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The Role of Technology in the Future of Wind Energy

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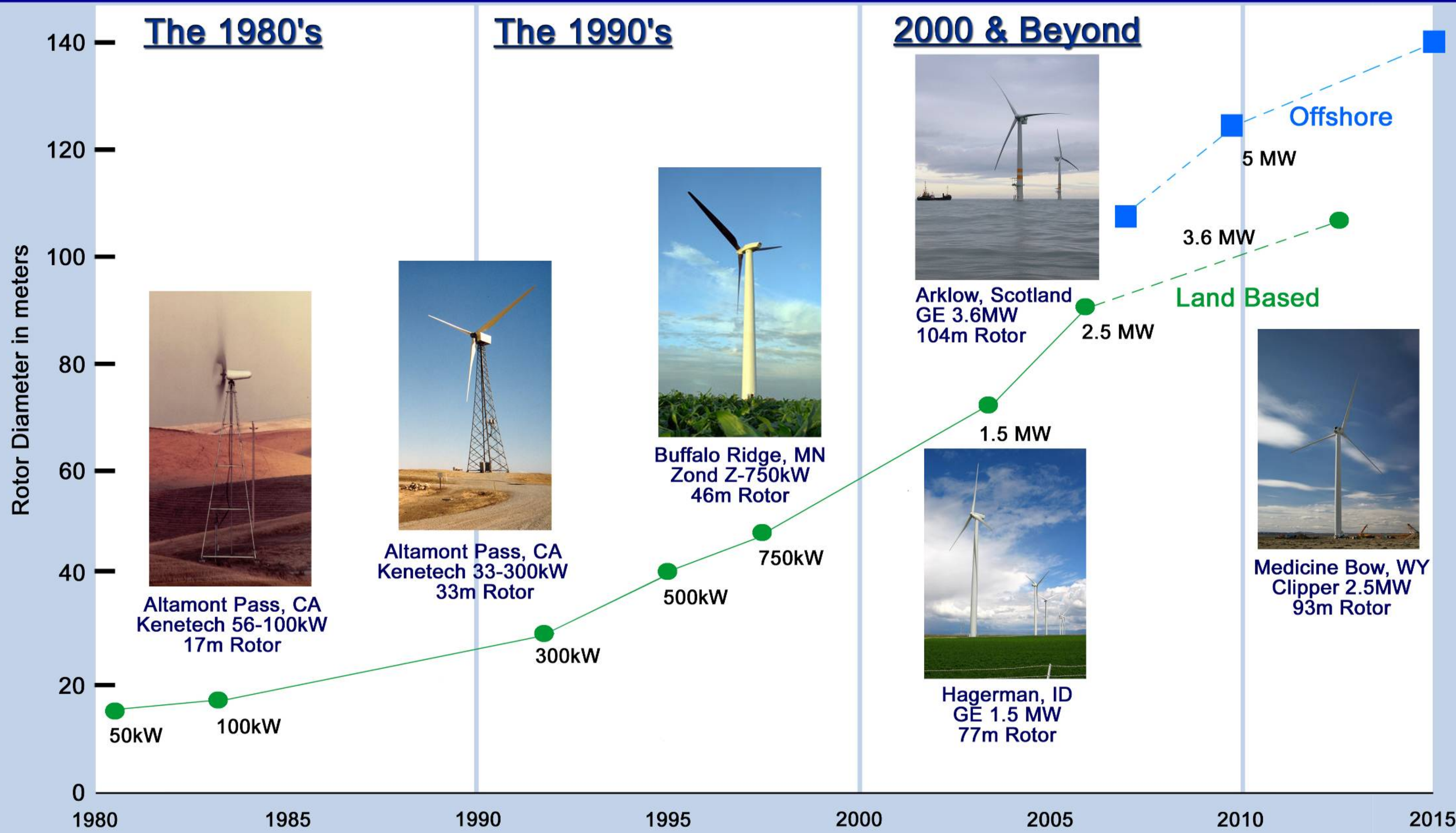
Outline

- Wind Turbine Evolution
- Wind Energy Basics
- The Role of Technology
  - Capacity Factor
  - Capital Cost
  - Operations &Maintenance
- Summary

Evolution of U.S. Commercial Wind Technology



The Change from Small Machines to Large Multi-Mega-Watt Machines

- **Above**: Tehachapi, CA – 65kW, 900kW, and 3MW machines
- **Left**: Palm Springs, CA – field of 65kW with four lager machines in foreground (~750kW)

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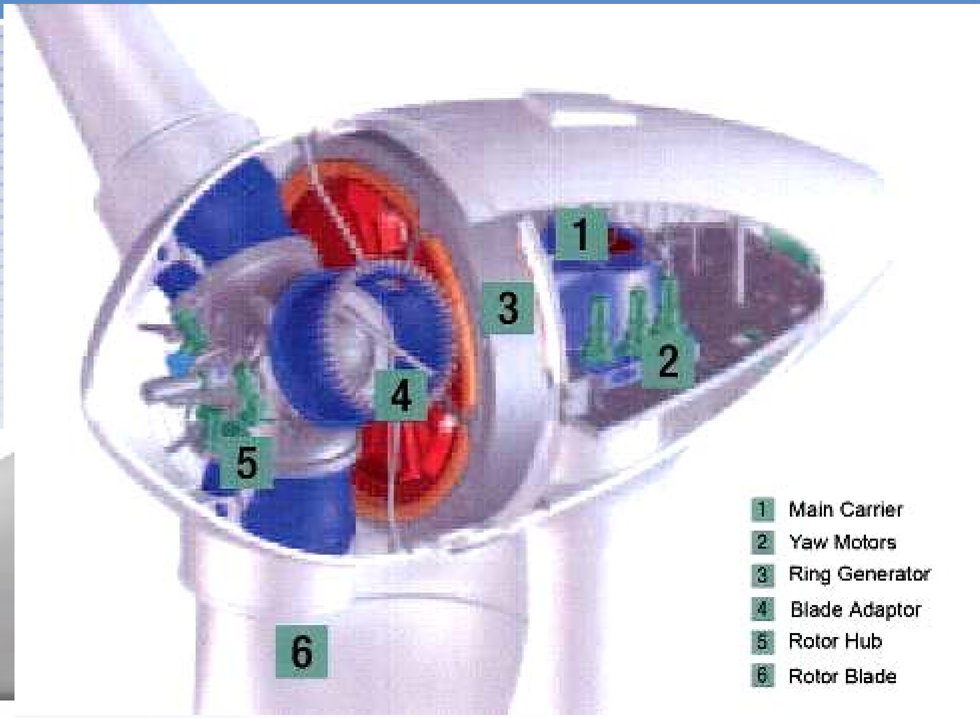
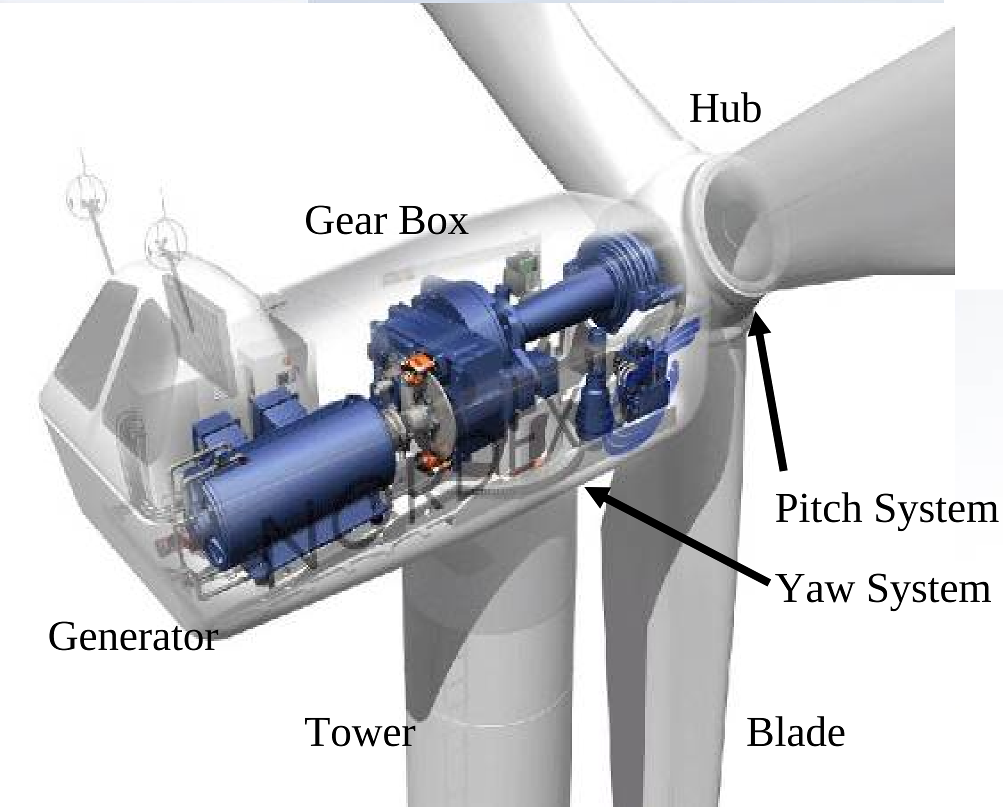
GE 1.5 MW machines in Fort Sumner, NM and Bonus (Siemens) 2.0 MW machines in Copenhagen Harbor

