Global Wind Turbine Technology Trends

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Andy Li
lb@consultmake.com
Summary

- MAKE is one of the global wind industry’s premier strategic consulting and research firms, serving the world’s leading wind companies from all parts of the value chain from raw material suppliers to IPPs and utilities.

- MAKE is based in Aarhus (DK) and has offices in Hamburg (D), Chicago, Boston (U.S.) & Shanghai (China).

- Publish industry leading wind energy research reports, analysis and databases

- Consult on wind farm investments, market assessment, supply chain dynamics, technology, operations & maintenance, M&A advisory, business & market modelling and offshore wind

- Due-diligence partner for European and international PE and industrial investors

Introduction

A few words about MAKE

Andy Li
Business Analyst

- Leads the execution of MAKE’s China advisory projects
- Solid background in the Chinese wind industry including product development at Envision Energy
- Extensive knowledge of wind turbine, wind farm solutions, and big data platform development
- B.Eng – Mechanical Engineering
- M.Eng – Industrial and Financial Engineering
Introduction
A sample of our industrial clients
Introduction
A sample of our financial clients
Contents

- Executive summary
- Global wind turbine technology trends
- Sources of innovation and ‘breakthrough’ technology
Executive summary
Executive Summary

2016 saw increased focus in growing rotors and towers in the 3MW class

Turbine Manufacturer (OEM) acquisitions present the biggest impact on global technology trends

- Siemens and Gamesa merger and resulting regional product strategy will shift global trends
- GE acquisition of LM may limit the world’s largest blade supplier innovation footprint
- Integration efforts of GE/Alstom and Acciona/Nordex will influence regional product deployment

Blades and MW ratings expected to continue growing in every global region

- Longer blades enabled by structural design, aerodynamics and material science
- Larger MW ratings in demand globally, N. America and China rapidly passing 2MW benchmark
- Logistics limitations continue to emerge as primary barrier to blade growth

Many technologies continue evolutionary pace, while others experiencing innovation boom

- Converters, gearboxes and generators subject to slow evolutionary improvements
- Quest for ‘intelligent’ turbine has led to new technology for turbine loads monitoring and controls

Source: MAKE
Global wind turbine technology trends

Acquisitions and competition will re-shape technology trends

Consolidation impact on OEM position

<table>
<thead>
<tr>
<th>2015 M/S OEMs</th>
<th>2015 Marketshare Capacity</th>
<th>Acquisition impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vestas</td>
<td>7.64</td>
<td></td>
</tr>
<tr>
<td>Goldwind</td>
<td>6.91</td>
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<tr>
<td>GE</td>
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<td>Siemens</td>
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<tr>
<td>United Power</td>
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<td>Enercon</td>
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<tr>
<td>Envision</td>
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<tr>
<td>Mingyang</td>
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<tr>
<td>Senvion</td>
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<tr>
<td>Sewind</td>
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<tr>
<td>CSIC</td>
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<tr>
<td>Nordex</td>
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<td>XEMC</td>
<td>1.59</td>
<td></td>
</tr>
<tr>
<td>DEC</td>
<td>1.30</td>
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</table>

Note: Based on MAKE 2015 Marketshare positioning

Global Turbine OEM 2015 Marketshare Research Note
Source: MAKE

Turbine OEM competition developments

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Number of OEMs</th>
<th>Other OEMs</th>
<th>Top 5 OEMs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td></td>
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<tr>
<td>'07</td>
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<td></td>
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<td>'09</td>
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<td></td>
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<tr>
<td>'15</td>
<td></td>
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</tr>
</tbody>
</table>

Note: Sub-MW turbine OEMs not included
Source: MAKE

Regional portfolio decisions made by Siemens/Gamesa will have lasting impacts
Consolidation is occurring but industry is still more intensely competitive than a decade ago
Global wind turbine technology trends

3MW class gaining ground in global markets

LCOE optimization for MW rating

- MW Limited
- Turbine Limited

High BOP and O&M and turbine limits prefer larger MW

Little difference until tipheight limit reached

LCOE (Euro/MWh)

1.5 2.0 2.5 3.0 3.5 4.0

Note: High Specific Rating (W/m2) = 240. Low=200
Windspeed @ 80m = 8.0m/s
Tipheight limitation in MW limited markets = 152m
BOP % of CAPEX" MW Limited=23%, Turbine Limited =30%

Global MW rating segmentation projections

- 2016e
  - 54 GW
  - 1% 20%
  - 56%

- 2021e
  - 61 GW
  - 50%
  - 29%
  - 6%

Note: 2016 and 2021 forecasted global annual installs shown
Source: MAKE

High cost of Balance of Plant (BOP) and performance gains makes 3MW more attractive
Lower than 2MW class due to drop substantially outside of select Asian markets
Global wind turbine technology trends
Modular product strategies have led to portfolio expansion

Mass customization in wind energy

- Tower tops
- Hubs
- Nacelles and structures
- Cross-platform common components
- Shaft/Bearing
- Gearbox
- Generator
- Converter
- Adjusted for MW variants
- Blade options
- Customized for site specific wind conditions
- Tower base options
- Controls/SCADA
- O&M packages
- Noise/Weather
- Mass customized to client needs

