20% Wind Energy – Chapter 2

Wind Turbine Technology

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Many, many co-authors, contributors, editors and reviewers

Outline of the Technology Chapter

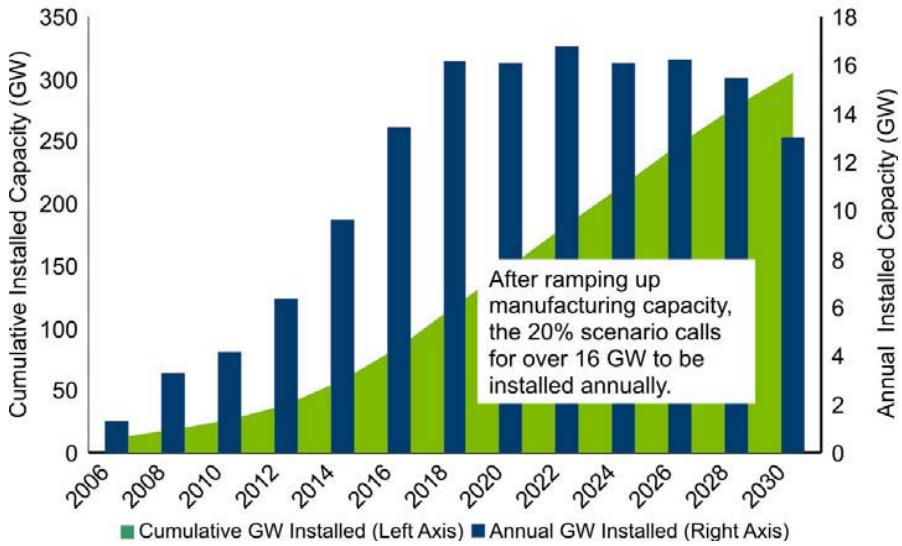
Energy Efficiency & Renewable Energy

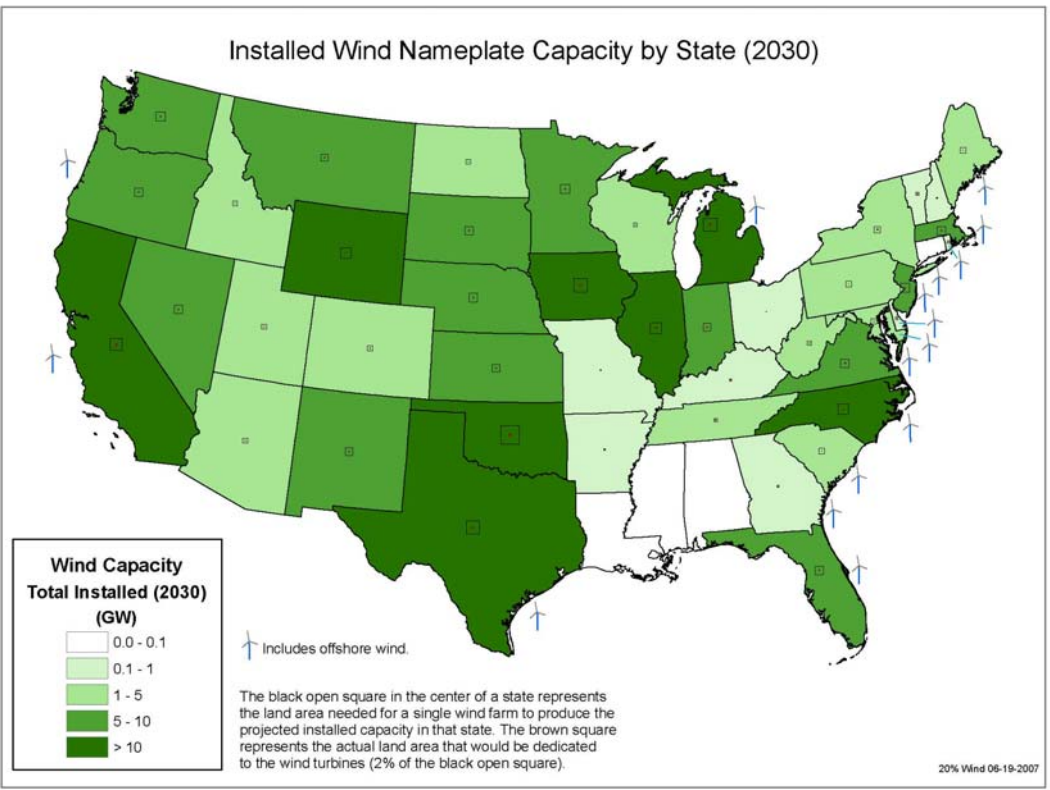
1. Introduction
2. Today's Technology
3. Technology Improvements on the Horizon
4. Addressing Technical & Financial Risks
5. Offshore Technology
6. Distributed Wind Technology
7. Summary of Technology Development Needs
   - *Mitigate the Risk of Large-Scale Deployment*
   - *Foster the Introduction of Technology Improvements*