Current Wind Turbine Systems

Direct Drive System



Conventional Drive Train



Clipper Drive Train

Wind Power Basics

Air Density → ρ, **Rotor Area** → A, **Wind Speed** → V_∞

$$WindPower = \frac{1}{2}\rho A C_P V_\infty^3$$

Wind Power output is proportional to wind speed cubed.

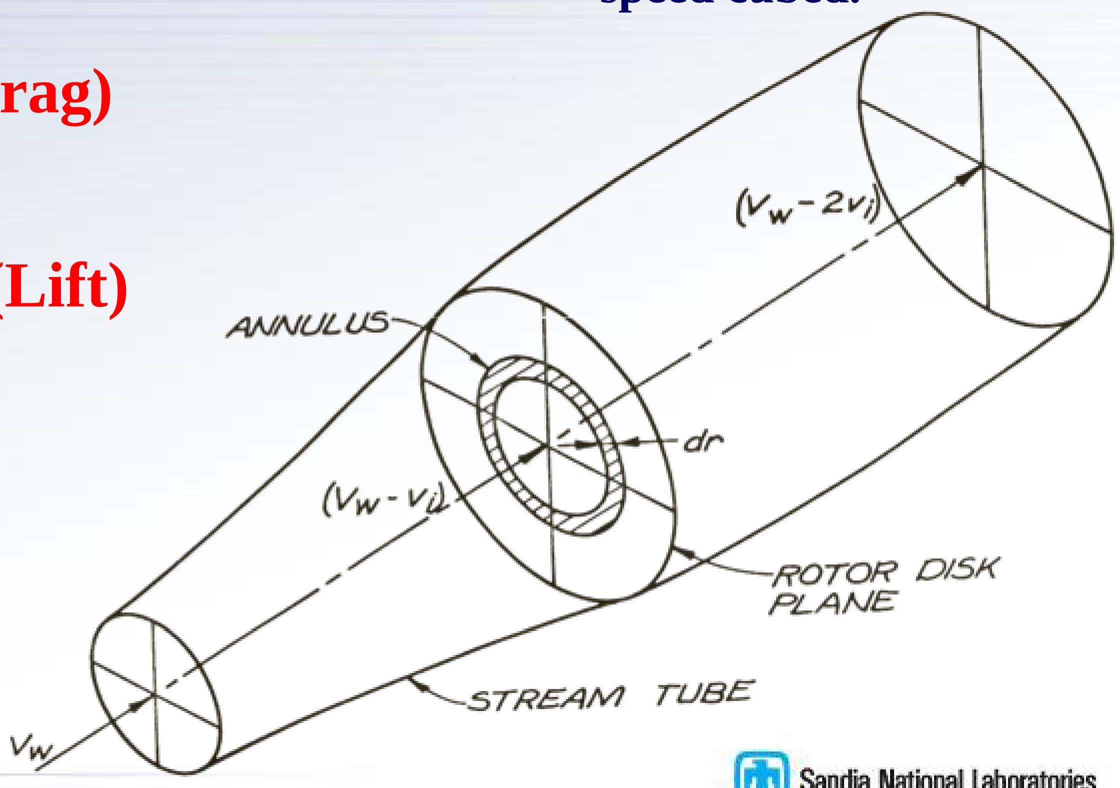
$$C_{P\max} \cong 0.3 \text{ (Drag)}$$

$$C_{P\max} \cong 0.59 \text{ (Lift)}$$

The Betz Limit

$$V_i = \frac{1}{3} V_w$$

$$P = \frac{16}{27}\left(\frac{1}{2}\rho A V_w^3\right)$$



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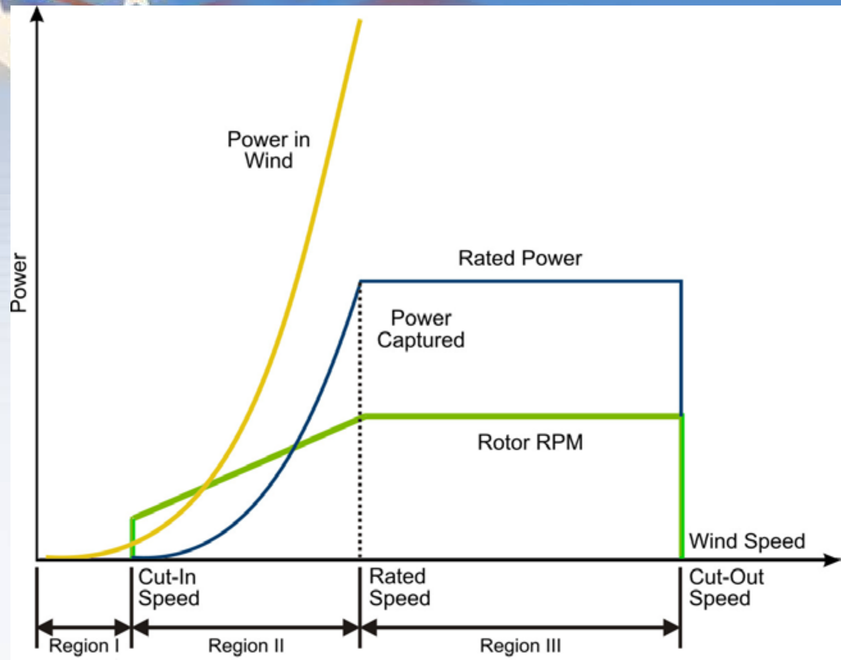
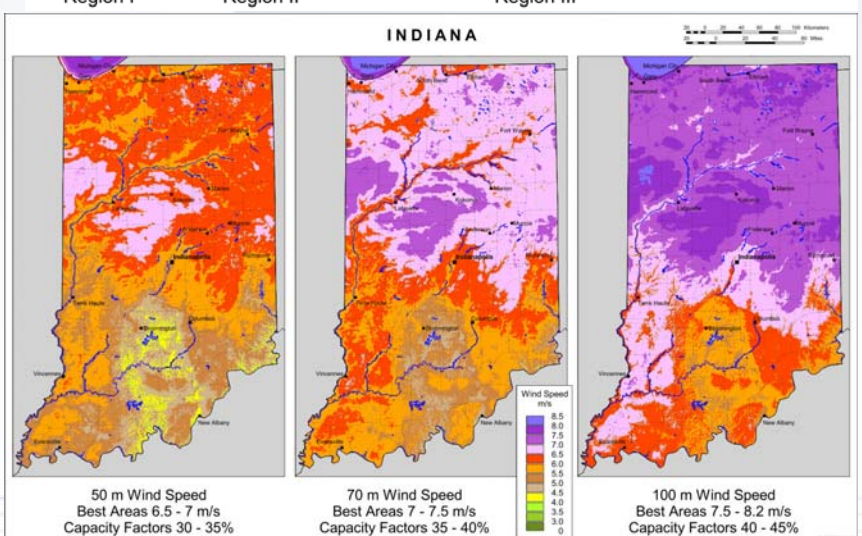
The Physics of the Power Curve Drives Technology Development



