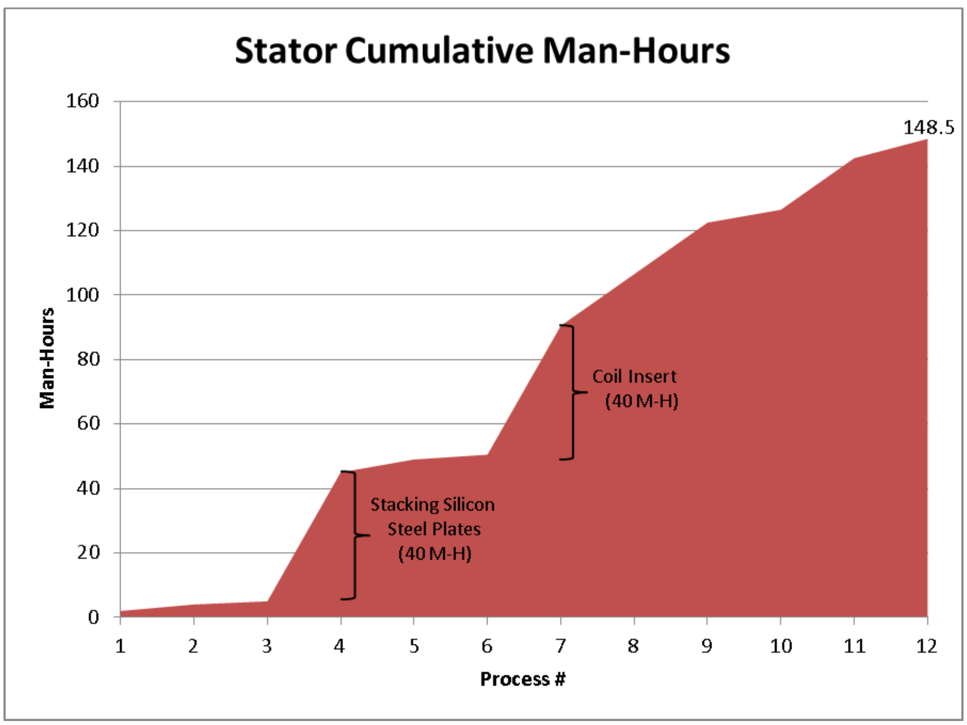


Fig. 1.3.10 – Stator Assembly Cumulative Man-Hours (2.5MW PM Generator)

Labor Cost Breakdown – 2.5MW PM Generators

Description: Labor – Cost is the sum of all direct labor hours to produce a part

- 20 Process Steps for Stator & Rotor Frames for 2.5MW
- 9 Process Steps for Stator Assembly, and

- 5 Process Steps for Rotor Assembly

Stator & Rotor Frames

1	Inspection Material	11	Heat Treatment and Annealing
2	Material Cutting - CNC and 2 Plasma	12	NDT
3	Welding Prep - Grooving, Drilling, Lining	13	Vertical Lathe - SF
4	Joint Welding - SF	14	Vertical Lathe - RF
5	Joint Welding - RF	15	Drilling, Boring, Milling - SF
6	Second Cutting	16	Final Assembly
7	Final Splice joint welding	17	Painting - SF
8	NDT inspection	18	Painting - RF
9	Cleaning Polishing	19	Final Inspection
10	Correction RF only	20	Packing

Stator Assembly

1	Inspection of Stator Frame	5	Coil Insert
2a	Install V notch plates	6a	VPI - Vacuum Pressure Impregnation
2b	Install Position Tooling	6b	Oven Cure
2c	Stacking Silicon Steel Plates	7	Painting -Red
3	Conducting ring installation	8	Wire and Electric Control Assembly
4	Coil production	9	Packing

Rotor Assembly

1	Finished Rotor Frame from XADF placed on holding fixture
2	Place holding fixture tooling against inside wall of rotor frame
3	Apply glue to magnets and drop into positioning fixture
4	Remove positioning fixture
5	Packing

Findings:

- Stator and Rotor Frame Welding are the largest Cost drivers at 339 total hours. Within the 339 hours the vertical lathe machining accounts for 104 hours and painting for 96 hours.
- Rotor Assembly has a total of 62 hours with the gluing operation of the permanent magnets at 32 of those hours.
- Stator Assembly has a total of 148 hours with Stacking of Steel Plates and coil insert at 40 hours each.

1.3.5 BURDEN – Regional Cost Breakdown for PM Generators

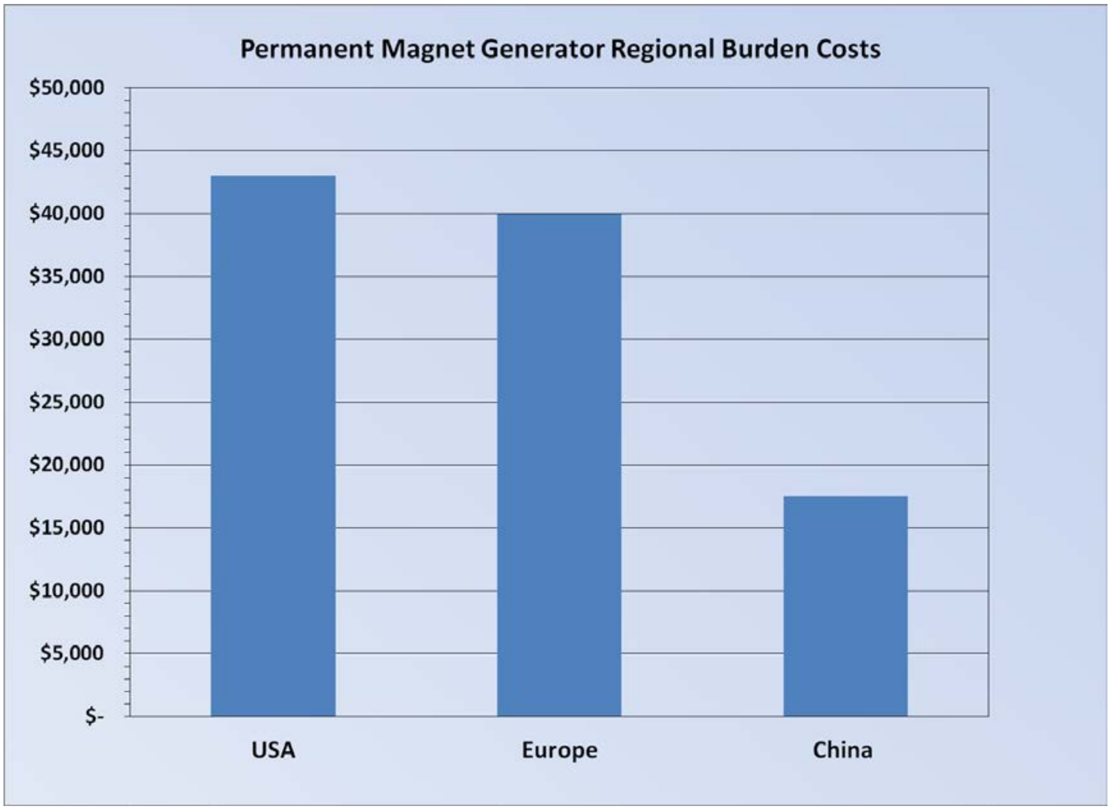


Fig. 1.3.11 Burden Regional Cost Breakdown (1MW PM Generator)

Burden Cost Breakdown – PM Generators

Description: Burden - the variable indirect labor cost and fixed plant cost

Findings: Burden

- Burden in China is 40% of the burden in U.S. and Europe

1.3.6 SGA (Sales, General, Administrative) – Regional Cost Breakdown for PM Generators

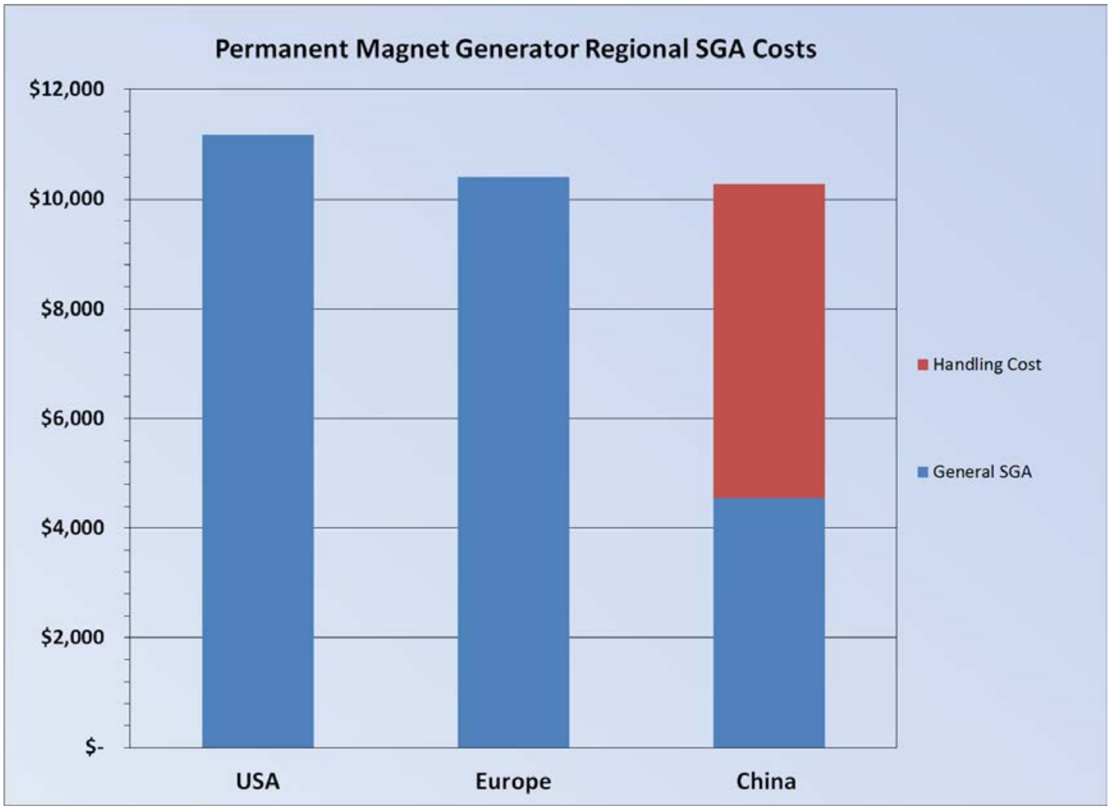


Fig. 1.3.12 SGA Regional Cost Breakdown in $

SGA Cost breakdown – PM Generator

Description: SGA - Cost of Sales, General, Administrative, Accounting, Executive Salaries, travel, and Special Handling as represented in Figure 1.3.12.

Findings: SGA

- SGA and Handling accounted for 6% of the U.S. cost, 4% of the Europe cost, and 8% of the China cost.
- The following was the breakdown by region
  - o U.S. $11,180 SGA
  - o Germany $10,400 SGA
  - o China $4,550 SGA and $5,726 Handling

1.3.7 ENGINEERING– Regional Cost Breakdown for PM Generators

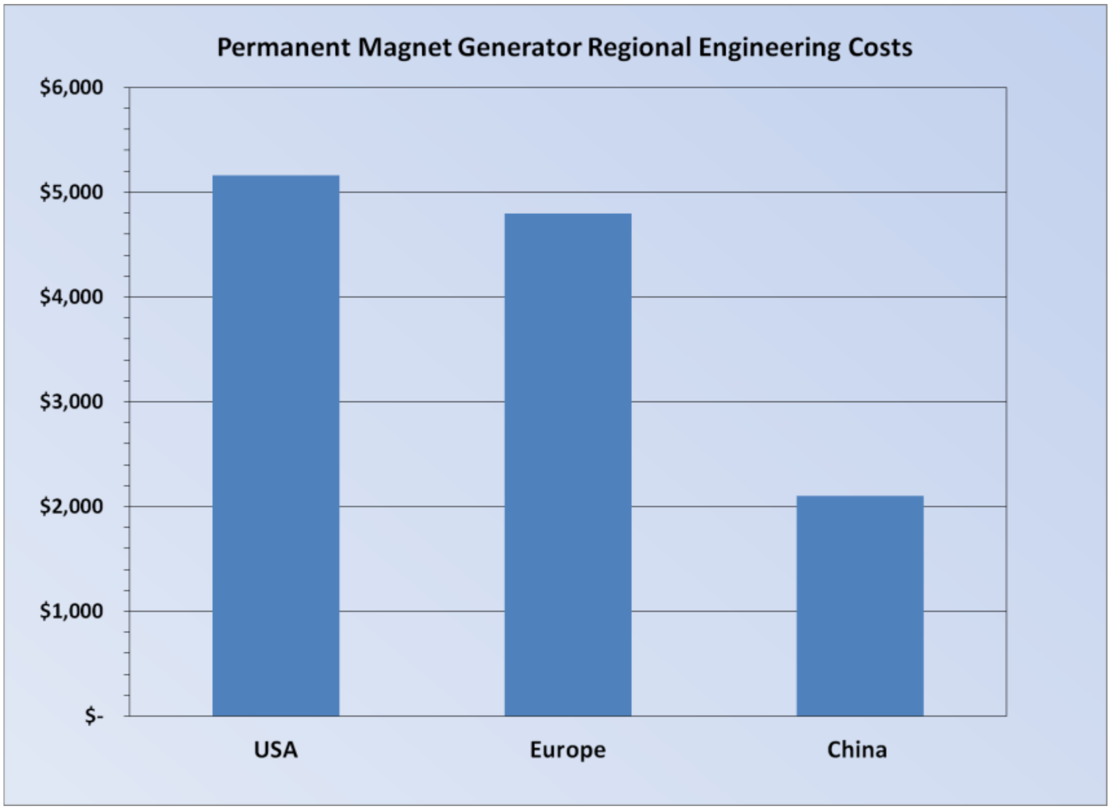


Fig. 1.3.13 Engineering Regional Cost (1MW PM Generator)

Engineering Cost Breakdown – 1MW PM Generators
Description: Engineering – Cost of all Engineering: product, development, and manufacturing

Findings: Engineering

- Chinese engineering is 40% of the U.S. and Europe
- Chinese suppliers spend little to no money on engineering. Their preference is to buy the design technology and manufacturing process technology. This enables them to focus on volume production.

1.3.8 LOGISTICS – Regional Cost Breakdown for PM Generators

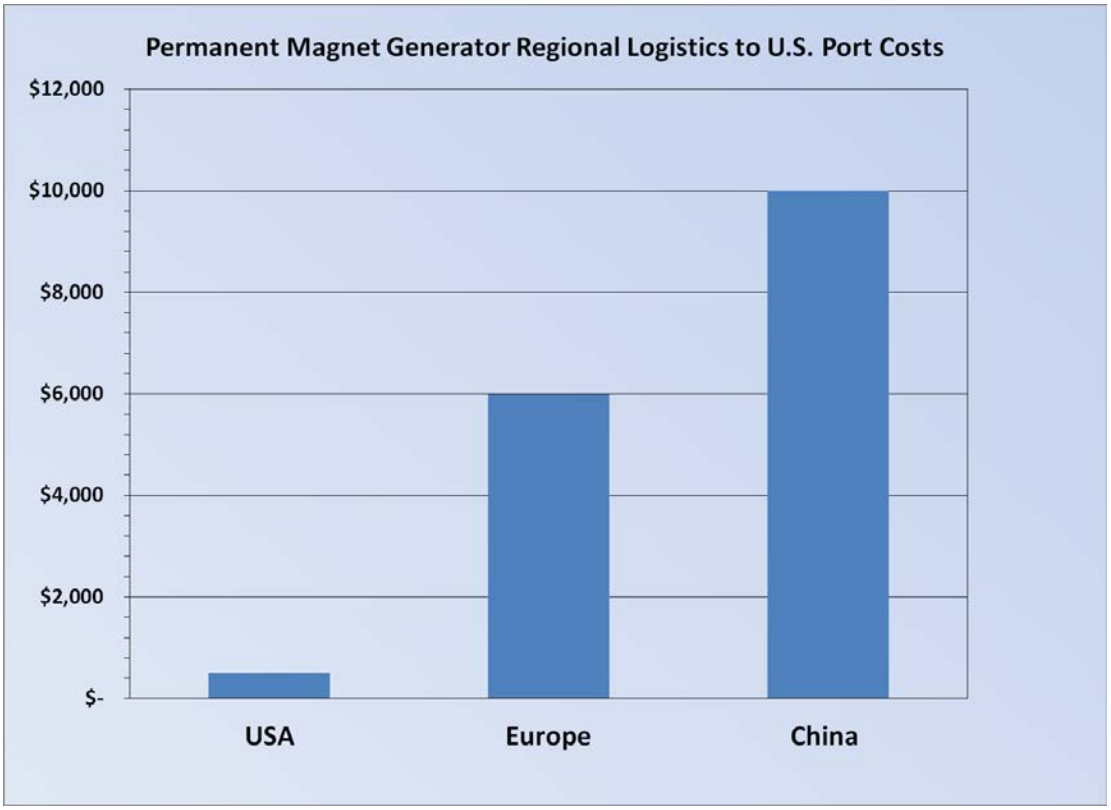


Fig. 1.3.14 Logistics Regional Cost Breakdown to US Port Costs (1MW PM Generator)

Logistics Cost Breakdown – 1MW PM Generators
Description: Logistics – The cost from manufacturers port to the Port of New Bedford, MA.

Findings: Logistics

- With common shipping space requirements, the cost is driven by total transport miles and time**.** The logistics cost from China is 7% or $10,000 of the Chinese total cost. The cost from Europe is approximately half and minimal cost within the U.S.

1.3.9 PROFIT – Regional Cost Breakdown for PM Generators

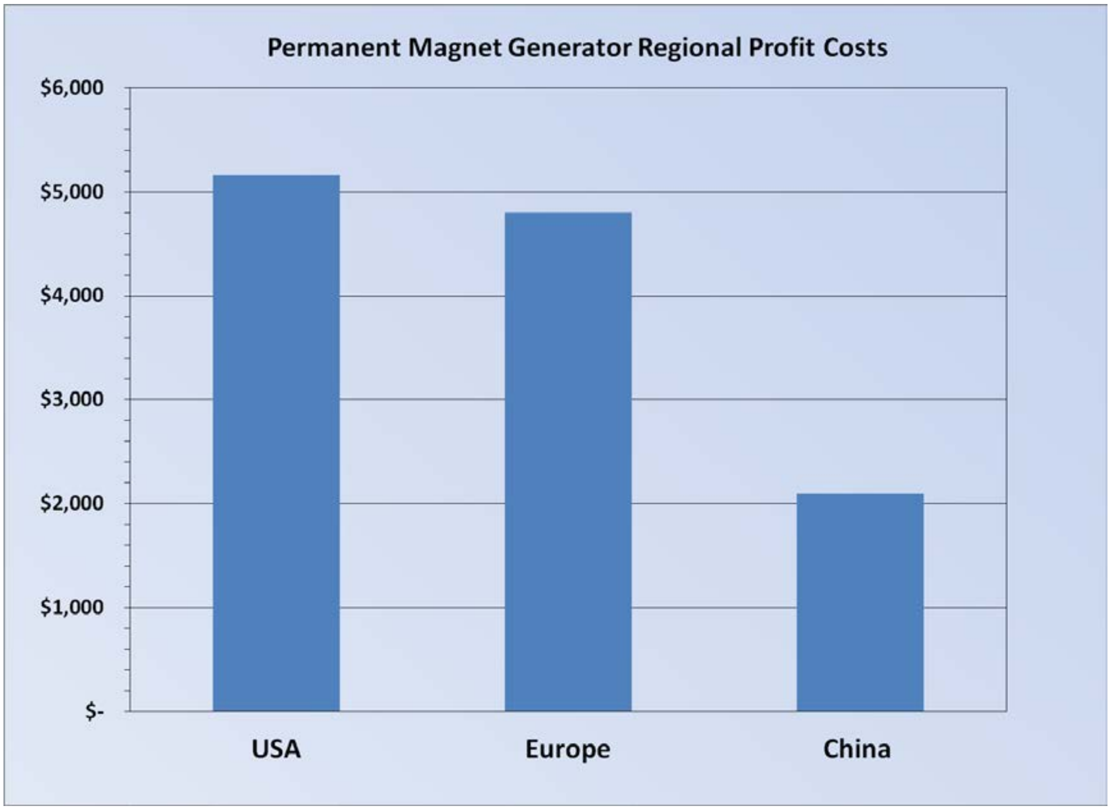


Fig. 1.3.15 Profit Regional Costs (1MW PM Generator)

Profit Cost Breakdown – 1MW PM Generators

Description: Profit – the reported profit portion of the selling price

Findings: Profit

- The reported profit range is from 2-3%. This could be verified with an on-site cost analysis.

1.3.9 Overall PM Generator Observations and Conclusions

PM generators could be manufactured at current facilities and shipped to wind turbine OEM Nacelle Assembly sites for integration. The cost is driven by the design, process, and materials used.

The following are the key points for future R&D

- Material is 54-62% of the cost of the PM generator of which stator assembly, bearing assembly, and magnet assembly's account for 75%. Alternate material types, shapes, properties and total pieces should be investigated. **An R&D project** with a focus on material selection, i.e. Design Value Analysis, and Design for Manufacturing is recommended. The project should include generator manufacturers, wind turbine OEMs, materials specialist (magnet, steel, copper, etc.), universities with electrical expertise, and supply chain experts.

1.4 Jacket Foundation - Main Lattice Competitive Cost Analysis

1.4.1 Introduction

The Jacket Foundation support structure contributes to +/- 15% of the total life cycle cost of an offshore wind turbine unit. This would compare to +/- 35% for the Wind Turbine itself. The main lattice is a main part of the jacket foundation that provides the support for wind turbines in water depths of 30m to 60m. The cost breakdown for the main lattice includes material, labor, burden, SGA (Sales General Administrative), engineering, logistics, and profit.