Focus of issues for meeting the 20% wind scenario

Actions







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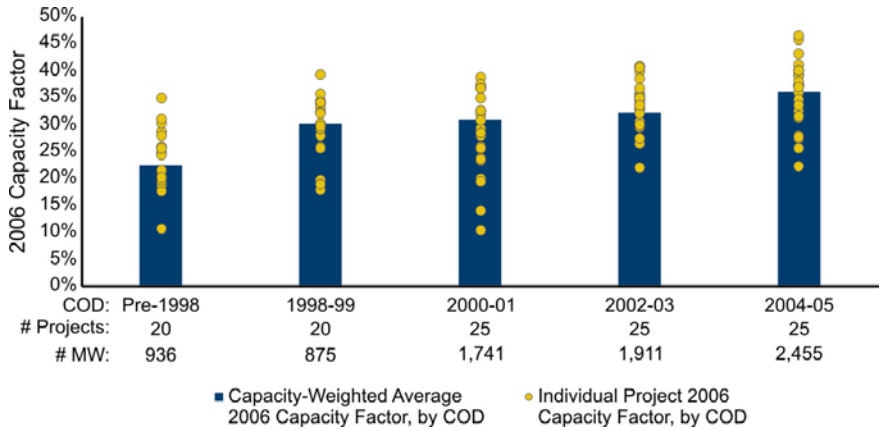
Challenges for Technology from the Analysis Results

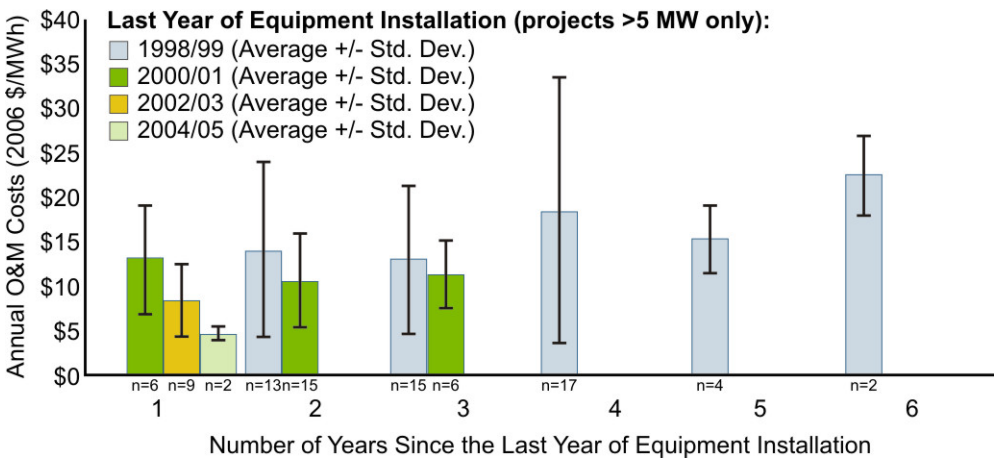
- Massive growth in installations
  - ~12GW in 2006
  - over 300GW in 2030
- Widely distributed across the nation
  - Many high wind sites
  - Substantial installation in moderate resource areas
  - Some offshore is needed
- Performance is critical
  - Capital cost
  - Capacity Factor
  - O&M
- ***Every 1 ¢/kWh of cost reduction saves the nation over $10 billion per year at 20% penetration***