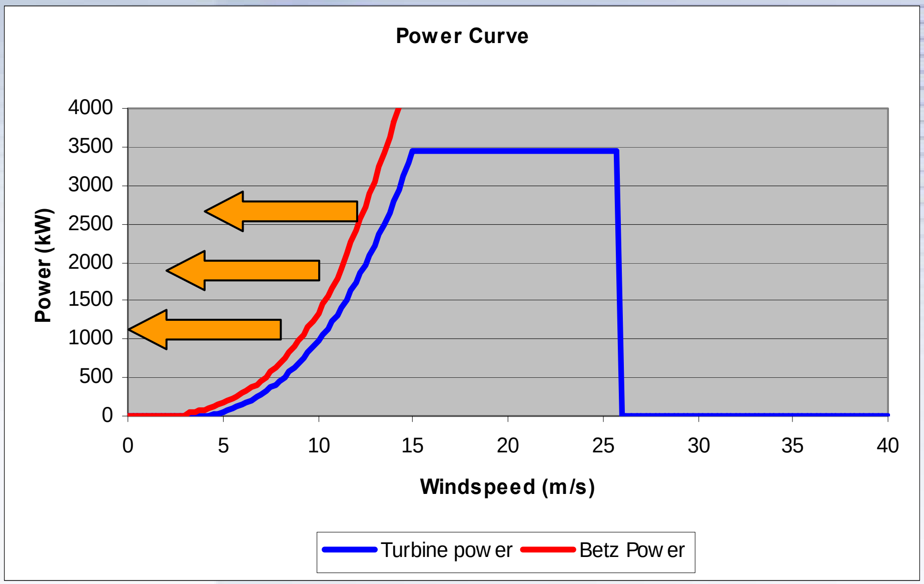


Facts about Wind Technology

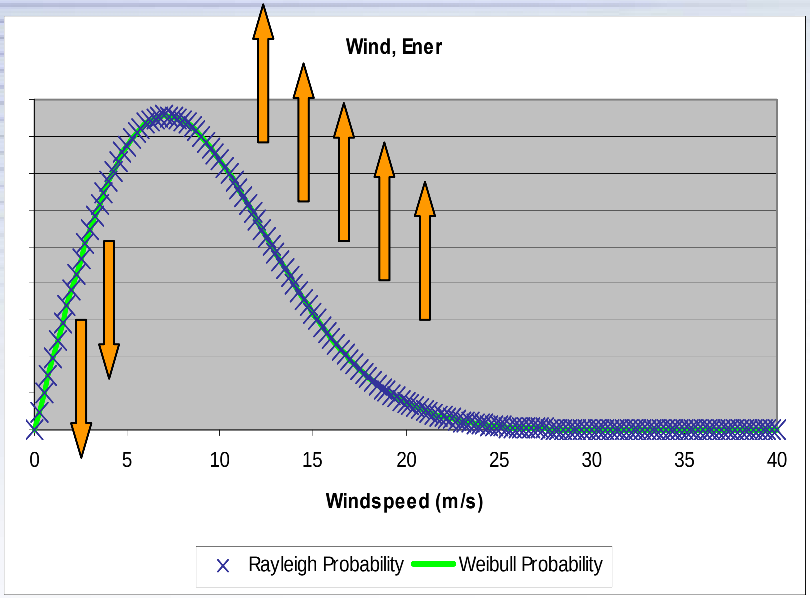
- Power in the wind is proportional to wind speed cubed
- At best, we can capture 59% (the Betz limit)
- "Rated Power" governs the size and cost of the entire turbine infrastructure
- Energy is power multiplied by the amount of time spent at that power level
- Capacity Factor is the ratio of total output to what would have been generated if always operating at Rated Power – Meaningful metric
- Wind shear puts higher winds at greater elevation

Performance Enhancement Options

Power



Resource



Larger Rotor

Rotor *costs* increase with diameter *cubed,* Rotor *power* grows with the diameter *squared*

Taller Tower

Tower costs increase with height to the *fourth* power

We can only win this battle if we build rotors that are smarter and components that are lighter to beat the squared-cubed law.