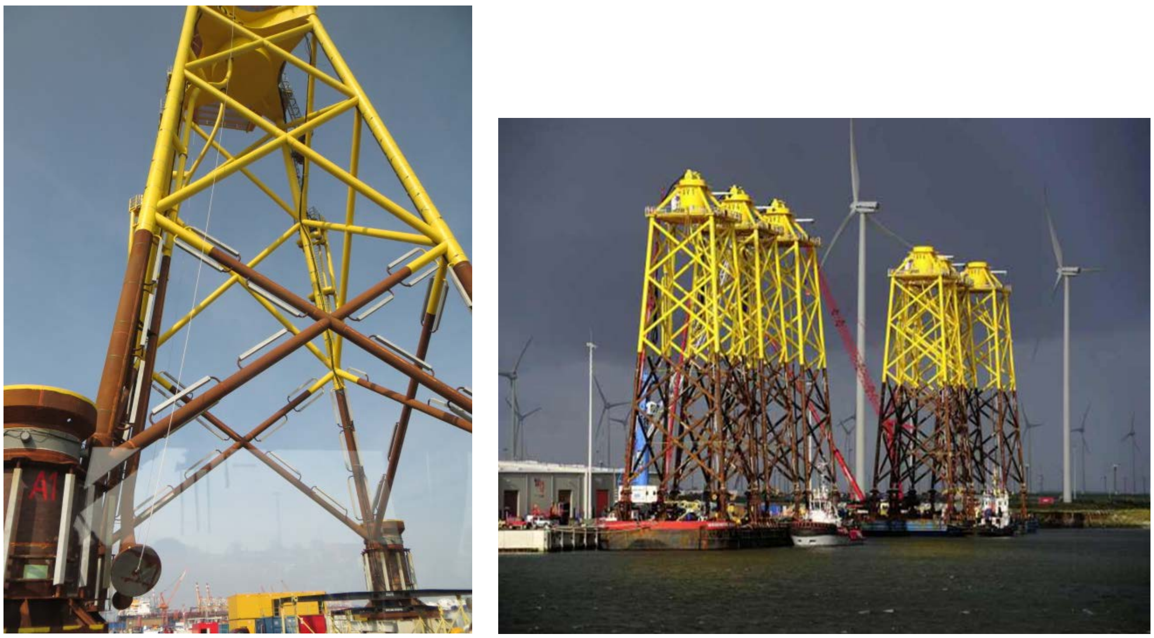


Fig. 1.4.1 Main Lattices for the German North Sea Projects staged in Bremerhaven

The Process of Obtaining a Global Cost Comparison

Design

One design was developed with a common bill of material (BOM) to obtain a global cost comparison. GLWN collaborated with NREL to develop a standard design that could be quoted globally. NREL had a 5MW system design in place that was being used for other analysis and project work. GLWN used this model and developed a detailed design with manufacturing drawings of the main lattice structural components. A drawing and bill of materials was developed that detailed all components, mass, and material specifications.

Identification of Global Suppliers

The current major global suppliers were identified in the U.S., China, and Germany. Targeted suppliers were asked to participate. The German suppliers were the only global suppliers making serial production jacket foundations for the offshore wind industry today. The U.S. suppliers had only made jacket foundations for the Oil & Gas industry on a one off basis. China had started to make a few for the Chinese Offshore Wind market.

Main Lattice Manufacturers Bio's (primary representation of offshore)

	Annual Main Lattice Sales 2012 (Combined)	Annual Main Capacity as of 2013 (Combined)	Main Lattice built to date
USA (1)	$0M	50	(~20 O&G)
China (2)	$8M	80	4
Germany (1)	~$38M	100	30 (130 jackets total)

Main Lattice Schematic

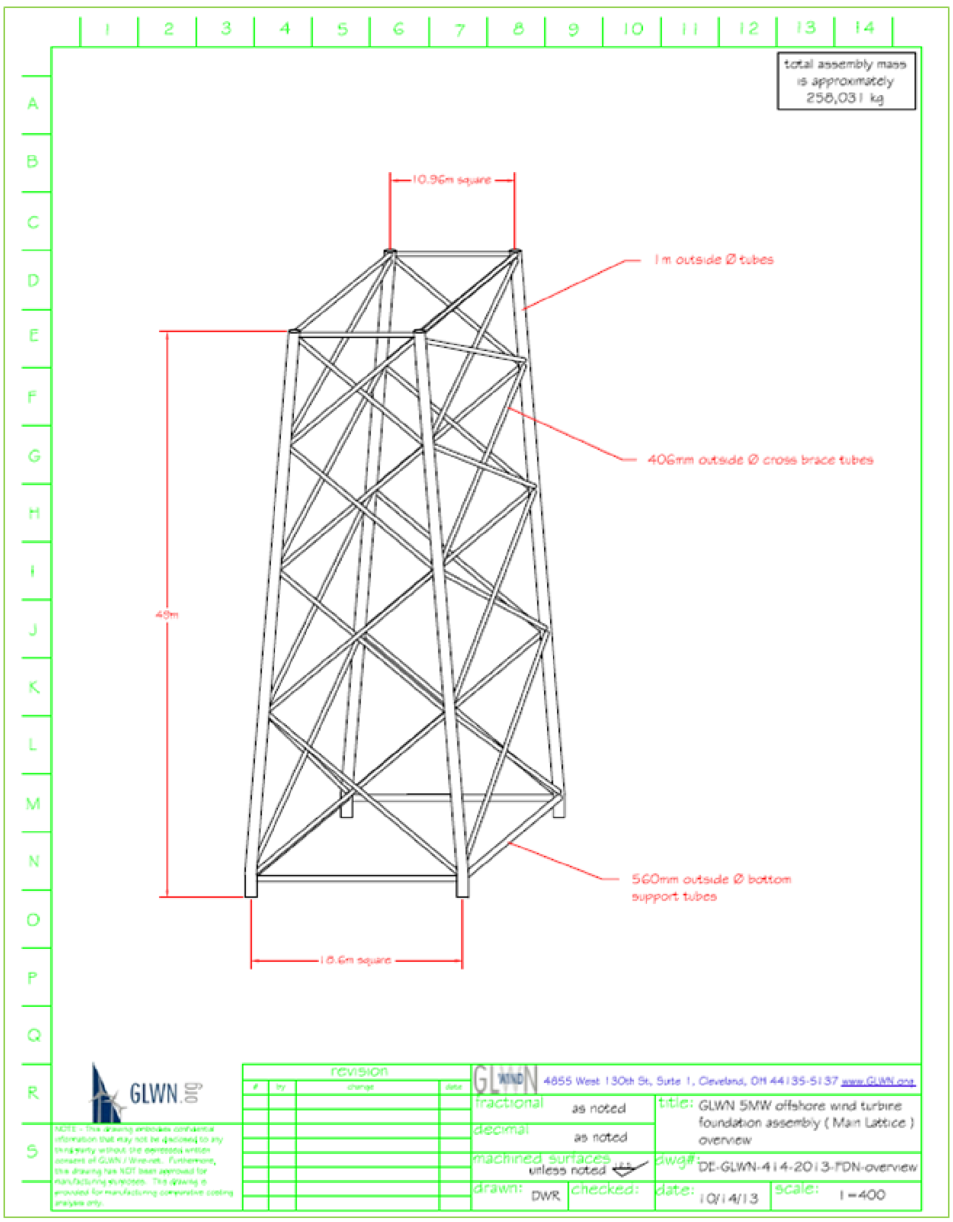


Fig. 1.4.2 Schematic of a Jacket Foundation, Main Lattice used in this study

1.4.2 AGGREGATED Regional Cost Breakdown for Main Lattice

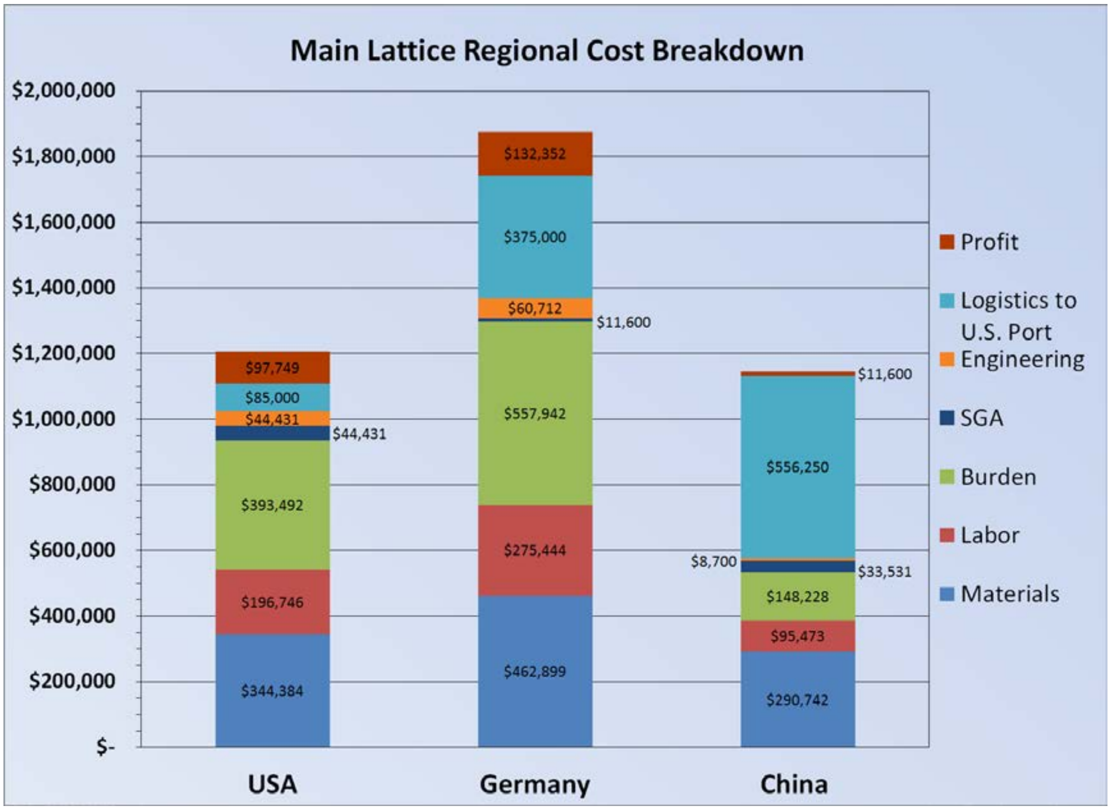


Fig. 1.4.3a Aggregated Regional Cost Breakdown in $

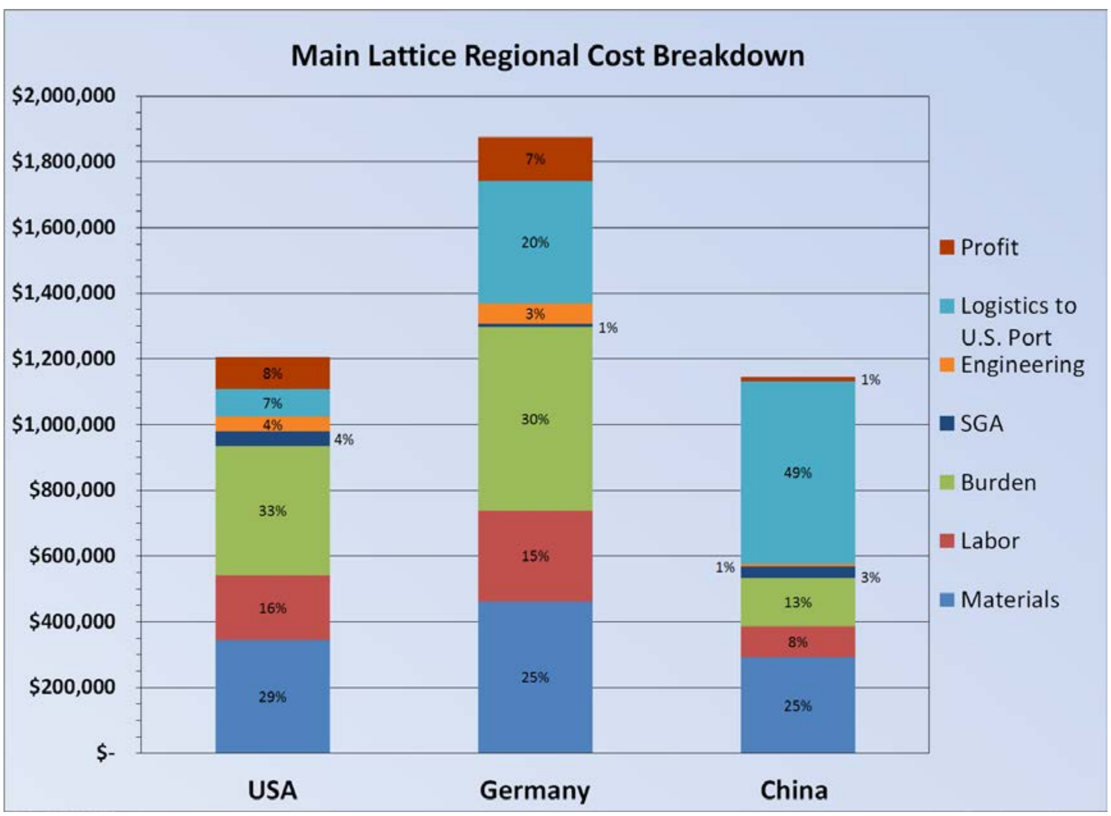


Fig. 1.4.3b Aggregated Regional Cost Breakdown in %

Aggregate Regional Cost Breakdown – Main Lattice

Description: Main Lattice - The Regional Cost Breakdown in the eight Cost Categories is represented in dollars in Figure 1.4.3a and represented in % in Figure 1.4.3b.

Findings: Main Lattice

- Labor and burden is the largest cost driver in U.S. and Germany running at 45-49% combined. Labor and burden cost in China is 21% of the total cost.
- Material is the second largest at 29% for the U.S. and 25% for Germany and China.
- A major international logistics company provided the shipping cost for a full vessel load. The cost reflected is from the port closest to the manufacturer to the Port of New Bedford, MA. The highest cost is from China at 49%, Germany at 20%, and the U.S. (transported via the Gulf of Mexico) at 7%.
- SGA for the U.S. is 4%, Germany is 1% and China is 3%.
- Engineering in Germany is 3%, U.S. is 4%, and China is 1%.
- Profit in Germany is 7%, U.S. is 8%, and China is 1%.

1.4.3 MATERIALS – Regional Cost Breakdown for Main Lattice

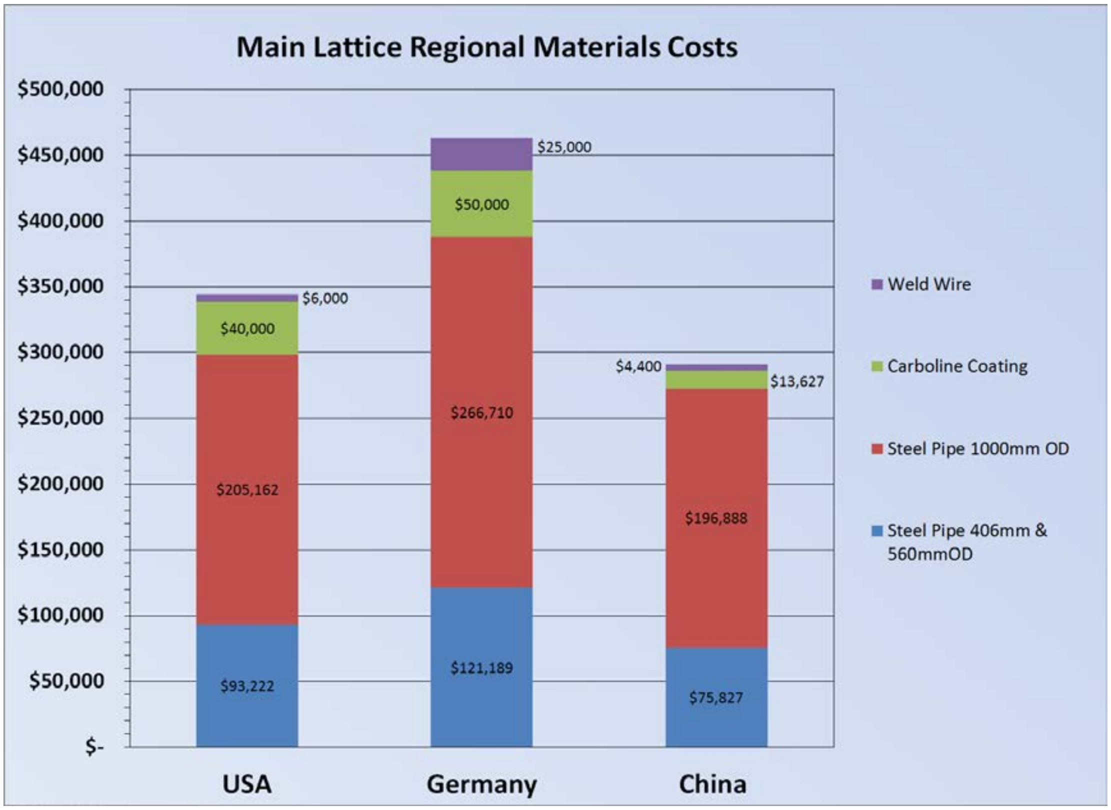


Fig. 1.4.4a Materials Regional Cost Breakdown in $

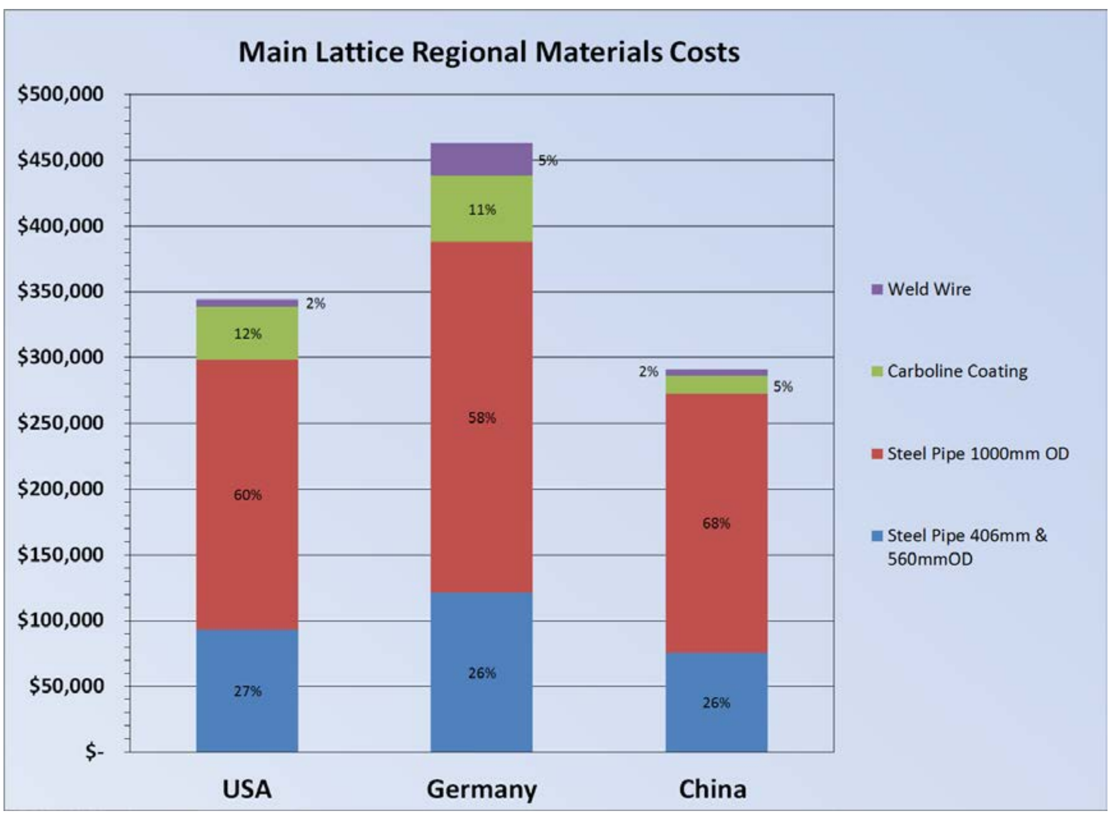


Fig. 1.4.4b Materials Regional Cost Breakdown in %

Materials Cost Breakdown – Main Lattice

Description: Materials - There are three components in the Material category:

- Steel Pipe
- Coating
- Weld Wire

Findings: Materials

- Material drives 25-29% of the total cost which is primarily steel pipe for the main lattice.
- Steel pipe accounts for 87% in the U.S., 94% in China, and 84% in Germany, although Germany has the highest total pipe cost.
- Paint costs for the U.S. and Germany are comparable around $45,000. China's paint costs were $13,000.
- Weld wire is 2-5%. Although weld wire, weld cavity and welding process play a larger role in the overall welding cost. R&D work in weld wire size-material and process could reduce cost. Design and automation would be a big contributor to cost reduction. Designing for a weld that can be automated would reduce the manual operator fatigue factor with the curved surface welding. CNC robot assist welding was seen as a benefit in Germany, since the weld operator guides the weld head with a joy stick.