OEM portfolio sizes and diversity

- Product mass customization
- Global portfolio
- # of markets installed, 2015

Unique turbine products offered, 2016

- Siemens
- GE
- Gamesa
- Goldwind
- Vestas

Source: MAKE
2015 Installed GW

Modular product strategies have enabled strategic component re-use across products
Allows for streamlined mass customization to meet global needs and wind conditions
Global wind turbine technology trends

Blades, tower and gearbox are majority of turbine cost

Cost distribution in typical turbine technologies

Increased cost of Balance of Plant is driving preference for larger turbines in EU and offshore
Cost-out focus will remain on blades and towers in order to reduce LCOE
Global wind turbine technology trends

New products announced in 2016 shifted competitive benchmarks

Capacity constrained leaders, 2016

Turbine constrained leaders, 2016

After years of rotor growth in 2MW class, many OEMs shift focus to 3MW giants

New products announced by Siemens and Senvion shift 3MW class landscape
Global wind turbine technology trends

<2MW turbines to disappear globally as 3MW class grows

Global MW rating and segmentation, 2016e and 2021e

Asia Pacific remains the last stronghold for the 1.5MW class, despite 2MW gains Europe and the Americas to see substantial growth in 3MW class installations

Note: Segmentation performed by total GW installed
Source: MAKE
Global wind turbine technology trends

Average turbine sizes to grow in all regions

Average MW rating growth per region

Average Rotor diameter growth per region

Economies of scale of larger turbines improve with volume and BOP cost escalation
Longer blades are continually stressing logistics limits in all regions

Source: MAKE
Sources of innovation and ‘breakthrough’ technology
Sources of innovation and ‘breakthrough’ technology

OEM’s reduce R&D spending to focus on product evolution

R&D as percent of revenue trends

- Gamesa
- Nordex
- Vestas

2011 Avg: 4.5% of Sales
2015 Avg: 2.0% of Sales

-2.5%

R&D spend (% of total revenue)

Note: R&D expense as identified on income statements
Source: MAKE, Company financials

Patent application filing trends

- Enercon
- MHI
- GE
- Siemens
- Vestas

-17% CAGR

Number of applications published

Note: Only patent applications in the European Patent (EP) database
Vestas includes MHI Vestas patent applications
GE includes Alstom, Blade Dynamics and LM
Source: MAKE

Product introductions accelerating, despite slowdown in IP filings and R&D spending
R&D spend expected to stabilize following years of solid profit gains
Sources of innovation and ‘breakthrough’ technology
Radically different technology still being pursued by large companies

Vestas Quad rotor energy comparisons

- Single Rotor
- Rotor 4
- Rotor 3
- Rotor 2
- Rotor 1

Aerial wind turbine state of the art

<table>
<thead>
<tr>
<th>Company</th>
<th>Investors</th>
<th>Technology</th>
<th>Status</th>
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<tbody>
<tr>
<td>Makani</td>
<td>Google</td>
<td>Airborne generators</td>
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<tr>
<td>Altaeros</td>
<td>MHI</td>
<td>Airborne ducted turbine</td>
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<td>Kite Power Systems</td>
<td>Shell, E.On Schlumberger</td>
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<td>Ampyx Power</td>
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<tr>
<td>Kitegen</td>
<td>Venture capital</td>
<td>Kites powering ground generator</td>
<td>![Symbol]</td>
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</table>

Hypothetical Laboratory prototypes Sub-scale prototype Full scale prototypes Commercial offering

Note: Vavg @ 80m=9.0 m/s. Shear = 0.15. Max Cp = 45.5%
Assuming 2% losses due to inter-array aerodynamics in Quad rotor. Source: MAKE

Although the industry has largely consolidated on a few turbine architectures, some long-term technology investment persists for radically different wind turbine architectures.
Sources of innovation and ‘breakthrough’ technology

Nabrawind looks to solve 2 critical technology scaling issues

Blade joint options being researched

<table>
<thead>
<tr>
<th></th>
<th>Bonded</th>
<th>T-Bolt</th>
<th>Double fitting</th>
<th>Tension fitting</th>
<th>nabrajoint</th>
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<tbody>
<tr>
<td>Strength / bolt sizing</td>
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Taller tower options available

<table>
<thead>
<tr>
<th></th>
<th>Tubular steel</th>
<th>Segment steel</th>
<th>Precast concrete</th>
<th>Lattice/Spaceframe</th>
<th>Nabralift</th>
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<tbody>
<tr>
<td>Tower material cost</td>
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<td>□</td>
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<td>Logistics cost and time</td>
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<td>Modal coupling</td>
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<td>●</td>
<td>●</td>
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</tbody>
</table>

Source: MAKE, Nabrawind

Segmented blades and cost effective taller towers are critical to onshore turbine growth
Nabrawind focusing on developing both technologies to solve scaling constraints
Contact

Andy Li
lb@consultmake.com