National Wind Technology Center

Technology Overview
Fundamentals of Wind Energy
AWEA Pre-Conference Seminar
WindPower 05
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NREL
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- Technology Description
- Costs and Trends
- Future Developments
Fundamentals

- Rotor
- Nacelle
- Tower
At it’s simplest, the wind turns the turbine’s blades, which spin a shaft connected to a generator that makes electricity. Large turbines can be grouped together to form a wind power plant, which feeds power to the electrical transmission system.
What’s in there?
Configuration Choices

- Fixed pitch or variable pitch
- Turbine rating
- Tower height
- Variable speed or not
- Lattice, tubular or guyed tower
- Special climate packages
Wind Farm Characteristics

- Rapid Construction Time
- Shared Land Use
- No Emissions
- No Fuel Payments
- Economies of Scale

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Reducing the Cost of Energy

Cost of Wind Energy

Levelized Cents/kWh

Assumptions:
Generating company ownership
Wind plant comprised of 100 turbines
30 year levelized cost in constant 2002 dollars
No financial incentives included

Low wind speed sites

High wind speed sites

Bulk power competitive price band

Cost of Energy Drivers

- Initial costs
- Project size & location
- Financing mechanism
- Taxes and other incentives
- Operating expenses
- Energy Production
  - Wind resource
  - Project performance
  - Project reliability
Initial Cost Elements

- Turbines, FOB USA: 49%
- Construction: 22%
- Towers (tubular steel): 10%
- Interest During Construction: 4%
- Interconnect/Substation: 4%
- Design & Engineering: 2%
- Financing & Legal Fees: 3%
- Development Activity: 4%
- Land Transportation: 2%
- Land: 2%
- Transportation: 2%

Evolution of Commercial U.S. Wind Technology

THE EVOLUTION OF COMMERCIAL U.S. WIND TECHNOLOGY

1980's
- Structurally stiff
- 3 bladed - upward yaw driven
- Constant speed and 2 speed
- Stall regulated/tip brakes or full-span pitch controlled
- Fiberglass blades
- Geared transmission
- Induction generator
- Steel truss or tube tower

1990's
- Structurally stiff
- 3 bladed - upward yaw driven
- Variable speed and constant speed
- Special airfoils - NREL
- Stall regulated and pitch controlled
- Planetary transmission
- Induction generator
- Large size to reduce COE

Future Innovation
- Scale to larger size
- Advanced blade materials and manufacturing
- Low speed direct drive generators
- Custom power electronics (high efficiency)
- Feedback control of drive train and rotor loads
- More flexible structurally
- O&M reduction features

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Do bigger turbines have lower COE?

- No simple answer
- Size range matters
- Balance of many factors
  - Equipment costs
  - Wind shear
  - Tower height
  - Terrain/Crane/Construction
  - Transportation costs
  - Operations and maintenance costs
Reliability

Monthly Availability for Two Windpower Projects

Average Availabilities:

<table>
<thead>
<tr>
<th></th>
<th>Months 1-5</th>
<th>Months 6-17</th>
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<tbody>
<tr>
<td>Project A</td>
<td>90.1</td>
<td>95.1</td>
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<tr>
<td>Project B</td>
<td>95.0</td>
<td>97.7</td>
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</table>

Month of Operation
Cost of Energy
Average Cost of Money 12%; O&M $0.01/kWh

Turnkey Cost/kW = $1300

Turnkey Cost/kW = $800
Where is the Money!?

Multiple sources of value:
- **Operating Cash Flow**
  - Power Purchase Agreement
  - Green attributes
  - Other incentives
- **Depreciation**
  - 5-6 year
- **Tax Credits**
  - Federal Production Tax Credits
  - State tax credits
Net Energy Calculations

- **WIND SPEED**
  - Terrain effects
  - Wind Direction
  - Multiple Heights
  - Hours/years at each wind speed

- **WIND TURbine POWER OUTPUT**
  - Power
  - Adjust for:
    - Hub height
    - Altitude
    - Temperature

- **GROSS ENERGY PRODUCTION @ 100% EFFICIENCY**

- **MISCELLANEOUS**
  - "Off-yaw"
  - Start - Stops
  - High wind cut-outs (gusts)

