Wind Technologies and Evolving Opportunities

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Senior Engineer

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
  • PTC
  • RPS

• Wind Technology Overview
  • Larger Rotors
  • Taller Towers
  • Improved Controls

• Wind Resource
  • Improved 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 on-site
- 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

LCOE
Blade Testing Facilities

New Large Blade Test Facility:
- Boston, MA with Massachusetts Technology Collaborative
- Static and Fatigue tests of blades up to 90 m
- NREL staff to operate facility

NREL has developed and patented advanced blade testing
NREL supports R&D blade testing for DOE and industry
Supporting development of new blade test facilities worldwide
Drivetrain Testing

• 2.5 MW Dynamometer
  – Commissioned 1999
  – Steady use by industry
  – Used in R&D activities
  – Key facility for Gearbox Reliability Collaborative
  – Basic shaft load capability added in FY2010

• Dynamometer Upgrade
  – $10M Recovery Act funding
  – New 5 MW driveline
  – Robust shaft loading system
  – Commissioned in 2013
Windplant Aerodynamics Problem

• Power performance and reliability influenced reduced in arrays.
• Understanding inflow / array interaction is key.
• Computational models, control paradigms and hardware development will be required.
• Requires a detailed understanding of:
  – Rotor Wake Interactions
  – PBL Characteristics
  – Inflow / Wind farm Interaction
  – Complex Terrain Effects
• Major “Grand Challenge”

Horn’s Rev

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

Interaction with low speed streak
## Wind –Market Update - Worldwide

### Table 1. International Rankings of Wind Power Capacity

<table>
<thead>
<tr>
<th></th>
<th>Annual Capacity (2012, MW)</th>
<th>Cumulative Capacity (end of 2012, MW)</th>
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</thead>
<tbody>
<tr>
<td>United States</td>
<td>13,131</td>
<td>China</td>
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<tr>
<td>China</td>
<td>12,960</td>
<td>United States</td>
</tr>
<tr>
<td>Germany</td>
<td>2,415</td>
<td>Germany</td>
</tr>
<tr>
<td>India</td>
<td>2,336</td>
<td>Spain</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>1,958</td>
<td>India</td>
</tr>
<tr>
<td>Italy</td>
<td>1,272</td>
<td>United Kingdom</td>
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<tr>
<td>Spain</td>
<td>1,112</td>
<td>Italy</td>
</tr>
<tr>
<td>Brazil</td>
<td>1,077</td>
<td>Spain</td>
</tr>
<tr>
<td>Canada</td>
<td>936</td>
<td>France</td>
</tr>
<tr>
<td>Romania</td>
<td>923</td>
<td>Canada</td>
</tr>
<tr>
<td>Rest of World</td>
<td>6,838</td>
<td>Portugal</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>44,958</strong></td>
<td><strong>TOTAL</strong></td>
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<td></td>
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<td><strong>285,558</strong></td>
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</table>

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


2012 Wind Technologies Market Report Summary, WPA All-States Summit, May 8, 2013
Wind As a Percentage of Electricity Consumption

Note: Figure only includes the countries with the most installed wind power capacity at the end of 2012.

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


2006 Wind Technologies Market Report Summary,
Wind Power Additions Hit a New Record in 2012

Expanding PTC-Driven Results

2012 Wind Technologies Market Report Summary, WPA All-States Summit, May 8, 2013
Incentives – Renewable Portfolio Standards (RPS)

Renewable Portfolio Standard Policies

www.dsireusa.org / March 2013

29 states +
Washington DC and 2 territories have Renewable Portfolio Standards
(8 states and 2 territories have renewable portfolio goals)

25% x 2025* (co-ops & munis)

Texas: 5,880 MW x 2015*

California: 33% x 2020

Oklahoma: 15% x 2015

Arizona: 15% x 2025

New Mexico: 20% x 2020 (co-ops)

Colorado: 30% by 2020 (104Us)

South Dakota: 10% x 2015

North Dakota: 10% x 2015

Montana: 15% x 2015

Wyoming: Variates by utility:

Wisconsin: 20% by 2025

Illinois: 25% x 2025

Michigan: 10% & 1,100 MW x 2015*

Minnesota: 25% x 2025 (Xcel: 30% x 2020)

Vermont: (1) RE meets any increase in retail sales x 2012;
(2) 20% RE & CHP x 2017