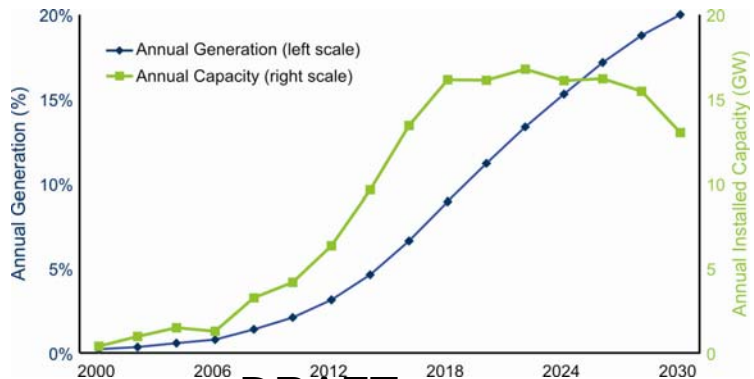
Critical Elements for Scenario Planning

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- Improved Performance
  - 10% reduction in capital cost
  - 15% increase in capacity factor
- 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



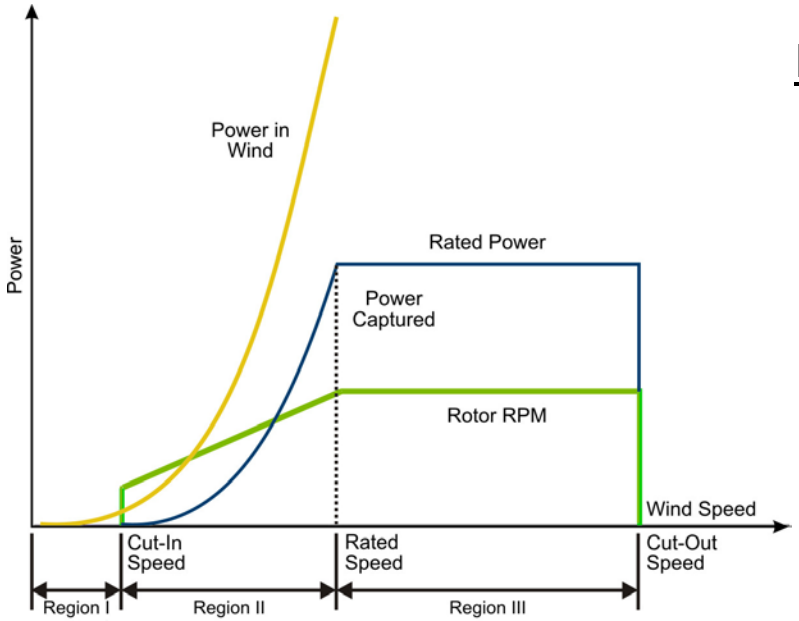


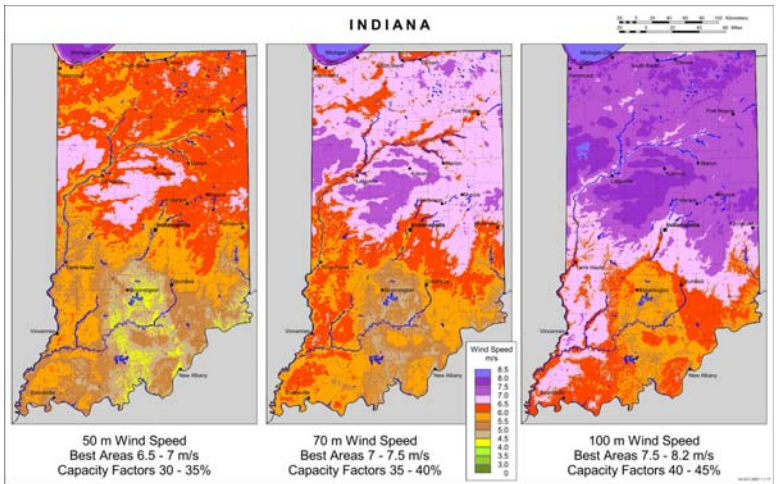


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The Physics of the Power Curve Drives Technology Development

