Research Needs in Wind Energy

Natural Gas – The Path to Clean Energy Forum

November 18, 2010

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NREL’s National Wind Technology Center

NREL/PR-5000-49975
Overview

• Genesis of 20% wind energy
• How much energy is 20%
• Is there enough wind to reach 20%
• Technology opportunities & challenges
A New Vision For Wind Energy in the U.S.

State of the Union Address

“...We will invest more in ... revolutionary solar and wind technologies”

Advanced Energy Initiative

“Areas with good wind resources have the potential to supply up to 20% of the electricity consumption of the United States.”
Administration's Renewable Energy Goals

- Double renewable energy capacity by 2012
- 10% renewable energy by 2012
- 25% renewable energy by 2025
- Create 5 million new green jobs
- 80% GhG reduction (from 1990 levels) by 2050
- Informed by “20% wind energy by 2030” landmark report issued by DOE in May 2008
Electrical Power Generation by Source

3700 TWh Annually
(0.42 TW Continuous energy use)

Source: Electric Power Monthly, March 15, 2010
http://www.eia.doe.gov/cneaf/electricity/epm/epm_sum.html
20% Requires 300 GW - Land & Offshore

Cumulative Installed Capacity (GW)

- Offshore
- Land-based

Projected and Actual Cumulative Capacity Over Time

Range:
- 2000 to 2030
- 0 to 300 GW
U.S. Wind Resource & Electrical Load

Composite Wind Resource Map

The remaining states use data from the 1987 "Wind Energy Atlas of the United States".

For more information, visit:
http://www.windpoweringamerica.gov/where_is_wind.html

<table>
<thead>
<tr>
<th>Wind Power Classification</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>2 Marginal</td>
<td>200 - 300</td>
<td>5.6 - 6.4</td>
<td>12.5 - 14.3</td>
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<tr>
<td>3 Fair</td>
<td>300 - 400</td>
<td>6.4 - 7.0</td>
<td>14.3 - 15.7</td>
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<tr>
<td>4 Good</td>
<td>400 - 500</td>
<td>7.0 - 7.5</td>
<td>15.7 - 16.8</td>
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<tr>
<td>5 Excellent</td>
<td>500 - 600</td>
<td>7.5 - 8.0</td>
<td>16.8 - 17.9</td>
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<tr>
<td>6 Outstanding</td>
<td>600 - 800</td>
<td>8.0 - 8.8</td>
<td>17.9 - 19.7</td>
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<tr>
<td>7 Superb</td>
<td>800 - 1000</td>
<td>8.6 - 11.1</td>
<td>18.7 - 24.8</td>
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* Wind speeds are based on a Weibull k value of 2.0
How Much Wind is Available … Really?

Excludes PTC; includes transmission costs to access 10% existing electric transmission capacity within 500 miles of wind resource.

Source: Black & Veatch/NREL
Required Manufacturing Capacity

AWEA 2009 Projections:
- Additional Installed Capacity ≈ 10 GW
- Total Installed Capacity ≈ 35 GW

Capacity additions in 20% Scenario

Actual installations
2007: 5,329 MW
2008: 8,500 MW
2009: 9,644 MW

2009: Wind was 47% of all New Domestic Power Generation
Electric Sector CO2 Emissions

---|---|---
15,300 MMTCO2 | 50 - 98 - 145 | 9.7 - 19 - 28.2

Significant Water Use Savings

Cumulatively, the 20% Wind Scenario would avoid the consumption of 4 trillion gallons of water through 2030.

