# GWEC | GLOBAL WIND BLADE SUPPLY CHAIN UPDATE 2020

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# PREFACE

This Global Wind Blade Supply Chain Update 2020 marks GWEC Market Intelligence's second key component assessment, which is part of the GWEC Market Intelligence service that provides a series of insights and data-based analysis on the development of the wind industry.

GWEC Market Intelligence services are built on top of the current GWEC reports and statistics, as well as selected reports and databases from the Clean Energy Intelligence Unit of FTI Consulting, which have now been transferred to GWEC under a signed agreement to help shape the basis for the new service. The report is an update of FTI Consulting's Global Wind Supply Chain Update that FTI granted GWEC the Intellectual Property Right on 3 April 2019.

The Global Wind Blade Supply Chain Update 2020 is authored by the GWEC Market Intelligence team with direct support from leading wind turbine producers and wind blade manufacturers around the world. This update includes more than 15 tables and figures covering not only the development in the global wind blade supply chain over the last past four years, but also presents leading turbine OEMs' blade supply chain strategies, wind blade demand and supply analysis by region, and blade technology trends.

## Acknowledgements

GWEC would like to thank those who provided the data and insights to support this publication. Specifically, we would like to thank (in no particular order):

Christian Edin, Senior Director, Investor Relations, TPI Composites
Hemkant Limaye, Senior Director, Global Marketing, LM Wind Power
Jovana Filipovic, Senior Analyst, Market Intelligence, LM Wind Power
Prasad T V K, Senior Analyst, Market Intelligence, LM Wind Power
Alexandre Sarnes Negrao, CEO, Aeris
Wang Xin, General Manager, Sinoma Wind Power Blade
Xie Yudan, Deputy General Manager, Zhuzhou Times New Material
Song Binghua, Customer Manager, Shanghai Aeolon
Wang Dan, Key Account Manager, Sino-Wind Energy
Wen Shuang, Marketing Director, Chongtong Chengfei New Material (CCNM)
Li Qingshu, Marketing and Strategy Manager, Titan Wind
Joffrey Dupuy, Head of Intelligence and Strategy, Vestas China
Madhava Krishna Pokala, Vice President and Head of Operations, Vestas Wind Technology India Pvt Ltd.
Steven Sun Zhu, Purchasing Manager, Vestas China
Armin Lindov, Head of Offshore China Technology Office, Siemens Gamesa (Shanghai) Co., Ltd.
Darío Pérez Campuzano, Corporate Development & Strategy, Siemens Gamesa



Published by Global Wind Energy Council (GWC)

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# 1. FUNCTION OF BLADE

Rotor blades account for approximately 15% of a wind turbine's costs. Over the last decade, longer wind blades have allowed asset owners to capture more wind resource, making them far more efficient and helping to reduce the LCOE. The turbine's blades connect to the rotor hub, which then connects to the drivetrain through the main shaft. As the wind blows, this interconnected system converts wind energy into rotational energy.

Typically, most utility-scale wind turbines have three blades with an upwind design made of fibre-reinforced epoxy composite material. There are other blade options available as well, however, this symmetrically balanced yet lightweight design allows for smoother and higher energy output.

Alternative options include two-bladed designs such as Envision E128- 3.6 MW PP 2B designs, and downwind designs such as Hitachi's HTW 2 MW and HTW 5 MW designs. Offshore wind developer 2-B Energy has adopted both the two-bladed and downwind options for their 6 MW offshore turbine currently under testing.

Most commercial turbines today use an electrical or hydraulic pitch drive system to control the blades. This maximises electricity generation while ensuring safe operation of the turbine under extreme weather conditions.

# 2. BLADE MANUFACTURING METHODS

In the early days, blades were manufactured using a manual wet lay-up technique in open moulds. The glass fibre reinforcement was impregnated manually using paintbrushes and rollers before the shells were adhesively bonded to the spars. The downside to the open mould method is it is labour intensive and prone to inconsistencies and defects. In the 1970s, filament winding technology was used, but soon the introduction of vacuum and prepreg technologies grew and became the norm for manufacturing wind blades. Currently, the automated tape lay-up, automated fibre placement, and enhanced finishing technologies are expected to come into use more widely to improve quality and reduce costs of composite blade manufacturing.

Table 1-1 shows a high-level comparison of existing commercial scale blade manufacturing methods, which are further described in the subsections on the following pages.

Table 1-1: Comparison of existing commercial-scale blade manufacturing methods by materials and process

| Technology | Materials | | | | Manufacturing Process | | |
|---|---|---|---|---|---|---|---|
| | Fibre | Resin | Sandwich Core | Surface Finish | Assembly | Curing | Level of Automation |
| Vacuum Resin Infusion | Glass/ Carbon | Polyester/ Epoxy | Balsa & polymer foam | In mould Gelcoat | Bonding of shells & web | Lower temperature | Lower |
| Pre-Impregnated | Glass/ Carbon | Epoxy (Prepreg) | Polymer foam | In mould Gelcoat & Polyurethane enamel | Bonding of shells & web | Higher temperature | Higher |
| Integral Blade® | Glass | Epoxy | Balsa | Sprayed-on polyurethane enamel | No bonding | Lower temperature | Lower |

Source: GWEC Market Intelligence, December 2020

## Vacuum Resin Infusion

Today, the most widely used method to produce wind blades, especially longer blades, is the Vacuum Assisted Resin Transfer Moulding (VARTM). With this resin infusion technology, fibres are placed in a closed and airtight mould before low-viscosity resin is injected into the mould cavity under pressure through multiple inlet holes throughout the blade. Finally, the resin cures and the temperature is raised to let the blade set after it cures. Longitudinal web parts are made separately, and once the plastic film is removed from the blade shells' inner surface, the blade halves are bonded together, along with the longitudinal web parts. In principle, this manufacturing method is ideally suited for upscaling, since the number of resin inlets and vacuum suction points can be increased. Large manufacturers using this method include Enercon, LM Wind Power, TPI, Tecsis and Sinoma.

## Pre-Impregnated

Adapted from the aircraft industry, the prepreg method is based on the use of "pre-impregnated" composite fibres, which already contain the matrix material (epoxy resins) and bond them together, before laying the prepreg into a mould. First, layers of a prepreg are cut to size and placed in the lower and upper mould part. A hollow spar is also laminated over a core-mandrel. A plastic film is placed over the three moulds, and a vacuum is applied to compress the laminate layers and remove any trapped air bubbles. While still in the vacuum, the moulds are heated to 120°C, which allows the epoxy polymer to have a very low viscosity. This low viscosity allows air to release and helps the prepreg layers to fuse. After a few minutes at a high temperature, the epoxy polymer is cured. The plastic films are then removed, and the blade parts can be glued together.

Although the prepreg process is typically more expensive than the infusion process, the prepreg composites have more stable and less variable mechanical properties than the composites produced by vacuum resin infusion. Blade fabricators adopting this method include Vestas, Gamesa and Nordex.

### Integral blade

This method of blade manufacturing is actually a special variant of the vacuum infusion method. Here, the dry glass materials are placed in one mould part with the help of a flexible core mandrel. This mandrel positions all reinforcement material around the blade shell and longitudinal web. Once all of the glass materials are combined, the second mould part is positioned on top. After closing the moulding, it is ready for the vacuum, which is followed by an infusion of the epoxy resin. Once the resin cures, the flexible core is removed, and a fully integrated blade, void of bonding zones, can be removed from the mould. Siemens Wind Power developed the IntegralBlade® process in 2000. Since then, it is the only turbine OEM using this technique.

## 3. BLADE STRUCTURAL OPTIMISATION

A wind blade consists of two faces (on the suction side and the pressure side), joined together and stiffened by an internal structure called spar, commonly used are I-Beam or Box ones. The I-beam spar is composed of two spar caps and one shear web, while the box spar is composed of two spar caps and two shear webs. In both cases, the spar caps are attached to the skin with adhesive.

Each of the blade structures has its pros and cons, and the decision of the structural design is primarily determined by the condition that the blade performs along with other considerations like the volume of production, investment cost and weight.

For example, Vestas – typically uses box spar turned for i-beam spar for its V110-2.0 MW, V126- 3.3 MW, V164-8.0 MW and V174-9.5 MW wind turbine blades, as this design demands substantially less investment in manufacturing and can be outsourced to third-party production. Either the vacuum infusion or prepreg manufacturing method can be used to make the two common structural designs. However, currently prepreg is used almost exclusively to build the Box-Spar & Shell design. Table 1-2 offers a detailed comparison of the two types of blade design.

Table 1-2: Comparison of different blade structural designs

| Structural Types | Box Spar Structure | I-Beam Spar Structure |
|---|---|---|
| Outboard Blade Section |  |  |
| Commonly Used By | Vestas, Siemens Gamesa, Nordex and Aeris | LM Wind Power, Tecsis, TPI, Aeolon, Times New Material, Sinoma and CCNM |
| Start-up cost | High volume, but higher start-up cost | High flexibility with lower start-up cost |
| Flexibility and Standardisation | Optimised for vertical integration | Designed both for “built to print” and in-house production; rapid product changes possible |
| Size matters | CAPEX grows with the length | Lighter/lower weight and breaks the capex cost curve |
| Offshore Application | Possible, but costly | Better solution for the large offshore blades, like Vestas V164-80m |

Source: GWEC Market Intelligence and Vestas, December 2020

## 4. GLOBAL BLADE SUPPLY CHAIN PATTERNS

Blades are among the most expensive and critical components of a wind turbine. Therefore, having the right supply chain strategy for blades is key for all turbine vendors. Like other manufacturing industries, vertical integration and outsourcing are two important supply chain sourcing patterns for the wind industry. However, pursuing either vertical integration or outsourcing in isolation appears to be sub-optimal. Both theory and recent successful practices observed across the wind industry support the need to balance between vertical integration and outsourcing, although finding the appropriate balance can be difficult. In general, choosing the right sourcing pattern for wind blades is a significant factor in a turbine vendor's strategy because it will influence competitiveness, costs, and differentiation, and will in turn affects a vendor's overall position in the market.