Maine: 30% x 2000

New Hampshire: 24.8% x 2025

Maryland: 20% x 2022

Delaware: 25% x 2026*

District of Columbia: 20% x 2020

New Jersey: 20.38% RE x 2021 + 4.1% solar by 2028

Pennsylvania: ~18% x 2021†

Rhode Island: 16% x 2020

Connecticut: 27% x 2020

New York: 29% x 2015

Ohio: 12.5% x 2024

West Virginia: 25% x 2025†

Indiana: 10% x 2025†

Virginia: 15% x 2025∗

Georgia: 25% by 2035

New Mexico: 80% by 2015

Pit: 20% x 2035

Utah: 20% by 2025∗

Oregon: 25% x 2025 (large utilities)*

5%-10% x 2025 (smaller utilities)

Nevada: 25% x 2025∗

California: 33% x 2020

20% by 2025

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At end of 2012:
- Texas > 2x wind capacity as 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%)

Innovate for Our Energy Future

Wind Capacity – State by State


2012 Wind Technologies Market Report Summary, WPA All-States Summit, May 8, 2013
Lower Turbine Pricing Starting To Show Up In Reported Total Project Costs

![Graph showing installed project cost over time from 1982 to 2012.](source)


2012 Wind Technologies Market Report Summary, WPA All-States Summit, May 8, 2013
Economies of Scale – Project Size Matters


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

Over 160 manufacturing plants capable of producing 12 GW/yr

2012 Wind Technologies Market Report Summary, WPA All-States Summit, May 8, 2013
1,000 MW of New Wind Power in Colorado

Wind energy’s economic “ripple effect”

Project Development & Onsite Labor Impacts

- Landowner Revenue:
  - $3 million/year
- Local Property Taxes:
  - $5.7 million/year
- Construction Phase:
  - 502 new jobs
  - $39 million to local economies
- Operational Phase:
  - 51 new jobs
  - $3.4 M/year to local economies

Turbine & Supply Chain Impacts

- Construction Phase:
  - 3,059 new jobs
  - $414.8 million to local economies
- Operational Phase:
  - 73 new jobs
  - $16.3 million/year to local economies

Induced Impacts

- Construction Phase:
  - 1,197 new jobs
  - $143.1 million to local economies
- Operational Phase:
  - 63 new jobs
  - $7.6 million/year to local economies

Totals (construction + 20 years)

- Total economic benefit: $1.32 billion
- New local jobs during construction: 4,758
- New local long-term jobs: 187

Construction Phase = 1-2 years
Operational Phase = 20+ years
Wind – 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) = $\pi D/4 = \pi r^2$ [m$^2$]
- $\rho$ = Density of the air [kg/m$^3$] (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 $\approx 2x$’s the power available
- If wind speed is doubled, power increases by a factor of eight ($2^3 = 8$)!

Small differences in average speed cause big differences in energy production!
This graph is of the GE 1.6-100 1.6 MW wind turbine with a 100m rotor (low wind speed turbine – suitable for Kaneohe) and an 82.5m 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 ~500kW with an 82.5m rotor, but with a 100m rotor it will produce ~700kW – that is a 40% increase!! Over the course of a year, it really makes a difference.
Wind Speed and Power Increase with Height Above the Ground

- **Wind power increase**
- **Wind speed increase**

Increase Compared to 30 ft

Tower Height, ft

- **0**
- **50**
- **100**
- **150**
- **200**
- **250**

- **1.0**
- **1.5**
- **2.0**
- **2.5**
- **3.0**
- **3.5**
Wind – Wind Resource
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 WPA 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/\text{m}^2</th>
<th>Wind Speed\textsuperscript{a} at 50 m m/s</th>
<th>Wind Speed\textsuperscript{a} at 50 m mph</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Poor</td>
<td>0 - 200</td>
<td>0.0 - 6.0</td>
<td>0.0 - 13.4</td>
<td></td>
</tr>
<tr>
<td>2 Marginal</td>
<td>200 - 300</td>
<td>6.0 - 8.8</td>
<td>13.4 - 15.2</td>
<td></td>
</tr>
<tr>
<td>3 Fair</td>
<td>300 - 400</td>
<td>7.5 - 9.5</td>
<td>15.2 - 16.8</td>
<td></td>
</tr>
<tr>
<td>4 Good</td>
<td>500 - 600</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Excellent</td>
<td>8.6 - 9.5</td>
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</tbody>
</table>

\textsuperscript{a}Wind speeds are based on a Weibull k of 2.4 at 500 m elevation.
New US Wind Resource Map – Wind Speed at 80-m

United States - Annual Average Wind Speed at 80 m

Georgia – New Turbines Provide Greater Wind Potential

Increasing hub height from 80 to 100m:
• Doubles the potential wind capacity in Georgia at sites with a 30% capacity factor from 200 to 400MW
• Quadruples potential wind capacity at 25% capacity factor sites from 500 to 2000 MW
Opportunities for Wind Technology

- National Wind Technology Center – Research
- Wind – Incentives & Markets
- Wind Technology Improvements
- Wind Resource Assessment Improvements