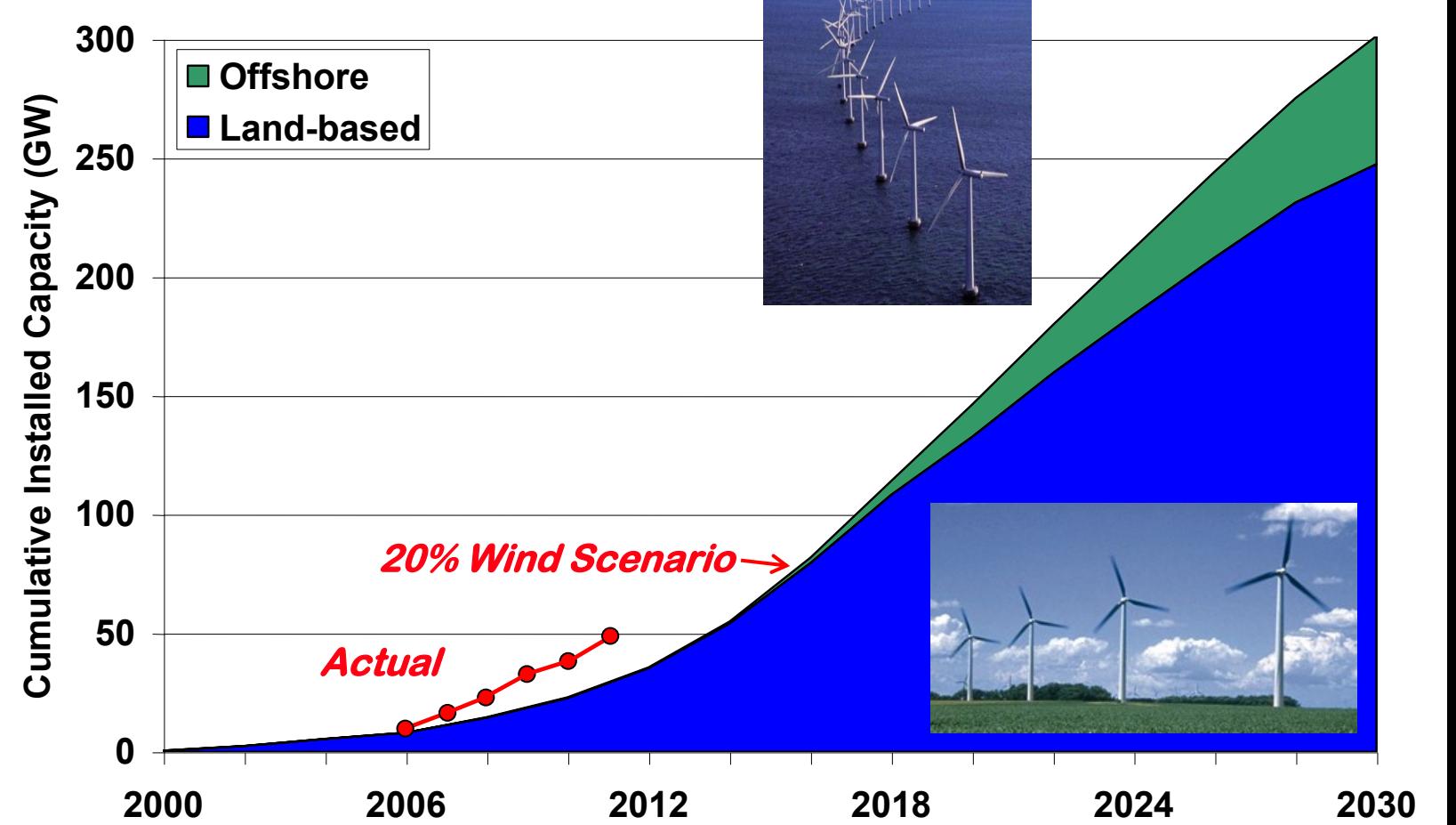


### Wind Potential

- Wind deployment experienced remarkable growth in past few years
- Current capacity above the curve for 20% wind by 2030 scenario



- Tremendous wind potential in the U.S.
- Wind provides the lowest-cost source of new renewable power
- With good resource and a PTC, wind can be the lowest cost source of power