Blade manufacturers can be classified into two groups: independent suppliers and turbine vendors with in-house blade manufacturing. The supply chain sourcing pattern for blades has changed over time. Before the boom of the wind market, in-house blade manufacturing accounted for the majority of the global market. At one point in time, all leading turbine vendors tried to pursue an upstream integration strategy to secure the supply of rotor blades, but the overall market share of in-house blade production has fallen since 2006 with in-house production capacity accounting for less than 50% of blade manufacturing in 2019. The increase in outsourcing blades to third party suppliers may be due to several market factors, including:

- Market fluctuation in the period of 2011-2014 has forced large OEMs to divest from in-house blade facilities or close some in-house capacity in countries without stability and with low utilisation;
- Several established European turbine vendors including Vestas, SGRE, and Enercon have adopted the taper integration supply chain strategy, a hybrid model of vertical integration and outsourcing. This strategy allows a company to become lighter and more flexible, and to adapt to changes in market conditions, for example in the context of auction schemes, which require turbine OEMs to become more cost-competitive;
- In response to a truly globalised wind market as well as an increased frequency of new product launches, it makes more economic sense for turbine vendors to increase "outsourcing" in order to control CAPEX while reducing the time to market for new products;
- The supply chain has matured, with qualified independent suppliers now found in different regions, and turbine vendors are willing to outsource;
- Investment made by large independent blade suppliers in emerging markets provides a cost-efficient solution for turbine suppliers to meet the local content requirement while keeping costs low;
- Emerging turbine suppliers from the Asia Pacific prefer to leverage the track record of leading independent suppliers in the overseas market and in the offshore wind sector.

## 5. INDEPENDENT BLADE SUPPLIERS

There are around 20 independent blade manufacturers in the world, of which the majority are located in Asia, and China in particular. Compared to 2016, 10 third party suppliers have ceased operations. LM Wind Power was the world's largest independent blade supplier with a truly global footprint before it was acquired by GE Renewable Energy in April 2017. LM Wind Power is now operated as an individual unit within GE Renewable Energy. Aside from serving GE, LM Wind Power continues to supply blades to other turbine OEMs, having established protocols and safeguards to protect customers' confidential data. For this reason, LM Wind Power is still listed as an independent supplier and is not listed as GE Renewable Energy's in-house blade production facility. Table 1-3 shows the independent blade suppliers and their manufacturing locations.

Table 1-3: Independent blade suppliers and manufacturing locations

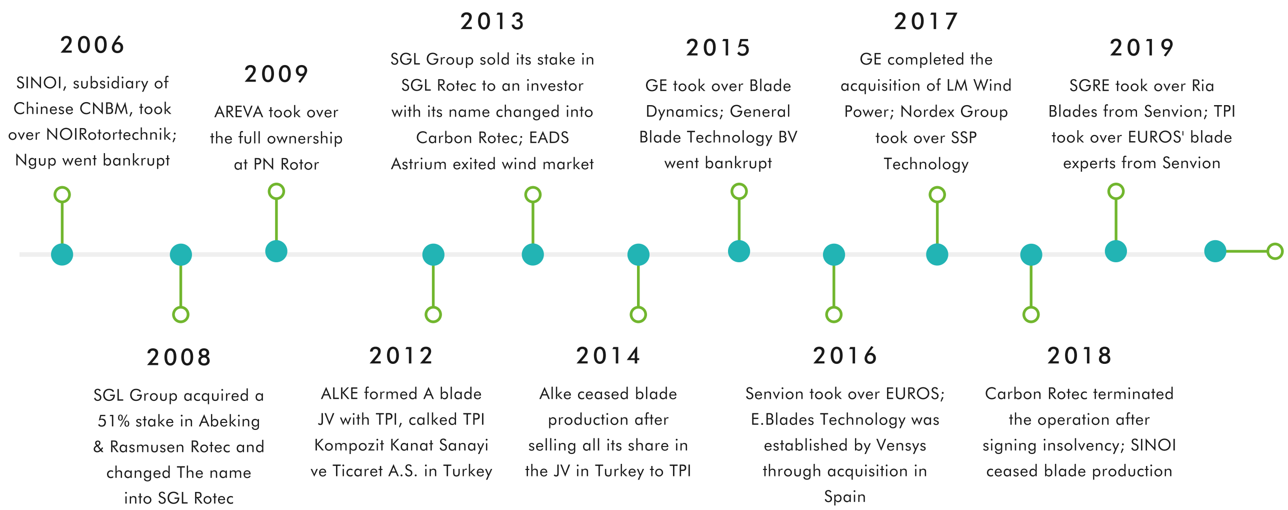
| Company | Manufacturing Location |
|---|---|
| **Europe** | |
| LM Wind Power (*owned by GE Renewable Energy) | France, Spain, Poland, Turkey, China, India, US, Canada, Brazil |
| eTa Blades | Italy |
| Cartflow | Italy |
| ACT Blade | UK |
| **Asia Pacific** | |
| Sinoma Wind Power Blade | China |
| Zhongfu Lianzhong (LZ Blades) | China |
| Shanghai Aeolon | China |
| Sino-Wind Energy | China |
| Zhuzhou Times New Material | China |
| Titan Wind | China |
| Luoyang Sunrui | China |
| Shanghai FRP | China |
| CCNM (CQGI) | China |
| Jiuding New Material | China |
| Tien Li Offshore Wind Technology | Taiwan, China |
| Human Composites | South Korea |
| **Americas** | |
| TPI Composites Inc | US, Mexico, China, Turkey, India |
| Molded Fiber Glass (MFG) | US |
| Tecsis Technology | Brazil |
| Aeris | Brazil |

Source: GWEC Market Intelligence, December 2020

## Europe

Europe is the birthplace of modern turbine technology and the turbine rotor blade design. Aside from blade production, many European independent blade suppliers offer services such as "build to print" blade designs and licences to new players from emerging markets. As of today, wind blade manufacturing has expanded from Europe to North America, Asia, Latin America and, to a lesser extent, Africa and the Middle East. This is largely due to unprecedented growth of the wind energy market outside of Europe, and to market challenges such as cost reduction, logistics, and local content requirements (LCRs). Independent blade suppliers in Europe are down to four from over ten a decade ago. Of the four remaining independent blade suppliers, two produce blades for kW turbines in Italy and one is a new offshore blade supplier based in the UK. The primary reasons for the drop of independent suppliers in Europe are market consolidation and the inability of small and medium size suppliers to compete in cost, R&D investment, and global footprint.

Figure 1-1: Market Consolidation in European Wind Blade Supply Chain




Source: GWEC Market Intelligence, December 2020

Before being acquired by GE Renewable Energy, LM Wind Power led independent blade manufacturing worldwide. After more than four decades of blade production, LM Wind Power currently has 13 production facilities in nine countries with 12-14 GW annual production capacity. Last year, it produced the world's largest wind turbine blade in France, making it the first blade to surpass 100 meters in length.

Carbon Rotec, formerly known as SGL Rotec, was the second largest European independent blade manufacturer with German turbine vendors Nordex and Senvion as its key clients. However, the German blade producer Carbon Rotec ceased operation from January 2018 and soon sold its rotor service business unit to SSC Wind (now owned by German Buss Group).

EUROS was the third largest Europe-based independent blade producer before it was taken over by its major client Senvion in November 2016. As Senvion entered insolvency in 2019, TPI acquired the Berlin-based blade engineering team from EUROS in July 2019.

The fourth largest Europe-based independent blade producer was SINOI, which was owned starting in 2006 by Chinese LZ Blade, a subsidiary of China National Building Material Group (CNBM). However, blade production activities have now ceased at SINOI after over a decade of operation by the Chinese group.

Beyond LM Wind Power, Carbon Rotec, EUROS and SINOI, the remaining European independent manufacturers are relatively small in terms of manufacturing capacity. The Danish blade specialist SSP, which can develop blades and moulds for the third parties and offer oversized offshore prototype development to the market, was acquired by Nordex Group in 2017 to reinforce the German OEM's technological position for the development of larger and more efficient turbines. After a quarter of a century designing and manufacturing wind blades, the Spain-based blade producer Aeroblade has now become a services and technological solution provider for the wind energy industry. Other European companies no longer active in blade manufacturing include NGup, General Blade Technology (GBT), EADS Astrium and Alke.

## Americas

The Americas previously had five notable local independent suppliers, of which three were in the US and the remaining two in Brazil (this does not include LM Wind Power which is active in both countries). However, the Michigan-based blade supplier Energetx Composites, which was established in 2008, filed for bankruptcy in 2015. TPI Composites has been a leading blade manufacturing in the US for many years, and it continues to grow at pace with its main competitor, LM Wind Power. After LM Wind Power was acquired by GE Renewable Energy, it became the only independent blade manufacturer with a truly global footprint. As of today, the US stock-listed producer has 13 blade manufacturing facilities in five countries. TPI's ability to capitalise on recent growth trends in emerging markets and on outsourcing trends enabled it to grow its revenue by 87% from 2016 to 2019 and to expand its global manufacturing footprint at the same time.

As the large local supplier in North America, TPI has a significant market share in the US and a strong relationship with GE, with GE outsourcing a significant percentage of its blade needs to TPI despite its acquisition of LM Wind Power. In July 2016, TPI went public and by that time, the company already had operations in China, Turkey, and Mexico. The past four years saw TPI continuing to grow with expansion in China and Mexico, as well as a new facility built in Chennai, India. To enhance its blade design, tooling, and other engineering capabilities, TPI acquired the former EUROS blade design team based in Berlin in 2019. On top of the relationships and partnerships already established with GE, Vestas, SGRE and Nordex, TPI signed a multi-year supply agreement with Enercon for two manufacturing lines in its Izmir facilities in Turkey in 2018.

Having German turbine vendor Enercon on board means TPI's customers represent all of the top six turbine manufacturers, excluding the Chinese market. With a nearly 80% production utilisation rate, TPI produced more than 3,000 sets of blades (> 9 GW) in 2019, accounting for 15% of the global wind market share. The company plans to increase its production capacity to 18 GW and its global market share to 20%. As of Q3 2020, the signed long-term supply agreements can provide around 5.1 billion US$ in potential revenue through the end of 2024.

With over three decades of blade production experience, Molded Fiber Glass Companies (MFG) is the third largest blade producer in the US after TPI and LM Wind Power. Although in December 2017 MFG announced the closure of its wind blade manufacturing plant located in Aberdeen, South Dakota, by 15 February 2018, the new orders won after the announcement have sustained operation of the facility. Today, MFG continues to produce blades in two dedicated wind product manufacturing facilities located in Aberdeen, South Dakota and Gainesville, Texas.

In South America, Tecsis and Aeris are the two largest local wind blade producers (with TPI and LM Wind Power excluded). Tecsis solidified its leading position in the region after local content requirements were introduced in Brazil. With more than 25 years of experience in blade production, the company has now repositioned itself as a solution provider and not simply a blade producer, meaning it delivers complete turnkey solutions for repowering and life extension projects as well. In fact, following dwindling orders in its home market Brazil, Tecsis saw the US partial repowering as a big opportunity. It introduced a tailor-made solution through its service business unit WindCom to address the demand in 2018 and signed multiple deals with US developers in 2019 to replace blades for aging wind turbines.

