Wind Technologies and Evolving Opportunities

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Society of American Military Engineers Webinar

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NREL is a national laboratory of the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy operated by the Alliance for Sustainable Energy, LLC
Opportunities for Wind Technology

• National Wind Technology Center – Research
  • Blades
  • Generators
  • Wind resource

• Wind Market Update
  • Recession impacts
  • PTC
  • RPS

• Wind Technology Overview
  • Larger rotors
  • Taller towers

• Wind Resource
  • Improved wind maps & assessment
National Wind Technology Center Overview

- Turbine testing since 1977
- Leader in development of design and analysis codes
- Pioneers in component testing
- Unique test facilities
  - Blade testing
  - Dynamometer
  - CART turbines
- Modern utility-scale turbines
- Approx. 150 staff onsite
- Budget approx. $35M
- Many CRADAs with industry
- Leadership roles for international standards.
The NWTC will be an essential partner for the technical development and large-scale deployment of wind power.

Goals:
- Improve windplant power production
- Reduce windplant capital cost
- Improve windplant reliability and lower O&M cost
- Eliminate barriers to large-scale deployment.
Innovation for Our Energy Future

Windplant Aerodynamics Problem

- Power performance and reliability influences are reduced in arrays.
- Understanding inflow / array interaction is key.
- Computational models, control paradigms, and hardware development will be required.
- A detailed understanding of the following is required:
  - Rotor wake interactions
  - PBL characteristics
  - Inflow / wind farm interaction
  - Complex terrain effects.

Horn’s Rev

Photo used by permission of Uni-Fly A/S
Physics-Based Array Aerostructural Dynamics

Interaction with low-speed streak

Images from Matt Churchfield and Sang Lee, NREL
Wind Energy Market Trends
# Worldwide Wind Market Update

## Table 1. International Rankings of Wind Power Capacity

<table>
<thead>
<tr>
<th>Annual Capacity (2012, MW)</th>
<th>Cumulative Capacity (end of 2012, MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>United States</strong></td>
<td><strong>China</strong></td>
</tr>
<tr>
<td>13,131</td>
<td>75,372</td>
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<tr>
<td><strong>China</strong></td>
<td><strong>United States</strong></td>
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<tr>
<td>12,960</td>
<td>60,005</td>
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<tr>
<td><strong>Germany</strong></td>
<td><strong>Germany</strong></td>
</tr>
<tr>
<td>2,415</td>
<td>31,467</td>
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<tr>
<td><strong>Spain</strong></td>
<td><strong>Spain</strong></td>
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<tr>
<td>2,336</td>
<td>22,462</td>
</tr>
<tr>
<td><strong>India</strong></td>
<td><strong>India</strong></td>
</tr>
<tr>
<td>1,958</td>
<td>18,602</td>
</tr>
<tr>
<td><strong>United Kingdom</strong></td>
<td><strong>United Kingdom</strong></td>
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<tr>
<td>1,272</td>
<td>9,113</td>
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<tr>
<td><strong>Italy</strong></td>
<td><strong>Italy</strong></td>
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<tr>
<td>1,112</td>
<td>7,998</td>
</tr>
<tr>
<td><strong>Spain</strong></td>
<td><strong>France</strong></td>
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<tr>
<td>1,077</td>
<td>7,593</td>
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<tr>
<td><strong>Brazil</strong></td>
<td><strong>Canada</strong></td>
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<tr>
<td>936</td>
<td>6,214</td>
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<tr>
<td><strong>Romania</strong></td>
<td><strong>Portugal</strong></td>
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<tr>
<td>923</td>
<td>4,363</td>
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<tr>
<td><strong>Rest of World</strong></td>
<td><strong>Rest of World</strong></td>
</tr>
<tr>
<td>6,838</td>
<td>42,368</td>
</tr>
</tbody>
</table>

**TOTAL** 44,958  **TOTAL** 285,558

Source: Navigant; AWEA project database for U.S. capacity

2012 Wind Technologies Market Report Summary; WPA All-States Summit; May 8, 2013
Wind Power Additions Hit a New Record in 2006

PTC-Driven Results

![Graph showing annual and cumulative growth in U.S. wind power capacity.](source: AWEA/SEC database)

**Figure 1. Annual and Cumulative Growth in U.S. Wind Power Capacity**


2006 Wind Technologies Market Report Summary

NATIONAL RENEWABLE ENERGY LABORATORY
Wind Power Additions: New Record in 2012

Expiring PTC-Driven Results

2006 Wind Technologies Market Report Summary
U.S. Wind Power Capacity Growth


Wind Power Capacity Completions by Quarter

Wind Power Capacity under Construction

As of December 31, 2013 there were a record-setting 12,300 MW under construction across 20 states. The previous high under construction total was 10,300 MW during the second quarter of 2012. The fourth quarter of 2013 also saw records fall for new construction activity as at least 10,900 MW of projects began physical work of significant nature.