1.4.4 LABOR – Regional Cost Breakdown for Main Lattice

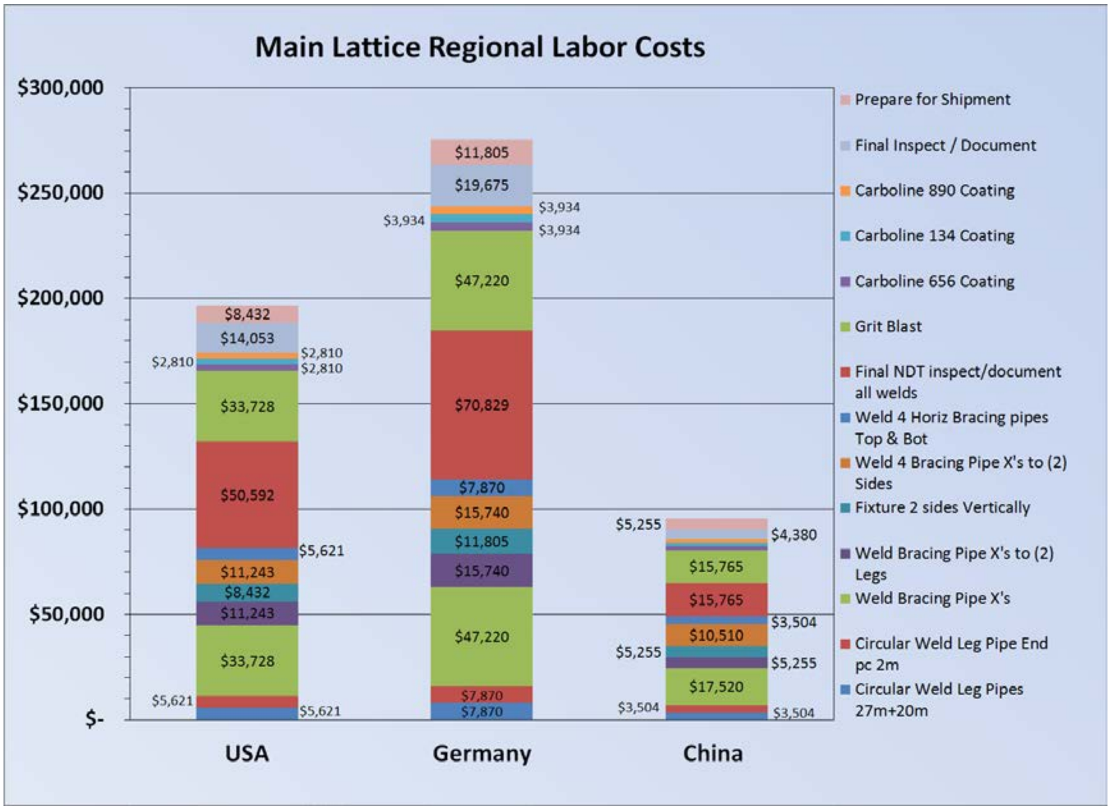


Fig. 1.4.5a Labor Regional Cost Breakdown in $

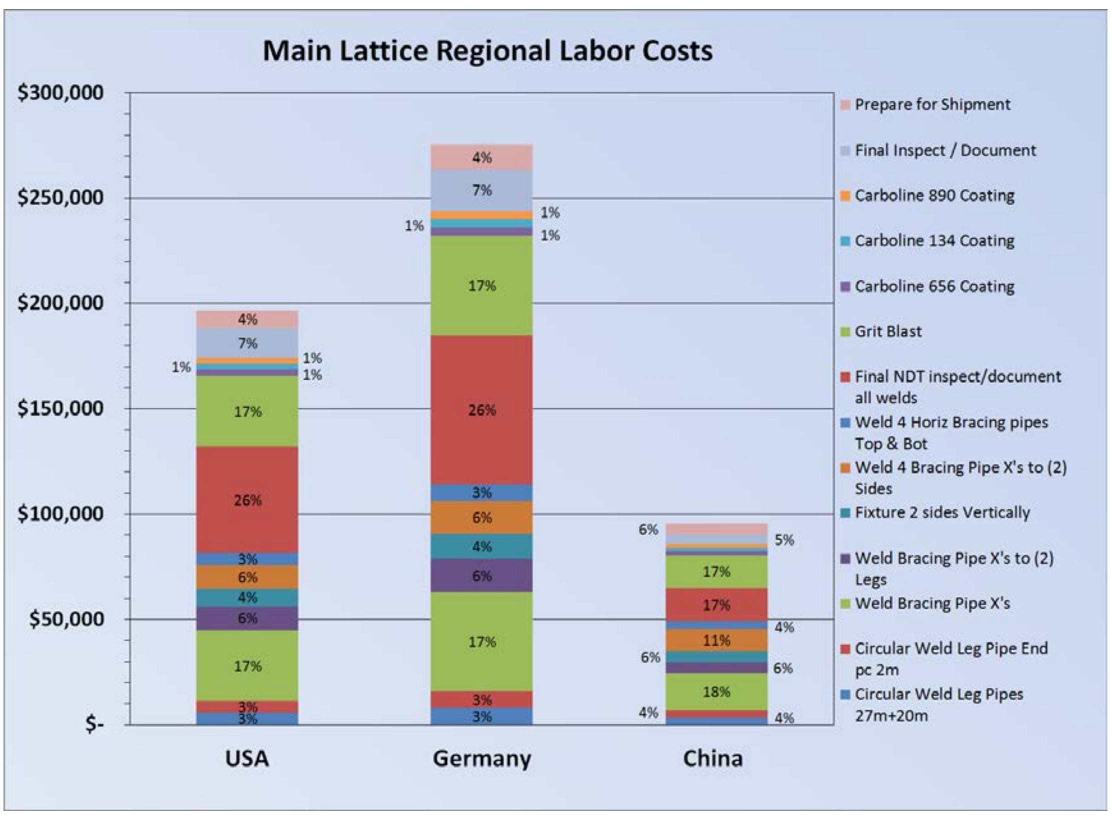


Fig 1.4.5b Labor Regional Cost Breakdown in %

Value Stream Map of - Main Lattice

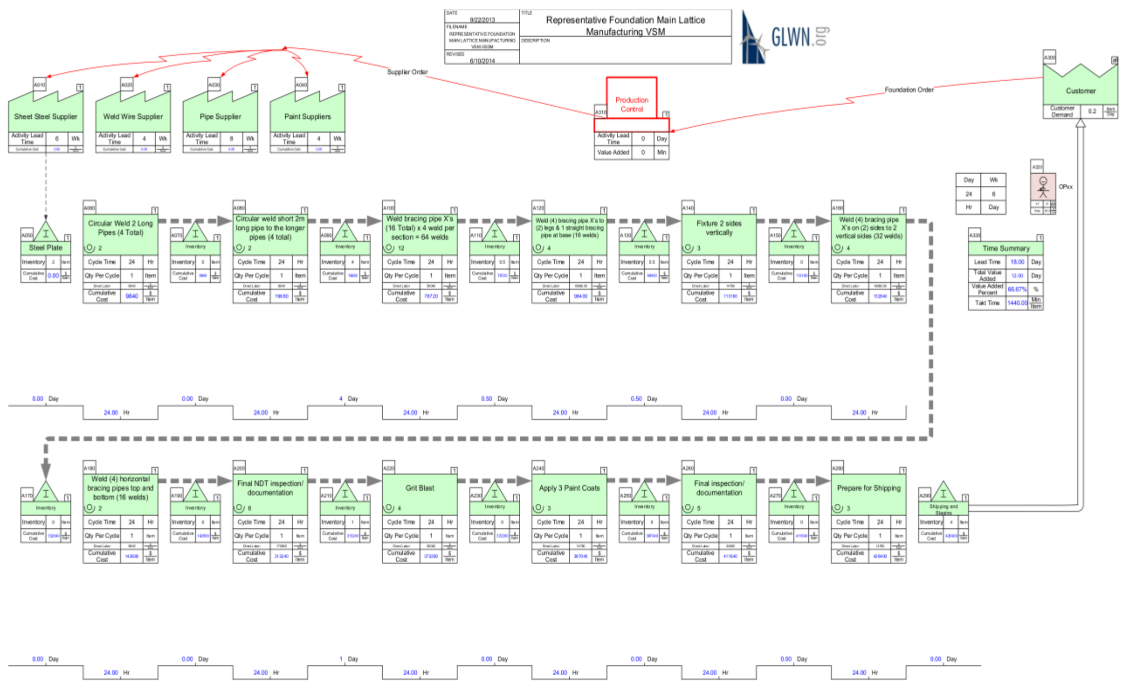


Fig. 1.4.6 Representative Manufacture Value Stream Map of Main Lattice

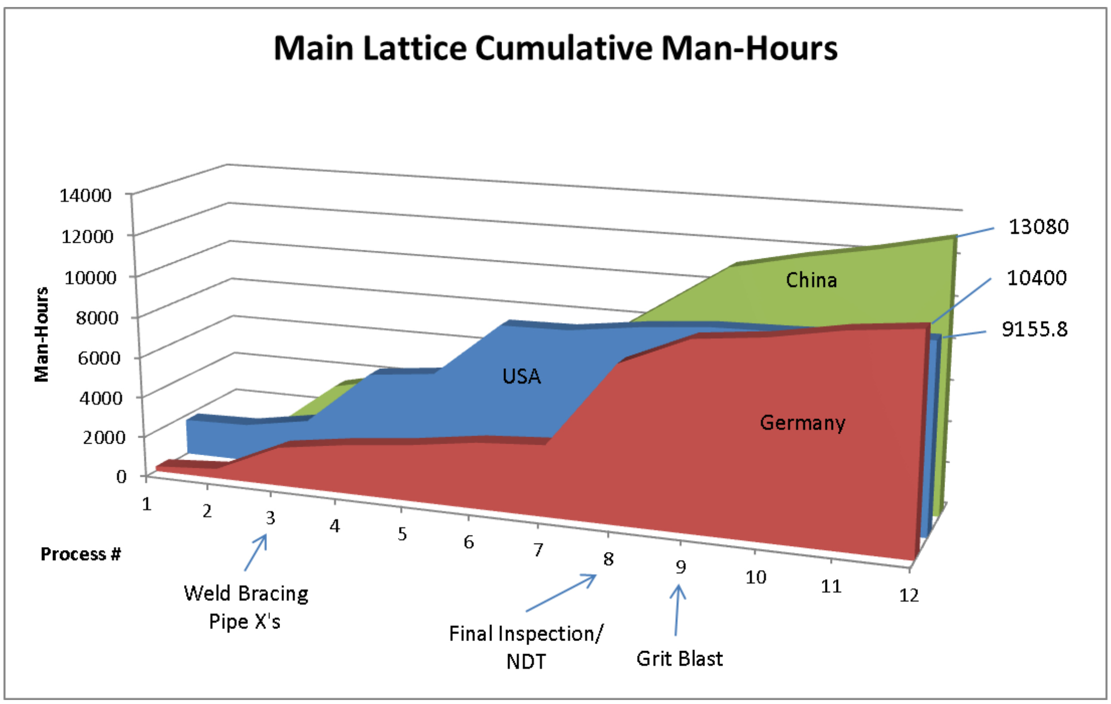


Fig. 1.4.7 Accumulative Labor Man Hours per Process

Labor Cost Breakdown – Main Lattice

Description: Labor has 14 Process Steps

1. Circular Weld Leg Pipes 27m+20m
2. Circular Weld Leg Pipe End pc 2m
3. Weld Bracing Pipe X's
4. Weld Bracing Pipe X's to (2) Legs
5. Fixture 2 sides Vertically
6. Weld 4 Bracing Pipe X's to (2) Sides
7. Weld 4 Horiz Bracing pipes Top & Bot
8. Final NDT inspect/document all welds
9. Grit Blast
10. Carboline 656 Coating
11. Carboline 134 Coating
12. Carboline 890 Coating
13. Final Inspect / Document
14. Prepare for Shipment

Description: Labor – Cost is the sum of all direct labor hours to produce a part.

- Figure 1.4.5 details the cost by process category which is driven by process category man hours.
- Figure 1.4.6 is a representative Value Stream Map which was developed for each manufacturer. Value stream mapping is a lean management principle used to analyze and design the flow of materials and information required to bring a product to a consumer. It identifies value added and non-value added activity.
- Figure 1.4.7 is the accumulative labor man hours per process for the main lattice.

Findings - Labor:

- The complex curvature welding is a large process cost driver and the bottle neck in most manufacturing processes visited.
- Most of the welding is done at heights. Developing a design and welding pattern that lend to automation would be helpful
- Final sand blasting and painting was also very labor intensive since it is a complex shape and at heights. Flexible and portable equipment would be beneficial.

1.4.5 BURDEN – Regional Cost Breakdown for Main Lattice

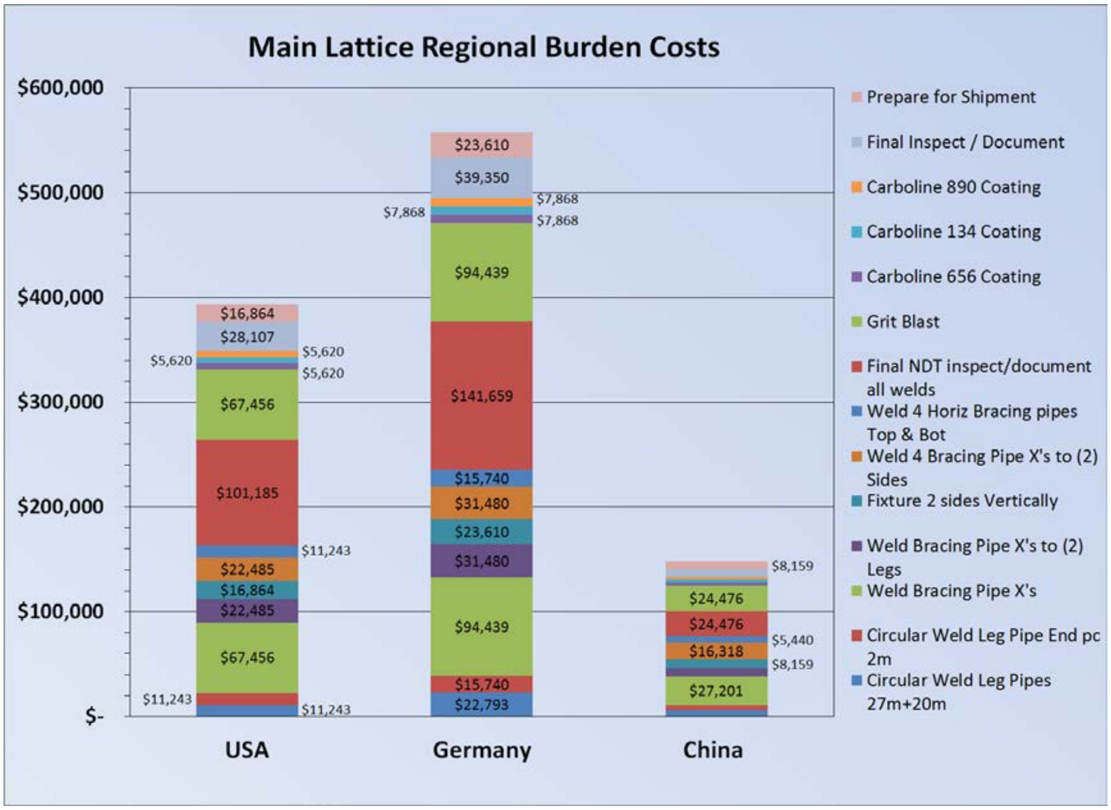


Fig. 1.4.8a Burden Regional Burden Cost Breakdown in $

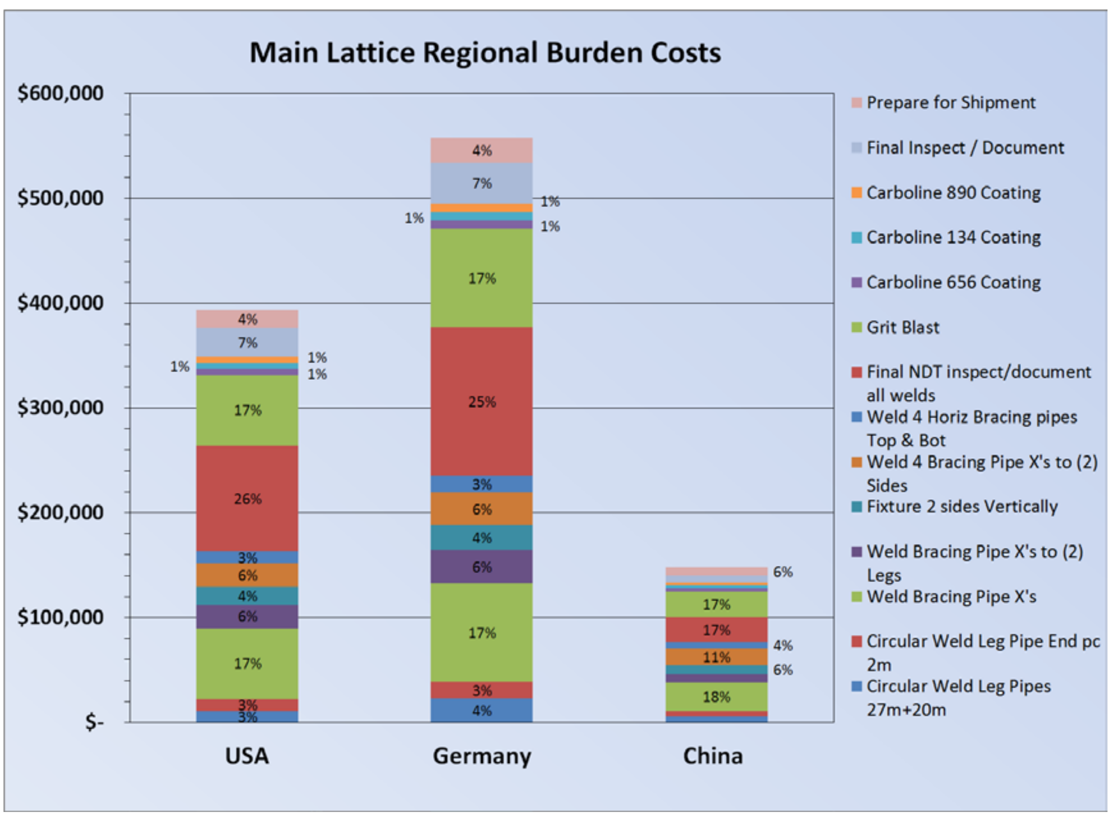


Fig 1.4.8b Burden Regional Cost Breakdown in %

Burden Cost Breakdown – Main Lattice

Description: Burden - Cost is the sum of the indirect variable cost and fixed cost.

Findings: Burden

- Burden costs at most of the manufacturers were applied as a % to direct labor**.** Improvements in labor would improve burden.
- Burden cost could be reduced in all areas by doing a full ABC cost analysis on all variable and fixed cost drivers. Power usage for each welder and all electric drive units could be a starter.

1.4.6 SGA (Sales, General, Administrative) – Regional Cost Breakdown for Main Lattice

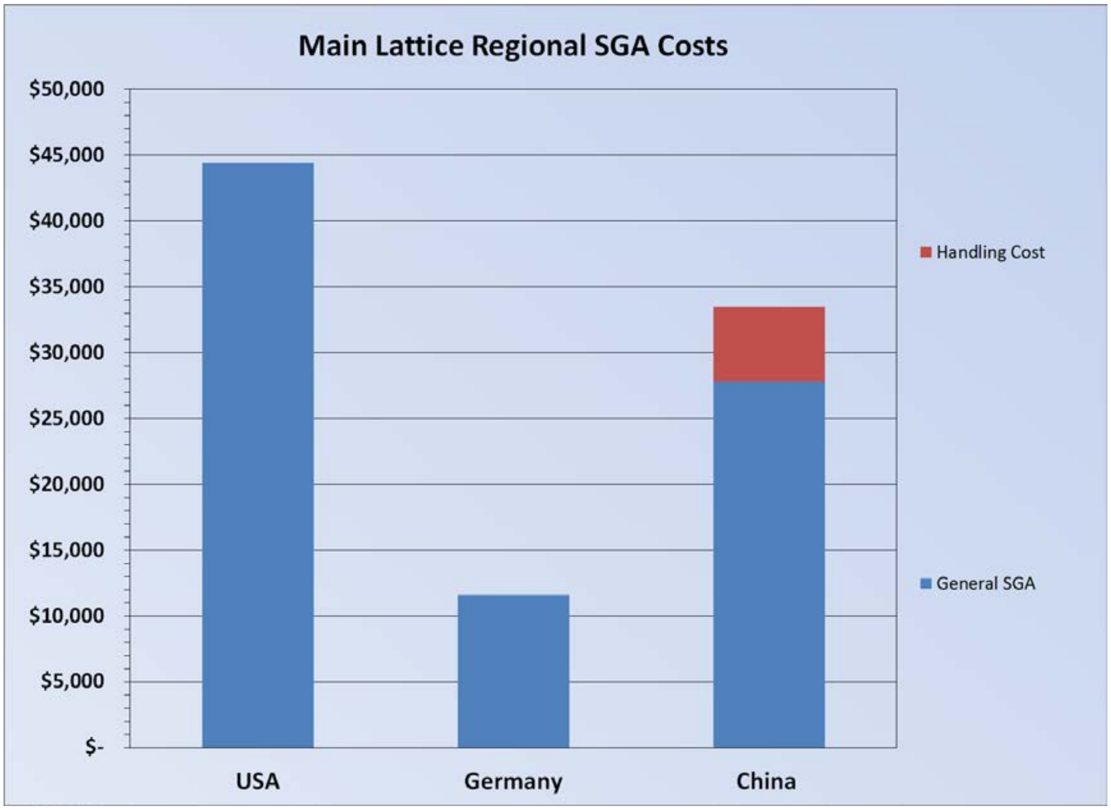


Fig. 1.4.9 SGA Regional Cost Breakdown in $

SGA Cost breakdown - Blades

Description: SGA - Cost of Sales, general, administrative, accounting, executive salaries, travel, and special handling as represented in Figure 1.4.9.

Findings: SGA

- SGA and handling accounted for 4% of the U.S. cost, 1% of German's cost, and 3% of China's cost
- The following was the breakdown by region
  - U.S. - $44,431 SGA
  - Germany - $11,600 SGA
  - China - $27,805 SGA and $5,726 handling.

1.4.7 ENGINEERING – Regional Cost Breakdown for Main Lattice

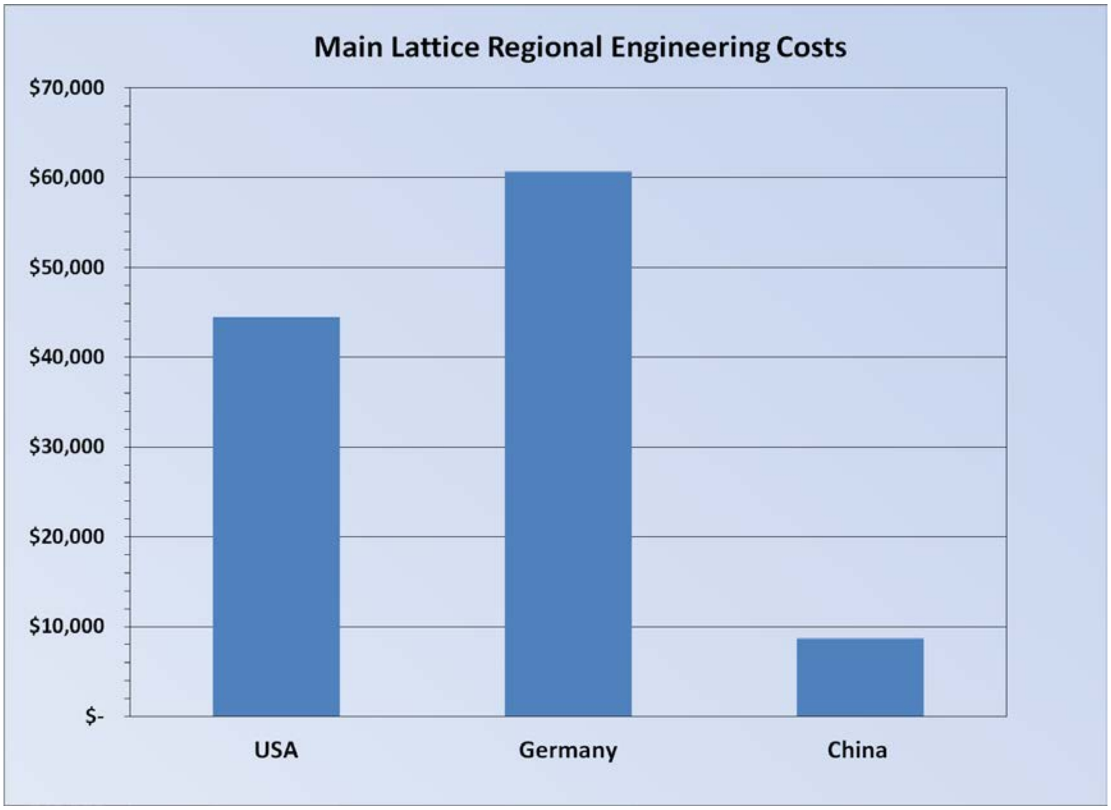


Fig. 1.4.10 Engineering Regional Cost Breakdown in $

Description: Engineering - Cost of all Engineering. i.e., Product, Development, Manufacturing

Findings: Engineering

- China suppliers spend little to no money on engineering. Their preference is to buy the design technology and manufacturing process technology. They stated they want to focus on volume production.
- Main Lattices are "not" engineering intensive, although real opportunities exist for a U.S. manufacture to develop a main lattice design that eliminates all the complicated weld interface curvatures.
- One current design incorporates cast steel nodes for connection points, decreasing corrosion at weld points, and allowing use of standard pipe. The complex weld angles and curvatures require manual cutting and welding. Minimizing welding length, using circular cuts, and applying simple automation could have a significant impact on labor and cost. In addition, a higher volume serial production manufacturing process needs to be developed and optimized to achieve LCOE (lowest cost of energy).