The 20% Wind Scenario cuts electric sector water consumption by 17% in 2030.
Technology Evolution

Evolution of Commercial Wind Technology

The 1980's

- Altamont Pass, CA
  - Kenetech 56-100kW
  - 17m Rotor
- 50kW
- 100kW

The 1990's

- San Clemente, CA
  - Micon 700-225/40
  - 29.6m Rotor
- 300kW
- 500kW
- 750kW

- Mehuken, Norway
  - Vestas V52-850kW
  - 52m Rotor

2000 & Beyond

- Liverpool Bay, UK
  - Siemens SWT-3.6MW
  - 107m Rotor
- 3.6 MW
- 5 MW

- Aberdeen, Scotland
  - North Sea (45m water depth)
  - REpower 5MW
  - 126m Rotor

- Medicine Bow, WY
  - Clipper 2.5MW
  - 93m Rotor
- 1.5 MW
- 2.5 MW

Credit: NREL Historical Photos
Wind Turbine Scale – Present and Future

- 2.5 MW - typical commercial turbine installation
- 5.0 MW prototypes being installed for testing in Europe
- Clipper Wind Power developing an 8.5 MW turbine
- Most manufacturers have a 10 MW machine in design
- Large turbine development programs targeting offshore markets
- Development Outpacing Test & Validation Capability
Technology Opportunities

Power Conversion

- High temperature silicon carbide device; improved reliability & reduce hardware volume
- Novel circuit topologies for high voltage & power quality improvement
- Medium voltage designs for multi-megawatt architectures

Tower Support Structures

- Tall tower & complex terrain deployment
- Advanced structures & foundations
- New materials and processes
- Self erecting designs
Technology Opportunities

Advanced Rotor Technology
- Extended rotor architectures through load control
- Incorporate advanced materials for hybrid blades
- Cyclic & independent blade pitch control for load mitigation
- Sweep and flap twist coupled architectures
- Light weight, high TSR with attenuated aeroacoustics

Power Train Enhancements
- Permanent Magnet DD Architectures
- Split load path multi-stage generation topologies
- Reduced stage (1-2) integrated gearbox designs
- Convoloid gearing for load distribution
Technology Opportunities

Critical need for advanced wake models
Key to understanding array effects for performance & loads

Current Activity:

NREL - Siemens 2.3 MW Aerodynamics Test
• Extensive pressure measurements
• LIDAR wake measurements
• Understand rotor / wake interaction
• CFD model validation
• Advanced aerodynamics / performance / loads control

Aeroacoustic array development – testing of Northwind, testing in Bushland with Sandia

Planned/Recommended:
• Wakes – Comprehensive effort including CFD, wind tunnel test, field test; leading to improved design codes
• Acoustic testing of Siemens (array) – GE, CART3 – removable tip testing for noise
• “Siemens Part II”: wind farm atmosphere/turbulent inflow/aero/wake
Serious Challenges Remain

Needs Improvement:

- Gearbox performance
- Operating expenses too high
- Capital expenses still exceed DOE performance goals
- Rotor stretching strategy
- Wind plants under-performing 10%

Why:

- Bearing failures; inaccurate internal loads?
- Unscheduled maintenance, low reliability, lack O&M automation
- Fatigue load & deflection control required
- Tower clearance limit, materials, aeroacoustics limiting tip speed, dynamic stability?
Wake Structure Development

Near wake

Far wake

Axial velocity

Turbulence intensity

Sørensen, EWEC 2007

Danmarks Tekniske Universitet
Turbine, wind farm, PBL; similar dimensional scales
Farm / inflow interactions not quantified
Characterization & prediction remain an issue
Detailed inflow information required for turbine design and optimized control
Diurnal variation
Growing concerns include:
- Quality of the downwind resource
- Microclimatatology changes
- Agriculture impacts
- Permitting
Multi-MW Turbines at NWTC

**DOE 1.5 MW GE Turbine:**
- Model: GE 1.5SLE
- Tower Height: 80 m
- Rotor Diameter: 77 m
- DOE owned; used for research and education

**Siemens 2.3 MW Turbine:**
- Model: SWT-2.3-101
- Tower Height: 80 m
- Rotor Diameter: 101 m
- Siemens owned and operated
- Multi-year R&D CRADA; aerodynamics and rotor performance
Large Facility Requirements

A 45-meter wind turbine blade undergoing fatigue testing at the NWTC, July 2004.

New Large Blade Test Facility
- Boston, MA with Massachusetts Technology Collaborative

New Dynamometer Test Facility
- Charleston, SC with Clemson University
Questions?

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