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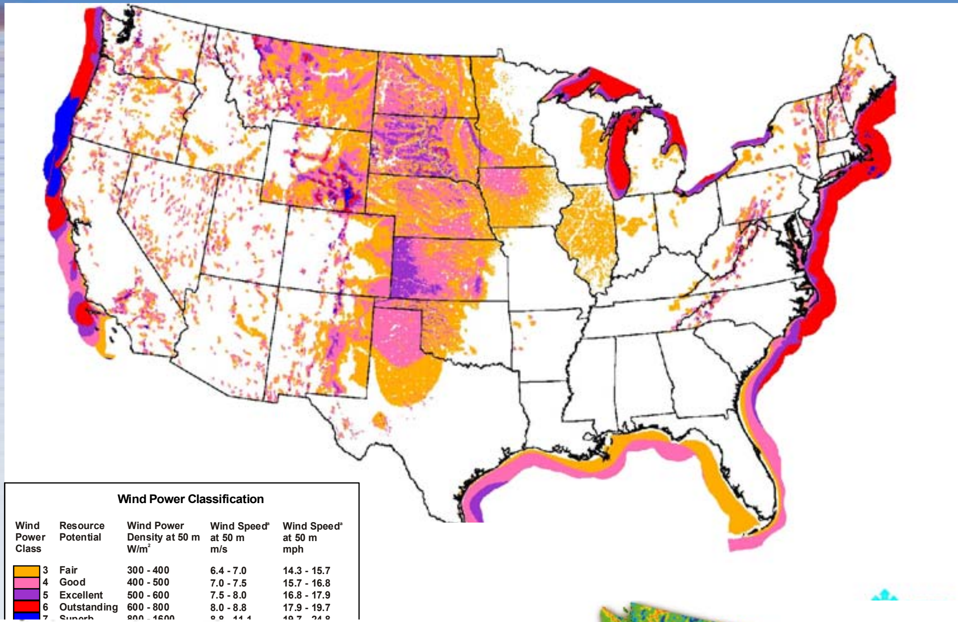
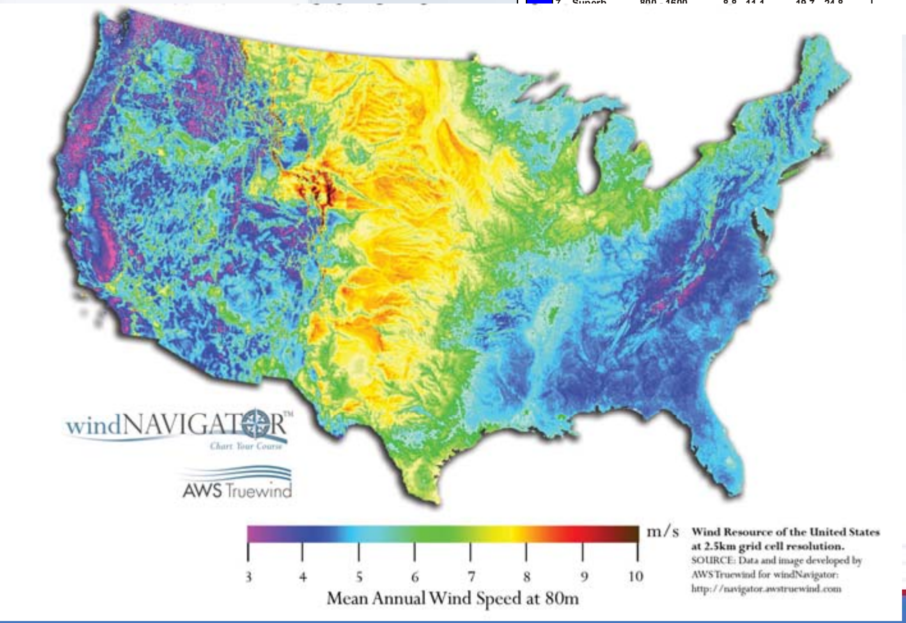
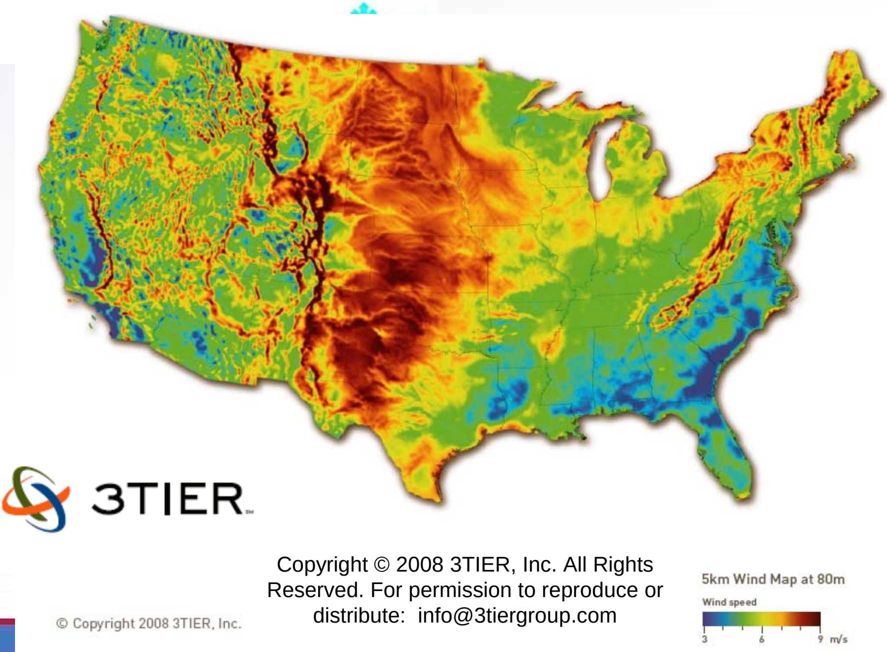
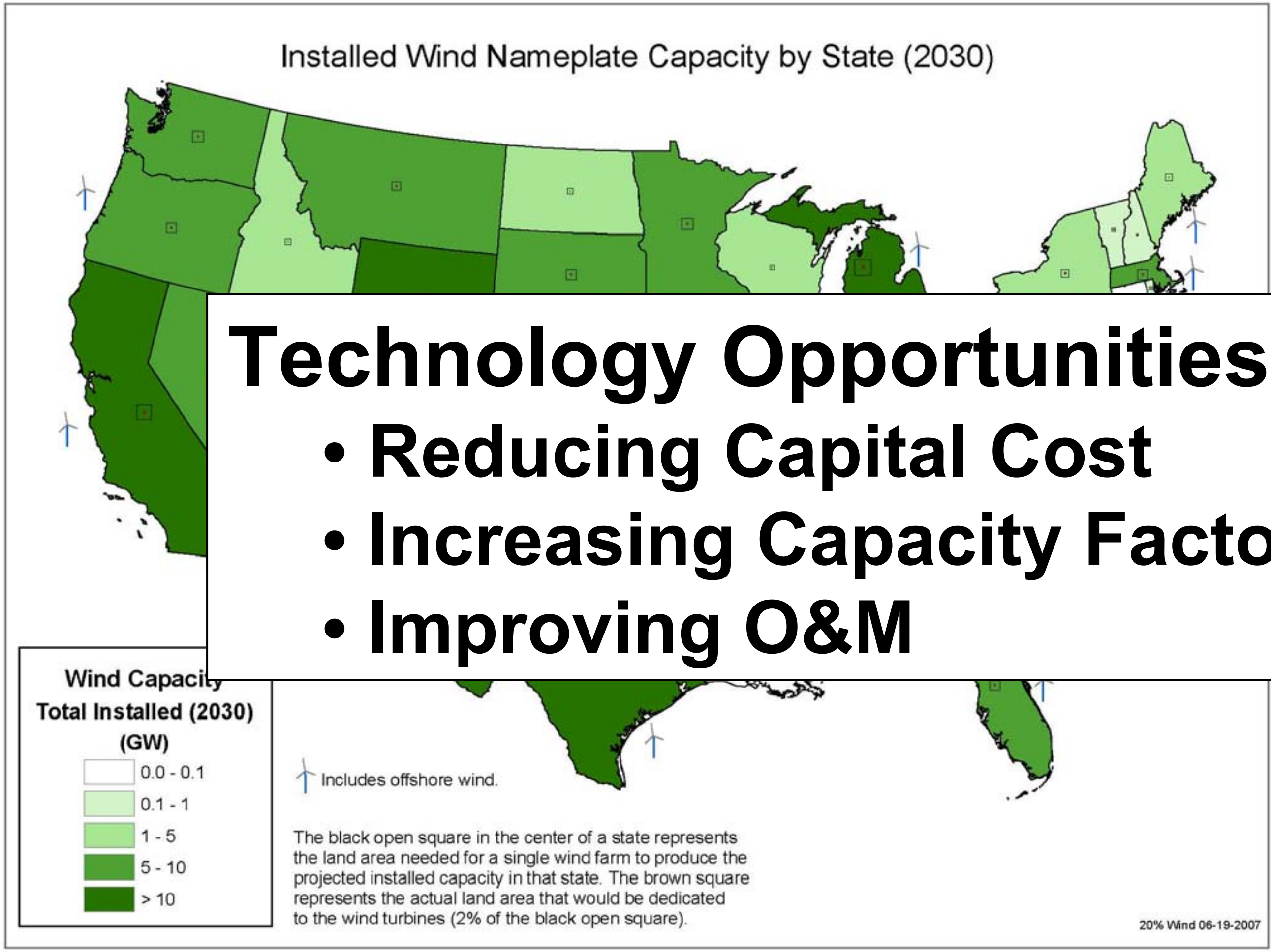
U.S. Wind Resource Maps







Challenges & Opportunities for Technology (20% Scenario)