1.4.8 LOGISTICS – Regional Cost Breakdown for Main Lattice

Fig. 1.4.11 Logistics Regional Cost Breakdown in $

Description – Logistics cost breakdown from manufacturer port to Port of New Bedford, MA.

Findings – Logistics

- Main lattices are very large and high cubic space consumption structures that do not package well on vessels for transport. Therefore you will not get as many on a vessel and therefore increase transport cost.
- Developing an improved method for serial production could provide large cost reduction opportunities
- Of all the components studied, main lattices for high MW jacket foundations need to be produced close to water access and close to the wind farm to achieve the lowest logistics cost. The pipe can be transported in by truck or rail, but final assembly / weld needs to be done close to the water and to the offshore wind farms.

1.4.9 PROFIT – Regional Cost Breakdown for Main Lattice

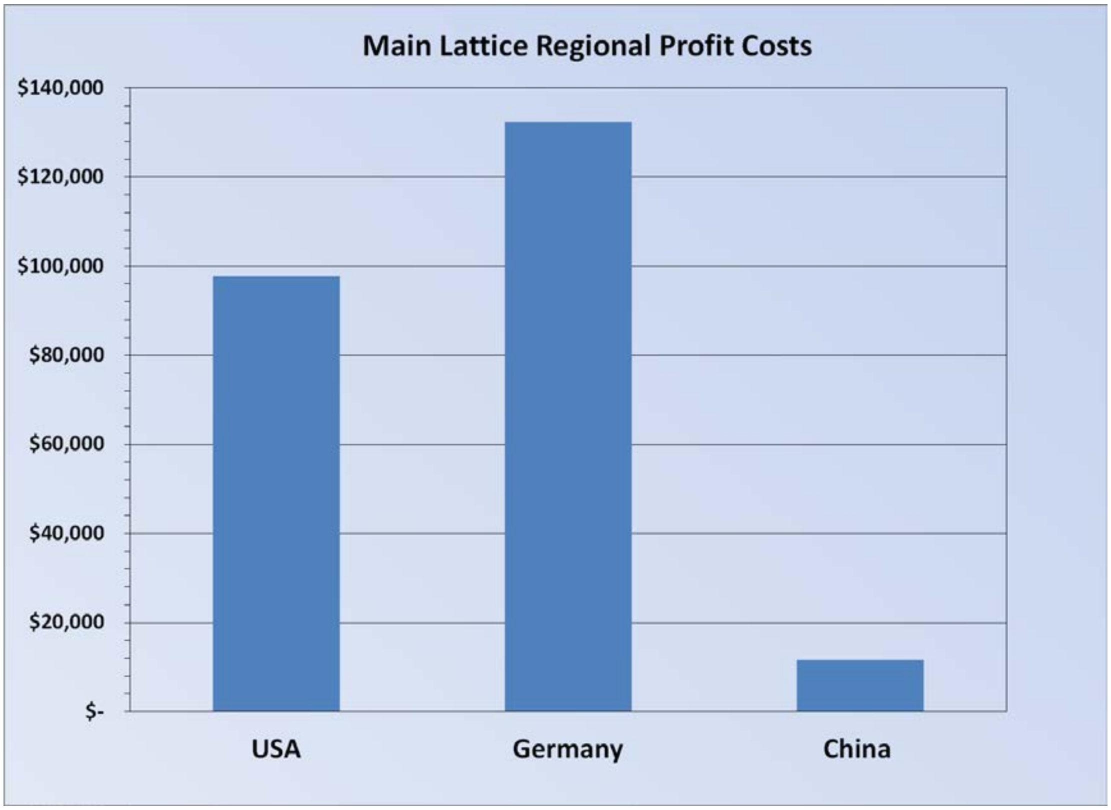


Fig. 1.4.12 Profit Regional Cost Breakdown

Description: Profit - is the reported profit portion of the selling price

Findings: Profit

- The reported profit range is 1-8%. This could be verified with a full on site cost analysis.

1.4.10 Overall Main Lattice Observations and Conclusions

Main Lattice fabrication will require coastal water access for transport to the wind farm. Those fabricators which supply product today to offshore oil & gas or bridge structures would be in the best position to participate. To be competitive any supplier would have to apply lean serial manufacturing and part flow to the main lattice.

The following are the key points for future R&D

- Labor and burden is the biggest cost driver at 45-50% of the cost of a main lattice. The current complex weld interface curvatures require primarily manual welding. A design that eliminates the complex welds to a standard weld would enable some automation and welding efficiencies. **An R&D Project that included the designer, manufacturer, and welding equipment supplier to develop a simple connection interface with the least welding is recommended. As an example, the design of the cast steel nodes that were developed by WeserWind.**
- The complete jacket foundation with main lattice and transition piece would be a good candidate for a **Design for Assembly (DFA) and Design for Manufacturing (DFM) study as an R&D Project.**
- Final sand blasting and painting was very labor intensive. Flexible and portable equipment would be beneficial**. Small R&D Automation Project is recommended.**
- Main Lattice final assembly/welding close to water access and close to the wind farm will have the lowest logistics cost and LCOE.

SECTION 2 - U.S. WIND SUPPLY CHAIN SCORECARD

2.1 Scorecard Summary of Findings and Overview

GLWN was tasked with developing a Wind Industry Supply Chain Scorecard that reflects U.S. manufacturers' readiness to supply the next generation wind turbines, 3MW and 5MW, for land-based and offshore applications. Manufacturers for 10 key wind turbine components and three balance-of-plant components were analyzed, including the four main components of this study, towers, blades, generators, and jacket foundations. The analysis was conducted on a national level, with particular emphasis on manufacturers located in coastal regions when considering the newly emerging offshore wind supply chain. Capabilities data was assimilated from over 280 companies that participated in a GLWN survey, through GLWN research, and from the GLWN Wind Supply Chain database which contains data on over 1700 U.S. companies active or interested in the wind industry.

2.1.1 SUMMARY OF FINDINGS – U.S. Wind Supply Chain Scorecard

As represented in Figure 2.1.1, GLWN's overall score of U.S. manufacturers' readiness to supply the next generation wind industry for both land-based and offshore applications can be summarized to the following:

- Capabilities exist in the U.S. to manufacture key components for next generation 3MW wind turbines, particularly for towers, blades, generators, gearboxes, composite housings, and fabricated support bases.

- Forgings and castings together make up 23% of wind turbines cost. U.S. manufacturers of forged rings, forged shafts, cast hubs, and cast support bases, although capable, are not competitive in the global supply chain for wind. Investments in casting and forge industry sectors will be necessary if the U.S. wants to recapture these markets for both land-based and offshore applications. *Further detailed analysis of the forge and casting industry is recommended to determine the root cause of this loss of market and non-competitive position.*

- Investment in facilities and equipment is likely within all of the industry sectors for scaling up to the 5MW requirements. Current tower and blade manufacturers in particular will require moderate-to-high investments in equipment and facility upgrades to support 3MW and larger turbines for land-based applications. For 5MW and larger offshore applications, the investment needed will be substantial (HIGH) assuming a new facility, located port side, is the most desirable for the larger components.

- The U.S. wind industry and supply chain is concentrated in the central and midwest United States. Location of the suppliers, current and potential, was taken into account when considering a manufacturers ability to supply the offshore industry. For several of these key components, the manufacturers' current distance from the coastal regions, would likely render them non-competitive, and that is if the component could even be transported given current road and rail infrastructure constraints. For the offshore industry, investment in new facilities is needed in coastal regions, preferably located at major ports equipped to support the offshore wind industry.

- Offshore wind will bring new market opportunities with jacket and monopole foundations. Capabilities exist with U.S. heavy fabricators but moderate-to-high investments will still be necessary to address this new product line, serial production for higher volumes required by wind farms, and potentially new coastal facilities.

- Subsea cable manufacturing, sufficient for offshore utility wind farm applications (continuous line cable) does not exist in the U.S. New portside facilities will be needed.

U.S. WIND INDUSTRY SUPPLY CHAIN SCORECARD

Land-based and Offshore Turbine Components

Offshore Balance-of-Plant Components

LAND-BASED - Turbine Components

	Towers	Blades	Generators	Gearboxes	Composite Housings	Fabricated Support Bases	Forged Rings	Forged Shafts	Cast Hubs	Cast Support Bases
3MW	LOW	LOW	LOW	LOW	LOW	LOW	MODERATE-HIGH	MODERATE-HIGH	HIGH	HIGH
5MW	MODERATE-HIGH	MODERATE- HIGH	LOW-MODERATE	LOW-MODERATE	LOW-MODERATE	LOW-MODERATE	MODERATE-HIGH	MODERATE-HIGH	HIGH	HIGH

OFFSHORE - Turbine Components

	Towers	Blades	Generators	Gearboxes	Composite Housings	Fabricated Support Bases	Forged Rings	Forged Shafts	Cast Hubs	Cast Support Bases
3MW	LOW-MODERATE	MODERATE-HIGH	LOW	LOW	LOW-MODERATE	LOW	MODERATE-HIGH	MODERATE-HIGH	HIGH	HIGH
5MW	HIGH	HIGH	LOW-MODERATE	LOW-MODERATE	MODERATE	LOW-MODERATE	MODERATE-HIGH	MODERATE-HIGH	HIGH	HIGH

OFFSHORE - Key Balance-of-Plant

	Jacket Foundations	Monopile Foundations	Subsea Cabling
3MW	MODERATE-HIGH	MODERATE-HIGH	HIGH
5MW	MODERATE-HIGH	HIGH	HIGH

Fig. 2.1.1 U.S. Wind Industry Supply Chain Scorecard

2.1.2 OVERVIEW – U.S. Wind Supply Chain Scorecard

As represented in Figure 2.1.2, criteria were established for the Scorecard to "rate" U.S. manufacturers based on the anticipated level of investment that may be necessary to produce the larger size components of the 3W and 5MW turbines.

Low	Can manufacturing the component today or a similar product (No real capital investment required)
Moderate	Requires some capital investment (Minor facilities upgrades and/or operations expenses)
High	Major capital investment required (New location/facility, major technology or equipment upgrades)

Fig. 2.1.2 Scorecard Criteria

The levels of investment took into consideration equipment and facility needs, and also a manufacturer's ability to produce to higher volumes in a consistent, serial production environment. GLWN also considered regional and transportation accessibility (or constraints) relative to current land-based OEM production (primarily in the Midwest) and anticipated coastal wind turbine assembly facilities.

The Scorecard provides not only an overall view of the readiness of U.S. manufacturers to supply the wind industry, but also establishes a baseline for discussing current and potential supply chain gaps, i.e. those industry sectors that may require further Department of Energy analysis or investment to advance a sectors competitiveness to participate in a global market.

Industry Scorecard Figures

Figure 2.1.3 represents GLWN's rating of the U.S. manufacturers' readiness to supply ten key turbine components for a 3MW, and 5MW, for Land-based installations.

Figure 2.1.4 represents GLWN's rating of the U.S. manufacturers' readiness to supply ten key turbine components for a 3MW and 5MW for Offshore installations.

Figure 2.1.5 represents GLWN's rating of the U.S. manufacturers' readiness to three supply balance-of-plant components for a 3MW and 5MW Offshore installations.

2.1.3 OVERVIEW – LAND-BASED Turbine Components Supply Chain

	LAND-BASED - Turbine Components									
	Towers	Blades	Generators	Gearboxes	Composite Housings	Fabricated Support Bases	Forged Rings	Forged Shafts	Cast Hubs	Cast Support Bases
3MW	LOW	LOW	LOW	LOW	LOW	LOW	MODERATE-HIGH	MODERATE-HIGH	HIGH	HIGH
5MW	MODERATE-HIGH	MODERATE- HIGH	LOW-MODERATE	LOW-MODERATE	LOW-MODERATE	LOW-MODERATE	MODERATE-HIGH	MODERATE-HIGH	HIGH	HIGH

Fig. 2.1.3 Land-based Turbine Components Supply Chain Scorecard

3MW Land-based:

U.S. manufacturers are well positioned to supply towers, blades, gearboxes, generators, composite housings (nacelle and spinner), and fabricated support bases for the next generation

3MW turbines. Most current manufacturers of these components have produced components up to a 2 or 2.5MW and could likely scale up to the 3MW with little or no additional capital investment. GLWN rated the level of investment required as **LOW** for towers, blades, generators, gearboxes, composite housings, and fabricated support bases.

Forged rings, forged shafts, cast hubs, and cast support bases components are not as well positioned for the 3MW turbines. Several U.S. manufacturers were identified that have the capabilities to forge (and machine) large diameter seamless rolled rings and forge shafts that exceed 40,000 lbs., the weight of the 3MW shaft. But few are supplying the wind industry today. GLWN rated these forged components **MODERATE-HIGH**. We anticipate that current facilities would need to invest in equipment, facilities, and efficiencies to improve their competitive position.

Current suppliers of cast hubs and support bases are even more limited than forged components. Today's current foundries are most competitive producing components for the 1-2MW market. GLWN scored cast components as **HIGH** for major investments that will be necessary for facility upgrades, new equipment, and optimally, a new foundry. GLWN also considered location –today's foundries are centralized in the Great Lakes region, far from the Atlantic, Pacific, and Gulf coasts.

5MW Land-based:
Components parts for the 5MW and larger turbines will present challenges for manufacturers for land-based applications. With blade and tower facilities primarily located in the Midwest, any long haul transport of oversized components will face challenges, and added expense, with current rail and road infrastructure. GLWN rated the tower and blade industry as **MODERATE-HIGH** for 5MW components**,** considering transportation challenges and the likely need for major capital investments to support production of these larger parts close to water transport.

Gearboxes, generators, composite housings, and fabricated support bases were all scored **LOW-MODERATE.** U.S. manufacturers of these components are better positioned to scale up to 5MW components with moderate investment in facilities or operations likely. GLWN also considered location of current manufacturers for these components and their ability to supply, and transport, these components. Gearboxes and fabricated bases are transportable, even at the 5MW size requirements. Permanent magnet generators and composite housings for the nacelle would likely face transport challenges for any long haul due to oversize and overweight (generators) loads.

GLWN's findings and score for forged rings and shafts, and cast hubs and support bases is the same for 5MW land-based applications as with the 3MW, **MODERATE-HIGH** and **HIGH** respectively

2.1.4 OVERVIEW - OFFSHORE Turbine Components Supply Chain Scorecard

	OFFFSHORE - Turbine Components									
	Towers	Blades	Generators	Gearboxes	Composite Housings	Fabricated Support Bases	Forged Rings	Forged Shafts	Cast Hubs	Cast Support Bases
3MW	LOW-MODERATE	MODERATE-HIGH	LOW	LOW	LOW-MODERATE	LOW	MODERATE-HIGH	MODERATE-HIGH	HIGH	HIGH
5MW	HIGH	HIGH	LOW-MODERATE	LOW-MODERATE	MODERATE	LOW-MODERATE	MODERATE-HIGH	MODERATE- HIGH	HIGH	HIGH

Fig. 2.1.4 Offshore Turbine Components Supply Chain Scorecard

The component scorecard changes slightly for the offshore applications from the land-based, primarily due to location of suppliers in proximity to the coastal regions. The supply chain for the land-based wind industry developed near the wind farms, in central and midwest U.S. That same investment in new facilities near the offshore wind farm sites would mitigate the impact of transportation challenges and extra costs.

As part of this study, GLWN did review the supply chain for a 3MW turbine for offshore applications, even though the offshore industry will most likely standardize on turbines at least 5MW in size. The privately funded Cape Wind project will be installing approximately 110 3.6MW Siemens turbines for their planned wind farm off the coast of Massachusetts. The most recent announcements though by the Department of Energy for the three demonstration projects are all at least 5MW units; Dominion Virginia Power with two 6MW turbines, Fisherman's Energy with five 5MW turbines, and Principle Power with five 6MW turbines.

3MW Offshore:
U.S. tower and blade manufacturing is established in the central U.S., built to supply the land-based wind industry. Both towers and blades become exponentially difficult to transport any long distances the larger the turbines become. GLWN scored towers as **LOW-MODERATE**, recognizing the limited number of regional coastal suppliers, and the hurdles in moving these large components to the coasts. Blades score elevated to **MODERATE–HIGH**, for the same reasons, location of current suppliers in relation to coastal ports. Only one U.S. blade facility today is in a coastal region (Gulf coast), and has portside access. Moving blades that are 45-55m in length, by rail or truck, to coastal regions is considered difficult and expensive. Composite Housings for the 3MW followed suite, with the scorecard increasing to **LOW-MODERATE** for offshore applications as current suppliers are not located in the coastal regions. Wind turbine OEM's have indicated to GLWN that there are sufficient composite manufacturers in coastal regions with the experience to produce nacelle housing and spinner covers. Investment would be required though to support a new product line, and facility and operations investments.

Generators, gearboxes, fabricated support bases, forged rings and shafts, and cast hubs and support bases were scored the same for 3MW offshore as they were for 3MW land-based. GLWN does not anticipate that transport of these 3MW components will present the same challenges as moving the larger tower, blade, and composite housing components, and are not considered to be an additional hurdle for offshore applications.

5MW Offshore:

Of the 10 turbine components reviewed, six are scored **HIGH** or **MODERATE-HIGH** for investments required to support the 5MW and larger offshore installations. As with land-based applications, the larger the turbines, the less “ready” U.S. manufacturers are to supply the wind industry. Tower and blade scorecards are elevated to **HIGH** for 5MW offshore applications, with major investment expected to establish new facilities in coastal regions, and portside. Transport of these components, if even doable, will be a huge challenge - blades that can be 60 to 70 meters and tower sections with diameters at 6.5 meters. The offshore industry will be best served by investment in new facilities that are located in each coastal region.

Forged rings and shafts, and cast hubs and support bases remain the same, **MODERATE-HIGH** for forged components and **HIGH** for castings, with location and proximity to the coast being less of factor than current manufacturers abilities to supply forge and cast components at a competitive price in the global market. Both industries though may be best served by investing in new, more modern facilities in coastal regions, to regain their once competitive position in the wind market, and to supply the offshore industry.

Gearboxes, generators, and fabricated support bases scores remain at **LOW-MODERATE** for the offshore application, current capabilities exist in the U.S. supply chain, but with some investment expected to scale-up to 5MW sizes.

Composite Housings score does increase to **MODERATE** for offshore applications, due to the lack of current nacelle housing or spinner cover suppliers in the coastal regions. These components did not elevate to a HIGH level of investment as there are sufficiently experienced composite manufacturers that could transition to supplying the wind industry, if the business case for offshore wind warrant the investment to manufacture a new product line.

2.1.5 OVERVIEW - Balance-of-Plant Offshore Supply Chain Scorecard

	OFFSHORE - Key Balance-of-Plant		
	Jacket Foundations	Monopile Foundations	Subsea Cabling
3MW	MODERATE-HIGH	MODERATE-HIGH	HIGH
5MW	MODERATE-HIGH	HIGH	HIGH

Fig. 2.1.5 Balance-of-Plant Supply Chain Scorecard – Offshore 3MW and 5MW

GLWN reviewed three balance-of-plant components for offshore wind farms, jacket foundations, monopole foundations, and subsea cabling, both in consideration of using 3MW and 5MW turbines.

Jacket foundations for both 3MW and 5MW installations were scored at **MODERATE-HIGH** as these large heavy fabricated structures will primarily be a new product for U.S. fabricators.

GLWN identified fabricators in coastal regions that have the capability and experience with supplying offshore civil structures, especially in the Gulf coast where the oil and gas industry has developed a mature offshore foundation/platform industry. But even these experience oil and gas foundation fabricators would likely require investment to support the higher volumes, and serial production, to supply offshore wind farms. The Atlantic, Pacific and Great Lakes regions also have experience fabricators in large heavy fab structures but again, investment would be likely to manufacture this new product line in the volumes necessary to support an offshore industry.

Monopile production for 3MW and 5MW foundations was scored at **MODERATE-HIGH** and **HIGH** respectively. This again would be a new product line for U.S. manufacturers, with major investments in facilities and equipment that to produce foundations that can be 73m in length, 6.5m diameter, and weighing over 900 tons. Current tower manufacturers could transition to manufacturing monopiles, but are primarily located in the central U.S. The size of these components, and the volumes that would be required if monopiles develop as a cost effective foundation for offshore, will dictate the need for new portside facilities in the coastal regions.

Subsea cabling is not dependent on the 3MW vs 5MW turbine. Instead the determining factor for the cable is the size of the wind farm (i.e. the MW and number of turbines – array cable, and the distance from shore – export cable). Currently the U.S. has no domestic suppliers of subsea cable that can be produced “continuous” cable that is necessary for offshore wind farms. Current cable manufacturers in Europe produce continuous cable that is manufactured portside and directly loaded into the installation vessel. GLWN rated subsea cable supply chain as **HIGH** for major investment being necessary for new portside subsea cable manufacturing.

The following sections detail the scoring of the 13 key turbine and balance-of-plant components.

Note: For the scorecard analysis, the Port of New Bedford, Massachusetts was selected as a common destination for calculating all transportation costs from point of manufacture. The New Bedford port, currently under renovation, is considered to be the first marine commerce terminal built to service the U.S. offshore wind industry and is the planned staging site for the Cape Wind project. These relative costs will vary with other offshore wind project locations.

2.2 Tower Scorecard Analysis

Tower Scorecard

3MW towers are approximately 90-120 meters in length and are typically comprised of 3 to 5 sections, with total weight of approximately 300-400 tons. Diameters of 3MW tower sections can range from 4-5meters.

5MW towers are approximately 90- 120 meters in length and are typically comprised of 3-4 sections, with total weight of approximately 500-600 tons. Diameters of tower sections can range from 5.5 – 6.5 meters.

Fig. 2.2.1 Trinity Tower Section

Component		LAND-BASED Considerations: Investment Req.	LAND-BASED Considerations: Major Hurdles	LANDBASED Notes
Towers	3MW	LOW	Capability Exists	**3MW:** Good diversity of tower mfgs in the US with capabilities for 3MW. Logistics challenges for transport of tower sections.
Towers	5MW	MODERATE-HIGH	Logistics: Rail/road challenges Fac/Equip: Upgrades likely	**5MW:** Investments likely to accommodate larger diameters. Road/rail transport constraints with diameters approaching 6.5m and tower sections weighing approx. 150-200 tons each.

Component		OFFSHORE Considerations: Investment Req.	OFFSHORE Considerations: Major Hurdles	OFFSHORE Notes
Towers	3MW	LOW-MODERATE	Logistics: Rail/road challenges to ports. Mfgs located in Midwest.	**3MW & 5MW**: Of the 16 manufacturers capable of producing towers, only six can potentially service the coast, and three of those are on the Great Lakes. Insufficient number of suppliers exist along the Atlantic, Gulf, and Pacific coast to cost effectively supply the offshore industry.
Towers	5MW	MODERATE-HIGH	Logistics: Rail/road challenges to ports. No tower mfg port side.	