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Motherhood and Apple-Pie Truths about Wind

- 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

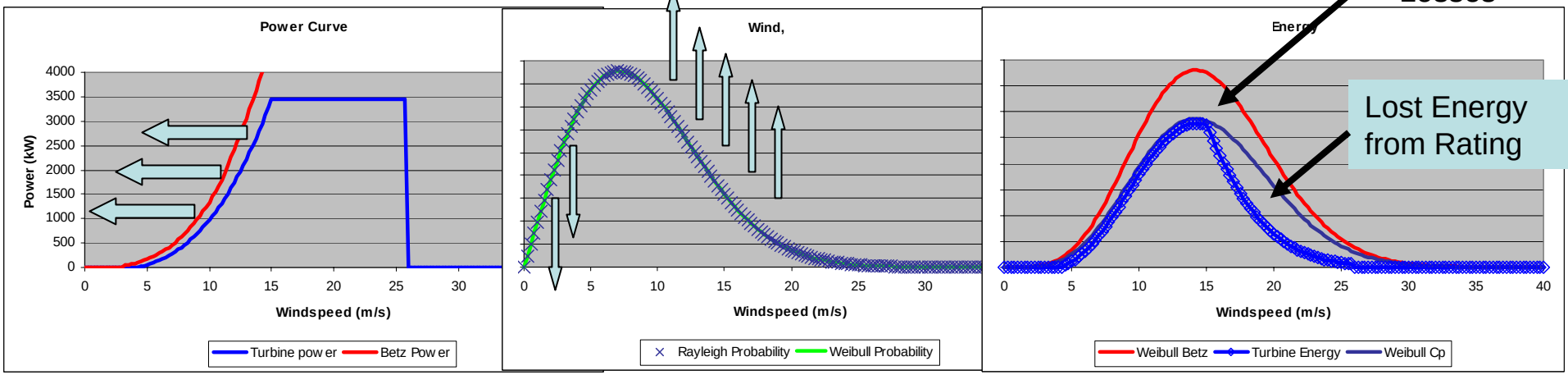
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Power

Resource

Energy

Imperfect Conversion Losses



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

Greater Output

The cost benefits are constrained by the *squared-cubed* law

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

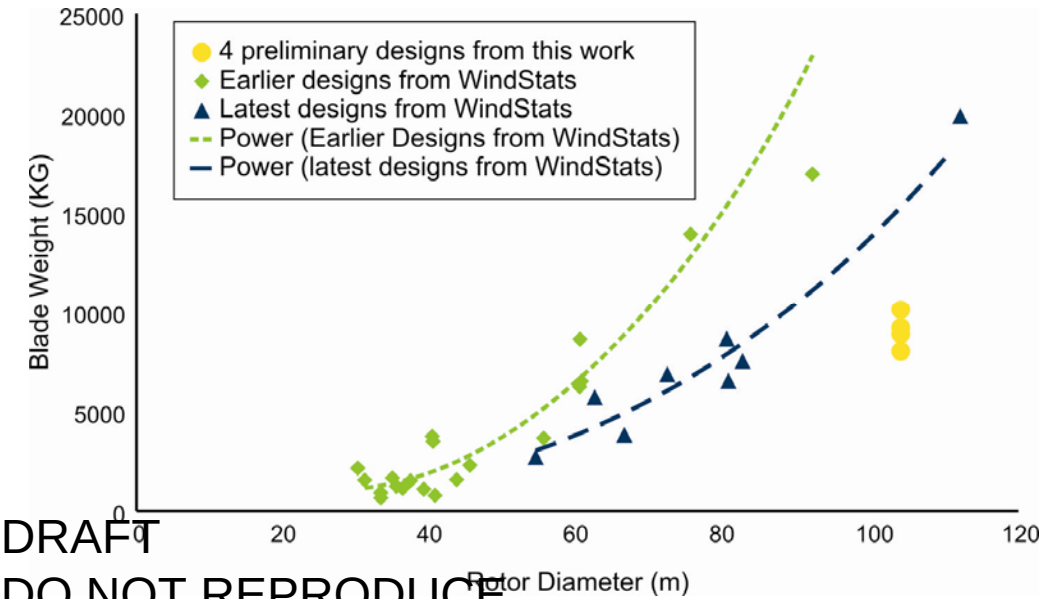
Improved Performance Capacity Factor (15%)

