Wind Energy Status and R&D Challenges

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The U.S. Energy Picture
by source - 1850-1999

United States - Wind Resource Map

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>2 Marginal</td>
<td>200 - 300</td>
<td>5.6 - 6.4</td>
<td>12.5 - 14.3</td>
<td></td>
</tr>
<tr>
<td>3 Fair</td>
<td>300 - 400</td>
<td>6.4 - 7.0</td>
<td>14.3 - 15.7</td>
<td></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>
<td></td>
</tr>
<tr>
<td>5 Excellent</td>
<td>500 - 600</td>
<td>7.5 - 8.0</td>
<td>16.8 - 17.9</td>
<td></td>
</tr>
<tr>
<td>6 Outstanding</td>
<td>600 - 900</td>
<td>8.0 - 8.8</td>
<td>17.9 - 19.7</td>
<td></td>
</tr>
<tr>
<td>7 Superb</td>
<td>800 - 1600</td>
<td>8.8 - 11.1</td>
<td>19.7 - 24.8</td>
<td></td>
</tr>
</tbody>
</table>

* Wind speeds are based on a Weibull k value of 2.0


Indian Reservations and Alaska Native Village Areas

U.S. Department of Energy National Renewable Energy Laboratory

DM Heimiller 31-MAY-2001 1.2.8
Cost of Energy Trend

1981: 40 cents/kWh

- Increased Turbine Size
- R&D Advances
- Manufacturing Improvements

NSP 107 MW Lake Benton wind farm
4 cents/kWh (unsubsidized)

2006: 3 - 6 cents/kWh with PTC
Clipper LWST Prototype
2.5 MW with 93 m Rotor
Wind Energy Research Activities

Turbine Development Programs
- Low Wind Speed Technology
- Distributed Wind Technology

Supporting Research Activities
- Advanced Rotor Development
- Generator, Drivetrain, and Power Electronics
- Systems and Control
- Technology Acceptance
- Utility Grid Integration
- Certification Testing
Measuring and Modeling Dynamic Stall and Unsteady Aerodynamics

NASA Ames 80’ by 120’ Wind Tunnel Test

ADAMS Model

Smoke Test
Measuring and Modeling the Low-Level Nocturnal Jet

Radial Velocity (m/s)

Date: 10/21/1999, Time: 1:12 to 1:48, Az = 225.00

km

Met tower and SODAR at Lamar, Colorado

Courtesy R. Banta NOAA
Blade Scaling for Multimegawatt Rotors

![Graph showing blade weight in kg versus rotor diameter (m).]

- 4 Preliminary Designs From This Work
- Earlier Designs From WindStats
- Latest Designs From WindStats
- Power (Earlier Designs From WindStats)
- Power (Latest Designs From WindStats)

[Source: National Renewable Energy Laboratory]
Industry’s Growing Needs

A new 45-meter wind turbine blade was shipped to the NWTC for testing in July 2004.
Advanced Drivetrain R&D

**Today**
1.5 MW Commercial Technology

**Tomorrow**
Prototype Technology
What are the Future R&D Needs?
Offshore Wind – U.S. Rationale

Why Go Offshore?

Windy onshore sites are not close to coastal load centers

The electric utility grid cannot be easily set up for interstate electric transmission

Load centers are close to the offshore wind sites

US Population Concentration

US Wind Resource

Graphic Credit: Bruce Bailey  AWS Truewind

Graphic Credit:  GE Energy
<table>
<thead>
<tr>
<th>Region</th>
<th>GW by Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 - 30</td>
</tr>
<tr>
<td>New England</td>
<td>10.3</td>
</tr>
<tr>
<td>Mid-Atlantic</td>
<td>64.3</td>
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<tr>
<td>Great Lakes</td>
<td>15.5</td>
</tr>
<tr>
<td>California</td>
<td>0.0</td>
</tr>
<tr>
<td>Pacific Northwest</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>90.1</td>
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</tbody>
</table>

Resource Not Yet Assessed
Offshore Wind Turbine Development for Deep Water

Current Technology

Onshore Wind Turbine

Monopile Foundation
depth 0 – 30 m

Tripod fixed bottom
depth 20 – 80 m

Floating Structure
depth 40 – 900 m
• Turbulent winds
• Irregular waves
• Gravity / inertia
• Aerodynamics:
  – induction
  – skewed wake
  – dynamic stall
• Hydrodynamics:
  – scattering
  – radiation
  – hydrostatics
• Elasticity
• Mooring dynamics
• Control system
• Fully coupled
A Future Vision for Wind Energy Markets

**Today 2005**

- Bulk Power Generator 4-6¢ at 15mph
  - Land Based
  - Bulk Electricity
  - Wind Farms

**Potential 20% of Electricity Market**

**Tomorrow**

- **LWST Turbines:**
  - 3¢/kWh at 13 mph
  - Electricity Market 2012

- **Offshore LWST Turbine:**
  - 5 cents/kWh
  - Shallow/Deep water
  - Electricity Market
  - Higher wind Sites 2014 and Beyond

- **Custom Turbines:**
  - Electricity
  - H2 production
  - Desalinate water
  - Storage
  - Multi-Market 2030 and Beyond

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**Land Based Electricity Path**

- Land Based LWST Large-Scale 2–5 MW

**Transmission Barriers**

- **Cost & Regulatory Barriers**

**Offshore Electricity Path**

- Offshore Turbines 5 MW and Larger

**Advanced Applications Path**

- Land or Sea Based:
  - Hydrogen
  - Clean Water

**Cost & Infrastructure Barriers**

- **Offshore LWST Turbine:**
  - 5 cents/kWh
  - Shallow/Deep water
  - Electricity Market
  - Higher wind Sites 2014 and Beyond

- **Custom Turbines:**
  - Electricity
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**Land Based Electricity Path Transmission**

- **Barriers**

**Offshore Electricity Path**

- **Barriers**

**Advanced Applications Path**

- **Barriers**

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**Land Based LWST Large-Scale 2–5 MW**

- **Barriers**

**Offshore Turbines 5 MW and Larger**

- **Barriers**

**Land or Sea Based:**

- **Barriers**

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