Aeris entered the blade production business much later than Tecsis, but the 2010 established company managed to grow at a fast pace. It began to export a large part of its production beginning in 2018 and delivered nearly 10,000 blades in just ten years. In July 2020, Aeris acquired production facilities in the Pecém Industrial and Port Complex, which were previously owned by Wobben Windpower, a subsidiary of Enercon, and then changed its name to Aeris Pecém II. As production at Tecsis has recently slowed down, Aeris is now positioned as the largest local producer in Brazil with annual production capacity up to 4,000 blades per year. Its customer list includes local turbine manufacturer WEG, whom they have recently entered a long-term agreement with, and international OEMs such as Vestas, GE, and the Nordex Group. This recently listed company expects its blade business to continue to grow in the next two years after securing financing from the Brazilian Development Bank (BNDES) and another two banks to execute the orders that are scheduled to be delivered in 2020-2022.

## Asia Pacific

In the Asia Pacific, nearly all the blade manufacturing capacity comes from the region's two largest markets: China and India. China is not only the world's largest turbine manufacturing hub, but it is also the world's largest blade production centre.

In 2008, there were more than 50 suppliers across different stages of the manufacturing process for blades in China. However, the situation changed significantly between 2011 to 2013, a period when local suppliers faced challenges such as overcapacity, slumped demand, delayed payments, and low margins.

Today, after another ten years of development,  only 10 independent blade producers still exist in China, of which the top three local, independent suppliers control two thirds of the domestic market. With Goldwind as a key client, Sinoma is now the market leader in the country. The Chinese stated-owned supplier expects to deliver 10 GW of rotor blade capacity in 2020, which is around 30% of local demand. It is worth mentioning that the Chinese central government gave permission for the merger of China National Materials (Sinoma) and China National Building Material (CNBM) in 2016. Over the past four years, the merging of these two giants did not have a significant impact on daily business operations for their blade subsidiaries, Sinoma Wind Power Blade and LZ Blade. However, on 3 December 2020, Sinoma Wind Power Blade publicly announced that it plans to take over LZ Blade from its shareholders. It will certainly further enhance Sinoma's leading position in China once the acquisition is finalised.

Zhuzhou Times New Material ranks as the second-largest market player in China, with an output of more than 3,000 sets this year. Shanghai Aeolon also has a production capacity of 3,000 sets, but part of this volume is for export. Generally, the top Chinese blade suppliers have a so-called "Going Overseas and Offshore" strategy to support the offshore wind installation rush, whereby they are either building new factories or expanding existing ones located in coastal areas.

In India, most of the local and international turbine suppliers have their own in-house blade production facilities. Looking at third-party blade producers in the country in addition to LM Wind Power's who two blade plants in Dabaspet and  Vadodara, TPI began operating a new plant in Chennai beginning in Q1 2020 in order to leverage the lower manufacturing costs and export opportunities in India. LM Wind Power's annual blade manufacturing capacity in India ranges between 1.5-2 GW per year, depending on the length of blades produced. Despite the temporary shutdown caused by COVID-19 crisis, the company may see maximum production loss of less than 10% at the end of 2020. In addition to meeting domestic demand, LM also exports to other markets such as Europe, US, and China. On top of the already established relations in India, LM also signed a partnership with Enercon in 2019. India is also an emerging offshore wind market and the supplier expressed their interest to supply offshore wind turbine blades.

TPI's new facility in Chennai is the second largest blade manufacturing facility in India, after Suzlon's facility which has 3 GW of annual manufacturing capacity. It is reported that its new facility will serve both local and global wind markets and TPI has already signed multi-year agreements with European turbine manufacturers such as Vestas and Nordex. Interestingly, its India facility has longer-term supply agreements compared to other global facilities, running until 2024, as reported ins TPI's Q3 2020 highlights.

Taiwan is home to a few well-known rotor blade materials suppliers, such as Swancor and Formosa, but a blade production facility did not exist until Tien Li Offshore Wind Technology Co., Ltd. (TLC) began construction on an offshore wind blade production facility in Taichung Harbour in June 2020. To meet local content requirements and create local jobs, MHI Vestas signed the final sub-supplier contract agreement with TLC in March 2020. With technical support including training provided from MHI Vestas, this facility will manufacture blades starting in 2021 for V174 wind turbines to be delivered in upcoming Taiwanese projects.

In South Korea, three independent blade producers have been identified in the past. However, two of them have ceased operations due to slow domestic wind power market development and fierce competition in the global market. As the only survivor, Human Composites, which commenced its first 2 MW onshore blade in 2013 and a 3 MW offshore blade in 2016, was selected together with Doosan Heavy Industries & Construction (DHIC) by a state project sponsored by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) in 2018 to develop an 8 MW offshore wind turbine. The blade will be produced by Human Composites and designed and tested by The Korea Institute of Material Science, with the project scheduled to be completed by 2022.

In Japan, GH Craft previously produced blades for local turbine OEM Komaihaltec's 300kW wind turbine. However, following the new management's business strategy, the Japanese supplier terminated its operations in the wind power industry.

## Africa & the Middle East

In Africa, South African turbine OEM start-up I-WEC (Isivunguvungu Wind Energy Converter) completed its first prototype for a 50m blade for its planned 2.5 MW turbine in 2012. This took place under the supervision of German Aerodyne. Since then, I-WEC has been taken over by its majority shareholder, DCD-Dorbyl under DCD Towers, which could allow DCD Towers to produce blades locally. However, local blade manufacturing has been held up because turbine OEMs have been unable to meet the LCRs in the REIPPP rounds 1, 2 and 3, based on towers, the Broad-Based Black Economic Empowerment (BBBEE) Act, and other electrical works. It was reported that DCD Towers facility in the Coega industrial zone near Port Elizabeth was empty and eventually auctioned off in June 2020 due to the challenging renewable energy market condition in South Africa.  In Egypt, SWEG-Elsewedy abandoned its previous strategy to manufacture blades locally due to political uncertainty and industry slowdown caused by two political revolutions that took place in this country. Therefore, there are no independent blade producers in Africa as of today.

In the Middle East, no independent blade producer exists, although the UK-based Blade Dynamics announced it had signed its first technology licensing agreement with Saudi Basic Industries Corporation (Sabic) in May 2013. Currently, the only wind blade production facility in Middle East is operated by Mapna Generator Engineering & Manufacturing co. (PARS), a subsidiary of MAPNA Group, but blade production is for its own 2.5 MW wind turbine.

## 6. IN-HOUSE BLADE PRODUCTION

There are around 15 wind turbine vendors in the world still producing blades in-house (see Table 1-4). Compared with the situation in 2016, four turbine OEMs have stopped blade production in Europe and North America, which is primarily due to market consolidation. For example:

- The merger between Siemens Wind Power and Gamesa which occurred in 2017;
- Adwen, which owns an in-house offshore blade production facility that was obtained through the acquisition of PN Rotor, was acquired by SGRE in March 2017 and later the production of Adwen 8 MW turbine was discontinued;
- German turbine producer Senvion filed for bankruptcy in 2019, and its Ria Blades factory in Portugal sold to SGRE in Oct 2019; and,
- The US-based turbine producer Northern Power's utility-scale wind turbine business, including its patent portfolio and assets, was acquired by WEG in October 2016 and then discontinued.

In Asia Pacific, Chinese supplier SANY resumed blade production following the recovery of its home market from 2018. Envision also started serial production at its blade facility in Jiangyin to support the domestic installation rush. In India, the market is still in the middle of a transition, with several challenges yet to be resolved, and four local turbine vendors including Wind World India and RRB Energy, have closed their blade production facilities.

Table 1-4: In-house blade manufacturing

| Company | Locations | Technology Source |
|---|---|---|
| Europe | | |
| Vestas | Denmark, Germany, Spain, Italy, Russia, US, China, UK, India | In-house |
| Siemens Gamesa | Denmark, Spain, Portugal, UK, France, US, China, India, Morocco | In-house |
| Enercon | Germany, Portugal, Turkey, Russia | In-house |
| The Nordex Group | Germany, Spain, Denmark, Mexico, India | In-house |
| Vensys | Spain from E. Blades Technology | In-house |
| EWT | Netherlands | In-house |
| Vergnet | France | In-house |
| Africa & the Middle East | | |
| MAPANA | Iran | Aerodyn |

| Company | Locations | Technology Source |
|---|---|---|
| **Asia Pacific** | | |
| **United Power** | China (Baoding, Lianyungang, Chifeng) | Aerodyn |
| **Mingyang** | China (Tianjin, Zhongshan, Xinyang, Dali, Yangjiang, Shanwei) | Aerodyn |
| **Dongfang** | China (Tianjin, Liangshan, Penglai) | Euros, Aerodyn |
| **Envision** | China (Jiangyin) | In-house |
| **SANY** | China (Zhangjiakou, Tongyu, Shaoshan) | In-house |
| **Suzlon** | India | In-house |
| **Inox Wind** | India | Windtec |

Source: GWEC Market Intelligence, December 2020

## Dynamics of leading turbine OEMs' blade supply chain management

Although the majority of large wind turbine manufacturers have in-house blade production capability and capacity, they must adjust their wind blade sourcing strategies continuously in order to follow changes in market conditions. From 2012-2014, the world's three largest wind markets – China, the US and India – saw some level of economic and political turbulence. During this time, several leading turbine OEMs either sold or suspended some of their in-house blade production to survive the crisis. Following the implementation of new measures such as government guaranteed price for renewable energy, for example, Feed-in tariffs or transition into an auction scheme/tender, cost reduction has become the top priority for turbine vendors. To control CAPEX while reducing the time to market for new products, large turbine producers, and especially western turbine OEMs, have made dramatic changes on their blade sourcing strategies over the past few years.