- Massive growth in installations
  - ~16.8 GW in 2007
  - over 300GW in 2030

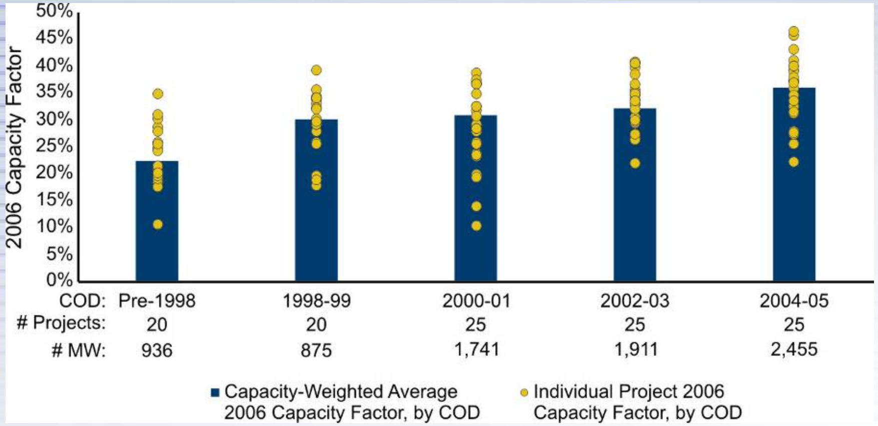
Technology Opportunities and Needs:

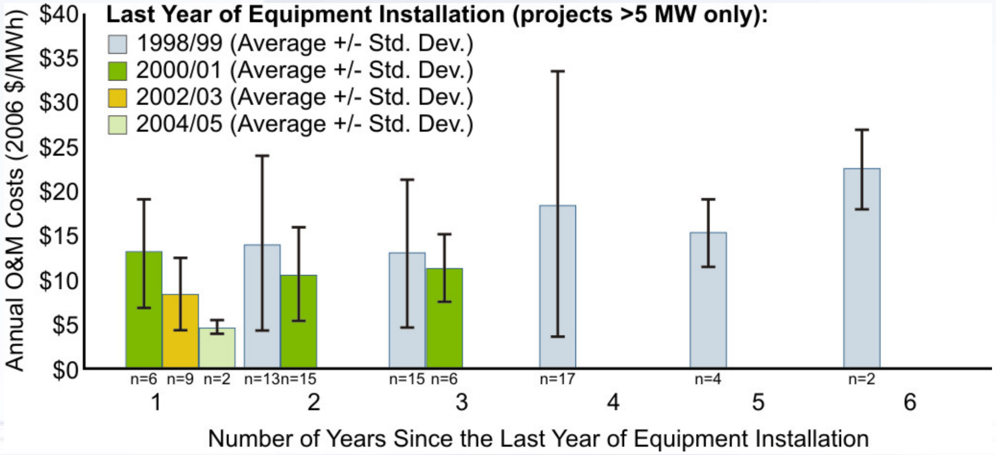
- Reducing Capital Cost
- Increasing Capacity Factors
- Improving O&M

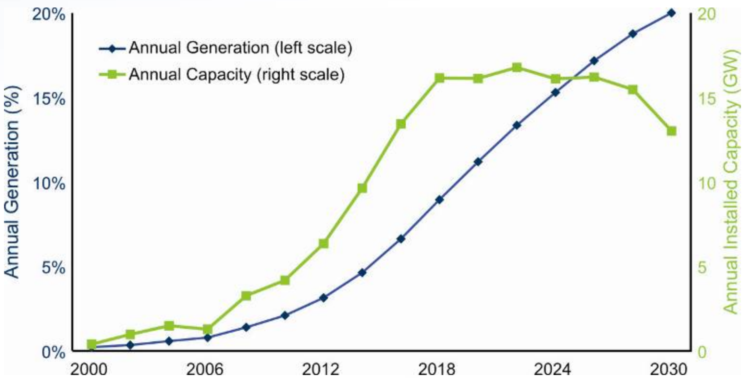
- Performance is critical
  - Capital cost
  - Capacity Factor
  - O&M

Critical Elements for Scenario Planning

- **Improved Performance**
  - **10% reduction in capital cost**
  - **15% increase in capacity factor**
  - **Net result: 1.3-2.2 cents/KWh**
- **Mitigate Risk**
  - **Reduce O&M costs by 35%**
  - **Foster the confidence to support continued 20% per year growth in installation rates from now until 2018**







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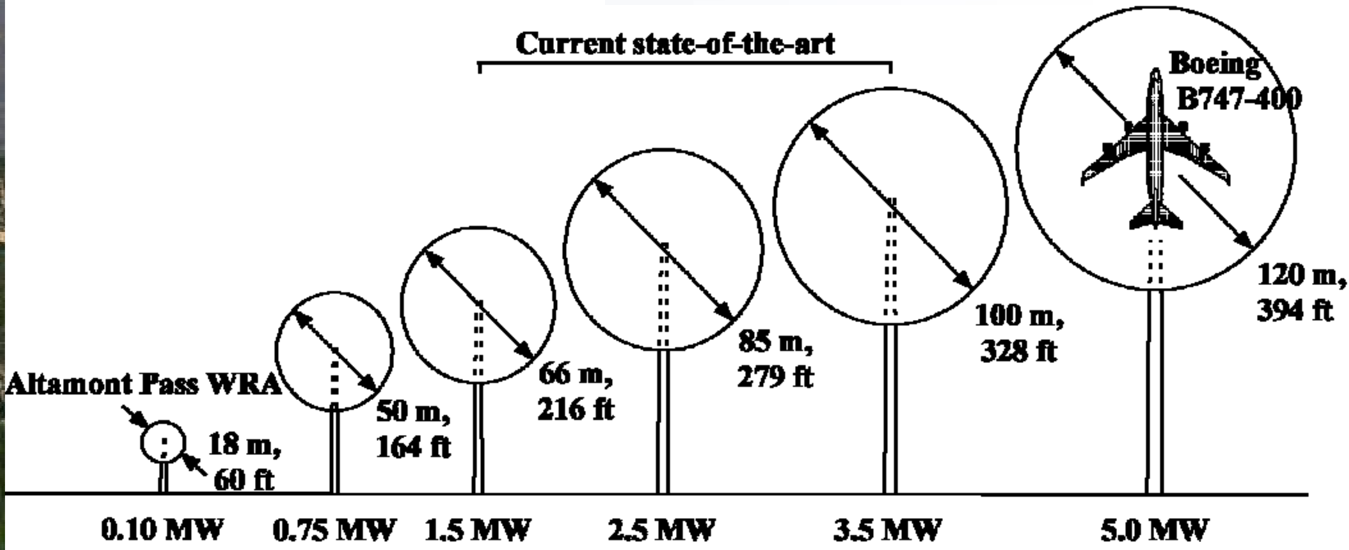
Wind Industry Trends & Challenges

- Costs (traditional)
  - System ~ $3/lb
  - Blades ~ $6/lb
  - ~ $1.00/Watt (2002)
  - $0.04-$0.06/kWh (2002)
- Recent cost of steel & copper increases have increased cost by 30 - 50%
- Currency exchange rate
- Limited Manufacturers & Suppliers