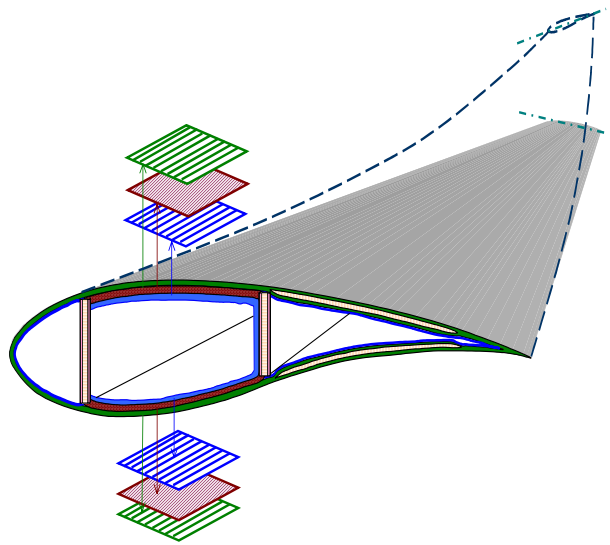
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- Larger Rotors: to sweep greater area
  - Longer and lighter blades (new materials and designs)
  - Load-mitigating control (passive and active)
- Taller Towers: to access greater resource
  - Lower tower-head mass (lighter components)
  - Innovations 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



Clipper's innovative drive train





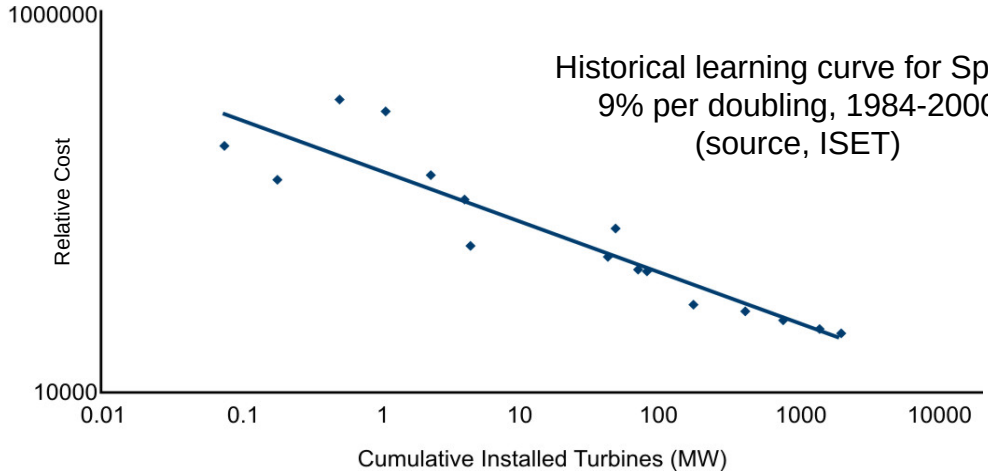
Blade with Passive Load Mitigation

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Reduced Capital Cost (10%)