Fig. 2.2.2 Tower Industry Scorecard

Legend:

Low	Can manufacturing the component today or a similar product (No real capital investment required)
Moderate	Requires some capital investment (Minor facilities upgrades and/or operations expenses)
High	Major capital investment required (New location/facility, major technology or equipment upgrades)

Tower Scorecard Summary

GLWN evaluated 16 fabricators and current tower suppliers capable of manufacturing wind turbine tower sections. Currently, the U.S. land-based market maintains a viable supply chain for towers for the 1-2.5MW turbines. These current and potential suppliers demonstrate the capabilities to produce 3MW towers with little or no facilities investment. Further, these same manufacturers have the ability to scale up to 5MW towers, but most will require further investment in their facilities to handle these large components, i.e. material handling upgrades, paint booth expansion, laydown yard considerations).

The offshore market could potentially be supplied by existing U.S. facilities as the capability currently exists for producing towers for 3MW units, and the ability to scale up to production for 5MW and larger. With Offshore, logistics must be considered as the largest percentages of tower manufacturers are not located in coastal regions. Manufacturers can produce the towers, but can they transport them to the coastal port, and remain competitive in the global market. Offshore wind farms will most likely be designed with larger turbines, 5MW and larger. Of the 16 manufacturers reviewed, only six are in close proximity to a U.S. coastal market, of which, three are located in the Great Lakes region. Insufficient suppliers exist along the Atlantic, Gulf, and Pacific coasts, most likely requiring future investment in new facilities capable of manufacturing towers for a 5WM and larger unit, located portside, or with minimal rail/road transport to an offshore wind port.

Regional Considerations

Current, dedicated tower manufacturers (red icons) are primarily concentrated in the Midwest. These wind tower manufacturing facilities are for the most part, new construction within the last 7 years, built to service the land-based wind industry. Manufacturers with capabilities to manufacture towers for 3MW-5MW turbines, but are also producing for other industrial markets (blue icons) present opportunities to supply the land-based and offshore industry but would most likely require upgrades to technology and facilities .

Fig. 2.2.3 Tower Manufacturers Locations

Tower Manufacturers Dataset

Company Name	City	State	Land-based/ Offshore	Coast	Notes
Broadwind (prev. Tower Tech)	Abeline	Texas	Both	No	Capabilities exist. Current tower supplier. Not coastal but transportable via rail to the Gulf
Johnson Plate and Tower Fabrication	Canutillo	Texas	Land-based	No	Current capabilities for large rolled product. Experienced tower supplier.
Marmen Energy (prev. Tower Tech)	Brando	South Dakota	Land-based	No	Capability exists. Current tower supplier.
Trinity Structural Towers	Clinton	Illinois	Land-based	No	Capability exists. Current tower supplier.
Trinity Structural Towers (prev. DMI)	West Fargo	North Dakota	Land-based	No	Capability exists. Current tower supplier.
Trinity Structural Towers (prev. DMI)	Tulsa	Oklahoma	Land-based	No	Capability exists. Current tower supplier.
Vestas	Pueblo	Colorado	Land-based	No	Capability exists. Current tower supplier.
Trinity Structural Towers	Newton	Iowa	Land-based	No	Capability exists. Current tower supplier.
EBNERFAB	Wadsworth	Ohio	Both	No	Current capabilities for large rolled product. Current tower manufacturer for low volume orders.
SMI Hydraulics	Porter	Minnesota	Land-based	No	Current capabilities for large rolled product. Experienced manufacturer of towers.
Broadwind (prev. Tower Tech)	Manitowoc	Wisconsin	Both	Great Lakes	Capability exists. Current tower supplier.
Ventower	Monroe	Michigan	Both	Great Lakes	Capability exists. Current tower supplier.
AT&F	Cleveland	Ohio	Both	Great Lakes	Current capabilities for large rolled product.
Enersteel	Natchez	Mississippi	Both	Gulf	Current capabilities for large rolled product. Good location for Offshore wind - 1.5 ml. from port - rail access to port.
Mass Tank	Quincy	Massachusetts	Both	Atlantic	Current capabilities for large rolled product. Facility strategically located at the Quincy MA shipyard.
T Bailey Inc.	Anacortes	Washington	Both	Pacific	Current capabilities for large rolled product. Experience manufacturing of 80 meter towers. Capabilities for floating platforms.

Fig. 2.2.4 Tower Manufacturers Dataset

Other Considerations

According to wind turbine component transportation companies, the average cost for transporting a tower section by rail in the U.S. is $1.00 - $2.00 per mile – not including any load or unload costs. Rail transport would likely also have a short haul trucking cost to the rail line.

Fig. 2.2.5 Tower Transport by Rail

Fig. 2.2.6 Tower Transport by Truck

The average cost for transporting a tower section in the central U.S. is $3.00 - $4.00 per mile by truck – not including any load or unload costs.

Estimated cost for transporting 25 towers that are each 77.6m in length and 6m diameter from Monroe, Michigan to the Port of New Bedford, Massachusetts (planned offshore port to service North Atlantic offshore wind) via the Great Lakes and the St. Lawrence Seaway is $40,620 per tower.

Fig. 2.2.7 Tower Transport by Barge

Fig. 2.2.8 Challenges of Rail Transport

U.S. manufacturers demonstrate the capability to produce the towers for both 3MW and 5MW turbines, but can they transport product to the coastal ports, and remain competitive in the global market? As mature as the Iowa wind industry is today, investment in transportation infrastructure is needed to safely and efficiently move large wind component parts.

Over the Roads **From Monroe, MI to New Bedford, MA Marine Port Terminal**	***3 MW tower**, weighing 300-400 tons, is estimated to cost $50,000 per section, plus 15% fuel surcharge and engineering studies (est. to be $20,000 - $30,000).* ***5 MW tower,** weighing 500-600 tons, is estimated at $70,000 per section, plus 15% fuel surcharge and route prep cost in the range of $100,000 to $200,000. With a diameter of 5-6.5 meters at the base, it is highly questionable that a suitable, and cost effective, route could be found to the New Bedford, MA port.*

2.3 Blades Scorecard Analysis

Blades Scorecard

3MW: Blades for a 3MW unit are typically 49 meters in length, each weighing approximately 10.9 tons.

5MW: Blades for the 5MW are approximately 60-70m in length, and 5-5.5 meters wide at their broadest point and a root diameter of 3.5 meters. Each blade has a weight from 19-26 tons.

Fig. 2.3.1 Knight and Carver Finished Goods

		LAND-BASED Considerations		
Component		Investment Req.	Major Hurdles	LANDBASED Notes
Blades	3MW	LOW	Capability Exists	**3MW:** Current U.S. blade manufacturers are well positioned to serve the land-based wind industry for the 3MW turbines.
Blades	5MW	MODERATE- HIGH	Logistics: rail & road limitations	**5MW:** Transportation challenges for blades greater than 50 meters. At 60+ meters, size and high cost of transport (20-30% higher) will create major challenges for suppliers.

		OFFSHORE Considerations		
Component		Investment Req.	Major Hurdles	OFFSHORE Notes
Blades	3MW	MODERATE-HIGH	Logistics: rail & road limitations Shipping/Port Access	**3MW & 5MW:** Of the 11 blade plants reviewed, 3 are located near a coast, with only one having direct port access. Rail and road limitations to coastal regions will necessitate investment in coastal and/or portside manufacturing facilities. Insufficient suppliers exist along the Atlantic, Gulf, and Pacific coast lines.
Blades	5MW	HIGH	New facility Investment Shipping/Port Access.	

Fig. 2.3.2 Blades industry Scorecard

Legend:

Low	Can manufacture the component today or a similar product (No real capital investment required)
Moderate	Requires some capital investment (Minor facilities upgrades and/or operations expenses)
High	Major capital investment required (New location/facility, major technology or equipment upgrades)

Blade Scorecard Summary

GLWN reviewed 11 blade facilities in the U.S. All of the current U.S. blade manufacturers have capabilities of manufacture blades greater than 50 meters, but with most limited to no more than 53-55 meters, without further investment. Typical limitations at several U.S. blade production facilities include facility physical size, plant location restrictions (limited land for expansion or additional storage area), and process equipment (need for larger paint booths, heavier cranes, etc.). Two of the 11 blade facilities listed in the Blade Dataset, will most likely require major capital investment to bring the facilities back into production. One potential facility is portside, but the company has not been producing blades as of yet at this site. This facility has the potential to supply the offshore market for the Atlantic Coast (equipment /investment required). The second facility has the capability to produce blades that are 50m and larger but could need investment to scale up to a serial production (larger, consistent volumes).

Regional Considerations

The land-based wind industry began in the Midwest, and the manufacturers set up production facilities in the Midwest. Today's current blade manufacturers are well positioned, both with technology and location, to service a majority of the land-based wind industry that is east of the Rocky Mountain range. Transport to move blades west from any of the Midwest manufacturers will only increase with difficulty as the blades reach lengths > 50 meters. For the offshore industry, of the 11 blade plants reviewed, only three are located near a coast, with only one currently having direct port access. Rail and road limitations to coastal regions will necessitate investment in coastal and/or portside manufacturing facilities to support the offshore industry. Although capable of manufacturing blades for a 3MW or 5MW turbine, the location of U.S. blade manufacturing facilities will prevent cost effective shipments to the coastal port regions. Insufficient suppliers exist along the Atlantic, Gulf, and Pacific coast lines. New blade facilities located at offshore wind port areas are needed.

Fig. 2.3.3 Blade Manufacturers Locations

Blade Manufacturers Dataset

Company Name	City	State	Land-based/ Offshore	Coast	Notes
Blade Dynamics	New Orleans	Louisiana	Land-based	Gulf	Capability exists. New Orleans port side facility. First large scale prototype segmented blade produced in 2010
LM Wind Power	Grand Forks	North Dakota	Land-based	No	Capability exists. Current wind supplier. Recent EU development on 100m blade for 8mw.
LM Wind Power	Little Rock	Arkansas	Land-based	No	Capability exists. *"…capacity to handle the largest blades made by LM, which measure 61.5m/200 ft. in length."*
Molded Fiber Glass	Aberdeen	South Dakota	Land-based	No	Capability exists – 44m. Currently supplier. Some investment likely for blades larger than 54m.
Molded Fiber Glass	Gainesville	Texas	Land-based	No	Capability exists – 48m. Currently supplier. Some investment likely for blades larger than 54m.
Siemens Blade	Fort Madison	Iowa	Land-based	No	Currently manufactures for Siemens 2.3MW unit. Capable of scaling up to the 3MW and larger blades.
TPI Composites	Newton	Iowa	Land-based	No	Capability exists – 44m. Currently supplier. Some investment likely for blades larger than 55m.
Vestas	Windsor	Colorado	Land-based	No	Capability exists – 48m. Currently supplier. Some investment likely for blades larger than 55m.
Vestas	Brighton	Colorado	Both	No	Capability exists – 57.5 meters. Most recently produced a test blade 189ft long, weighing 16.5 tons, for 3.3MW
Energetx Composites	Holland	Michigan	Both	Great Lakes	Currently producing for a 2MW. Could ramp to 3MW with some capital investment.
Gamesa	Fairless Hills	Pennsylvania	Both	Atlantic	Gamesa's Fairless Hills PA plant has rail and port access. Would require capital investment for blade production. [01/14 Ebensburg blade plant closed]

Fig. 2.3.4 Blade Manufacturers Dataset

Other Considerations

According to wind turbine component transportation companies, the average cost for transporting a wind turbine blade by rail in the U.S. is $2.00 per mile – not including any load or unload costs.

Fig. 2.3.5 Blade Transport by Rail

Fig. 2.3.6 Blade Transport by Truck

The average cost for transporting a blade in the central U.S. is typically $15-$20 per mile by truck for blades < 50 meters. For blades > 50 meters, the price will increase 20-30% per mile. And then there are permits, which can vary as much as 150% from state to state.

When practical, waterways are considered the most cost effective method for transporting blades of any length. Transport by ship or barge is estimated at $1.50 to $4.00 per nautical mile (the shorter the distance, the higher per mile due to fixed costs). Currently, there are no U.S. blade facilities in production, located on coastal waterways.

Fig. 2.3.7 Blade Transport by Barge

Over the Roads **From Aberdeen, South Dakota to the Port of New Bedford, Massachusetts**	*Estimates for transporting a 61.5 meter blade from Aberdeen, SD to the Port of New Bedford, MA (planned Offshore port to service North Atlantic offshore wind) is $51,000 per blade. Using truck and ship combined, is estimated at $40,000 per blade.*

2.4 Generator Scorecard Analysis

Generator Component Scorecard

3MW: A Goldwind 3MW unit is 4.5m in diameter and 1.2m in height [15 ft. diam. x 4 ft. height] weighing approximately 40 tons.

5MW: Generators for a 5MW unit can weigh in excess of 65 tons with a diameter of 6.5m and a height of 1.4 meters [21.3 ft. diam. x 4 ft. height].

Fig. 2.4.1 Teco Westinghouse and Indar Generators

Component		LAND-BASED Considerations: Investment Req.	LAND-BASED Considerations: Major Hurdles	LANDBASED Notes
Generator	3MW	LOW	Capability Exists	**3MW:** Capability exits in the U.S today but with only three viable companies. Generator technology is transferrable if the business case supports it.
Generator	5MW	LOW-MODERATE	Fac/Equip: Possible upgrades for crane capacity & finish tanks	**5MW:** Capability exists with U.S. suppliers but with a limited number. Increased size for 5MW will likely require facilities investments for larger cranes and varnishing tanks.

Component		OFFSHORE Considerations: Investment Req.	OFFSHORE Considerations: Major Hurdles	OFFSHORE Notes
Generator	3MW	LOW	Capability Exists	**3MW:** Capability exits in the U.S today but with only three viable companies. Generator technology is transferrable if the business case supports it. No special considerations for land-based vs offshore.
Generator	5MW	LOW-MODERATE	Fac/Equip: Possible upgrades for crane capacity & finish tanks	**5MW:** Capability exists with U.S. suppliers but with a limited number. Increased size for 5MW will likely require facilities investments for larger cranes and varnishing tanks.

Fig. 2.4.2 Generator Industry Scorecard

Legend:

Low	Can manufacturing the component today or a similar product (No real capital investment required)
Moderate	Requires some capital investment (Minor facilities upgrades and/or operations expenses)
High	Major capital investment required (New location/facility, major technology or equipment upgrades)

Generator Scorecard Summary

Five U.S. generator manufacturers were reviewed by GLWN. Three are currently supplying the wind industry and capable of supplying generators for a 3MW wind turbine, with little or no additional facility or capital investment. One company, not a current supplier to the wind industry, does have the capabilities but would likely require major investment to produce generators for 3MW and larger turbines. The fifth U.S. company capable of supplying generators for 3MW and 5MW turbines, has a strong global presence in supplying the wind industry but maintains generator production in Europe. Major investment would be necessary to build a U.S. based generator production facility. As the land-based and offshore markets develop, and the fact that generator technology is transferrable, we should see more U.S. companies willing to invest in generator production.

Some industry enthusiasts assume that as turbine MW's increase and offshore wind develops, that permanent magnet direct drive generators will be utilized as believed to be more reliable and less maintenance. In Figure 2.4.3 - A 2013 study by The Center for Electric Technology, Department of Electrical Engineering Technical University of Denmark, suggests that of the latest products available at the time from some of the largest wind turbine manufacturers that the industry is far from a consensus regarding drivetrain configuration.

Manufacturer	Model	Details
Alstom	Haliade 150	Direct drive - PMSG
Areva	M5000	1-stage gearbox - PMSG
Enercon	E-126	Direct drive - EESG
Gamesa	10X-4.5	2-stage gearbox - PMSG
GE	GE4.1-113	Direct-drive - PMSG
Goldwind	2.5MW	PMDD Direct drive - PMSG
Nordex	N150 (6MW)	Direct-drive - PMSG
REPower	6M	3-stage gearbox - DFIG
Siemens	SWT-6.0-154	Direct drive- PMSG
Suzlon	S9X-2.1	Geared - DFIG
Vestas	V164-7.0	Medium speed gearbox - PMSG

Fig. 2.4.3 Wind Turbine OEM generator design-of-choice

	**PMSG** [Permanent Magnet Synchronous Generator] – Permanent magnet generators do not require a DC supply for the excitation circuit, nor do they have slip rings and contact brushes. However, large permanent magnets are costly. Pictured: Indar PMSG.
	**DFIG** [Doubly Fed Electric Machines] - Doubly fed machines are typically used in applications that require varying speed of the machine's shaft. Today doubly fed drives are the most common variable speed wind turbine concept. Pictured: Siemens Loher 5.3MW DFIG
	**EESG** [Electrical Excited Synchronous Generator] - Electrically excited synchronous generators are characterized by their tough design. Generally a very low maintenance product that is extremely reliable and uses no magnets. Pictured: Enercon EESG

.

Regional Considerations

Generators for the 3MW and 5MW turbines can be shipped via truck or rail but will face some constraints for any long haul transport. For rail, the diameters of 15 ft. and 21.5 ft. respectively, will have issues of tunnel and overpass clearance. For truck transport, the weight will be the deciding factor with a 3MW unit weighing in the area of 40 tons and the 5MW at 68.3 tons. Both units are considered oversize and overweight loads. Of the current U.S. generator manufacturers 3 are located in the Midwest [Ingeteam/Indar, Swiger Coil, and Hyundai Ideal Electric] and one in Texas [Teco Westinghouse]. Shipment by barge or vessel is also a consideration for these large parts.

Fig. 2.4.4 Generator Manufacturers Locations

Generator Manufacturers Dataset

Company Name	City	State	Land-based/ Offshore	Coast	Notes
ABB - *no US mfg*	Bland	Virginia	Both	Atlantic	Capability exist – but not in the U.S. No current ABB U.S. generator manufacturing facilities. Bland, VA facility currently produces transformers only.
Hyundai Ideal Electric	Mansfield	Ohio	Both	No	Low & Medium Speed synchronous generators. 4-pole generators.
Indar/Ingeteam	Milwaukee	Wisconsin	Both	Great Lakes	Capability exists. Current supplier of generators and transformers for U.S. and Europe.
Swiger Coil Systems	Cleveland	Ohio	Both	Great Lakes	Build to print generators.
Teco-Westinghouse	Round Rock	Texas	Both	No	Build to print generators. Manufactures double-fed induction, synchronous, PMDD for 1-5MW turbines.

Fig. 2.4.5 Generator Manufacturers Dataset

Other Considerations

Fig. 2.4.6 Truck transport of Exxon Mobile refining equipment for Canadian Tar Sands project. Load width is 24ft – compare to the 5MW generator at 21.3 ft.

By Truck: *According to a transportation specialist, transporting a 3MW, 40-ton wind turbine generator, an over-sized and over-weight load, from Ingeteam's facility in Milwaukee, WI to the Port of New Bedford, MA, is estimated at $36,000 per generator. Size limits shipments to one generator per truck.*

A 5MW 68-ton generator on the same route to New Bedford, Ma from Milwaukee, WI is estimated at $92,000 per generator.

By Rail: *According to a transportation specialist, transporting the 3MW wind turbine generator from Ingeteam's facility in Milwaukee, WI to the Port of New Bedford, MA is estimated at $11,500 per generator. Shipments can handle two 3MW generators per rail car.*

For the 5MW 68-ton generator shipped to New Bedford, Ma from Milwaukee, WI, a transport specialist doubts that a 21.3 ft. diameter generator could make the clearance in tunnels and underpasses via rail without the use of special gondolas. No estimate was provided.

Fig. 2.4.7 Schnabel car - a twenty-two axle rail car, built in 1969, originally owned by Westinghouse. This car, used to deliver generators, is now owned by Siemens-Westinghouse, Ontario, CAN.

The Schnabel car *is a specialized type of long railroad freight car with low gravity center. It is designed to carry heavy and oversized loads (such as heavy-duty transformers, parts of hydraulic turbines, stators and rotors of generators, columns, frames) that cannot be transported by other cars due to their weight and/or size.*

By Vessel **From Milwaukee, WI to Port of New Bedford, MA via the St. Lawrence Seaway**	*Estimates for transporting a 3MW generator is $9,500 per generator, which includes the vessel charge of $1000, a cartage charge of $6000, and a port charge of $2500.* *A 5MW generator is estimated at $29,200 per generator, which includes a vessel charge of $2,700, a cartage cost of $24,000, and a port charge of $2,500.*

2.5 Jacket Foundation Scorecard Analysis

Jacket Component Scorecard

3MW: Jacket structures are typically designed for use in water depths greater than 40 meters, can weigh in the area of 500 U.S. tons, with a height of 45-60 meters.

5MW: The total mass of the Weserwind 5 MW VARIOBASE Jacket® for a 30-metre water depth application is approx. 800 U.S. tons (including foundation piles). The jacket itself (legs and bracings) is only about 1/3 of the total weight per installation. Foundations (piles) also contribute about 1/3 and the remainder is other items like the transition node or pile sleeves.

Fig. 2.5.1 Weserwind Jacket – Port of Bremerhaven GmbH

Fig. 2.5.2 Weserwind cast steel nodes

Designs by Weserwind and RePower, incorporates cast steel nodes for connection points, decreasing corrosion at weld points, and allowing for use of standard straight-cut tubular steel pipes, and more automated weld processes, thus reducing time intensive hand-weld hours, and overall cost

Component		OFFSHORE Considerations: Investment Req.	OFFSHORE Considerations: Major Hurdles	OFFSHORE Notes
Jacket Fnd. Main Lattice	3MW	MODERATE-HIGH	Offshore experience in Gulf & Pacific coasts. Investments likley to support serial production. Portside facilities needed for Atlantic and Great Lakes regions.	**3MW & 5MW**: U.S. maintains a robust heavy fab industry across the country. Gulf and Pacific coasts have a mature heavy fabrication industry seasoned in offshore applications from oil & gas. Manufacturing of jacket foundations will require portside facilities. Current oil & gas platform fabricators will likely require investment to support serial production and higher volumes.
	5MW	MODERATE-HIGH		

Fig. 2.5.3 Jacket Foundation Industry Scorecard

Legend:

Low	Can manufacturing the component today or a similar product (No real capital investment required)
Moderate	Requires some capital investment (Minor facilities upgrades and/or operations expenses)
High	Major capital investment required (New location/facility, major technology or equipment upgrades)

Jacket Scorecard Summary

GLWN reviewed 11 companies considered capable of manufacturing jacket foundations for offshore wind. Two are located in the North Atlantic, five on the Gulf coast, three in the North Pacific, and one on the Great Lakes. More than half have experience producing jacket type structures (but only one-off production) for the offshore oil and gas industry, primarily those located in the Gulf and northern Pacific region. Only one company, Signal Corporation, in Orange Texas, maintains a modern facility, 450,000 sq. ft. under roof, that is capable of producing multiple jackets simultaneously, supporting serial production, and with direct load to barges. Keppel AmFELS in Brownsville, Texas, is the fabricator in line to produce “hurricane resistant” jacket foundations that will support three 6MW direct-drive wind turbines for the proposed Baryonyx, DOE demonstration project, to be developed off the coast of Port Isabella, Texas. Energy Management has announced that the Cape Wind offshore substation will be produced by Cianbro at their Brewer, Maine facility.