•High-end Military ~ $1000/lb
•Aerospace Industry ~ $100/lb

2008: ~$1.6 – $2.0/Watt

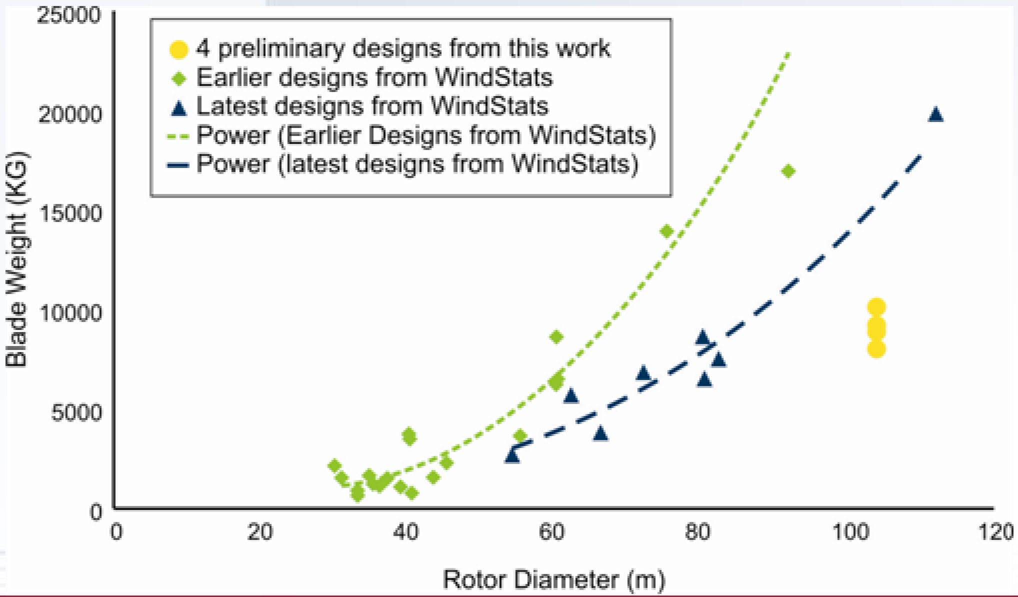
- Size
  - 1.5-5.0 MW
  - Towers: 65-100 meters
  - Blades: 34-50 meters
  - Weight: 150-500 tons

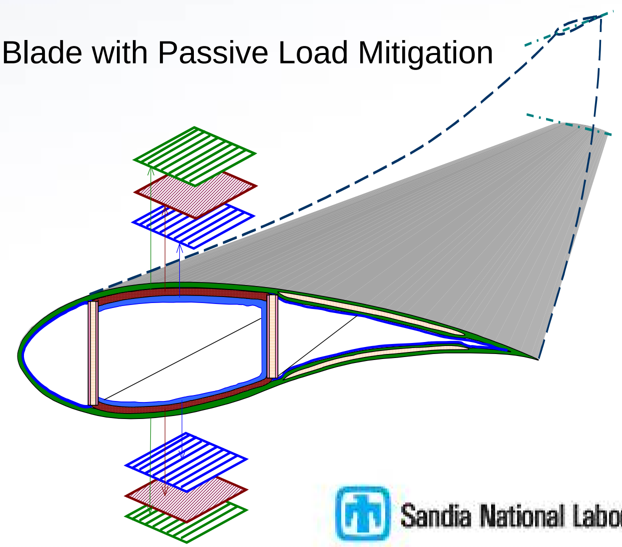


Improved Performance Capacity Factor

- **Larger Rotors**: to sweep greater area
  - Longer and lighter blades (new materials and designs)
  - Load-mitigating control (passive and active)
- **Taller Towers**: to access greater resource
  - Lower tower-head mass (lighter components)
  - Innovations in towers, foundations, erection and maintenance access
- **Reduced Losses**: to deliver what is generated
  - Power electronics, gearboxes, generators, medium-voltage, etc.
  - Arrays, wakes, and siting issues

Knight & Carver "STAR" Rotor





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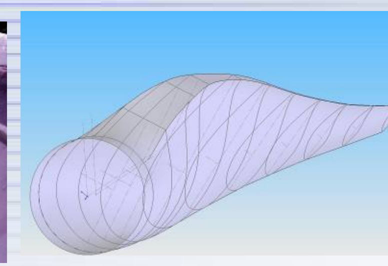
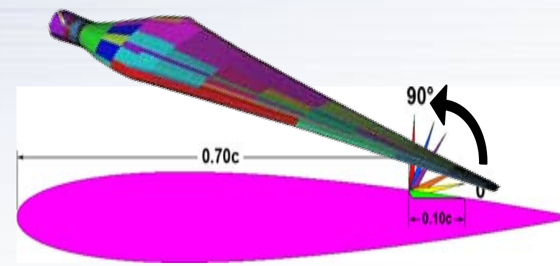
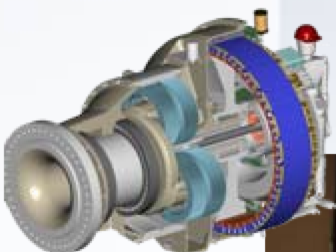
Technology Improvement Options

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





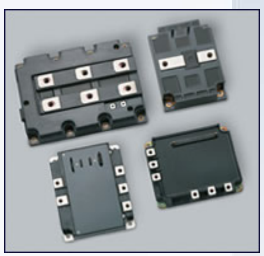
- **Power Train Enhancements**
  - **Permanent Magnet Direct Drive Architectures**
  - **Split load path multi-stage generation topologies**
  - **Reduced stage (1-2) integrated gearbox designs**
  - **Convoloid gearing for load distribution**

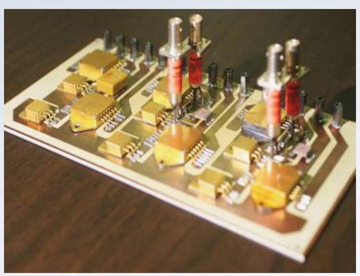


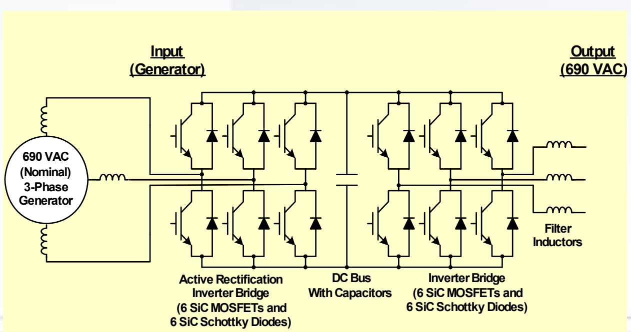
Technology Improvement Options

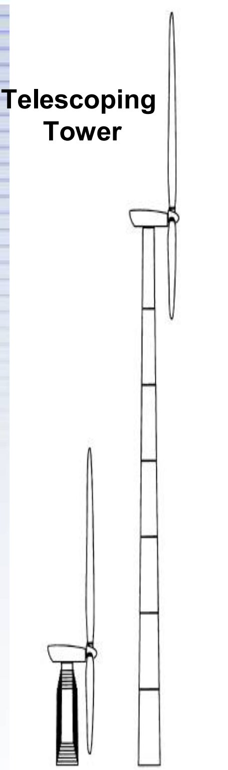
Power Conversion

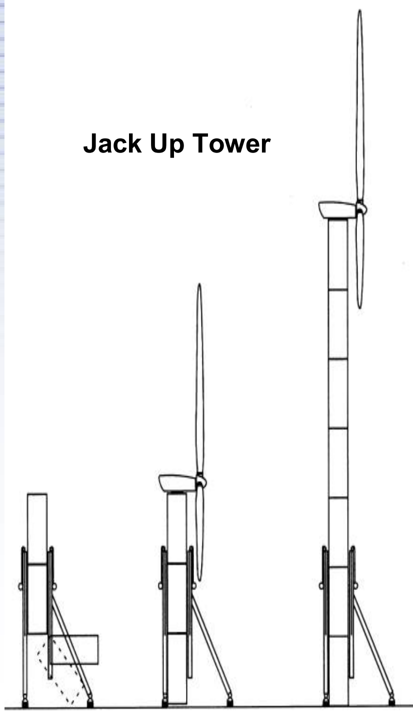
- High temperature silicon carbide device; improved reliability & reduce hardware volume
- Novel circuit topologies for high voltage & power quality improvement
- Medium voltage designs for multi-megawatt architectures









