Characteristics of The Wind Turbine Blades Industry

Jacques Nader & Peter Fuglsang - Siemens Wind Power
Outline

- Facts on Siemens Wind Power
- Company growth and Intro to the Boulder Center of Excellence
- Characteristics of The Wind Turbine Blades Industry
  - Growth in Rotor Size
  - Manufacturing Characteristics
  - Blade Design and Innovation
- Challenges and long term outlook
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Siemens Wind Power
Facts at a glance

<table>
<thead>
<tr>
<th>Siemens Wind Power facts</th>
</tr>
</thead>
<tbody>
<tr>
<td>One of the world’s leading suppliers of wind power solutions</td>
</tr>
<tr>
<td>Acquired Danish wind turbine manufacturer Bonus Energy A/S in 2004</td>
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<tr>
<td>Total Installed Base: &gt; 17,600 turbines with ~ 35 GW capacity</td>
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<tr>
<td>2016 Installed base : &gt; 1,370 turbines with &gt; 4 GW capacity</td>
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<tr>
<td>~14,500 employees globally incl. Wind Service</td>
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Onshore Wind – Siemens with considerable experience and track record of installed projects

Cumulated Siemens onshore installations (GW)

ON installed base as of June 2016: >26 GW

First project
1979: 2 x 22 kW (10.2m)
Vindeby, Denmark

First 1MW turbines
1998: 17 x 1.0-54
Wilsikow, Germany

First project w/o subsidies
2009: 62 x 2.3-82
Wellington, New Zealand

First Commercial DD
2011: 3 x 3.0-101
Lejølle, Denmark
Offshore Wind – Leading player with >7,3 GW installed base in strongest growing market

Cumulated Siemens offshore installations (GW)

OF installed base as of June 2016: >7,3 GW

First project
1991: 5 MW Vindeby, DK

MW turbines
2000: 40 MW Middelgrunden, DK

GW project
2011: 630 MW London Array, UK

Master Agreement
2012: 1.8 GW DONG Master Agreement
Wind Turbine Blade R&D Center of Excellence in Boulder, Colorado

- Established in 2008
- 50 full-time engineers
- Rotor research, design and technology
- 30% PhD & 70% Masters
- Investing in American engineering
- Global footprint

Attractive Location for Top Talent:
- Forbes: “Boulder Tops List of America’s Smartest Cities”
- Money: “Louisville Best Places to Live”

![Map of Boulder](image)
NREL-SWP CRADA Test Turbine
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Characteristics of The Wind Turbine Blades Industry

1. Growth in Rotor Size
2. Manufacturing
3. Design & Innovation
The most dramatic and overwhelming representation of innovation – the growth in size

30 years of growth...

Driven by strong market growth
Relatively short product market cycle time

* Expected
Source: IRENA, EWEA
Fundamental changes in shape and design
30 years of blade development scaled to the same size

We have come a long way…
Fundamental changes in shape and design
30 years of blade development scaled to the same size

Two blades scaled to same size

75 m blade for SWT 8.0-154

5 m blade from Bonus 27 kW
Fundamental changes in shape and design
30 years of blade development scaled to the same size

Two blades scaled to same size

- Profiles changed from 1930s aircraft types to modern custom-made types
- Solidity changed from ~10% to much less than 5% (Blade area divided by swept area)
- A 75 m scaled version of the 27 kW blade would weight over 50 Tones (Approximately the weight of 30 mid size cars)
SWP 8.0-154 with 75 m blades
One of the world’s largest fiberglass component cast in one piece

• 75 m long blades and a rotor diameter of 154 m.
• Blade weight of 25 tons equal to 16 mid-sized cars.
• The rotors swept area is equivalent to 4½ football fields.
The 154 m rotor for the 8.0 MW is a large piece of equipment … Here with an Airbus A380
Prototype installation ...
75 meter blade mould ...
B75 blade, during transportation
Preparing B75 flapwise blade load test …
Characteristics of The Wind Turbine Blades Industry

- GROWTH IN ROTOR SIZE
- MANUFACTURING
- DESIGN & INNOVATION
IntegralBlade®
Patented Manufacturing Method by Siemens

We can make the world’s largest composite structures infused as one piece (NO GLUE JOINTS!!)
Manufacturing: Still very manual...and relatively fast
Mold cycle time less than 24 hrs
Over 2300lb of glass per hour
Some Facts

Blade Manufacturing

- We make the world’s largest composite structures infused as one piece
- On average it takes 24 hours to make a blade
- Layup speed is over 2300 lbs per hour
- Less than $10 per KG
Characteristics of The Wind Turbine Blades Industry

- Growth in Rotor Size
- Manufacturing
- Design & Innovation
25 years of Fatigue loads

Over 100 million cycles

Source: WMC (TU Delft-ECN)
TIP deflection and Buckling challenge...

Up to 50 ft of tip deflection!
Innovation: Aerodynamics, Materials, Loads reduction

- Aeroelastic tailored blade
- Pre-bend
- Dino Tails®
- High airfoil thickness
- Wind turbine airfoils
- Reduced max. chord
- Flatback airfoils

Strain or Stress vs. Number of cycles:
- Fatigue resistant materials

Stiffness vs. Density:
- Engineered cores
- Balsa
- Foam cores

Stress vs. Strain:
- Carbon
- HM Glass
- Glass

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Some Facts

Blade Design

- Over 100 million fatigue cycle over a lifetime of 25 years
- The first 30% of the blade can weigh over 50% of the total blade mass
- The 75 m blade has tip deflection of over 15 meters (~50 ft)
- Blade density in 2015 is 1/3 the blade density in 2004
- 30% of blade mass is from resin
To summarize some highlights…

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
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<tr>
<td><strong>SIZE</strong></td>
<td>Rapid Growth</td>
</tr>
<tr>
<td></td>
<td>&gt; 150 meters</td>
</tr>
<tr>
<td><strong>Product Market Life Cycle</strong></td>
<td>Short</td>
</tr>
<tr>
<td></td>
<td>&lt;3 years</td>
</tr>
<tr>
<td><strong>Production Speed</strong></td>
<td>&lt; 24 hours</td>
</tr>
<tr>
<td></td>
<td>&gt;2300 lbs per hour</td>
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<tr>
<td><strong>Manufacturing Method</strong></td>
<td>Manual</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>&lt;$10 /KG</td>
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<tr>
<td><strong>Product Life Time</strong></td>
<td>&gt;25 years</td>
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Future challenges

Leading edge erosion

Testing

Transportation

Maintenance

Manufacturing/automation

Size

Tip deflection

AEP
Generic long term outlook

Cost efficient turbines

Smart wind turbines and farms

Competitive wind energy LCOE
Thank you for your attention

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