Even with fabricators experienced in producing jacket structures for the oil and gas industry, GLWN suggests that investments will be required for these facilities to support wind farm volumes and serial production of turbine foundations. For those heavy fabricators without direct experience in jacket structures, we anticipate there will be a cost associated with the learning curve for this new industry and product, possible capital investment in facilities equipment necessary for handling structures of this size, and again, investments to support the transition to serial production.

Regional Considerations

A mature fab industry exists throughout the U.S. Large heavy fabricators can be found along most of the coastal regions. Further research would most likely identify even more capable U.S. manufacturers well positioned to serve the industry while still recognizing that moderate-high investments are likely to meet production and capacity requirements, or to bring production directly to the ports.

Fig. 2.5.4 Jacket Dataset Potential Manufacturers Location

Jacket Manufacturers Dataset

Company Name	City	State	Land-based/ Offshore	Coast	Notes
American Bridge	Reedsport	Oregon	Offshore	Pacific	Capability exists. Experienced in large civil construction projects. Could support floating foundations in the Pacific. Port access.
American Tank & Vessel	Moss Point	Mississippi	Offshore	Gulf	Capability exists - Offshore experience. Platform Legs for Offshore Jackets.
Bath Iron Works (General Dynamics)	Bath	Maine	Offshore	Atlantic	Capability exists. Potential investments to support serial production and higher volumes. Port access.
Cianbro Corporation	Brewer	Maine	Offshore	Atlantic	Capability exists. Current supplier of the Cape Wind offshore substation foundation. Port access.
Gulf Island Fabricators	Houma	Louisiana	Offshore	Gulf	Capability exists - Offshore oil platforms. Port access.
Gulf Marine Fabricators	Aransas Pass	Texas	Offshore	Gulf	Capability exists - Offshore oil platforms. Port access.
Keppel AmFELS	Brownsville	Texas	Offshore	Gulf	Capability exists - Offshore oil platforms. Current partner with Barynox DOE demonstration project for advanced jacket design. Port access.
Kiewit Offshore Services	Ingleside	Texas	Offshore	Gulf	Capability exists - Offshore oil platforms. . Port access.
Simko Industrial Fabricators	Hammond	Indiana	Offshore	Great Lakes	Capabilities exist for large structural steel projects. Investment required for port side final assembly.
Signal Corporation	Orange	Texas	Offshore	Gulf	Capabilities exist - current jacket structure supplier to offshore oil &gas. *"Capability to build multiple structures simultaneously."* Manufacturing facility with direct load to barges.
T Bailey Inc.	Anacortes	Washington	Offshore	Pacific	Capabilities exist for large rolled and structural steel projects. Candidate for floating foundations.
TMF - Thompson Metal Fab	Vancouver	Washington	Offshore	Pacific	Capabilities exist - Offshore oil platforms. Capabilities in large rolled steel vessels. Candidate for floating foundations. Port access via Columbia River.

Fig. 2.5.5 Manufacturers Dataset for Jacket Foundations

Other Considerations

Transporting jackets from a port in TX to the New Bedford, Massachusetts staging port would not be easy but is doable. Jackets would likely be transported horizontally for long distance ocean travel. Estimates for this 7 day journey from Texas to Massachusetts:

•*$1,065,000 for the barge, tugs, equipment, surveys, and labor, to transport 2 horizontally stacked jackets.*

•*i.e. $532,500 per jacket, or $250 per nautical mile*

Fig. 2.5.6 - Muller Dordrecht horizontal transport of a 900 ton jacket foundation near Belgium.

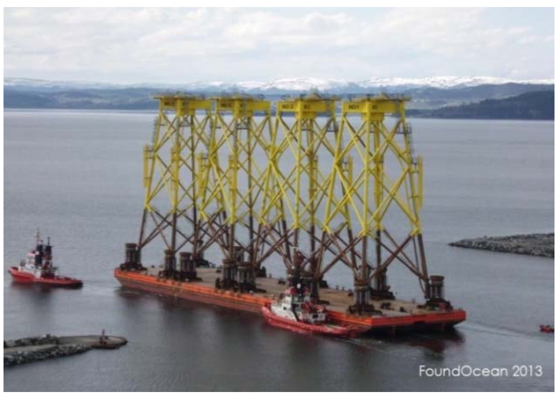


Fig. 2.5.7 – Traditional vertical transport of RWE jackets.

Transporting 4 jackets from New Bedford, Massachusetts port to a wind farm 40 meters offshore (where waters are 40 meters deep), is estimated at:

- *$198,000 for the barge, tugs, equipment, surveys, and labor, to transport 4 jackets per barge*
- *i.e., $49,500 per jacket, or $1235 per nautical mile, per jacket.*

2.6 Monopile Foundation Scorecard Analysis

Monopile Component Scorecard

3-5MW: Monopiles typically can weigh in the area of 650 U.S. tons with a 5 meter diameter, and a wall thickness of 6 inches (150mm). Historically, monopiles are most commonly used in water depths not exceeding 30-35 meters.

Fig. 2.6.1 Weserwind Monopile at Bremerhaven GmbH

Siemens 3.6 MW turbines were installed in 19 - 23 meter water depths at the UK Walney Wind Farm in 2012, on monopiles that were up to 68 meters long, with a weight of 805 tons. [Additionally, the transition piece was up to 24 meters long and weighed about 300 tons.]

XL Monopiles: More recently in Europe, monopiles have been produced for water depths over 50 meters. Figure 2.6.2 is an example of the foundations at EnBW's offshore wind farm Baltic 2, also supporting a Siemens 3.6MW turbine. Bladt/EEW-SPC JV produced the XL monopiles that are no less than 73.50 meters long, with a diameter of 6.5 meters and a weight of 930 tons - more than 15% larger than the present generation of monopiles.

Fig. 2.6.2 Bladt/EEW XL Monopile

Component		OFFSHORE Considerations: Investment Req.	OFFSHORE Considerations: Major Hurdles	OFFSHORE Notes
Monopile Fnd.	3MW	MODERATE-HIGH	Capability exists for rolled product. Learning curve for new product. Limited facilities portside.	**3MW & 5MW:** U.S. fabricators experienced in large rolled steel, including wind towers, are good candidates for monopiles. Expected learning curve, as these foundations will be a new product for U.S. manufacturers. Current tower manufacturers have capability but some investment expected for equipment and facility upgrades. Monopiles most likely in the Atlantic, Gulf, and Great Lakes.
	5MW	HIGH	Investment likely for rolling thicker steel plate. New portside facilities likely needed.	

Fig. 2.6.3 Monopile Industry Scorecard

Legend:

LOW	Can manufacturing the component today or a similar product (No real capital investment required)
MODERATE	Requires some capital investment (Minor facilities upgrades and/or operations expenses)
HIGH	Major capital investment required (New location/facility, major technology or equipment upgrades)

Monopile Scorecard Summary

The EWEA (European Wind Energy Association) January 2014 report, *European Offshore Wind Key Trends and Statistics,* indicates that "*monopile substructures remained the most popular substructure type in 2013 with 490 installed (79%). 87 tripod foundations were installed, 14% of all newly installed substructures, followed by jackets (39, 6%), tri-piles (8, 1%) and 1 gravity foundation*".

GLWN reviewed nine manufacturers with capabilities to manufacture offshore wind monopile foundations. Although all had experience in manufacturing large circular welded products, seven of the nine would most likely require capital investments in equipment and facilities, such as upgrades in rolling equipment that can process larger and thicker steel plate, and material handling equipment that can support finished product sizes greater than 50m in length and weights in excess of 500 tons. Only four of the nine have facilities located on waterways, with direct access. The other five are within close proximity (less than 5 miles) to a port, with rail or truck access. Two companies not located on a waterway, suggested that final weld and assembly of the monopile structures could take place portside.

As we found with jacket foundations, those fabricators that could ramp up the fastest and be the most competitive in the production of monopiles, are located in the Gulf coast. Four of the nine fabricators that GLWN reviewed are located along the Gulf and are well positioned to supply monopoles for offshore wind. We anticipate that the monopile market for the offshore wind farms will be in the Great Lakes, the Atlantic, and the Gulf. Investments in monopile production at an east coast port facility will be key to cost effectively supplying the Atlantic coast wind farms.

Regional Considerations

As with the jacket foundations, a larger number of fabricators, capable of producing monopiles today, exist along the Gulf coast. During our research, GLWN did not identify any fabricators along the southeast coast (located on a waterway) that had the equipment for, or experience in, large rolled steel product similar to monopiles.

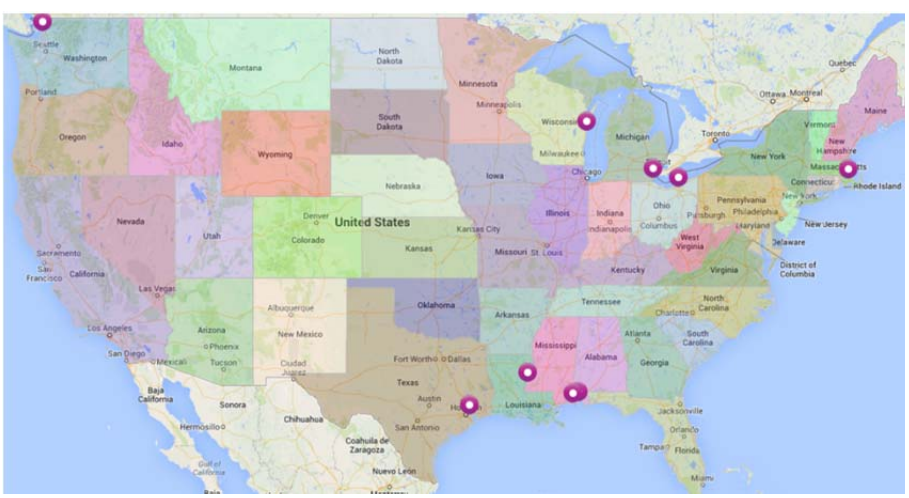


Fig. 2.6.4 Monopile Manufacturers Locations

Monopile Manufacturers Dataset

Company Name	City	State	Land-based/ Offshore	Coast	Notes
Alabama Roll Products	Theodore	Alabama	Offshore	Gulf / South Atlantic	Capabilities exist. Current facility is not portside. Investment likely to support final assembly port side.
American Tank & Vessel	Moss Point	Mississippi	Offshore	Gulf / South Atlantic	Capabilities exist. Experienced offshore oil & gas supplier. Some investment likely to support serial production. Waterfront facility - Barge or ship out of Moss Point, MS.
AT&F (American Tank & Fab)	Cleveland	Ohio	Offshore	Great Lakes	Capabilities exist. Current facility is not portside. Investment likely to support final assembly port side.
Broadwind (formerly Tower Tech)	Manitowoc	Wisconsin	Offshore	Great Lakes	Capabilities exist. Current wind tower manufacturer. Capital investment likely to support monopile production. Waterfront facility - Barge or ship out of Manitowoc, WI.
Enersteel	Natchez	Mississippi	Offshore	Gulf	Capabilities exist. Investment likely to support monopile production. Port accessible via the Mississippi River.
Greens Bayou Pipe Mill	Houston	Texas	Offshore	Gulf	Capabilities exist. Experienced offshore oil & gas supplier. Minimal investments expected to support monopile production. Port access via the Houston Ship Channel [connects directly to the Gulf of Mexico].
Mass Tank	Middleboro	Massachusetts	Offshore	Atlantic	Capabilities exist. Investment likely to support monopile production. Current Massachusetts facility is not portside.
T Bailey Inc.	Anacortes	Washington	Offshore	Pacific	Capabilities exist for rolled and structural. Facility is not portside but within 3 miles. Potential for final assembly port side. Potential supplier for floating foundations in the Pacific.
Ventower	Monroe	Michigan	Offshore	Great Lakes	Capabilities exist. Current wind tower manufacturer. Capital investment likely to support monopile production. Port access less than 1 mile via truck.

Fig. 2.6.5 Monopile Dataset

Other Considerations

Today's most experienced fabricators of large rolled steel products, for offshore applications, are in the Gulf coast. With little or no investment needed by these Gulf companies to begin production of monopiles for the offshore wind industry, we considered transport costs to the Atlantic coast where monopiles may be the foundation choice in the near term.

Fig. 2.6.6 EEW monopiles transported from Rostock, G8

TX Supplier to New Bedford, MA Staging Port:
Cost for shipping 650-ton monopiles from a U.S. supplier in Texas to the New Bedford, Massachusetts offshore wind staging port, approx. 2100 nautical miles:

- *Transporting 6 monopiles per barge, estimated cost is $177,000 per monopile, or $84 per nautical mile.*

MA Staging Port to Wind Farm Installation:
Cost for shipping 650-ton monopiles from the New Bedford, Massachusetts offshore wind staging port to an offshore wind farm installation (approx. 20 nautical miles):

- *Transporting 6 monopiles per barge, estimated cost is $24,750 per monopile, or $465 per nautical mile.*

Fig. 2.6.7 Barge transport by Bilfinger Construction – London Array

2.7 Cast Hub and Support Base Scorecard Analysis

Cast Hub and Support Base Component Scorecard

CAST HUB

Fig. 2.7.1 Cast 1.5MW cast hub, ready to be machined. Location: HPM in OH.

3MW: Acciona hub for 3MW turbine is approx. 40,000 lbs. of ductile iron.

5-6MW: The Bard 5W unit has a hub weighing 88,000 lbs. and is approx.., 4x 3.5 meters. The Siemens 6MW hub is 50 metric tonnes, or 110,000 lbs., with a diameter of 5 meters.

CAST SUPPORT BASE

Fig. 2.7.2 Cast Support Base. Location: Hodge Foundry in PA.

3MW: Acciona cast base for 3MW turbine is approx. 35,000 lbs. Base material is ductile iron.

5-6MW: Cast support bases for the 5-6MW can weigh up to 176,000 lbs., having a size of approx. 3m x 4m x 10m. Siemens 6MW support base weighs in at 100,000 lbs.

Component		LAND-BASED Considerations: Investment Req.	LAND-BASED Considerations: Major Hurdles	LANDBASED Notes
Cast Hubs & Support Bases	3MW	HIGH	Capability does not exist [for larger than 2.5MW]. Cost and efficiency of aging facilities.	**3MW & 5MW:** Capability does not exist for casting forms larger than 2.5MW. U.S. foundries are primarily located in the Midwest, acceptable proximity to supply the central U.S. wind corridor turbine manufacturers, if foundries can produce the product and be cost effective.
	5MW	HIGH	Capability does not exist [for larger than 2.5MW]. Cost and efficiency of aging facilities.	

Component		OFFSHORE Considerations: Investment Req.	OFFSHORE Considerations: Major Hurdles	OFFSHORE Notes
Cast Hubs & Support Bases	3MW	HIGH	Capability does not exist [for larger than 2.5MW]. No coastal locations.	**3MW & 5MW:** Capability does not exist for casting forms larger than 2.5MW. No U.S foundries, with capabilities to produce large castings, are located in any coastal region. New modern casting facilities, located in the coastal regions is recommended to support the offshore market.
	5MW	HIGH	Capability does not exist [for larger than 2.5MW]. No coastal locations.	

Fig. 2.7.3 Cast Hub and Support Base Industry Scorecard

Legend:

Low	Can manufacturing the component today or a similar product (No real capital investment required)
Moderate	Requires some capital investment (Minor facilities upgrades and/or operations expenses)
High	Major capital investment required (New location/facility, major technology or equipment upgrades)

Cast Hub and Support Base Scorecard Summary

There are seven foundries in the U.S. with the capability to cast ductile iron hubs or support bases for the 3MW wind turbine. Of the seven companies reviewed by GLWN, all but St. Mary's foundry in Ohio have supplied the wind industry with cast hubs, support bases or gearbox housings within the last 7 years.

Three companies, ATI Casting Services, Hodge Foundry, and Ellwood Quality Castings, have the ability to pour for the sizes required for the 5MW, i.e. 88,000 to 200,000 lbs. Although the foundries we assessed do have the experience in wind, and the equipment necessary to produce cast hubs or support bases for the 3MW and/or the 5MW, it is our opinion that these companies may not be competitive once the sizes go beyond those required for a 2 or 2.5MW unit. Most of the experience has been supplying components for the 1 or 1.5MW with limited production in the 2 or 2.5MW sizes, and no production for 3MW or larger turbines.

Today's foundries are likely in need of major investment in facilities, updated process equipment, and implementing substantive change using process improvement strategies such as lean, in order to remain competitive in the global market. Currently, there are no serial manufacturers of large castings in the U.S. for the wind industry. Ultimately, investments in new, modern foundries that can supply large cast parts, produced to rigorous quality standards and testing, are needed. The last major investment in a U.S. foundry took place in the 1980's at Minster Machine (dba Midwest Manufacturing) in Minster, Ohio, but maintains a maximum size capability of 38,000 lbs., not large enough for even the 3MW.

Regional Considerations

The seven foundries that GLWN found capable to produce ductile iron hubs or support bases for a 3Mw or 5MW turbine are located in just four states, and all in the Great Lakes region. Figure 2.7.4 Foundry Locations, clearly shows the concentration of foundries in the Midwest with none west of the Mississippi.

As offshore wind develops, and turbines get larger, it will be advantageous to have a foundry in reasonable proximity to OEM's wind turbine assembly facilities in coastal regions. Transport of components for a 5MW and larger turbines, from current Midwest foundries, will present its own constraints, especially for the hub. The Siemens 6MW hub is 50 metric tonnes, or 110,000 lbs., with a diameter of 5 meters. A 5 meter diameter hub is reaching the limits of rail and truck constraints for any long haul of these parts.

Current facilities, if capable of manufacturing components for a 3MW or larger, are positioned geographically to supply a number of U.S. wind turbine OEM's with facilities primarily located in the central Midwest for land-based wind market. Rail and truck transport of 3MW components will not present the challenges as for the 5MW components with max height or diameter of less than 15ft.

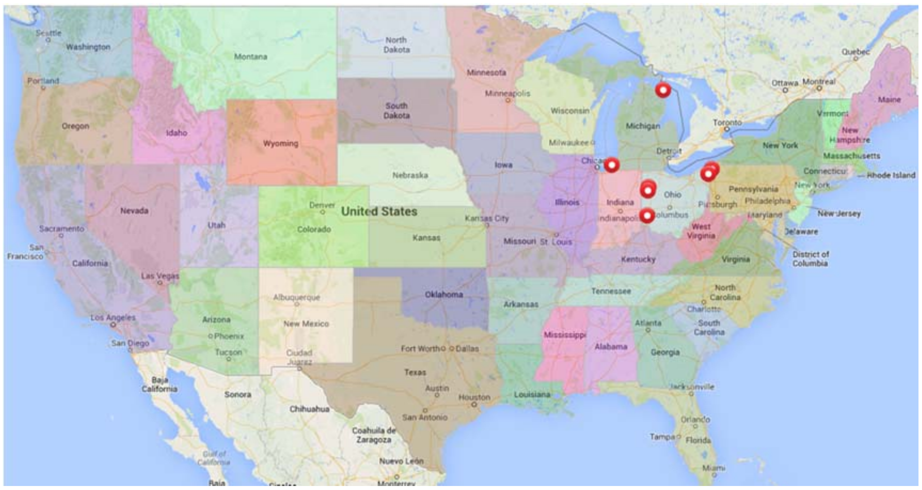


Fig. 2.7.4 Foundry Locations

Cast Hub and Support Base Manufacturers Dataset

Company Name	City	State	Land-based/ Offshore	Coast	Notes
ATI Casting Services [NOTE: Plant closing announced 4-2014]	La Porte	Indiana	Both	Great Lakes	**Can [Could] produce castings up to 200,000lbs. Has produced cast components for wind.**
ATI Casting Services	Alpena	Michigan	Both	Great Lakes	Can produce casting up to 100,000lbs. Has produced cast components for wind.
Cast-Fab	Cincinnati	Ohio	Both	Great Lakes	Can produce castings up to 80,000lbs. Has produced cast components for wind.
Ellwood Quality Castings	Hubbard	Ohio	Both	Great Lakes	Can produce castings up to 200,000lbs. Has produced cast components for wind.
Hodge Foundry	Greenville	Pennsylvania	Both	Great Lakes / Atlantic	Can produce castings up to 200,000lbs. Has produced cast components for wind.
Midwest Manufacturing (Minster)	Minster	Ohio	Both	Great Lakes	Can produce castings up to 38,000lbs. Has produced cast components for wind.
St. Mary's Foundry	St. Mary's	Ohio	Both	Great Lakes	Can produce castings up to 60,000lbs

Fig. 2.7.5 Cast Hubs and Support Bases Dataset

Other Considerations

Fig. 2.7.6 Cast support base in transport

Support Bases By Truck:
An Acciona 3MW cast main frame, with an approximate weight of 35,000 lbs., is estimated to cost $7900 to transport from La Porte, Indiana to the Port of New Bedford, Massachusetts.

The cast base for a Siemens 6MW turbine, weighs approximately 100,000lbs., and is estimated at almost *$46,000,* for this same transport from La Porte, IN to New Bedford, MA, due to the overall size and weight factors.

Fig. 2.7.7 Cast hub in transport

Hubs By Truck:
A cast hub for the Acciona 3MW turbine, at approximate weight of 40,000lbs., is estimated to cost $7185 per hub, to transport from La Porte, Indiana to the the Port of New Bedford, Massachusetts.

The cast base for the Bard 5-6MW turbine, weighs approximately 88,000lbs., and is estimated at $14,850 per hub, to transport from La Porte, IN to New Bedford, MA, due to the overall size and weight factors.

Moving cast components via truck is doable, but not practical with higher, consistent volumes. Shipment by rail or vessel remains the most cost effective when shipping large heavy components for any industry.

By Vessel **From La Porte, IN to the Port of New Bedford, MA via the St. Lawrence Seaway**	***Support Bases:*** *The estimated cost to move a 3MW cast support base by vessel from La Port, IN to New Bedford, MA is $$5400 compared to $7900 by truck. And a 6MW base is $10,800 by vessel compared to $46,000 by truck.* ***Cast Hubs:*** *The estimated cost to move a 3MW cast hub by vessel from La Porte, IN to New Bedford, MA is $2025 compared to $7185 by truck. And a 5MW base is $3,150 by vessel compared to $14,850 by truck.*

2.8 Fabricated Support Base Scorecard Analysis

Fabricated Support Base Component Scorecard

5MW: The REpower main frame support base measures 9m long, 2.5m wide, and approximately 1.25m varying height, with a weight of 69 tons.

3-MW: A typical fabricated rear frame, or generator frame, for a 3MW unit weighs approximately 6 tons, or 12,000 lbs.

Fig. 2.8.1 REpower 5MW Fabricated main frame ready for assembly.

Fabricated support bases are typically used to support the generator, referred to as the "rear frame". Most wind turbine designs utilize a cast support base, or "main frame", which supports the nacelle and rotor. REpower is one of the few wind turbine designs that utilizes a fabricated structure for the main frame.