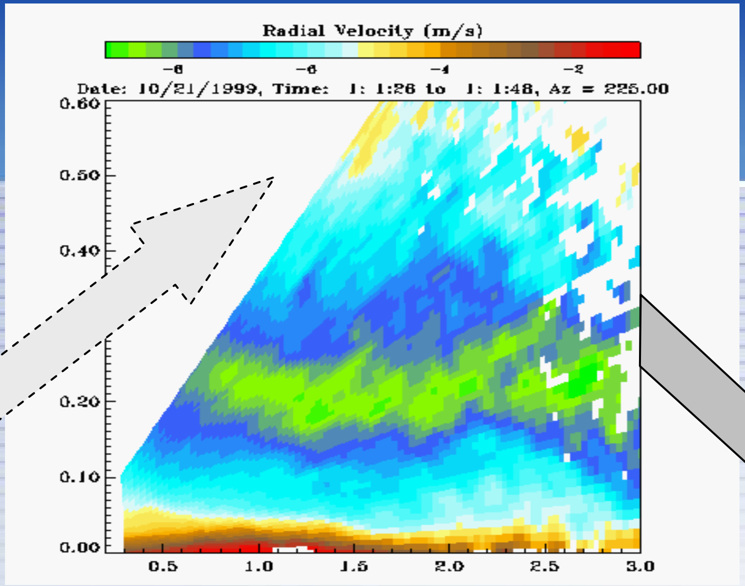


Tower Support Structures

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

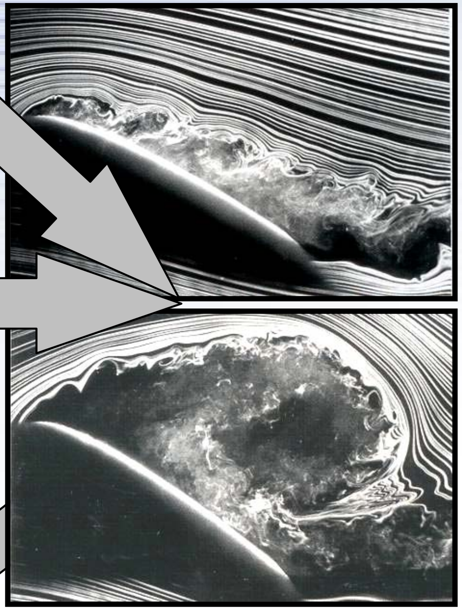
Powerful winds

U_∞, direction vary
Coherent turbulence
Turbine wakes



Energetic flow-field

Globally separated
Steep gradients
Dynamically active

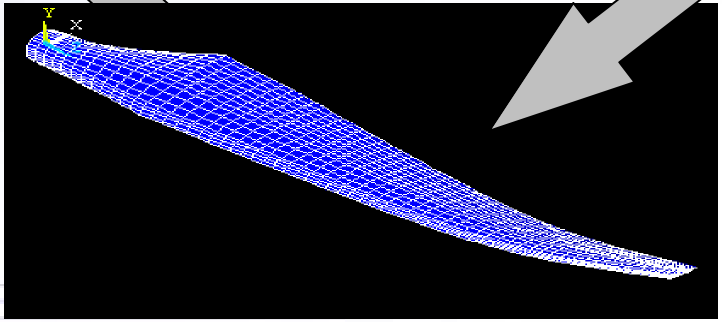


Basic R&D Needs:

Aeroelasticity
Nonlinear & coupled
Multiple physics
Multiple Scales

Complex wake

Trailed vortices
Shed vortices
Persistent



Responsive structure

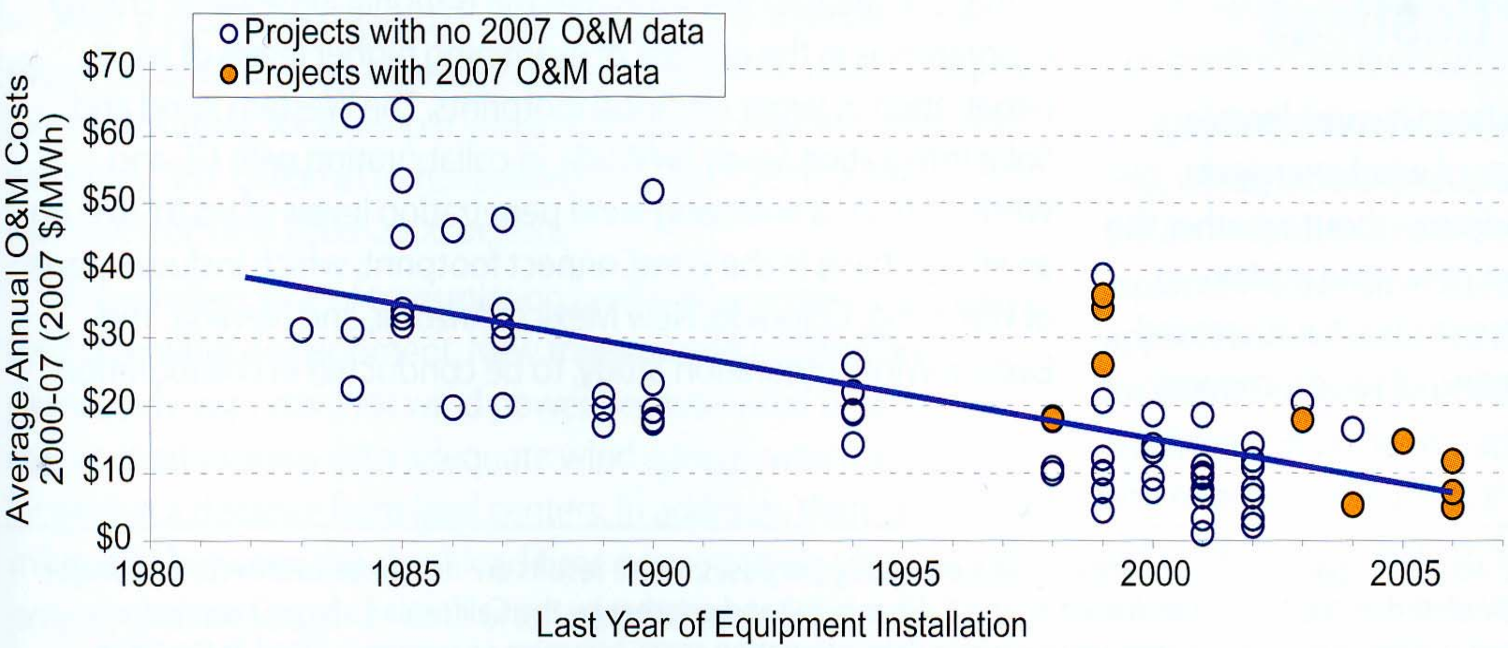
Light and flexible
Advanced materials
Aeroelastic load control

Reductions in Capital Cost

- **Learning Curve Effects**
  - **Measures cost reduction in each doubling of capacity**
    - Greater Efficiency & New Technology
  - **Historical rates were about 9% per doubling**
  - **4.6 doublings from 2006 to 2030.**
  - **A 10% reduction – 2.2% per doubling**
- **Opportunities – Design, Manufacturing, & Transportation**
  - **Lighter – less material, advanced materials**
  - **More automation**
  - **Design for manufacturability**
  - **Segmented Blades - ??**

Addressing O&M Costs

- Operating wind plants require continuous monitoring and care
- The DOE 20% by 2030 report targets O&M costs of about $5/MWh
- Costs have historically risen to about $20/MWh
- Better equipment and improved operations will be required



Source: Berkeley Lab database; five data points suppressed to protect confidentiality.