The most notable developments are summarised in the table on the following page.

| Company | Developments |
| --- | --- |
| Vestas | As the world's number one wind turbine manufacturer, the Danish company currently has blade production facilities in nine countries. Vestas used to produce most of its onshore wind blades in-house, but the company scaled down its in-house blade production in countries like Denmark, where the manufacturing and salary levels are high and started outsourcing more blades from independent blade suppliers. At present, Vestas has signed a multi-year supply agreement to outsource onshore blades from TPI in China, Turkey, India, and Mexico. In the Asia Pacific, the company outsources 60% of its onshore rotor blades from third-party suppliers. Aside from TPI, it also outsources blades from Aelon and Zhuzhou Times New Materials in China. In Latin America, Vestas signed a partnership with TPI in Mexico and built a relationship with local blade supplier Aeris starting in 2015. In Europe, Vestas entered a supply agreement with TPI in Turkey beginning in 2016 and established a joint venture called "Vestas Manufacturing Rus" with local partners in 2018 to produce blades in order to meet the local content requirements in Russia. In the offshore sector, Vestas recently acquired full ownership at MHI Vestas, which operates two offshore blade factories in Europe: one in Naskov, Denmark and another in Isle of Wight, in the UK. To support growth in emerging markets while meeting local content requirements, MHI Vestas signed a sub-supplier contract agreement with local company TLC in Taiwan instead of building an in-house blade production plant. |
| Siemens Gamesa (SGRE) | Siemens Gamesa has become the world's second-largest turbine manufacturer after the merger of the two wind business units. Currently, SGRE is also operating in-house wind blade manufacturing facilities in nine countries. To meet local content requirements, SGRE inaugurated a blade manufacturing plant in Morocco in 2017. SGRE acquired the Ria Blades de Vagos in Portugal from Senvion in 2019 to take the advantage of port location as well as the larger capacity and dimension. The company's most recent onshore wind supply chain strategy is to optimise in-house manufacturing operations to adopt to demand in terms of volume, product and cost, to reduce supply chain complexity, and to increase third-party outsourcing by >5% per year. In line with this strategy, SGRE closed the Aoiz and Aalborg onshore blade production plants located in Spain and Denmark and plans to continue outsourcing blade production from low-cost countries, such as China, India, Turkey, Poland, Brazil, and Mexico in order to optimise supply cost. In general, under the new leadership, SGRE plans to keep its in-house blade production capacity and outsourcing volume at a ratio of 55:45 for onshore wind. For offshore wind, the company decided to keep blade production in-house and will optimise the logistical set-up to deliver world class products globally with clear links to customer contracts. SGRE is currently operating offshore blade plants in Aalborg, Denmark; Hull, UK; and Lingang, China. SGRE has an offshore blade factory currently under construction in Le Havre, France, and is investigating a potential offshore blade plant in the East Coast of the United States. |
| Goldwind | Goldwind brought two wind blade production facilities from GCL Wind Energy at the end of 2010 to secure both the supply and quality of its rotor blade. Following an operating loss in 2011, the leading Chinese turbine producer sold its 100% stake at the two blade factories to the largest Chinese independent blade producer Sinoma Wind Power Blade in 2012. In the same time, Goldwind invested 145 million RMB at the latter, through which Goldwind owns 8.42% stake at Sinoma Wind Power Blade. However, Goldwind sold all of its stakes at Sinoma Wind Power Blade in 2016 and right now outsource all of its wind blades to third party suppliers including LM Wind Power. |

| Company | Developments |
| --- | --- |
| Enercon | Enercon used to pursue vertical integration for its blade supply chain strategy, and its level of vertical integration was the highest among the global top ten turbine OEMs. However, following the collapse of the German onshore wind market in 2018, the German turbine vendor has adjusted its supply chain strategy. Previously, Enercon had in-house blade production facilities located in Germany, Portugal, Turkey, and Brazil. With the group's new business strategy now focused on international markets with a good growth perspective, Enercon decided to increase cooperation with external suppliers and production partners in "best cost" countries, to survive on the highly competitive international market where cost pressure among major global turbine OEMs is intense. In 2018, Enercon signed a multiyear supply agreement for two manufacturing lines in TPI's facility in Izmir, Turkey. In addition, it worked with LM Wind Power to deliver the custom-developed 78.3 m blade for its 4.6 MW E-160 EP5 E1 low wind speed turbine. In 2020, Enercon also signed a contract with a blade supplier located in India, to supply its EP3 and EP5 turbines for international projects. As the cost of a blade made in India is 30-40% cheaper than that in Europe and domestic demand is low, Enercon said it will no longer produce wind blades in Germany. Furthermore, Enercon shut down its blade production at the Sorocaba plant in Brazil last year and sold its other Brazilian blade production facilities in the Pecém Industrial and Port Complex, owned by its subsidiary Wobben Windpower, to local blade producer Aeris in the summer of 2020. Nevertheless, to meet local content requirements, its joint venture company Red Wind, established in Russia with local partner NovWind, will produce key components including blades in the new factory in Voglodonsk under a licensing agreement. |
| The Nordex Group | The Nordex Group is only active in the onshore wind market. Before the merger of the two wind businesses, the German and Spanish suppliers had their own in-house blade production facilities located in Germany and Spain. Although The Nordex Group took over the blade specialist SSP and built their own blade factories in India and Mexico after the merger, the group is still aiming to make use of low-cost locations, to enable cost-effective supplies in all core market, and eventually to reach a strategic balance of in-house production and outsourcing to third parties. Limiting vertical integration allows the group to effectively manage its CAPEX and to respond flexibly to market changes. In 2013, Nordex signed a multi-year supply agreement with TPI in Turkey in and the group not only extended it long-term contract with TPI in Turkey through to 2023, but it also signed a multi-year agreement with TPI for two manufacturing lines in Chennai, India in 2020. In addition, The Nordex Group built relationships with local supplier Aeris in Brazil and Zhuzhou Times New Materials in China. In total, outsourcing accounted for two-thirds of its blade demand in 2019. By the end of 2020, the group plans to bring its annual turbine production output up to 6 GW. According to its strategic target for CY2022, it will expand its supply chain capacity in India to 4 GW and to move current European partners to India as well. |

## 7. SUPPLIER RELATIONSHIP MATRIX

The supplier relationship matrix below shows that out of the top 10 turbine vendors, all suppliers except for Chinese Goldwind and Windey have in-house blade manufacturing capacity. At present, only LM Wind Power and TPI have a track record of working with five of the world's top ten wind turbine suppliers (in terms of new installations in 2019), but the matrix blow shows Chinese suppliers Zhuzhou Times New Material and Aeolon have established a relationship with European OEMs among the global top 10.

Table 1-5: Blade supplier relationship matrix

| Supplier | Vestas | SGRE | Goldwind | GE Renewables | Envision | Mingyang | The Nordex Group | Enercon | Windey | Dongfang |
|---|---|---|---|---|---|---|---|---|---|---|
| In-house | X | X | | via LM | x | X | X | X | | X |
| LM (owned by GE) | | x | X | X | X | | | x | | |
| TPI | X | X | | X | | | X | X | | |
| Aeris | X | | | x | | | | x | | |
| Sinoma (including LZ Blades) | | | X | x | X | | | | X | |
| Zhuzhou Times New Material | x | | | | X | | x | | X | |
| Sino-Wind | | | X | | | | | | X | |
| Aeolon | X | x | X | | x | | | | | |
| CCNM (CQGI) | | | x | | | X | | | x | |
| Luoyang Sunrui | | | x | | | | | | | |
| Titan Wind | | | | | X | | | | | |

Source: GWEC Market Intelligence, December 2020

X = main supplier
x = small supplier

## 8. GLOBAL BLADE MANUFACTURING CAPACITY

Table 1-6 and Table 1-7 show the annual blade manufacturing capacity of turbine vendors and the largest independent suppliers. Data in both tables have been collected through direct contact with the companies, or through their annual reports, industry reports, or most recent press releases. Some companies did not disclose their data. In such cases where data was not available, GWEC Market Intelligence has estimated their capacity based on the known relationships with turbine OEMs, and on second-hand data.

Table 1-6: In-house blade manufacturing capacity (by region) of large turbine OEMs

| Company | Location | Estimated in-house capacity by region (MW/year) | | | % of total demand | Total | Offshore Production |
|---|---|---|---|---|---|---|---|
| | | Europe | US | APAC & Others | | | |
| **Vestas** | Denmark, Germany, Spain, Italy, Russia, US, China, UK, India | 5,500 | 3,000 (Two factories) | 1,000 China, 920 India (Mostly exported) | 85% | 10,420 | Yes |
| **Siemens Gamesa (SGRE)** | Denmark, UK, Spain, Portugal, France, US, China, India, Morocco | 4,500 (Offshore plant under construction in France) | 1,500 (In the midst of investigating a new offshore plant) | 2,000 China, 700 India, 200 Morocco | 85% | 8,900 existing, >1,000 planned | Yes |
| **Enercon** | Germany, Portugal, Turkey, Russia (JV) | 2,000 (German facilities to be closed) | 0 (closed or sold facilities in Brazil) | 0 | 80% | 2,000 | No |
| **The Nordex Group** | Germany, Spain, Demark, Mexico, India | 1,200 | 1,000 | 300 | 30% | 2,500 | No |
| **VENSY** | Spain | 300 | 0 | 0 | 100% | 300 | No |
| **EWT** | Netherlands | 200 | 0 | 0 | 100% | 200 | No |
| **MAPNA** | Iran | 0 | 0 | 100 | 100% | 100 | No |
| **Suzlon** | India | 0 | 0 | 3,600 (India) | 100% | 3,600 | No |
| **INOX** | India | 0 | 0 | 1,600 (India) | 100% | 1,600 | No |
| **United Power** | China | 0 | 0 | 1,000 (Three facilities in China) | 50% | 1,000 | No |
| **Mingyang** | China | 0 | 0 | 4,500 (Six facilities in China) | 80% | 4,500 | Yes |
| **Dongfang** | China | 0 | 0 | 1,500 (Three facilities in China) | 100% | 1,500 | Yes |
| **SANY** | China | 0 | 0 | 2,000 (Three facilities in China) | 100% | 2,000 | No |
| **Envision** | China | 0 | 0 | 400 | 5% | 400 | No |
| Total | | 39,020 existing (>1,000 planned) | | | | | |