Fig. 2.8.2 K&M Machine Fabricators main frame in production

		LAND-BASE and OFFSHORE Considerations		
Component		Investment Req.	Major Hurdles	LANDBASED and Offshore Notes
Fabricated Support Bases	3MW	LOW	Capability exists.	**3MW & 5MW:** U.S. has good resources for large structural fabrications - inland and in coastal regions, with several coastal region fabricators familiar with fabricating structures for offshore applications.
	5MW	LOW-MODERATE	Capability exists. Some investment expected for crane capacity and serial production.	**5MW:** Fabricated main frames can exceed 3m in width and 9m in length, weighing over 65 tons, which can present challenges if transporting by rail or truck.

Fig. 2.8.3 Fabricated Support Base Industry Scorecard

Legend:

LOW	Can manufacturing the component today or a similar product (No real capital investment required)
MODERATE	Requires some capital investment (Minor facilities upgrades and/or operations expenses)
HIGH	Major capital investment required (New location/facility, major technology or equipment upgrades)

Fabricated Support Base Scorecard Summary

Currently throughout the U.S. there are a sizable number of companies that manufacture large structural steel fabrications. GLWN identified 17 manufacturers with the capabilities today to fabricate support bases for a 3MW or 5MW turbine, with minimal investment required. With further research, we are confident that there are several more domestic fabricators that could produce the support base components for these next generation turbines.

For production of 5MW support base components, we would expect some investment to increase crane capacity for frame sizes that can exceed 65 tons. Manufacturers could also experience some operational expense to support higher volumes and serial production.

Most turbines today are designed with a cast ductile iron main frame support base and a fabricated rear frame support base (i.e. the generator frame). Of the group reviewed, two have experience in the wind industry as suppliers of structural frames for units that are less than 3MW.

Regional Considerations

GLWN is confident that all coastal regions could find regional fabricators capable of supplying support bases for 3MW and larger turbines. The Gulf coast region boasts the largest number of fabricators with experience in both large fabricated steel structures and offshore applications stemming from the offshore oil and gas industry. Proximity to a wind turbine assembly plant will be advantageous for the 5MW and larger bases so facilities with rail onsite could have an advantage in transport costs to an OEM.

Fig. 2.8.4 Fabricated Support Base Manufacturers Locations

Fabricated Support Base Manufacturers Dataset

Company Name	City	State	Land-based / Offshore	Coast	Notes
American Bridge	Reedsport	Oregon	Both	Pacific	Capabilities exist for 3MW and 5MW. Civil construction. Offshore applications in heavy marine works.
AT&F	Cleveland	Ohio	Both	Great Lakes	Capabilities exist for 3MW and 5MW. Large custom fabrication with structural steel. Crane capacity exceeds 100T.
Bath Iron Works (General Dynamics)	Bath	Maine	Both	Atlantic	Capabilities exist for 3MW and 5MW. Large fabrications for civil construction. Experience in offshore applications.
Cast-Fab	Cincinnati	Ohio	Both	Great Lakes	Capabilities exist for 3MW and 5MW for rear frames. Current manufacturer of machined ductile iron components for the wind industry.
Cianbro	Brewer	Maine	Offshore	Atlantic	Capabilities exist for 3MW and 5MW. Large fabrications for civil construction. Experience in offshore applications.
Distefano	Omaha	Nebraska	Land-based	No	Capabilities exist for 3MW. Experienced wind supplier for structural frames and brackets.
Gulf Island Fabrication Inc.	Houma	Louisiana	Both	Gulf	Capabilities exist for 3MW and 5MW. Large fabricated structures - civil construction and offshore experience with oil & gas platforms.
Gulf Marine Fabricators (sub of Gulf Island Fabricator)	Arkansas Pass	Texas	Both	Gulf	Capabilities exist for 3MW and 5MW. Large fabricated structures - civil construction and offshore experience with oil & gas platforms.
IDE (Integrated Drilling Equipment)	Humble	Texas	Both	Gulf	Capabilities exist for 3MW and 5MW. Large fabricated structures - civil construction and offshore experience with oil & gas platforms.
K&M Machine Fabricating Inc.	Cassopolis	Michigan	Both	Great Lakes	Capabilities exist for 3MW. Experience wind supplier for fabricated main frames, machine hubs, and gearbox housings.
Keppel AmFELS	Brownsville	Texas	Both	Gulf	Capabilities exist for 3MW and 5MW. Large fabricated structures - civil construction and offshore experience with oil & gas structures.
Kiewit Offshore Services	Ingleside	Texas	Both	Gulf	Capabilities exist for 3MW and 5MW. Large fabricated structures - civil construction and offshore experience with oil & gas structures.

Metal Trades	Hollywood	South Carolina	Offshore	Atlantic	Capabilities exist for 3MW and 5MW. Located on deep water port, less than 20 miles from Charleston ports via barge. 200' Heavy Loading Pier with high capacity to load modular units in excess of 300 ton.
O'Neal Manufacturing Services	Greensboro	North Carolina	Land-based	Atlantic & Great Lakes	Capabilities exist for 3MW and 5MW. Current wind supplier for generator (or rear) frames. Nine U.S. based facilities, primarily east of the Mississippi.
Simko Industrial Fabricators	Hammond	Indiana	Offshore	Great Lakes	Capabilities exist for 3MW. Not portside but rail within 1/4 mile. Currently limited to frames < 25ton (Crane capacity).
Springs Fab	Colorado Springs	Colorado	Land-based	No	Capabilities exist for 3MW. Medium size structural steel fabrication.
Starr Manufacturing	Vienna	Ohio	Both	Great Lakes	Capabilities exist for 3MW and 5MW. Large, heavy steel fabricator, components with 30ft bases.
TMF - Thompson Metal Fab	Vancouver	Washington	Offshore	Pacific	Capability exists for 3MW and 5MW. Large fabricated structures. Rail access and portside with access to Columbia River.

Fig. 2.8.5 Fabricated Support Base Dataset

Other Considerations

There are no particilar tranport conisderations for this fabricated structure. With the dimensions for the 5MW, they are still transportable by truck, rail, or vessel. The REpower support base design for their 5MW unit is approximately 1.3m x 2.5m x 9m with a weight of 69 tons, or 138,000 lobs.

Transport from Cleveland, Ohio fabricator to the Port of New Bedford, Massachusettes

By Truck:	**By Rail:**	**By Vessel:**
Estimated to cost $20,280 to transport one fabricated support base by truck, *or $30 per mile.*	Estimated to cost $6,760 to transport one fabricated support base by rail, *or $ 10 per mile.*	Estimated to cost $1,572 per fabricated support base by vessel.

2.9 Gearbox Scorecard Analysis

Gearbox Component Scorecard

3-MW:
The Acciona 3MW gearbox at 3m x 3m x 3m is approximately 23.5 tons.

A Brevini Hyrid Compact 3W weighs approximately 35 tons.

5MW and larger:

The Winergy 6.5MW Gearbox at 5m x 5m x 5m weighs approximately 62 tons.

Fig. 2.9.1 Winergy HyridDrive Compact 3MW

		LAND-BASE and OFFSHORE Considerations		
Component		Investment Req.	Major Hurdles	LANDBASED and Offshore Notes
Gearboxes	3MW	LOW	Capability exists.	There are 3 major players in the U.S. capable of manufacturing gearboxes for 3MW. Some investment is likely for scaling up to 5MW gearboxes but capability exists. Units are transportable by rail, even for larger 5MW units. Good geographical spread for supplying onshore and offshore regions.
	5MW	LOW-MODERATE	Capability Exists. Some investment likely for scaling to 5MW production.	

Fig. 2.9.2 Gearbox Industry Scorecard

Legend:

LOW	Can manufacturing the component today or a similar product (No real capital investment required)
MODERATE	Requires some capital investment (Minor facilities upgrades and/or operations expenses)
HIGH	Major capital investment required (New location/facility, major technology or equipment upgrades)

Gearbox Scorecard Summary

Currently throughout the U.S. there are three companies that today manufacture gearboxes for the wind industry. GLWN identified five manufacturers that have the capabilities to produce gearboxes. Two of the five companies are experienced in contract assembly work but have the knowledgebase and experience to manufacture gearboxes, however, investment would be expected to support full gearbox manufacturing and serial production.

One manufacturer, who was actively supplying the wind industry, has turned their production to more lucrative opportunities in the oil and gas industry. If the wind market warrants investment, this company could return to supplying the wind industry with facility and equipment investments likely.

Both land-based and offshore could be supplied from current manufacturers' facilities. Although transport to either coast from the primarily Great Lakes region suppliers, will add significant cost for transport of the 5MW and larger units, especially for truck transport.

Regional Considerations

Current U.S. gearbox manufacturers are primarily located east of the Mississippi, with one supplier, Moventas, located on the Pacific coast. Current suppliers are located in closest proximity to the central U.S. wind turbine OEMs. Gearboxes, even for the 5MW, are transportable by rail and vessel. 5MW weights may present some challenges for long distance truck transport. Offshore wind could be supplied by current manufacturers but we would anticipate that more gearbox manufacturers would enter the industry if the market warrants new facility investments.

Fig. 2.9.3 Gearbox Manufacturers Locations

Gearbox Manufacturers Dataset

Company Name	City	State	Land-based / Offshore	Coast	Notes
Brevini Wind USA	Yorktown	Indiana	Both	Great Lakes	Capability exists. Indiana facility recently retooled for market opportunities in oil and gas industry. Significant investment likely to return to producing wind turbine gearboxes.
Horsburgh & Scott	Cleveland	Ohio	Both	Great Lakes	Capability exists. Experience in contract gearbox assembly and repair for up to 2MW units. Could manufacture gearboxes for 3MW and 5MW with investments to support full manufacturing and serial production.
Moventas	Portland	Oregon	Both	Pacific	Capability exists. Experience in contract gearbox assembly up to 2MW. Investment likely to support full manufacturing and serial production. European facilities produce for 3MW-10MW units.
Winergy Drive Systems Corporation	Elgin	Illinois	Both	No	Capability exists. Current manufacturer for up to 3MW. Some investment likely to manufacturing 5MW units.
ZF Wind	Gainesville	Georgia	Both	No	Capability exists. Current manufacturer for up to 3MW. Some investment likely to manufacturing 5MW units.

Fig. 2.9.4 Gearbox Dataset

Other Considerations

GLWN does not anticipate any constraints for transport of the 3MW or larger 5MW units by rail or vessel. Gearboxes, greater than 5MW, could present some challenges for truck transport with weights exceeding 64 tons.

Transport 1035 miles from Elgin, Illinois to the Port of New Bedford, Massachusettes

By Truck: For a 3MW gearbox, 3m x 3m x 3m and weighing 47,000 lbs., GLWN's transport specialist estimates the cost at $5,185 to transport one gearbox by truck, or $5.00 per mile. A 6.5MW, 4m x 4m x 4m and weighing 124,000 lbs., is estimated at *$36,295* due to the overweight load.

By Rail: For the 3MW gearbox transported from Elgin, IL to the New Bedford, MA port , GLWN's transport specialist estimates the cost at $1,620 per gearbox by rail. And for the 6.5MW gearbox cost of rail transport is estimated at *$*11,661.

By Vessel: For the 3MW gearbox transported from Elgin IL to the New Bedford, MA port, GLWN's transport specialist estimates the cost at $1,080 per gearbox by vessel via the St. Lawerence Seaway, and the 6.5MW gearbox at *$*10,080.

2.10 Composite Housing Scorecard Analysis

Composite Housing Component Scorecard

3MW: The Acciona nacelle Housing weighs approximately 9,000lbs and the spinner, 2500lb. The Siemens 3. 0 model measures 6.7m (22 ft.) in length x 4.27m (14 ft.) in width.

5MW: For a 5MW unit, nacelle housings are estimated to be approximately 15,000lbs., with a spinner weighing in at 4200lbs.

Fig. 2.10.1 Nacelle housings and spinner covers produced by MFG and Wausaukee Composites

Component		LAND-BASE Considerations: Investment Req.	LAND-BASE Considerations: Major Hurdles	LANDBASED Notes
Composite Housings and Covers	3MW	LOW	Capability exists.	**3MW:** Current U.S. wind turbine composite component suppliers are well positioned to supply next generation land-based wind. Minimum investments, if any, to produce parts for 3MW turbines.
Composite Housings and Covers	5MW	LOW-MODERATE	Capability exists. Some investment expected for 5MW sizes.	**5MW:** The REpower 5MW nacelle is 6m x6mx18m. Some challenges are likely to transport any significant distances. Modular or sectional nacelle housing designs would minimize these challenges.

Component		OFFSHORE Considerations: Investment Req.	OFFSHORE Considerations: Major Hurdles	OFFSHORE Notes
Composite Housings and Covers	3MW	LOW-MODERATE	Capability exists. Transport challenges to coastal regions.	Offshore wind is generally expected to standardize on turbines 5MW and larger. There are limited current suppliers along the Atlantic, Pacific, and Gulf coasts. The U.S. maintains a mature composite boat industry in coastal regions which, according to wind turbine OEMs, could easily transition to supplying nacelle housings, spinner covers, and nose cones, if the business model warrants.
Composite Housings and Covers	5MW	MODERATE	Some investment expected for 5MW and larger. Transport challenges to coastal regions.	

Fig. 2.10.2 Composites Industry Scorecard

Legend:

LOW	Can manufacturing the component today or a similar product (No real capital investment required)
MODERATE	Requires some capital investment (Minor facilities upgrades and/or operations expenses)
HIGH	Major capital investment required (New location/facility, major technology or equipment upgrades)

Composite Housing Scorecard Summary

GLWN reviewed ten manufacturing facilities specializing in molded composite components. Of the ten, seven of the facilities have actively supplied the land-based wind industry over the last several years and demonstrate the capability to supply nacelle housings, spinner covers and nosecones for the next generation wind turbines, with little investment required. Three of the companies have not participated in wind, but demonstrate the capability. These "new" suppliers would require facility and process investments to support a new product line.

Of the ten facilities reviewed, six of those are divisions of one company, MFG Composites, with facilities in Alabama, California, Ohio, South Dakota, Texas, and Pennsylvania. All of the MFG facilities are experienced and well positioned to supply composite parts for the land-based wind industry with moderate investment expected at some of the facilities to support 5MW and larger units.

There is a concentration of current suppliers in the central U.S, developed for the land-based market. The Atlantic, Gulf, and Pacific coasts lack current suppliers that could manufacture wind composite components today. However, in GLWN's interviews with wind turbine OEM's, they indicate that the U.S. large molded fiberglass boat industry is mature and capable of manufacturing wind turbine component parts. OEMs did not present any major concerns in identifying future qualified U.S. coastal suppliers (current boat manufacturers) for composite housings and covers. This transition of new suppliers into the market to support offshore will be dependent on the market and opportunity development.

GLWN considers the U.S. composite industry capable of supplying both the land-based and offshore markets, with new players able to supply the industry, if the business case supports the investments.

As turbines get larger…

The mass and volume of the nacelle housing can vary significantly depending on the drive train configuration used by the manufacturer. Direct drive units require less mass and therefor smaller nacelle housing structures.

Housing dimensions of the 5MW and larger units will present challenges for any rail or roadway transport. Modular or sectional nacelle housing designs, as was utilized by Nordex USA at their Jonesboro, Arkansas plant, would minimize these challenges.

Regional Considerations

With limited suppliers located in coastal regions, current suppliers will face challenges of transporting the larger nacelle housings for any long distances via road or rail, especially if delivering to coastal regions. Land-based is well positioned with experienced and qualified suppliers, located within reasonable proximity to current land-based OEMs, and capable of manufacturing and supplying nacelle housings, spinner covers and nosecones for the 3MW and larger turbines.

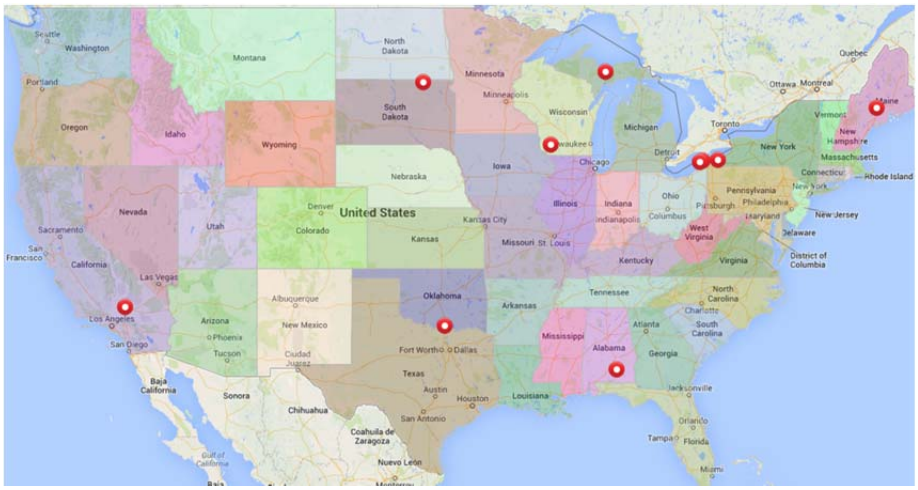


Fig. 2.10.3 Composite Housing Manufacturers Locations

The REpower 5MW nacelle housing measures 6mx6mx18m (19.5ft x 19.5ft. x 59ft.). Picture taken at REpower staging area in Bremerhaven GmbH port facility.

Consider the logistics challenges of transporting a nacelle composite housing of this size to an OEM assembly site if you were limited to truck or rail. Notice the individual standing under the housing.


Fig. 2.10.4 REpower 5MW nacelle ready for deployment from the Bremerhaven GmbH port.

As the Offshore industry develops, with turbines 5MW and greater, it will be adventageous to have more composite suppliers in the coastal regions, nearest to OEM assembly facilities as possible.

Composite Housing Manufacturers Dataset

Company Name	City	State	Land-based / Offshore	Coast	Notes
Creative Concepts	Rapid River	Michigan	Both	Great Lakes	Not a current wind industry supplier but capabilities exist. Facility and process investments would be expected to support wind components production.
Hadlock Plastics	Geneva	Ohio	Both	Great Lakes	Capability exists for spinner cover and nosecone. Some investment expected to support a new product line and industry.
Kenway Corporation	Augusta	Maine	Both	North Atlantic	Not a current wind industry supplier but capabilities exist. Facility and process investments would be expected to support wind components production.
MFG Alabama	Opp	Alabama	Both	Gulf	Capability exists. Currently manufactures nacelle housings. Can support both 3MW and 5MW production with minimal investment required.
MFG West	Adelanto	California	Both	Pacific	Capability exists. Currently manufactures nacelle housings. Can support both 3MW and 5MW production with minimal investment required.
MFG Composite Systems	Ashtabula	Ohio	Both	Great Lakes	Capability exists. Currently manufactures spinners. Could manufacture nacelle housings or spinners for 3MW or 5MW but with some investment required.
MFG South Dakota	Aberdeen	South Dakota	Both	No	Capability exists. Currently manufactures blades. Could manufacture nacelle housings or spinners for 3MW and 5MW with minimal investment required.
MFG Texas	Gainesville	Texas	Both	Gulf	Capability exists. Currently manufactures blades. Could manufacture nacelle housings or spinners for 3MW and 5MW with minimal investment required.
MFG Union City	Union City	Pennsylvania	Both	Great Lakes	Capability exists. Could manufacture nacelle housings or spinners for 3MW or 5MW but with some investment required.
Wausaukee Composites, Inc.	Cuba City	Wisconsin	Both	Great Lakes	Capability exists. Past supplier of nacelle housings and spinners. No major investment expected to produce parts for 3MW or 5M.

Fig. 2.10.5 Composite Housing Manufacturers Dataset

2.11 Forged Rings Scorecard Analysis

Forge Ring Component Scorecard

There are four principal large forged rings in the wind turbine; the tower flanges, the yaw bearing ring, the pitch bearing ring, the main shaft bearing rings. Sizes and specifications are similar in all four applications for the 3MW and 5MW respectively.

Yaw and pitch bearing rings: The yaw bearing connects the tower to the nacelle bedplate which allowed the nacelle to rotate into the direction and speed of the wind. Three smaller slew rings connect the turbine blades with the hub to adjust the pitch angle of the blades.

3MW: Diameters range from 3 to 4 meters for the yaw bearing seamless rolled ring and 1.5 to 2.5 meters for the 3MW pitch bearing ring.

5WM: Diameters range from 5.5 to 6.5 meters for the yaw bearing seamless rolled ring and 2.5 to 3.5 meters for a 5MW pitch bearing ring.

Fig. 2.11.1 Forged and machined yaw ring for a 1.5MW application. A product of Rotek, Aurora, Ohio

Main bearing ring: The main bearing ring supports the rotor and transfers load to the nacelle bedplate. The Siemens 3.6MW and the REpower 5MW and 6MW units, utilize *two* main bearings for their offshore applications supporting the shaft at both ends. Diameters can span 1 to 2 meters depending on the shaft design.

Tower flanges: Seamless rolled forged flanges are used to connect the 3-5 steel sections used in the wind tower, plus a tower top flange used to connect to the nacelle bedplate. For offshore applications, a forged flange is also used to make the connection to the wind tower.

3MW: Diameters range from 4 to 5 meters
5WM: Diameters range from 5.5 to 6.5 meters

Fig. 2.11.2 Forged tower flanges ready for cleaning and tower assembly in Germany.

Component		LAND-BASE and OFFSHORE Considerations: Investment Req.	LAND-BASE and OFFSHORE Considerations: Major Hurdles	LANDBASED and Offshore Notes
Forged Rings	3MW	MODERATE-HIGH	Capability exists. Some concerns with rail and road transport for rings larger than 4.5m diameter.	**3MW & 5MW:** Several manufacturers identified in the U.S. capable of supplying forged and machined rings for tower flanges and yaw, pitch, and main bearings. Currently, domestic manufacturers are NOT supplying forged rings to the U.S. wind industry. Suppliers from Asia, Europe, and South America dominate today's forged ring global wind market.
	5MW	MODERATE-HIGH		

Fig. 2.11.3 Forged Ring Industry Scorecard

Legend:

LOW	Can manufacturing the component today or a similar product (No real capital investment required)
MODERATE	Requires some capital investment (Minor facilities upgrades and/or operations expenses)
HIGH	Major capital investment required (New location/facility, major technology or equipment upgrades)

Forge Ring Scorecard Summary

GLWN identified and reviewed six companies that forge and machine rings for bearings and flanges. All of these companies are believed to be capable of supplying the wind industry, with forged elements such as tower flanges, and rings for yaw bearings, pitch bearings, and the main shaft bearings. Of the six companies reviewed, two have actively supplied the wind industry in the past, but even with large capital investments to increase their capabilities to produce these large key forged components, these manufacturers quickly lost their market share to South American, Asian, and European suppliers. They have not been able to regain their position as active suppliers of flanges, yaw and pitch bearings, or main bearings.

Transportation of these forged ring bearings and flanges does not present any unmanageable constraints. There could be some challenges in rail or truck transport for the 5MW yaw ring bearings as they exceed 5 meter diameters, but not significantly enough to render domestic suppliers non-competitive.