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Courtesy TPI Composites



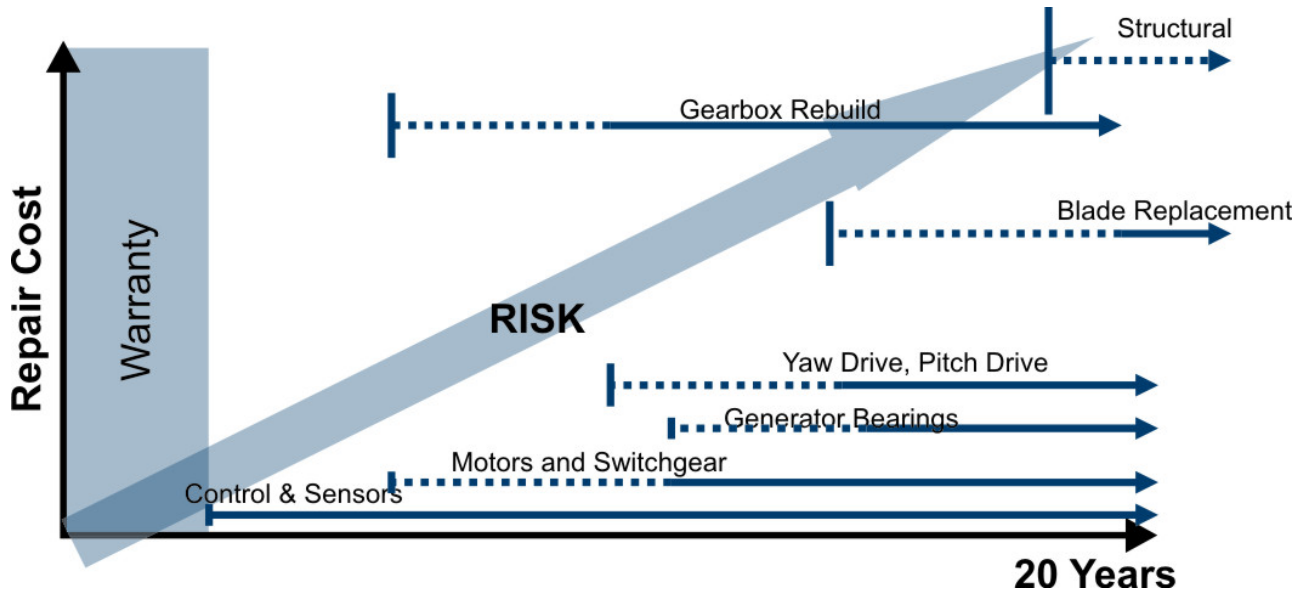
Historical learning curve for Spain, 9% per doubling, 1984-2000 (source, ISET)

- 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% total cost reduction – 2.2% per doubling
- Opportunities
  - Lighter – less material, advanced materials
  - More automation
  - Design for manufacturability

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Risks to continued large-scale deployment

- Direct impacts – Poor performance
  - Energy payments – lost revenue
  - O&M costs – above expectations
  - Component failure – early replacement
- Indirect impacts – Loss of confidence
  - Cost of financing and insurance
  - Slowing development
  - Loss of public support (drives policies)





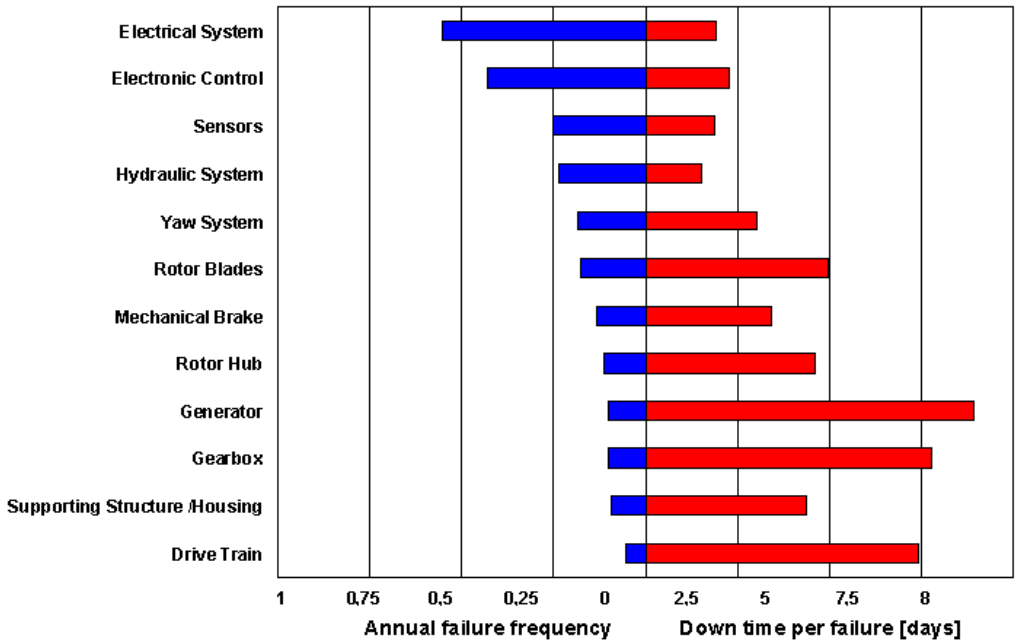
Initiatives to Mitigate Risk

- 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 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