Source: GWEC Market Intelligence, December 2020

Table 1-7: Blade manufacturing capacity of independent suppliers

| Company | Manufacturing locations | Maximum annual capacity (MW/Year) | Product Size | Offshore Product |
|---|---|---|---|---|
| **Europe** | | | | |
| LM Wind Power (owned by GE Renewable Energy) | France, Spain (two facilities), Poland, Turkey, China (four facilities) , India (two facilities), US, Canada, Brazil | 12,000-14,000 including 3,000 China 1,500-2,000 India; 1,500 Turkey, 800 Brazil; 2,000 France | Up to 107m (13 MW) | GE Haliade X-13MW<br>GE Haliade 6MW<br>Adwen AD 8.0 MW<br>Senvion 6.X MW<br>Goldwind 6.X MW<br>Haizhuang 5.0 MW<br>Envision 4.X/5.X MW |
| eTa Blade | Italy | n.a. | 60-200kW | No |
| Cartflow | Italy | n.a. | 60-200kW | No |
| ACT Blade | UK | Offshore prototype testing | 13m lightweight blade for testing at present | Yes (planned) |
| **Asia Pacific** | | | | |
| Sinoma Wind Power Blade | China (seven facilities) | 10,000 | Up to 8.0 MW (90m) | Goldwind GW6.45-184<br>Goldwind GW8.0-175 |
| LZ Blades | China (eight facilities) | 6,000 | Up to 6.X MW | Sinovel 5/6 MW<br>XEMC 5 MW |
| Zhuzhou Times New Material | China (six facilities) | 10,000 | Up to 84m | Sewind 6.25MW-172<br>Envision EN161-5.2MW |
| Shanghai Aeolon | China (five facilities) | 9,000 (plan 50% export in 2021) | Up to 8.0 MW (90m) | Goldwind GW6.45-184<br>Goldwind GW8.0-175<br>Hyosung 5.0 MW |
| Sino-Wind Energy | China (five facilities) | 5,000 | Up to 85m | Under R&D |
| CCNM (CQGI) | China (five facilities) | 4,500 | Up to 83.6m | Yes |
| Luoyang Sunrui | China (8 facilities) | 4,500 | Up to 83.6m | Haizhuang H171-5 MW |
| Titan Wind | China (3 facilities, one under construction) | 3,000 | Up to 90m | Yes |
| Shanghai FRP | China | 1,400 | Up to 4.X & 6.0 MW | Yes |
| Human Composites | South Korea | n.a. | 2.0/3.0 MW (8.0MW under development) | Doosan 3.0 MW (Doosan 8 MW prototype) |
| Tien Li Offshore Wind Technology | Taiwan | n.a. (under construction) | Up to 10 MW | MHI Vestas V174-9.5 MW |
| **Americas** | | | | |
| TPI Composites | US, Mexico (four facilities), China (two facilities), Turkey (two facilities) and India | 15,000-18,000 (1,200 from US, 6,000 from Mexico, 2,800 from Turkey, 5,000 from China; 3,000 from new factory in India) | Up to 5.X MW | No |
| Molded Fiber Glass (MFG) | US (two facilities) | 1,000 | Up to 3.X MW | No |
| Tecsis Technology | Brazil | 5,000 (production stopped at present) | Up to 3.X MW | No |
| Aeris | Brazil (two facilities) | 4,000-5,000 | Up to 4.X MW | No |

Source: GWEC Market Intelligence, December 2020

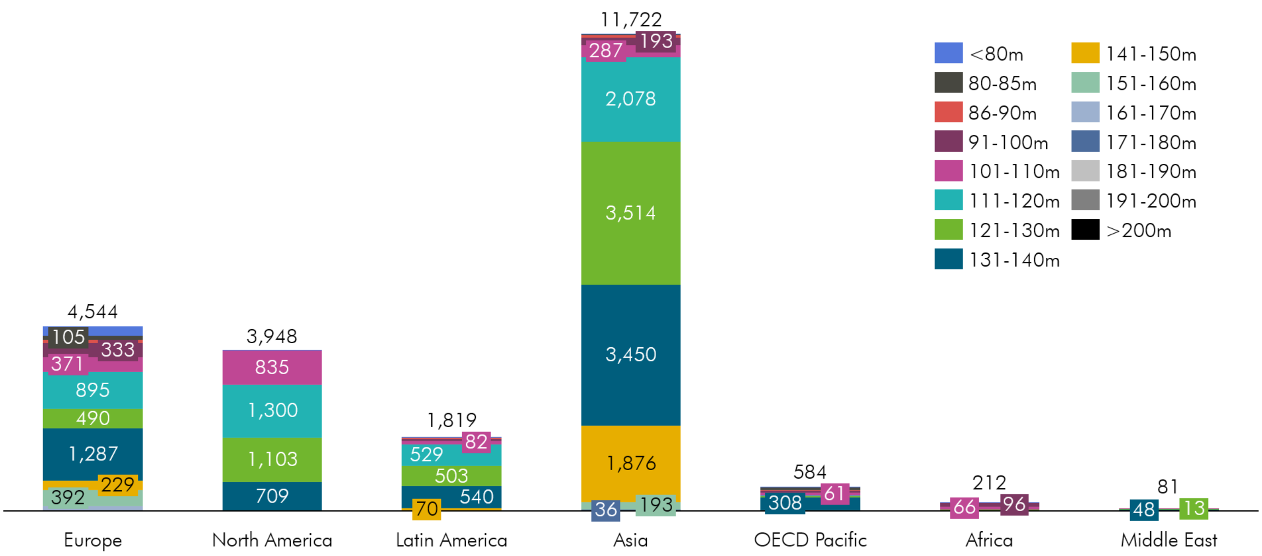
# 9. GLOBAL BLADE DEMAND AND SUPPLY ANALYSIS

## Wind turbine blade size: Today vs. Tomorrow

GWEC Market Intelligence's global wind turbine supply side database shows that the turbine rotor diameter has increased in size over the past five years. Turbines with rotor diameter in the size range of 91 m-110 m were the most installed products in 2014, accounting for 49.5% global market share. However, its market share dropped to 10.7% in 2019, and we saw turbines with a rotor diameter in the size range of 121 m-140 m become the mainstream product, accounting for 52.5% global market share (see figure 1-2). The drivers behind such shift from small to larger blades include:

1. Increasing pressure to bring down the LCOE, thus turbine OEMs continue to launch new onshore models with bigger rotors;
2. Increase in onshore wind turbines installed in low wind speed sites in key markets such as China and Germany; and,
3. Increased installation of offshore wind turbine with rotor diameters greater than 150 m in Europe and China.

Figure 1-2: Rotor diameter of wind turbine installed by region in 2019




Source: GWEC Market Intelligence, December 2020

Nevertheless, the next generation of onshore and offshore turbines released by leading turbine OEMs in the past 12 months has indicated that the length of rotor blades will continue to grow moving forward. Table 1-8 presents the new onshore and offshore products launched by the world's top ten turbine OEMs in 2020. A rotor diameter in the size range of 150 m-170 m and 185 m-220 m could become the norm for the 4-6 MW onshore turbines and +10MW offshore turbine models respectively within five years.

Table 1-8: New onshore and offshore turbine released by the top 10 OEMs in 2020

| Turbine OEMs | Turbine Model | Rotor Diameter | Type of turbine | Status |
|---|---|---|---|---|
| Vestas | Enventus V150-6.0 MW™ | 150 | Onshore | Upgraded version of V150-5.6 MW, with prototype installed in 2020 for testing |
| | Enventus V162-6.0 MW™ | 162 | Onshore | Prototype installed in 2020 and serial production from 2021 |
| Siemens Gamesa (SGRE) | SG 4.7-155 | 155 | Onshore | Prototype to be ready by mid-2021 and production planned for the end of 2021 |
| | SG 5.8-155 | 155 | Onshore | Prototype planned for mid-2020, with flexible power rating operating at 6.6 MW |
| | SG 5.8-170 | 170 | Onshore | Prototype planned for Q3 2020 and production will start in Q1 2021, with flexible power rating operating at 6.2 MW |
| GE | Cypress 5.5MW-158 | 158 | Onshore | To be delivered in mid-2021, with two-piece blade design |
| | Cypress 6.0MW-164 | 164 | Onshore | Launched in November 2020, with two-piece blade design |
| The Nordex Group | N149/155/163-5.X MW | 155 | Onshore | Series production scheduled for 2021 |
| Enercon | E-160 EP5 E2 5.5 MW | 160 | Onshore | Prototype installed in July 2020 and serial production in 2021 |
| | E-160 EP5 E1 4.6 MW | 160 | Onshore | Prototype installed in July 2020 |
| | E-147 EP5 E2 5 MW | 147 | Onshore | Prototype planned in late 2020 |
| GoldWind | GP21:GW165 -4.0 MW | 165 | Onshore | Launched at China Wind Power 2020 |
| | GP21: GW165-5.x MW | 165 | Onshore | Launched at China Wind Power 2020 |
| Envision | EN-161/5.0 MW | 161 | Onshore | Launched at China Wind Power 2020 |
| Mingyang | MySE6.25 MW-173 | 173 | Onshore | Launched at China Wind Power 2020 |
| Windey | WD 4.8 MW-147/156 | 147/156 | Onshore | Launched at China Wind Power 2020 |
| | WD175-5.x MW | 175 | Onshore | Launched at China Wind Power 2020 |
| Dongfang | DEW-D5.55-172 | 172 | Onshore | Launched at China Wind Power 2020 |
| | DEW-D6-164 | 164 | Onshore | Launched at China Wind Power 2020 |
| Siemens Gamesa | SG 14-222 DD | 222 | Offshore | Prototype ready in 2021; commercially available in 2024 |
| GE | GE Haliade-X 13 MW DD | 220 | Offshore | 12 MW prototype in 2019, started operating at 13 MW for testing in 2020 and serial production will kick off in 2021 |
| Vestas | V164-10.0 MW | 164 | Offshore | Ready for installation from 2021 |
| Goldwind | GW175-8.0 DD | 175 | Offshore | First installation in April 2020 |
| Envision | EN-171/5.5 MW | 171 | Offshore | Launched at China Wind Power 2020 |
| Mingyang | MySE11 MW-203 | 203 | Offshore | Prototype planned in 2021 and commercialised in 2022 |
| Dongfang | DEW-D7.5-186 | 186 | Offshore | Launched at China Wind Power 2020 |
| | DEW-D10- 185 | 185 | Offshore | Prototype already installed in China |

Source: GWEC Market Intelligence, December 2020

## Global overview of demand vs supply

Table 1-9 shows the maximum blade manufacturing capacity available by region by the end of 2020. With the identified in-house and independent blade facilities operating at full capacity use, more than 120 GW of annual blade supply capacity can be achieved globally. Assuming that the global wind market growth will be in line with GWEC Market Intelligence's Q3 2020 global wind market forecasts, there will be sufficient capacity to meet blade demand between 2020-2024. In fact, the total capacity available by the end of 2020 is about 1.7 times greater than the forecasted demand in 2020-2024.

