North American Wind Energy Academy Meeting – an Industry Perspective

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&
Co-chair AWEA R&D Committee
A Story of Technology - 1989

1989 Tour de France (23 days, 2,025 mi)

Greg Lemond
- Underdog
- 50 sec behind entering last day

Last Day Time Trial – 15.2 mi
- Consensus – best could pick up was 25 sec
- Finished in 26min 50 sec – Avg 34 mph!!!
- Gained 58 sec, won tour by 8 sec

The Rest of the Story - Technology
- Aero bars – up to 60 sec
- Aero helmet – up to 15 sec
What a Difference a Decade Makes!!!

Growth Enabled by . . .
. . . Technology
. . . Research and development
. . . Innovation
. . . Engineers

U.S. Wind Projects Installations

46,916 MW
Total Wind Installations

35%
5-yr avg annual growth

GE Renewables ...

World’s most efficient & reliable wind turbine fleet

- 27GW+ installed ... ~18k WTGs in 22 countries
- 98%+ availability
- Energy capture ↑50%
GE products ... customer value through technology

1.6-100

- Swept Area: +47% (vs 1.6-82.5)
- AEP: +19% (@ 7.5 m/s)
- GCF: 53% (@ 7.5 m/s)

2.85-103

- Swept Area: +6% (vs 2.5-100)
- AEP: +9% (@ 8.5 m/s)
- Low Noise Trailing Edge
Technology Drives Wind Performance

 Units >> 1,000th  5,000th  10,000th  18,000th  21,000th

Model Introduction

- 1.5i
- 2.5s
- 2.5xl
- 1.6
- 1.5sle
- 1.5xle
- 1.6
- 1.6-82.5
- 1.6-100
- 1.6-87
- 2.75
- 2.75-100
- 2.75-103
- 2.53
- 2.53-120

Technology Drives Wind Performance

- ’96 ’02 ’03 ’04 ’05 ’06 ’07 ’08 ’09 ’10 ’11 ’12 ’13

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<th>’02</th>
<th>’11</th>
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<tr>
<td>AEP (GWh/yr)*</td>
<td>6.0</td>
<td>11.6</td>
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<td>Availability (%)</td>
<td>85</td>
<td>98</td>
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(* @8.5m/s AMWS)

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Technology Brings Value to Customer

Based on GE 1.x Wind products

AEP Energy Output (GWhrs)

U.S. homes powered per turbine

+47% swept area

 Avg Capacity Ratio (%)
Sources of Technology, R&D, Innovation

- Universities
- National Labs
- Department of Energy
- Industry
Validation by Test and Learn – a Must for any Engineer

Shaft

Pitch Bearing

Bedplate

Gearbox
Key US Validation Facilities

NREL (CO) – drive train & blade test

MA Clean Energy Center – Blade Testing

Clemson (SC) – Drive train test

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AWEA R&D Committee - Technology Needed . . . 3 yrs . . . 5 yrs

Component Technology
- Adv drivetrains
- Adv blades – aero & mechanical
- Adv manufacturing
- Adv towers

Grid Integration
- Flexibility, intermittency
- Weather forecasting
- Wind farm operation

Transmission Capacity

Siting Issues – understanding & solutions
- Wildlife interactions
- Radar interactions

Small Wind Technology
- Materials, components, manufacturing
- Certification

Offshore Wind
- Unique technical challenges –
- Siting & permitting with government agencies
- Early demonstrations

Technical Workforce for Tomorrow
- Engineers
- Technicians

Reduce Cost of Electricity & Address Siting Constraints or Barriers

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Technologies Needed ... 3 yrs ... 5 yrs
Wake interactions ... extending Wind performance

Turbine centric view

- Design
  - Design as standalone unit
- Micrositing
  - Optimize layout for max AEP/min COE
- Due Diligence
  - Turbine Suitability Analysis, Mechanical Loads analysis
- Operation
  - Operate as independent units in wind farm

Farm level approach

- Design for op. in wind farm
- Very large farms Terrain interaction Farm interactions
- Remove excess margins
- Cooperative operation, park level control

Adv. prediction capabilities
Learning from data
New technology developments
Technologies Needed ... 3 yrs ... 5 yrs

Tools ... innovate by understanding the physics

Global
(1Mm)

Regional
(100km)

Retaining physics through boundary interfaces

Today:
Mesoscale


Source: NOAA Aviation Weather Center (http://aviationweather.gov/dive/ads/winds/)

Mesoscale

Turbine
(100m)

Linear modeling
CFD (RANS)
DES/LES
Multi-physics
• Actuator disk
• Vortex models

Blade
(1m)

BEM
Modal
Vortex models
Multi-body
FSI

BEM
Vortex models
CFD (RANS)
DES/LES
FSI
Technology

... R&D

... Innovation

... Engineers

- Key to getting here
- Key to going forward
Thank You