Offshore

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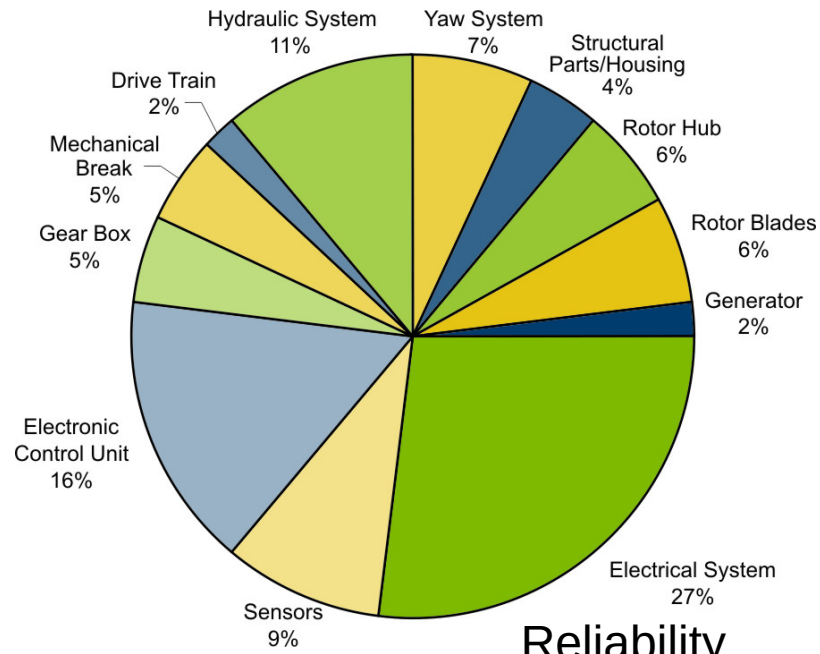
- Short-Term R&D Needs
  - Define Exclusion Zones
  - Certification and Standards
  - Design Codes, Tools, Methods
  - Siting and Array Configurations
  - Hybrid Wind-Wave Databases
- Long-Term R&D Needs
  - Minimization of Work at Sea
  - Enhanced Manufacturing and Deployment
  - Service and Accessibility
  - Foundations, Anchors, and Moorings
  - Resource Modeling and Remote Sensing
  - Offshore Turbine Reliability
  - Ultra-large Turbines



Distributed Wind Energy

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- Innovation Opportunities
  - Incorporating technology from large machines
  - Acoustic Emissions
  - Improved Reliability
  - Optimized Aerodynamics
  - Towers and Foundations



Reliability issues span the entire system







Summary:
Critical Issues to Meet 20%

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Mitigate the Risk of Large-Scale Deployment

1. Reducing the innovation risk of commercializing technology by public-private sector cost sharing of technology development and demonstration.
2. Building and equipping the next generation full-scale test facilities
3. Supporting effective certification standards that promote performance and operational excellence
4. Establishing a national program to monitor and archive the U.S. fleet reliability, including system performance and plant operations and maintenance
5. Establishing a national facility for offshore wind technology

Foster the Introduction of Technology Improvements

1. Targeting RD&D initiatives including towers, blades, controls, drive trains and power electronics.
2. Increasing the capacity factor by placing larger rotors on taller towers with lighter components and load-mitigating rotors
3. Reducing the capital cost with steady learning curve improvements driven by innovative manufacturing improvements
4. Creating a wind speed and atmospheric environments database to define opportunities for increased resource with greater hub height and offshore.
5. Accelerating offshore wind technology RD&D programs

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