This data suggests that the market may experience significant overcapacity in 2020-2024; however, this is unlikely to happen in reality due to:

1. The reported blade production capacity from suppliers include the volume from smaller moulds for blades blow 45 m, which are gradually being phased out and only accounted for less than 3% total global demand in 2019;
2. Global wind blade production was disrupted worldwide by the impacts of the COVID-19 pandemic in the first half of 2020, and blade producers had to suspend production for at least two weeks to comply with health and safety protocols;
3. Blade materials bottlenecks, also due to the pandemic, such as balsa wood from Latin America and PVC from Italy, have impacted global wind blade production, especially in China;
4. Transition of blade production lines to accommodate larger blades has already started in Europe and is expected to take place in other regions, thus full utilisation rates are unlikely to be achieved;
5. Turbines with rotor diameter ≥150 m are expected to become the mainstream product within five year, and additional investment on larger facility and moulds will be needed.

Table 1-9: Global blade demand vs. supply

| Region | Europe | North America | Latin America | Asia Pacific | Africa and Middle East | Total World |
|---|---|---|---|---|---|---|
| Maximum supply by 2020 (MW/year) | 22,500 | 8,500 | 11,800 | 82,420 | 300 | 125,520 |
| Demand forecast for 2020 (MW/year) | 13,392 | 12,562 | 5,706 | 38,611 | 1,074 | 71,345 |
| Demand forecast for 2024 (MW/year) | 19,100 | 12,378 | 3,918 | 31,185 | 3,150 | 69,731 |

Source: GWEC Market Intelligence, December 2020

In Europe, in-house blade capacity was approximately 17 GW in 2016, but it dropped to 13.7 GW in 2020 as a result of the closure of some blade factories of leading European turbine OEMs who have opted for an outsourcing strategy to remain competitive. 2020 is expected to be a slow year for Europe due to the impact of COVID-19, and there will thus not be much scope for independent blade suppliers. However, according to GWEC's Q3 2020 market outlook, the European wind market is likely to grow in annual installations from 16 GW in

2021 to 19 GW in 2024, which suggests that the demand from third-party suppliers will grow from 2021. Leading European turbine vendors and large suppliers like TPI have already started the transition of their blade manufacturing lines at their blade production facilities located in Europe, and a balance between demand and supply is likely to be reached in 2024.

In North America, current in-house blade production capacity from Vestas and SGRE along is around 4.5 GW, which accounts for around 35% of market demand in 2020-2024. This does not account for the capacity that GE owns at LM Wind Power's two blade facilities located in the US and Canada. However, turbine OEMs in the region can meet local demand by relying on imported blades from their own facilities located outside North America or on the volume provided by local independent blade suppliers such as TPI and MFG. Considering the trade war between China and the US, imported blades are most likely to come from Mexico, Brazil, India, and, to a lesser extent, from Europe.

In Latin America, The Nordex Group has a 1 GW in-house blade production capacity, the only -in-house facility in the region. Therefore, the market is generally free for independent suppliers such as TPI, Aeris, and Tecsis Technology. The total blade supply capacity in Latin America is greater than 11 GW, of which only half would be enough to meet local demand. This explains why Latin America also serves as a blade export hub to North America or other markets.

In the Asia Pacific, current in-house capacity for blades is around 19.5 GW. This can cover approximately half of the demand expected to be installed in this region in 2020. The remaining demand is not enough for independent blade suppliers, as existing supply capacity from independent suppliers as of December 2020 is about 63 GW, which is more than three times industry demand. Therefore, competition between independent suppliers in this region is intense.

In China, 61.4 GW of blade production capacity was identified from the third-party market. On top of this, 12.4 GW can be provided by local Chinese and foreign turbine OEMs. Although 2020 will be a record year with 34 GW of new installation predicted to be built in China, it is impossible for the local Chinese wind market to absorb all the capacity potentially available from the third-party market. This explains why some local independent blade suppliers have terminated production in the past four years, and why tier one independent Chinese blade suppliers are keen to seek more opportunities in the overseas market.

Subsidies for onshore wind in China will cease from 2021. In response to this crucial change, all the top ten Chinese turbine suppliers have launched the next generation 4-6 MW onshore turbine with 155 m-175 m rotor diameters in 2020. Although the total blade supply capacity available in China is large enough to meet the 50-60 GW annual installation recommendations included in recently released Beijing Declaration, GWEC Market Intelligence believes that Chinese local blade producers must complete the transition of their blade manufacturing lines on time in order to avoid bottlenecks for the production of longer blades.

China was a blade exporter to the US. However, the China-US trade war has also disrupted the smooth flow of blades made in China into the US. This is the same supply chain challenge that GWEC Market Intelligence reported in 2019 for wind gearboxes.Nevertheless, international turbine OEMs and independent suppliers with blade facilities in China can leverage their global footprints to mitigate the risk caused by the increased tariff imposed on goods produced in China.

As the second-largest wind manufacturing hub, India has more than 12 GW of blade production capacity, of which 40% is from independent suppliers and the rest is owned by local and international turbine manufacturers. It is evident that the transition from Feed-in-Tariffs to competitive bids in 2017 has disrupted local market growth. India's annual wind installation capacity declined from an average of 3-4 GW annually in 2016-2017 to 1.5-2.2 GW annually in 2020. This decline also reduced the number of turbine OEMs in India from around 14 to 9 major players who are ready to meet the upgraded platform (> 1- 1.5 MW WTG) technology demand. In turn, this has led to the underutilisation of domestic annual blades manufacturing capacity to between 12-17% after 2017. However, GWEC's Global Wind Market Outlook Update Q3 2020 indicates new installations are likely to bounce back from 2021 with 3-4 GW likely to be installed annually in 2021-2024. Though intensified policy efforts, India's annual wind installation trend could reach more than 5-10 GW to meet the country's wind power target of 60 GW by 2022 and 140 GW by 2030. Assuming that market development will follow this accelerated growth scenario, India's 12.2 GW annual blade manufacturing capacity is more than enough to meet its demand. For India, to meet future demand, local blade suppliers must start preparing for the transition of their blade manufacturing lines as larger turbines with bigger rotors, like SGRE's SG3.4-145 and Vestas' V155-3.3 MW, have already been introduced to India and will be commercially ready from 2021-2022. The Indian government is promoting the country as a favourable destination for the global wind manufacturing industry, and it is expected that along with in-house blade manufacturing OEMs, the two major independent blade manufacturers in India will have equal opportunities to capture and meet both local and global demand.

In Africa and the Middle East, only two in-house blade production facilities were identified, of which one is owned by SGRE in Morocco and another by MAPNA in Iran. Although manufacturing blades locally can help to meet LCRs and create local jobs in countries such as South Africa, it is still too difficult for established independent blade suppliers to justify investment in this region, chiefly due to the relatively low and unstable volume demand and political uncertainty. Thus, most of the demand from this region must rely on imports unless new production facilities are built in the future.

## Market situation for offshore wind blades

The offshore wind market is relatively small compared to the market for onshore wind. At of the end of 2019, 29.1 GW offshore wind is installed globally, accounting for 4.5% of total global wind installations. However, the market is expected to grow dramatically over the next decade. According to GWEC Market Intelligence, on 2019 offshore wind made up 10% of new wind power installations globally, but this is expected to double to 20% by 2024.

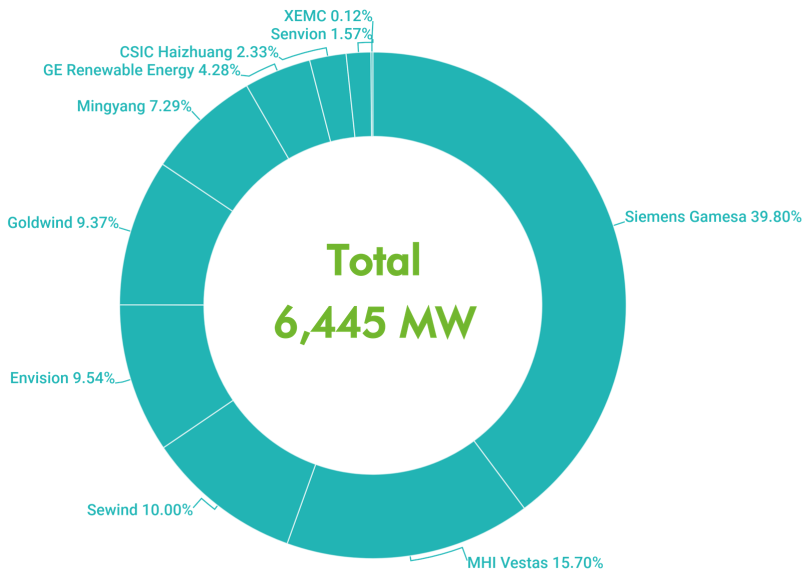
Table 1-10: Global offshore wind blade demand

| Region | Europe | North America | Latin America | Asia Pacific | Africa and Middle East | Total World |
|---|---|---|---|---|---|---|
| Demand forecast for 2020 (MW/year) | 2,264 | 12 | 0 | 4,269 | 0 | 6,545 |
| Demand forecast for 2024 (MW/year) | 5,545 | 2,878 | 0 | 4,550 | 0 | 12,973 |

Source: GWEC Market Intelligence, December 2020

Historically, the offshore wind market has been dominated by European turbines. Siemens Gamesa and MHI Vestas (now fully owned by Vestas) together hold nearly 70% of the global market share in cumulative installation as of the end of 2019. Siemens Gamesa maintained its market leadership position for new installations in 2019, followed by MHI Vestas (see figure 1-3). As Senvion filed for insolvency last year, all offshore turbine suppliers on the top ten suppliers list are all from China with the exception of GE Renewable Energy.

Figure 1-3: Top offshore wind turbine suppliers' annual installed capacity 2019




Source: GWEC Market Intelligence, December 2020

An analysis of global offshore wind blade supply chain strategies shows that the world's leading offshore wind turbine vendors, Siemens Gamesa and MHI Vestas, source all their blades for offshore development in-house. Three years ago, GE Renewable Energy acquired full ownership of its offshore wind blade partner LM Wind Power, which has enough capacity to cover GE's blade demand moving forward. For Chinese manufacturers, all OEMs outsource blades for their offshore operations from the third-party market, with the exception of Mingyang.

Following the license agreement signed with SGRE, the leading offshore turbine OEM in China Shanghai Electric outsources the majority of their offshore blades from SGRE's Lingang blade factory located in Shanghai. Goldwind, Envision and Haizhuang all outsource offshore blades from LM Wind Power, and have also started outsourcing 75-90 m blades from local blade suppliers such as Sinoma Wind Power Blade, Zhuzhou Times New Materials, Aeolon, and CQGI.