Figure 28. Average O&M Costs for Available Data Years from 2000-2007, by Last Year of Equipment Installation

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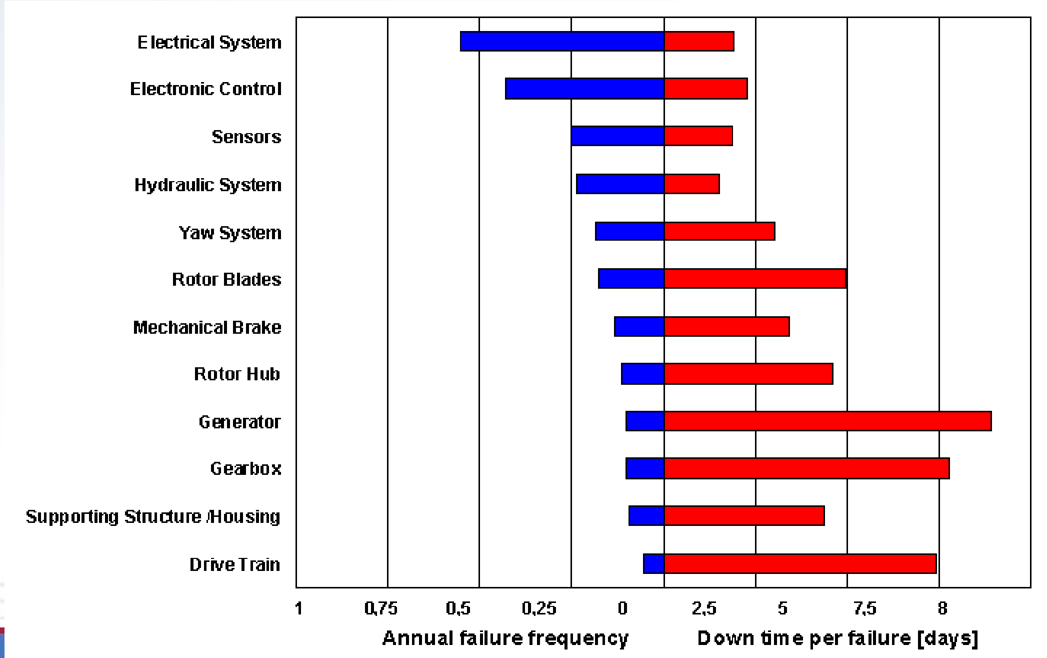
Initiatives to Mitigate Risk

- **Avoid Problems before they get Installed**
  - Full Scale Testing
  - Appropriate design criteria (specifications and standards)
  - Validated design evaluation tools
- **Monitor Performance**
  - "Tracking, tracking, tracking"
  - Maintain reliability tracking database
  - Define the problems before they get out of hand
- **Problem Resolution Initiatives**
  - Targeted activities in to address critical issues
  - Example: Gearbox Collaborative

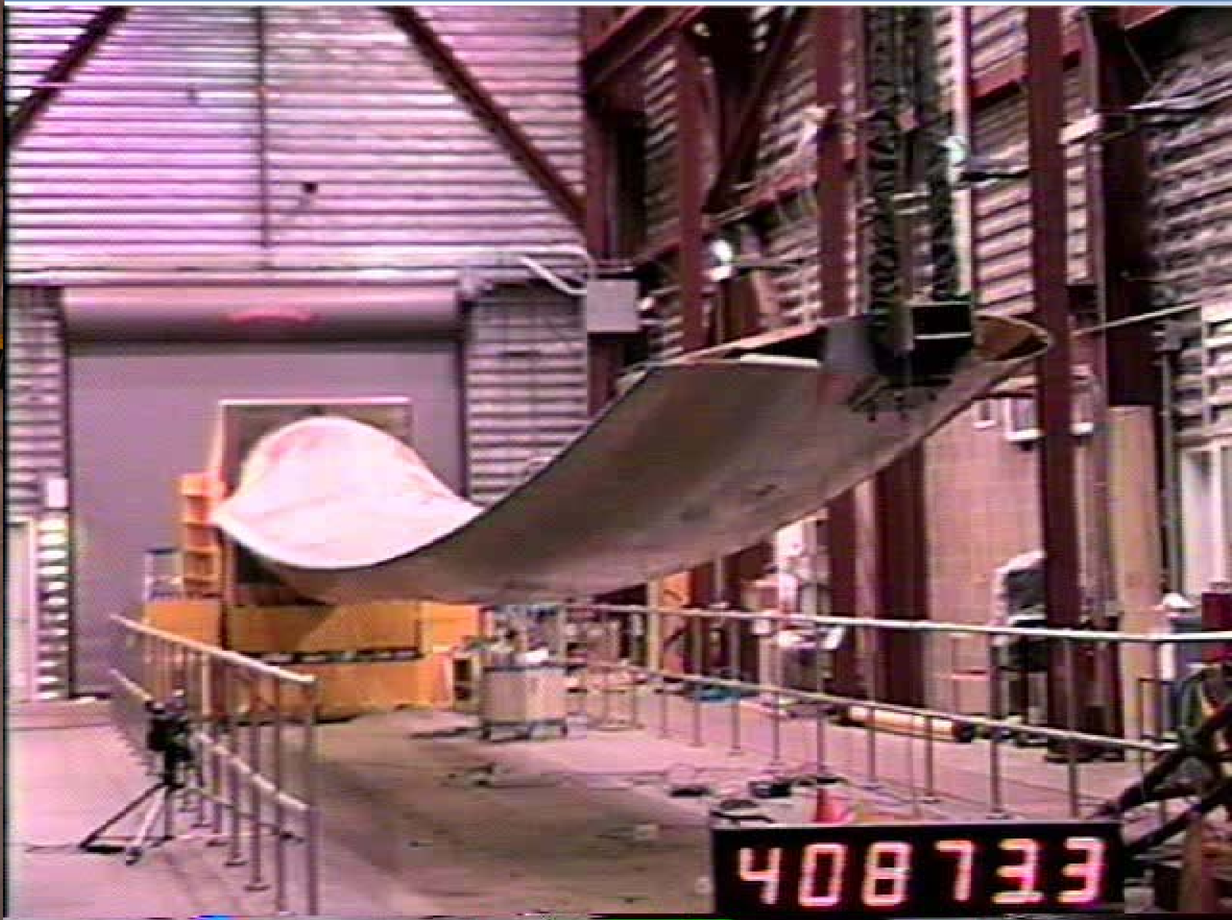
Photo by Lee Jay Fingersh



Testing Innovative Wind Industry Blades Designs

Structural Test of Knight and Carver Blade

Test preparation of a swept blade providing twist-flap coupling for gust load reduction



Ultimate Strength Testing of a new Blade Design

Technology Improvement Summary

Subsystem	Description	Increased Energy	Capital Cost
Towers	Taller with new materials/self erecting	+11/+11/+11	+8/+12/+20
Rotors	Lighter & larger with smart structures	+35/+25/+10	-6/-3/+3
Site Energy	Improved reliability – less losses	+7/+5/0	0/0/0
Drive Train	Innovative designs – high reliability	+8/+4/0	-11/-6/+1
Manufacturing	Process evolution and automation	0/0/0	-27/-13/-3
Totals		+61/+45/+21	-36/-10/+21

20% Report, Table 2-1, page 41 (working from 2002 baseline)

Thank You!

DOE/NREL NASA Ames Test

Courtesy of LM Glassfiber