GLWN believes that the U.S. wind market could be served by existing domestic manufacturers for forged components, if they could prove competitive with global suppliers. Further analysis of U.S., South American, Asian, and European forge ring suppliers is recommended by GLWN to understand domestic suppliers' loss of market share and continued inability to be competitive in the wind industry.

Regional Considerations

GLWN identified forge ring suppliers that could support both land-based and offshore markets. Suppliers exist in proximity to Pacific, Atlantic, Gulf and Great Lakes coastal regions. Location of suppliers is not as significant for the forge rings and flange components as it is with other key wind turbine components where size can dictate tremendous cost burden for overweight and oversized long haul. Some challenges may exist for as diameters approach 6 meters.

Fig. 2.11.4 Forged Ring Manufacturers Locations

Fig. 2.11.5 Forge ring tower flanges in transport

New developments in tower designs:

Vestas March 2014 press release: *Vestas has launched the Large Diameter Steel Tower, a cost effective solution to increase tower height for 3 MW turbines to over 140m. The increased diameter of the tower presents a challenge in terms of transportation. Vestas has solved this by delivering the bottom tower section in three lengthways segments. These can easily and cost effectively, be transported on a flatbed truck and reassembled on site using **vertical flanges** to ensure strength.*

This new design for towers by Vestas would potentially mitigate any transportation challenges associated with 5MW tower designs for flanges approaching 6.5 meter diameters.

Forge Ring Manufacturers Dataset

Company Name	City	State	Land-based / Offshore	Coast	Notes
Ajax Rolled Ring	York	South Carolina	Land-based	Atlantic	Capability exists for 3MW. Seamless rolled and machined rings. Diameters to 3m (120 in.)
Frisa Forjados S.A. de C.V.	Santa Catarina	Mexico	Both	Gulf	Capability exists for 3MW, 5MW, and larger. Located in Brownsville, TX development zone. Diameters to 8.1m (320 in.)
Jorgenson Forge	Tukwila	Washington	Both	Pacific	Capability exists for 3MW and 5MW. Seamless rolled and machined rings. Max Diameters to 5.7m (225 in.)
Philadelphia Forgings	Wyncote	Pennsylvania	Both	Atlantic	Capability exists for 3MW and 5MW. Seamless rolled and machined rings. Diameters to 6.1m (240 in.)
Rotek (ThyssenKrupp)	Aurora	Ohio	Both	Great Lakes	Capability exists for 3MW and 5MW. Seamless rolled and machined rings. Diameters to 6.1m (240 in.)
Scot Forge	Spring Grove	Illinois	Both	Great Lakes	Capability exists for 3MW and 5MW. Seamless rolled and machined rings. Diameters to 6.1m (240 in.)

Fig. 2.11.6 Forge Ring Dataset

2.12 Forged Shafts Scorecard Analysis

Forge Shaft Component Scorecard

3MW: The main shaft is estimated 6m long (20 ft.) with a head diameter of 2.5m (8 ft.) and a weight of 40k lbs.

Fig. 2.12.1 Main shaft with flange for a 1MW. Forging is 28 in x 74 in x 7 ft. at the head

Fig. 2.12.2 Machine shaft 45,000 lb., 15' long and 8' diameter. McSwain Manufacturing, Ohio.

5MW: The main shaft for a 5MW turbine is estimated to weigh over 60k lbs.

Siemens 6.0MW direct drive technology replaces the main shaft, gearbox and high-speed generator with only a low-speed generator, eliminating two-thirds of the conventional drive train arrangement.

Component		LAND-BASE and OFFSHORE Considerations: Investment Req.	LAND-BASE and OFFSHORE Considerations: Major Hurdles	LANDBASED and Offshore Notes
Forged Shafts	3MW	MODERATE-HIGH	Capability exists. Some transport limitations for 5MW depending on shaft design and diameter.	**3MW & 5MW :** U.S. forge companies demonstrate the experience and capability to supply shafts for the 3MW. Currently, domestic manufacturers are NOT supplying forged, or final machined, shafts to the U.S. wind industry. Suppliers from Asia and Europe dominate today's forged, and machined, shaft market.
	5MW	MODERATE-HIGH		

Fig. 2.12.3 Forge Shafts Industry Scorecard

Legend:

LOW	Can manufacturing the component today or a similar product (No real capital investment required)
MODERATE	Requires some capital investment (Minor facilities upgrades and/or operations expenses)
HIGH	Major capital investment required (New location/facility, major technology or equipment upgrades)

Forge Shaft Scorecard Summary

GLWN found the forge industry in the U.S. to have the capabilities to produce shafts, but overall, major capital investments would be likely to support next generation wind turbines, and to become competitive to newer, more modern and efficient foreign facilities.

Eight companies were reviewed with the capabilities to forge shafts. Of the eight, three will likely require major capital investments to support shaft production for 3MW or 5MW turbines, to expand their capabilities to produce shafts with diameters of 2.5 meters and larger. The remaining five are considered capable of supplying diameters up to 2.5 meters, but major investments are likely for any shaft diameters greater than that. Ellwood National Forge has been an active supplier to the wind industry for several years, but recent competition from Asia, Spain, and Europe has significantly eroded their market share.

GLWN believes that the U.S. wind market could be served by existing domestic manufacturers for forged components for the 3MW turbine, if they could prove competitive with global suppliers. Most forge companies would require major capital investment to produce forge shafts for the 5MW. Further analysis of forgers from the U.S., Asia, South America and Europe is recommended by GLWN to understand domestic suppliers' loss of market share and continued inability to be competitive in the wind industry.

Regional Considerations

Although the forging industry is primarily located in the Midwest, in the Great Lakes region, GLWN identified companies that forge large components in each of the coastal regions. Location of suppliers is not as significant for the forge shafts as it is with other key wind turbine components where size can dictate tremendous cost burden for overweight and oversized long haul. Forgers reviewed by GLWN are currently supplying large product for mining, transportation, and oil & gas industries. If domestic forge companies can become competitive in producing next generation main shafts, GLWN believes they could serve the land-based and offshore wind markets from current locations.

Fig. 2.12.4 Forge Shaft Manufacturers Locations

Forge Shaft Manufacturers Dataset

Company Name	City	State	Land-based / Offshore	Coast	Notes
A. Finkl & Sons Co.	Chicago	Illinois	Both	Great Lakes	Capabilities exist for 3MW. Ingots sizes to 2.5m diameter and 200k lbs. Shafts to 125k lbs. Investment expected to support 5MW designs that exceed 2.5m diameters.
All Metals & Forge Group	Fairfield	New Jersey	Both	Atlantic	Capabilities exist. Limits on sizes for 3MW or 5MW. Investment required supporting diameters > 2m.
Anderson Shumaker Company	Chicago	Illinois	Both	Great Lakes	Capabilities exist. Limits on sizes for 3MW or 5MW. Investment required to support diameters > 1m and weights > 20lbs.
Ellwood National Forge	Ellwood City	Pennsylvania	Both	Great Lakes	Capability exists for 3MW. Active supplier of shafts to the wind industry. Investment expected to support 5MW designs that exceed 2.5m diameters.
Forge USA	Houston	Texas	Both	Gulf	Capability exists for 3MW. Investment expected to support 5MW designs that exceed 2.5m diameters or 40k lbs.
Lehigh Heavy Forge	Bethlehem	Pennsylvania	Both	Great Lakes	Capability exists for 3MW and 5MW. . Currently supports diameters up to 3.5m and weights to 330 tons.
Jorgensen Forge Corporation	Seattle	Washington	Both	Pacific	Limited capabilities for 3MW and 5MW. Investment expected to support diameters > 1.5m and weights > 70k lbs.
Scot Forge Co	Spring Grove	Illinois	Both	Great Lakes	Capability exists for 3MW. Investment expected to scale up to 5MW diameters, depending on shaft design.

Fig. 2.12.5 Forge Shaft Manufacturers Dataset

2.13 Subsea Cabling

Subsea Cable Component Scorecard

There are two types of subsea cable used in an offshore wind farm:

Export Cable connects the offshore and onshore substations. Most wind farms developed to date, have one offshore substation, but that is changing in Europe, as farms increase in size and distance from shore. Examples of suppliers (non US): ABB, Nexans, NKT and Prysmian. According to the UK 2012 “A Guide to an Offshore Wind Farm”, export cables are laid in as long sections as possible, of up to 70km (43 miles) in length, to avoid subsea connections.

Inter-Array Cable connects the turbines to offshore substation platforms to allow the power generated at each turbine to be collected before being sent on to shore. Examples of suppliers (non US) include ABB, JDR Cable Systems, Draka, Nexans, NKT, NSW, Parker Scanrope and Prysmian.

Fig. 2.13.1 Subsea cable cross section, 19” diameter cable. Wolf Island Wind Project Canadian Renewable Energy Corp.

Fig. 2.13.2 ABB DC and AC Subsea Cable

Component		OFFSHORE Considerations: Investment Req.	OFFSHORE Considerations: Major Hurdles	OFFSHORE Notes
Subsea Cable	3MW	HIGH	No U.S. mfg facilities producing subsea export or array cable for offshore utiltiy installations, i.e.5 miles or greater.	**3MW & 5MW:** Port side production of continuous line, subsea cable is needed. Current U.S. mfg of subsea cable limited to short distance installations using spliced cable. Spliced cable presents transmission and reliability concerns.
	5MW	HIGH		

Fig. 2.13.3 Subsea Cable Industry Scorecard

Legend:

LOW	Can manufacturing the component today or a similar product (No real capital investment required)
MODERATE	Requires some capital investment (Minor facilities upgrades and/or operations expenses)
HIGH	Major capital investment required (New location/facility, major technology or equipment upgrades)

Subsea Cable Scorecard Summary

According to Navigant's recently release 2013 report, U.S. Offshore Wind Manufacturing and Supply Chain Development, the global suppliers of inter-array and export cable for offshore wind farms are centered in Europe and Asia. GLWN reviewed four U.S. cable manufacturers for this report, with the consideration that although they do not produce offshore utility wind farm subsea cable today, do they have the expertise to expand into the market.


Fig. 2.13.4 ABB cable manufactured and loaded onto installation vessels

No production of submarine cable appropriate for offshore utility wind farms exists today in the U.S. Offshore wind farm subsea cable that is manufactured in Europe and Asia, is loaded directly onto cable installation ships that are adjacent to coastal manufacturing facilities.

Kerite, a current U.S. manufacturer of submarine cable, is limited to "short-run" offshore installations. Cable lines greater than 3-5 miles from connection hub require splicing, which can result in transmission and reliability concerns for offshore applications greater than 5 miles from shore. During April 2013, **nkt cables** completed a submarine cable with a continuous length of 31km, approximately 20 miles, for the West of Duddon Sands (WoDS) offshore wind farm project in the UK.

To satisfy the U.S. offshore market, current domestic cable manufacturers would need to make major investments in current production, or pursue joint venture opportunities with current global suppliers of offshore wind submarine cable for new stateside, and portside, manufacturing facilities.

Regional Considerations

Due to the continuous lengths utilized for offshore wind farms, cable manufacturing facilities ultimately should be located at coastal regions, portside, with direct access to loading finished cable directly onto the installation vessel.

The newest cable manufacturing facility is the Nexans Extra High Voltage plant located in Charleston, South Carolina, strategically located to expand into offshore subsea cable production with the plant being "*ready access to navigable waters*".

Fig. 2.13.5 Nexans Extra High Voltage, Charleston, South Carolina

"*The commitment of $85 million toward the construction of our newest extra high voltage plant in South Carolina demonstrates Nexans' position in the fast growing North American market.*"

The facility is scheduled for completion in 2014.

Fig. 2.13.6 Subsea Cable – *Potential* U.S. suppliers

Subsea Cable Manufacturers Dataset

Company Name	City	State	Land-based / Offshore	Coast	Notes
General Cable	Highland Heights	Kentucky	Land based (current)	No	No U.S. production of subsea cable. Experienced from European division NSW, Nordenham German
Kerite	Seymour	Connecticut	Both	No	Capability exists for installations < 5 miles from connection hub. Experience in submarine trans link cabling in the Great Lakes.
Nexans High Voltage	Charleston	South Carolina	Land based (current)	Atlantic	New facility in Charleston, SC manufacturing underground power cable. Experienced from Europe production. Port accessible.
Prysmian Cable and Systems	Abbeville	South Carolina	Land-based (current)	No	Producing land-based transmission cable for Cape Wind in Abbeville, SC plant. No U.S. production of subsea cable. Experienced from Europe production.

Fig. 2.13.7 Subsea Cable Dataset

SECTION 3 - U.S. WIND SUPPLY CHAIN MAP AND DATABASE

3.1 Map Overview

As part of the public dissemination of the project results, we utilized the GLWN Wind Supply Chain, viewable at www.glwn.org. GLWN has been developing this on-line, free access, wind supply chain map over the past five years, creating a platform for identifying active and emerging suppliers for the land-based wind industry, including turbine component manufacturers and wind farm construction service suppliers. The map supports several search features as seen in Figure 3.1.1 below.

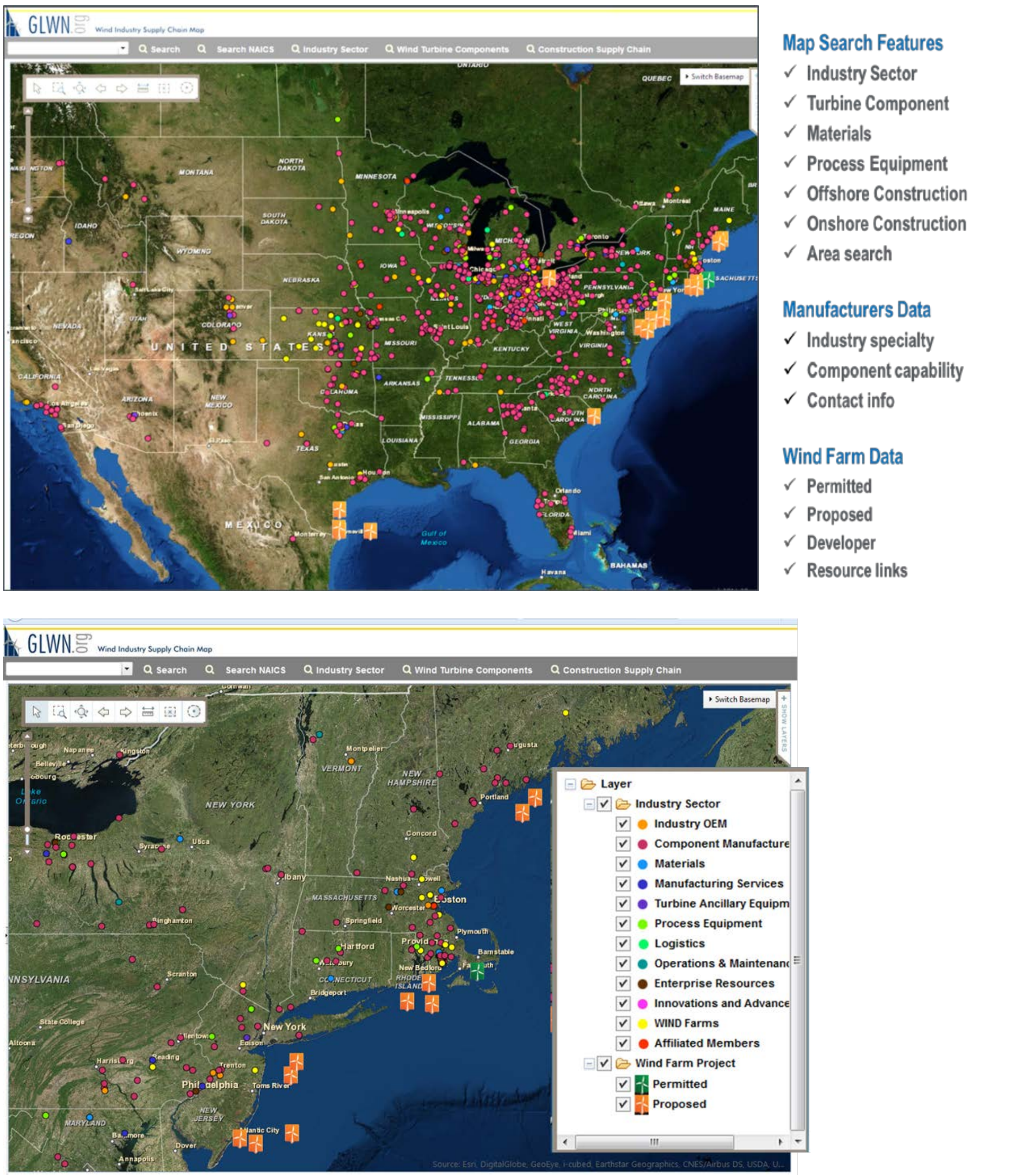


Fig. 3.1.1 GLWN Wind Supply Chain Map, Search Features, and Legend

GLWN has expanded the Map to include data from the Scorecard Manufacturer's Survey, listing all companies that responded to the survey on the map, including their wind industry specialty, and relevance to land-based vs offshore applications. Over 260 companies were added to the GLWN wind data base and wind supply chain map as a result of this project.

The search features now provide filtering for offshore vs land-based component suppliers, offshore balance-of-pant component searches, and Offshore Wind Farm locations (planned and permitted) and general farm data. Figure 3.1.2 shows a Profile page available on a Permitted wind farms, with data on the developer, wind farm logistics, and wind farm technology being utilized.

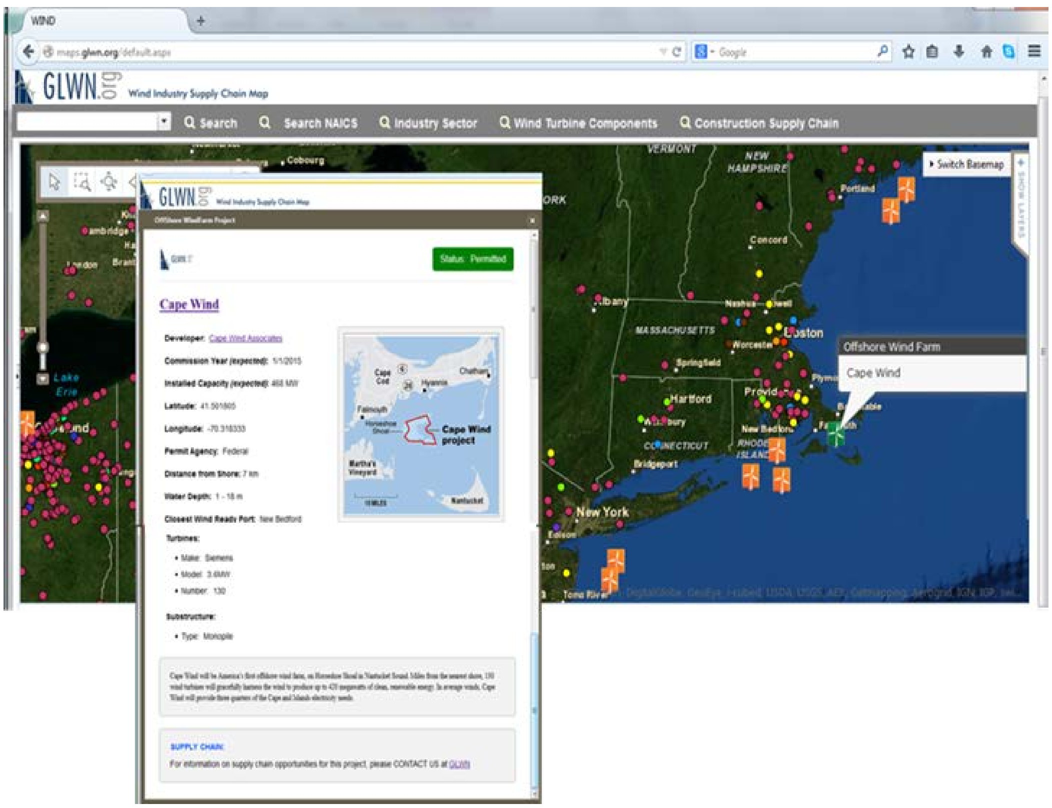


Fig. 3.1.2 Permitted Wind Farm Profile page and data

GLWN's Wind Supply Chain map will continue to be a valuable supply chain search and information tool for manufacturers and OEMs alike, as land-based wind continues to grow and offshore wind emerges.

3.2 Offshore Component Database Taxonomy

An Offshore Component Taxonomy was developed to expand the land-based wind supplier map to suppliers of components and services to the offshore wind industry. This taxonomy was used to classify firms as well as allow for buyers to search for specific types of firms involved in the construction of offshore wind farms using the GLWN Wind Supply Chain Map.

- Energy Company/Developer
- EPC Firm/General Contractor
- General
  - Architects/Engineers
  - Civil Architects/Engineers
  - Electrical Architects/Engineers
  - Environmental Engineers & Consultants
  - Foundation Architects/Engineers
  - Geotechnical Engineers
  - Quality Control/Material Testing
  - Surveyors
  - Security Access and Surveillance
- Site Construction & Contractors
  - Pile Driving Contractors
  - Drilling Contractors
  - Seabed Work
  - Erosion and Sediment Control
  - Geopiers
  - Caissons
  - Anchors
- Specialty Construction/Contractors
  - Electrical Contractors
  - Plumbing Contractors
  - Environmental Contractors
  - Inspection Contractors
  - Meteorological Towers and Accessories
  - Meteorological Tower Installation
  - Wind Turbine Erection
- Concrete
  - Aggregate
  - Concrete Contractor
  - Concrete Forms and Accessories
  - Concrete Pumping
  - Grouting
  - Ready Mix Supplier
  - Reinforcement Steel Erector
  - Reinforcement Steel Supplier
- Metals

  - Foundation Anchor Bolts
  - Fasteners
  - Steel Conduit
  - Steel Pipe and fittings
  - Structural Steel Supplier

- Electrical
  - Electrical Cable
  - Electrical Distribution Products
  - Electrical Testing and Equipment
  - Fiber Optic Cable
  - Lighting
  - Lighting – FAA Obstruction
  - Subsea Cable
  - Subsea Cable Installation
  - Transformer
  - Transmission Installation
  - Weld Wire
  - Welding Supplies
  - Wind Tower Wiring
  - Wind Tower Wiring Installation

- Logistics Services
  - Barge/Tug Services (Inland)
  - Transport Equipment
  - Material Handling Equipment
  - Packaging
  - Project Cargo Services
  - Third Part y Logistics
  - Other Logistics Services

- Offshore Foundations
  - Gravity Foundation
  - Jacket Foundation
  - Tripile Foundation
  - Tripod Foundation
  - Cement
  - Coatings
  - Rebar
  - Steel Plate
  - Structural Steel
  - Other

- Offshore Substation
  - Transformer
  - Inverters
  - Structural Steel framework
  - Power Electronics
  - Power Controls
  - Other

- Offshore Vessels
    - Installation Vessel
    - Material Transport Vessel
    - Crew Transport Vessel
    - Crew Accommodation Vessels
    - Other