Incentives – Renewable Portfolio Standards (RPS)

Source: Database of State Incentives for Renewables & Efficiency (funded by the U.S. Department of Energy)
Wind Capacity by State

At end of 2012:
- Texas > 2 X wind capacity of any other state
- 22 states had >500 MW of capacity (15 > 1 GW, 10 > 2 GW)
- 2 states >20% of total in-state generation from wind (9 > 10%, 17 > 5%)

Source: www.windpoweringamerica.gov/pdfs/workshops/2013_summit/wiser.pdf
2012 Wind Technologies Market Report Summary; WPA All-States Summit; May 8, 2013
Lower Turbine Pricing

Starting to Appear in Reported Total Project Costs

Source: www.windpoweringamerica.gov/pdfs/workshops/2013_summit/wiser.pdf
2012 Wind Technologies Market Report Summary; WPA All-States Summit; May 8, 2013
Economies of Scale – Project Size Matters

Sample includes projects built in 2011 and 2012

2012 Wind Technologies Market Report Summary; WPA All-States Summit; May 8, 2013
Domestic Wind-Related Manufacturing

More than 160 manufacturing plants capable of producing 12 GW/yr

2012 Wind Technologies Market Report Summary; WPA All-States Summit; May 8, 2013
Wind Turbine Technology Trends
Power in Wind Equation

Wind energy is kinetic energy – mass and momentum

Derived from K.E. = \( \frac{1}{2} mv^2 \)

\[
P = A \times \rho \times \frac{V^3}{2}
\]

- \( P \) = Power of the wind [Watts]
- \( A \) = Windswept area of rotor (blades) = \( \pi D/4 = \pi r^2 \) [m²]
- \( \rho \) = Density of the air [kg/m³] (at sea level at 15°C)
- \( V \) = Velocity of the wind [m/s]

Wind energy is proportional to velocity cubed (\( V^3 \)):

- 25% higher wind speed \( \approx 2 \) times the power available
- If wind speed is doubled, power increases by a factor of 8 (\( 2^3 = 8 \))!

Small differences in average speed cause big differences in energy production!
This power curve graph illustrates the GE 1.6-100 1.6-MW with 100-m rotor (low wind speed turbine – suitable for Kaneohe) and an 82.5-m rotor (suitable for sites without extreme wind or turbulence). The enlarged rotor moves the power curve to the left so the turbine produces more power (and energy) at lower wind speeds.

At 7 m/s, it might have produced ~500 kW with an 82.5-m rotor, but with a 100-m rotor it will produce ~700 kW – a 40% increase!!
Wind Speed and Power Increase with Height above the Ground

- Wind Speed and Power Factor
- Height Above Ground (m)

- [Graph showing the increase in wind speed and power factor with height]
  - Green line: Wind Power Increase
  - Blue line: Wind Speed Increase
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Turbine – Sized to Economic Project Goals

Vestas V-90
3-MW
~ 1,000 homes

GE 1.5sle
1.5-MW
~ 500 homes

Vestas V47
600-kW
~ 200 homes

Bergey Excel 10-kW
~ 1 home

THE SCALE OF WIND POWER
Wind Resource – Improved Tools
50-m wind mapping (2001-2009)

- Culmination of long-term project that began in 2001; jointly funded by states and DOE/WPA
- Comprehensive validation of maps using available measurement data
- Incorporated state maps by others to produce a national wind map ("patchwork quilt" evident in some regions)
- 50-m wind potential estimates to support U.S. 20% wind scenario study.
Changes in Wind Maps over Time: Kansas Example

Kansas 50 m Wind Power Maps Over Time

1987 - Map from U.S. Wind Atlas

2004 - Map from Kansas Corporation Commission

2008 - Unvalidated map from numerical mesoscale model

2008 - NREL Validated Map using 92 measurement stations

Wind Power Classification

<table>
<thead>
<tr>
<th>Wind Power Class</th>
<th>Resource Potential</th>
<th>Wind Power Density at 50 m W/m²</th>
<th>Wind Speed at 50 m m/s</th>
<th>Wind Speed at 50 m mph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>0-200</td>
<td>0.0 - 0.0</td>
<td>0.0 - 13.4</td>
<td></td>
</tr>
<tr>
<td>Marginal</td>
<td>200 - 300</td>
<td>0.0 - 0.8</td>
<td>13.4 - 15.2</td>
<td></td>
</tr>
<tr>
<td>Fair</td>
<td>300 - 400</td>
<td>0.8 - 7.5</td>
<td>15.2 - 19.1</td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td>400 - 500</td>
<td>7.5 - 8.1</td>
<td>19.3 - 23.1</td>
<td></td>
</tr>
<tr>
<td>Excellent</td>
<td>500 - 600</td>
<td>8.1 - 8.6</td>
<td>23.1 - 26.7</td>
<td></td>
</tr>
<tr>
<td>Outstanding</td>
<td>600 - 800</td>
<td>8.6 - 9.5</td>
<td>26.7 - 31.3</td>
<td></td>
</tr>
</tbody>
</table>

Wind speeds are based on a Weibull k of 2.4 at 500 m elevation.

U.S. Department of Energy National Renewable Energy Laboratory
Increasing hub height from 80 to 100 m:
• Doubles the potential wind capacity in Georgia at sites with a 30% capacity factor, from 200 to 400 MW
• Quadruples potential wind capacity at 25% capacity factor sites, from 500 to 2,000 MW
Opportunities for Wind Technology

• National Wind Technology Center – research
• Wind – incentives & markets
• Wind technology improvements
• Wind resource assessment improvements.
Questions?

For more info:

www.nrel.gov/wind
www.windpoweringamerica.gov
www.awea.org
www.nrel.gov/wind/resource_assessment.html

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