Geographically, the capacity from existing offshore wind blade facilities owned by SGRE, MHI Vestas, and GE Renewable Energy in Denmark, UK, and France can meet the forecasted demand for Europe in the next five years. As of today, all offshore blades installed in American offshore wind projects were produced in Europe, thus new facilities need to be built to support an emerging demand in the United States. With more than 4 GW of offshore orders won in the US, SGRE is now investigating a potential blade manufacturing facility on the East Coast of the United States.

Leading Chinese offshore wind turbine suppliers reported key bottlenecks for the provision of wind blades larger than 80m. Local and international suppliers in turn have invested to build facilities along the Chinese coast to meet market demand for larger blades. Since most of these new facilities have been ready for production since summer 2020 and the demand in the Chinese offshore market is expected to drop after the current installation rush, GWEC Market Intelligence does not anticipate any supply chain bottlenecks in China over the next five years. In Taiwan, MHI Vestas signed a sub-supplier contract agreement with local company TLC to meet local content requirements and SGRE signed an agreement with Swancor to supply resin used in blades slated for their offshore wind power projects in Taiwan, but so far they have no intention to build a new blade factory in Taiwan.

## 1,400 GW of offshore wind by 2050: can the global blade supply chain deliver?

On 18 November 2020, the European Commission presented the EU Offshore Renewable Energy Strategy, as part of the EU Green Deal. This strategy sets a target for 300 GW of offshore wind in Europe by 2050, up from 24 GW in 2020. Two weeks later, the Ocean Renewable Energy Action Coalition (OREAC) called on governments to ramp up their ocean renewable energy ambition to achieve the coalition's vision of 1,400 GW of offshore wind by 2050. Is the wind power blade supply chain ready to deliver such ambitious regional and global offshore wind targets? The answer from leading turbine OEMs and suppliers is a resounding, yes. From a technological point of view, leading turbine OEMs believe that there is no barrier to meet those targets. However, before making further investments to accommodate such growth, suppliers must have clear pipeline visibility, and strongly recommend national governments to include long-term targets into auction schedules to ensure market growth certainty and stability, as well as to drive technology innovation and bring down the cost of future products.

# 10. TRENDS IN THE DEVELOPMENT OF BLADE TECHNOLOGIES

Technology and innovation have not only been key to ensuring the highest performance and efficiency of wind blades, but also help wind turbine manufacturers yield optimal annual energy production and reduce the LCOE for wind power. Over the past few decades, leading wind turbine OEMs and blade manufacturers have been through a learning curve and made great breakthroughs in blade aerodynamics, structural designs, production process and materials. To support further growth of the global wind market, OEMs together with leading research centres continue to devote themselves to innovation. The recent trends in blade technology development are outlined below:

## i. Reinvent the Blades

As turbine blades are continuously exposed to different types of mechanical impacts and in some cases extreme weather conditions, design of blades is a challenging yet exciting endeavour. Trends covered under this category include advanced blade materials, segmented blades and aerodynamic designs.

### Advanced Blade Materials

As wind turbine continues to scale in terms of size to boost energy production, the two key factors, stiffness and weight, have become even more critical for blade design. Most utility-scale wind blades are made of glass fibre composites that have a relatively stiff, lightweight design with a high fatigue life. To increase the stiffness, blade manufacturers such as Vestas, LM Wind Power and The Nordex Group have started incorporating carbon fibre reinforcement into their larger blades starting in the 2000s. Carbon fibre is almost five-times the axial stiffness per kilogram of weight compared with fibreglass, which enables longer blades without increased rotor loads, exemplified by the world's longest wind turbine rotor blade of today – the 107 m LM blade for the GE Halliade-X 12 MW wind turbine. However, carbon fibre is expensive. Thus, continual efforts in research and development are being made with the aim to further improve wind blade material properties that are more affordable.

In collaboration with DTU Wind Energy based in Denmark, LM Wind Power successfully developed three 88.4 m long blades made from a hybrid carbon/glass fibre main spar cap along the length of its standard glass fibre base shell laminate using the company's existing manufacturing process but introduces the structural benefits of carbon fibre to the blade. This combination of factors allows the blade length to be extended without increasing weight too much while keeping the cost of the blades down.

To increase the production efficiency for larger blades, there is a shift towards materials that reduce cycle times and energy consumption. Stemming from initial research to substitute epoxy-based resins, which requires heated post-curing and slower infusion speed for their high viscosity, Covestro, Goldwind and LZ Blades scaled the research to co-develop the world's first 64.2 m full polyurethane (PU) wind turbine blade, which displayed better mechanical properties and a faster production process than blade made with traditional epoxy-based resins. As of late 2020, small scale production of this blade prototype has commenced.

Furthermore, thermoplastic materials such as Polyurethane can better facilitate end-of-life blade recycling by reheating and decomposing the materials, which is a limitation of existing turbines. There has already been a successful manufacturing demonstration for a 9 m thermoplastic composite wind turbine blade at the National Renewable Energy Laboratory (NREL), and now the work is on scaling up for real impacts to be seen at the commercial level.

In addition, due to supply chain challenges, leading blade producers and designers are looking for alternative materials such as polyethylene terephthalate (PET) for Balsa Wood – one of the key components of many wind turbine's blade core for its strength and lightweight nature. An exacerbated situation caused by COVID-19 coupled with the change in climatic conditions in Ecuador, the supplier of 95% of the world's commercial Balsa wood, has disrupted both the harvesting and the transportation of Balsa Wood for export to blade manufacturing facilities worldwide. This may have been a reason for Aerovide (previously known as Aerodyne) to hasten its R&D efforts announce models of balsa-free rotor blade in 2020.

## Segmented Blades

The trend in upscaling wind turbines has resulted in a steep increase in costs related to the manufacturing and transportation of blades, to the extent that further up-scaling may no longer be cost beneficial. This has given rise to the concept of segmented wind turbine blades, whereby segments can be transported separately and are jointed on-site, a solution that inaccessible with traditional non-segmented blades.

Launched in 2017, one of the key features of GE's Cypress platform (4.8-6.0 WM with 158-164 m rotor diameter) is its revolutionary two-piece wind turbine blade design, which allows the wind turbine blades to be manufactured at even longer lengths and improves logistics to offer more siting options. GE moved segmented blade design in-house with its acquisition of Blade Dynamics in late 2015, which has given GE an advantage in this niche-application-turned-commercial-necessity in recent years. The inauguration of the new Technology Center Americas facility in 2018, originally part of Blade Dynamics and now part of LM Wind Power, will continue its innovation of new techniques for designing and building wind turbine blades.

Additionally, Siemens Gamesa announced that it is working on a modular design where experience can be taken from a previous Gamesa's trademarked Innoblade® design and can offer the option of segmented blades to improve the transportability for its SGRE 5.x platform with 170m rotor diameter. GWEC Market Intelligence believes that conventional manufacturing and logistical concerns will steer more turbine OEMs and blade manufacturers to adopt two-piece blades for their longer blades going forward.

### Aerodynamic Designs

Equally important to wind blade design is the ability to improve the aerodynamic efficiency of blades to maximise the generation of energy, as this helps to mitigate damaging fatigue loads while increasing lift. Today, many utility-scale wind turbines already come equipped with vortex generators or aerodynamic "turbulators" to prevent flow separation on wind turbine blades.

Aerodynamic improvements have also been made through the InnoTip project - a collaboration led by LM Wind Power (LM), that aims at designing and demonstrating three innovative tips for offshore wind farms: the winglet tip, the turbulator and the shark fin. The winglet tip consists of a bend on the tip, the turbulator involves wake reduction geometry and the shark fin improves flow characteristics around the tip area. This project came to an end in 2017, with promising test results using attachable tips on existing wind turbines concluding that the tips can increase power output by as much as 6%. The findings of this research have been used in new blade developments.

New innovative ideas are largely borrowed from the aerospace industry or nature, and are mostly still in the early phase of R&D. For instance, a Segmented Ultralight Morphing Rotor (SUMR) wind turbine is bio-inspired by palm trees, whose trunks have evolved to withstand hurricane gales by folding and yielding in the direction of the wind, which reduces structural mass, fatigue and damage. Ongoing work is focused on collecting and analysing data from an upwind two-bladed prototype on a 12-story turbine tower installed at NREL's National Wind Technology Center in Golden, Colorado. The insights from this field campaign will inform the design of the eventual SUMR-50 MW rotor.

## ii. Digitalisation of Blades

Digitalisation has already been playing a crucial role in the growth of wind energy for its ability to enable pro-active management of live turbine performance. With regards to blades, digital solutions have gained popularity in blade condition monitoring systems, erosion control systems, robotics and drones.

## Blade Condition Monitoring Systems (BCMS)

Known to be the most cost-effective maintenance strategy, turbine monitoring and controls have already been widely utilised. This O&M tool combines sensors and data acquisition hardware to provide real-time measurements in monitoring the health of wind turbine components and related electrical components. Ground scopes, fibre optic devices, vibration sensors, acoustic monitors, and tap testing are just a few of the methods that operators such as Ping Monitor or Fibersail have used to measure blades in a precise and remote way, therefore preventing against failures both small and catastrophic.

For instance, GE Renewable Energy launched a new ground-based blade inspection system that combines thermal imaging technology and wide-band acoustic spectral analysis, which allows for the detection of anomalies on wind blades and is said to reduce operations and maintenance costs by about 25%.

This may have been a key reason for PNE Group's recent acquisition of Rope Access Solutions, a company which has strong expertise in blade maintenance, inspection services along with training programmes, expanding the portfolio of services offered under the umbrella of the PNE Group. Similarly, turbine blade specialist PolyTech has recently acquired German fibre optic sensor technology and data analytics outfit fos4X to further strengthen its portfolio of blade condition monitoring products that ensure the performance and life cycle of wind turbines.

## Robotics and Drones

Robotic engineering using autonomous drones is gaining momentum in combination with IIoT (Industrial Internet of Things) applications to digitally control production of wind turbines and wind farm O&M and inspections. Driven by longer blades, farther offshore and harsher environmental conditions, these technologies are able to deliver much quicker and more cost-efficient O&M services for the wind industry to result to help lower LCOE. Table 1-11 details selected robotic and drone systems that are known in the market.

# iii. Smart Blade Protection Solutions

## Leading edge protection solutions

Composites material is known for poor performance under traverse impacts and is sensitive to environmental factors like heat, moisture, icing, salinity and/or UV. The additional stress of erosion reduces the blade aerodynamics performance and increases the cost for frequent maintenance.