- **AIRFOIL SOILING**
  - Bugs
  - Dirt

- **ARRAY EFFECTS**
  - Wind Turbine spacing
  - Wind Turbine orientation
  - Wind Turbine characteristics

- **WIND TURBINE DOWNTIME**
  - Utility outages
  - Station outages
  - Wind turbine failure
  - Scheduled maintenance

- **PARASITIC LOSSES**
  - Power handling/conditioning
  - Station energy consumption

- **NET ENERGY**
Future Cost Reductions

- Financing Strategies
- Manufacturing Economy of Scale
- Site Specific Turbine Design
- Technology Improvements
Future Technology Developments

- Offshore
- Drive Train Innovations
- Transportation or construction limitations
- Blade Design Innovations
- Controls
- Improved Design Tools

®Middelgruden.dk
U.S. Offshore Wind Energy Opportunity

DOE Offshore Wind Energy Strategy

R&D Program Phases
- 2012 Near Term (5% of available resource; <30 m depth)
- 2015 Mid Term (25% of available resource; <60 m depth)
- 2020 Long Term (75% of available resource; < 900 m depth)
- Remaining Deep Water Resource (25% of available resource)
- Area for future resource assessment

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<tr>
<th>Depths</th>
<th>Resource Estimates</th>
<th>Exclusion Criteria</th>
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<tr>
<td>&lt;30M</td>
<td>50GW</td>
<td>67%</td>
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<tr>
<td>30-60M</td>
<td>200GW</td>
<td>33-67%</td>
</tr>
<tr>
<td>60-900M</td>
<td>750GW</td>
<td>67%</td>
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New England Offshore Resource

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>
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</thead>
<tbody>
<tr>
<td>2</td>
<td>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</td>
<td>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</td>
<td>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</td>
<td>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</td>
<td>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</td>
<td>Superb</td>
<td>&gt; 800</td>
<td>&gt; 8.8</td>
<td>&gt; 19.7</td>
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</table>

Wind speeds are based on a Weibull k value of 2.0

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Wind Energy Potential by Depth

5 - 50 Nautical Miles Offshore

Potential (GW)

Depth (m)

2012 2015 2020

Wind Energy Potential by Depth
5 - 50 Nautical Miles Offshore

New England
Mid-Atlantic
Great Lakes
California
Pacific Northwest
Wind Energy Potential by Depth
5 - 50 Nautical Miles Offshore

Potential (GW)

Depth (m)

New England
Mid-Atlantic
Great Lakes
California
Pacific Northwest

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Offshore Wind Turbine Development for Deep Water

- Onshore Wind Turbine
- Monopile Foundation: depth 0 – 30 m
- Tripod fixed bottom: depth 20 – 80 m
- Floating Structure: depth 40 – 900 m
GE Wind Energy
3.6 MW Prototype

• Design concept similar to offshore GE 1.5 / 70.5

• Offshore GE 3.6 MW
  104 meter rotor diameter

• Offshore design requirements considered from the outset:
  – Crane system for all components
  – Simplified installation
  – Helicopter platform
Advanced Drivetrain R&D
Future Technology Developments

- Reduced Loads, Lower Costs and Improved Performance
  - Rotors
  - Controls
  - Drive Train/Power Electronics
  - Towers
Technology Challenges: Blade scaling for multi-megawatt designs onshore & offshore

Scaling of Rotors

Finite Element Computer Model

Commercial Blade Data

Modeling Results - $R^{2.9}$

Commercial Blades - $R^{2.35}$
• Wind field = U(y,z,t)

• Steady wind shear superimposed

• Rotational sampling effect increases effective wind fluctuations

Dynamic Loading Environment
Future Key Research Areas

- Developing offshore deep water resources
- Integrating wind into utility grid
- Opening federal lands to renewable energy production
- Using wind and hydropower to produce hydrogen and clean water.
Current 45-Meter Fatigue Test

- Testing is facility limited – blade extends out of building 40-ft.
- Damping higher than expected. Wind was a factor.
- Test stand load capacity is at maximum.
- Building may be too narrow for two axis testing.
- Stop-gap solutions are underway.
- Long term solutions have been planned by DOE but funding is uncertain.

Nov.24.2004

Single-axis Flap Fatigue Test Using B-REX Test System.

45-meter Blade Root Mount
controls