For example, Siemens Gamesa had to launch individual repair and upgrade campaigns at Ørsted's Anholt and London Array offshore wind farms in 2018 due to erosion on the blades' leading edge, only five years after the farms began operation. Lessons learnt from the past

Table 1-11: Robotics and Drones solutions for wind rotor blades

| Technology Provider | Solution | Phase of Development |
|---|---|---|
| Multi-Platform Inspection, Maintenance and Repair (MIMRee) collaborative project | Smart blade crawlers repair drone | Prototype and testing program underway, in development of variety of spin-off technologies |
| Tethys Energy Services (Tethys) and Aerones | Robotic automated maintenance | Prototype demonstration phase in collaboration with GE Renewable Energy |
| Sulzer & Schmid | Drone-based blade inspection | UAV DJI Matrice 210 used by Vestas across APAC region |
| SkySpecs | Autonomous drone inspections | Agreement to service for Siemens Gamesa |
| EWPL Ocean | Blade inspections and AI damage assessment | Full scope contract with Eneco |
| Clobotics | Autonomous drone inspections with automatic analysis on the cloud-based client portal | Commercial scale |

Source: GWEC Market Intelligence, December 2020

have indicated that leading edge erosion is a serious and expensive issue for the wind industry, with magnified effects on offshore turbines. Thus, blade protection against erosion using appropriate materials has become of great interest and huge economic necessity for the industry.

Today, both in-mould gel coating or post-mould leading edge protection of interphase coatings are used for protection against rain corrosion, but these are still not a one-size-fits-all solution for the wind industry. Rain erosion has therefore become a scientific challenge for the wind industry, considering there are no well-defined methodologies to design such coatings and it is unclear how to modify their properties depending on location and external conditions.

Coming from two different angles, there are two ongoing research projects working towards the same goal. Firstly, the DNV GL-led Joint Industry Project with ten commercial partners to develop a comprehensive methodology for Blade Rain erosion Analysis (COBRA) aims to deliver recommendations on methodologies and models for leading edge protection systems, which becomes vital for future innovations to tackle rain erosion issues. On the other hand, Leading Edge for Turbines (LEFT), a two-year research collaboration, sets off to develop a nickel-cobalt leading edge rain erosion protection coating for turbine blades. This is product-driven research that analyses the impacts of the coating on wind turbines and more importantly, the performance of the coating under raindrop impact tests.

Techniques for improving rain erosion resistance of the leading-edge using carbon nanotubes and graphene nano-additives have also been discussed as possible solutions.

### Ice protection systems

Turbine vendors have begun introducing de-icing and anti-icing solutions into their systems, which is a trend that is likely to continue as OEMs will deploy more turbines in markets with colder climates, such as Finland. Two main types of ice protection systems are available on the market today: action and passive systems.

Active systems use energy to remove ice using techniques such as pneumatic, ultrasound, chemical or expulsive etc. The most widely used technique combines thermal and hot air injection, whereby electrothermal surface heat the leading edge of the blade and hot air circulates inside rotor blades. Blade manufacturers such as Vestas launched its Anti-Icing System based on the active system outlined, and is said to ensure a minimum of 90% production retention, improving the asset owner's business case certainty by reducing potential losses.

A passive approach uses physiochemical methods to modify the surface with superhydrophobic coating so that it repels water instantly due to its low energy surface. Commercially, Teflon or polydimethylsiloxane (PDMS) coatings are the best cost-effective solutions to overcome ice accretion problems in cold regions. However, active ice-removal solutions are preferred on large span wind turbines for its performance, but these solutions are more expensive due to regular maintenance costs

## iv. Making Blades Recyclable - From Concept to Reality

The wind industry has historically focused on getting more wind turbines up and running, with the decommissioning phase receiving little attention. With the number of turbines due for decommissioning set to rise significantly from 10,000 in 2020 alone to 25,000 turbines in 2030, asset owners are already having to make difficult decisions about what to do with these old wind turbines.

The composite nature of fiberglass blades, which gives turbines their strength and stiffness, also makes blades difficult to deal with at the end-of-use stage. Recycling options are currently still limited and not satisfactory. Currently, most blades are either incinerated or transported to a landfill. The only commercially viable recycling method for glass fibre is using the material as a replacement feedstock for the cement manufacturing process, which reduces the carbon footprint of cement manufacturing by up to 16%, according to BNEF. This solution is used by OEMs such as GE Renewable Energy, who announced recently the first US wind turbine blade recycling multi-year agreement with Veolia North America (VNA) to repurpose fiberglass for cement production.

However, to build a sustainable global wind supply chain, efforts and commitments in finding alternative solutions to decommissioning turbines are underway. For instance, Vestas announced its new sustainability strategy, "Sustainability in everything we do", a strategy consisting of four ambitious goals, including a commitment to produce zero-waste wind turbines by 2040. A target like this will require technical and innovative capabilities to manage the current decommissioning situation, as well as to consider recycling from the outset for the next generation of wind turbines.

Given the challenge in recycling conventional turbine blades, the industry is now exploring the possibility for a complete re-design and make new turbine blades fully recyclable through initiatives such as the ZEBRA (Zero wastE Blade ReseArch) project. Finding a solution to recycle wind turbine blades is crucial for the sustainability of the industry and the planet, and will further reduce the environmental impact of the industry to achieve carbon neutrality. Table 1-12 details the end-of-life wind blades developments in progress.

Table 1-12: Selected end-of-life wind blades solutions

| Technology Provider | Products |
|---|---|
| Carbon Rivers (US) | Break down and reuse fiberglass from used turbine blades into commercial products. Recycling work has started in partnership with two large US utilities – PacificCorp and Mid American Energy |
| Re-wind | Project ideas for reusing and repurposing fiberglass blades as part of other structures and even in pedestrian bridges along greenways. |
| Geocycle (DE) | Recycling turbine blades into cement |
| Veolia North America (VNA) | Germany, Spain, Denmark, Mexico, India Shred blades for cement production. Recycling work has commenced with agreement signed with GE Renewables |
| Global Fiberglass Solutions (US) | EcoPoly Pellets for warehouse pallets or flooring material |
| ZEBRA (Zero wastE Blade ReseArch) project | Cross sector consortium on a project to design and manufacture the wind industry's first 100% recyclable wind turbine blade |

Source: GWEC Market Intelligence, December 2020

## 11. CONCLUSIONS

Blades are one of the most critical and expensive components of a wind turbine, and having the right supply chain strategy is crucial for all wind turbine manufacturers. This report has provided an overview of the global wind blade supply chain, covering both in-house blade production and the third-party market, leading turbine OEMs' supply chain strategies, forecasts on the future of the market, as well as the latest technology trends and innovations. Below you will find a summary of the key findings and themes that have emerged from this report.

## Number of Independent blade suppliers continues to dwindle

There are about 20 independent blade manufacturers globally, of which the majority are located in Asia and China in particular. Compared to 2016, 10 third-party suppliers are no longer active in the market. The primary reasons for the decrease of independent suppliers are: market consolidation; inability to compete in cost; insufficient R&D investment; and, lack of a global footprint.

## In-house blade production becomes less popular

As of today, 15 OEM wind turbines have in-house blade manufacturing facilities worldwide. Turbine production at 8 turbine OEMs with blade produced in-house, including 4 in India, 3 in Europe and 1 in the US, has been halted since 2016, mainly due to market consolidation of wind turbine OEMs in Europe and America and the tough market conditions in India since 2017.

## Global blade supply chain consolidation continues

Over the past five years, large blade producers continued to consolidate their global market share. Today, the top five independent blade producers make up 55% of the total global blade production capacity. Together with the volume produced in-house by large wind turbine OEMs, 10 producers (5 independent blade producers and 5 turbine OEMs with in-house blade production facilities) account for 80% of the total global blade supply.

## The pressure of cost reduction has impacted OEM strategies

In response to the global transition away from government-guaranteed prices for renewable energy through mechanisms such as Feed-in-Tariffs to auction and tender schemes, cost reduction has become the top priority for turbine manufacturers. To manage CAPEX while reducing the time to market for new products, large turbine producers, and especially western turbine OEMs, have dramatically changed their blade sourcing strategies over the past five years. As a result, the overall market share of in-house blade production has continued to fall, dropping to less than 50% in 2019.

## Wind turbine rotor diameter increase in size

Turbines with a rotor diameter in the 91 m-110 m size range were the most installed products in 2014, accounting for 49.5% of the global market share. However, the situation has changed rapidly in the past five years, with the market share for wind turbines in this size range dropping to 10.7% in 2019. Currently, turbines with a rotor diameter in the 121m-140m size range are the mainstream product, accounting for 52.5% of the global market share.

## COVID-19 impacts on global wind blade production capacity

With the identified in-house and independent blade facilities operating at a 100% utilisation rate, more than 120 GW of annual blade supply capacity is available globally. The COVID-19 pandemic disrupted wind blade production globally, as many blade producers had to suspend production for at least two weeks to comply with health and safety protocol. Suppliers, especially those in China, also suffered from blade materials bottlenecks like balsa wood from Latin America and PVC from Italy. Despite these disruptions, most blade manufacturing facilities worldwide returned to pre-COVID-19 capacity levels in H2 2020.

## Manufacturers must begin to prepare for larger blades

Assuming that wind power market growth will be in line with GWEC Market Intelligence's Q3 2020 global wind market outlook, there will be sufficient capacity to meet blade demand over the next five years (2020-2024). In fact, the total global blade production capacity available by the end of 2020 is about 1.7 times greater than the forecasted demand in 2020- 2024. However, blade suppliers must start to prepare the transition of their existing blade manufacturing lines to accommodate for larger blades and avoid any future bottlenecks, considering that turbines with a rotor diameter ≥o150m are expected to become the norm within five years.

## Scaling-up production to meet future offshore wind demand

From a technological point of view, leading blade producers believe that there is no barrier to meet the world's ambitious offshore wind targets, such as the Ocean Renewable Energy Action Coalition (OREAC)'s 1,400 GW by 2050 vision. However, suppliers require pipeline visibility through policy certainty and long-term targets to create market stability and certainty in order to justify investment in new manufacturing facilities.

## Technology and innovation driving down LCOE

Technology and innovation have been key to ensure the performance and efficiency of wind power blades, helping turbine manufacturers yield optimal annual energy production and bring down the LCOE. To support further growth of the global wind market, recent technology developments are now focusing on alternatives blade materials, segment blades, digitalisation in blade performance and operations, and blade recycling.

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