### Turbines are Complex Machines

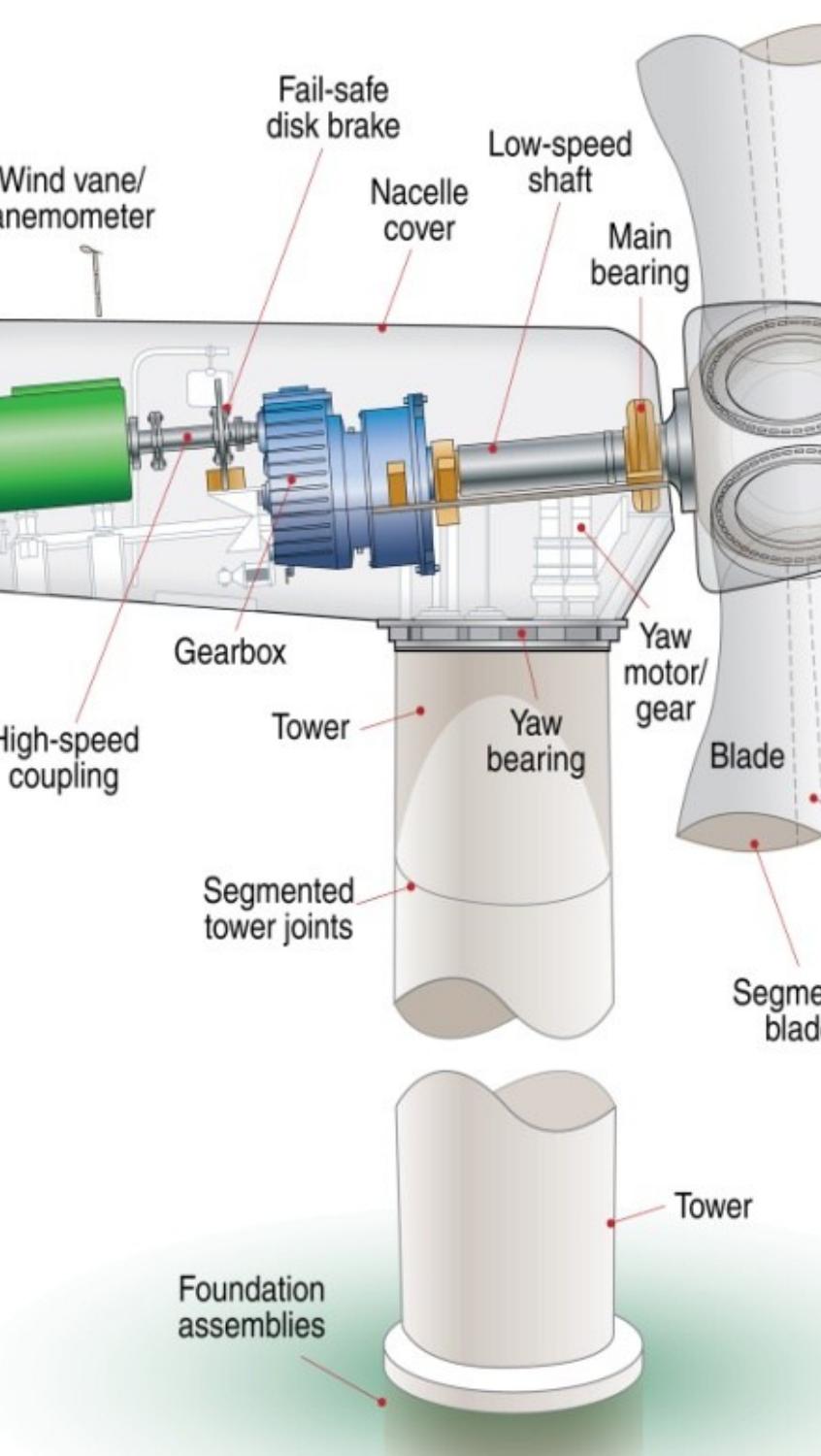


#### Average Land-based Machine

- Power Rating: 1.5 – 2 MW
- Tower Height: 80 – 90 meters
- Nacelle Mass: 50 – 00 tons
- Blade Length: 34 – 45 meters
- Blade Weight: 6 – 10 tons

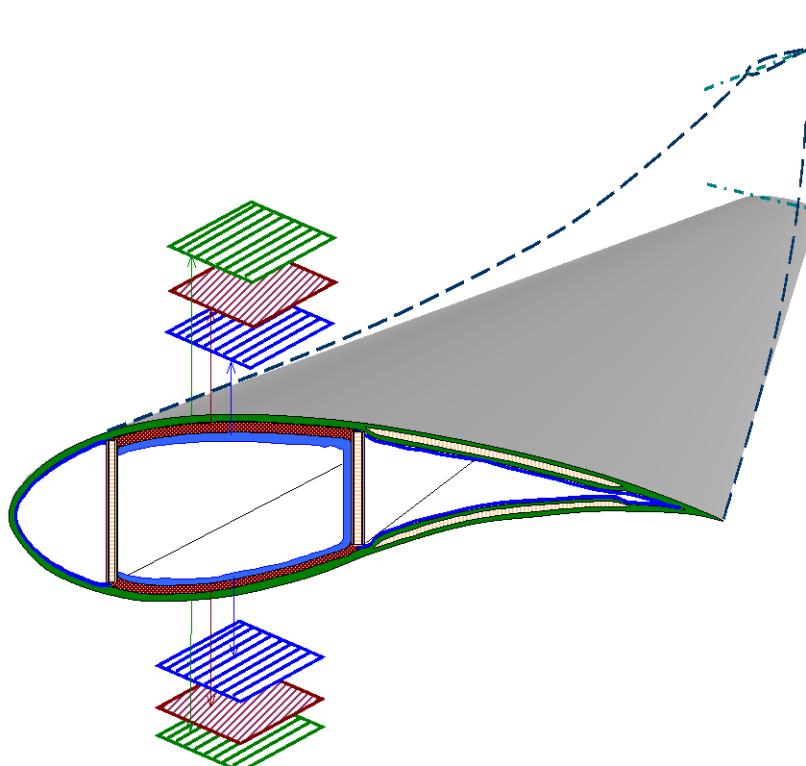
#### Typical Sensors on Commercial Turbines

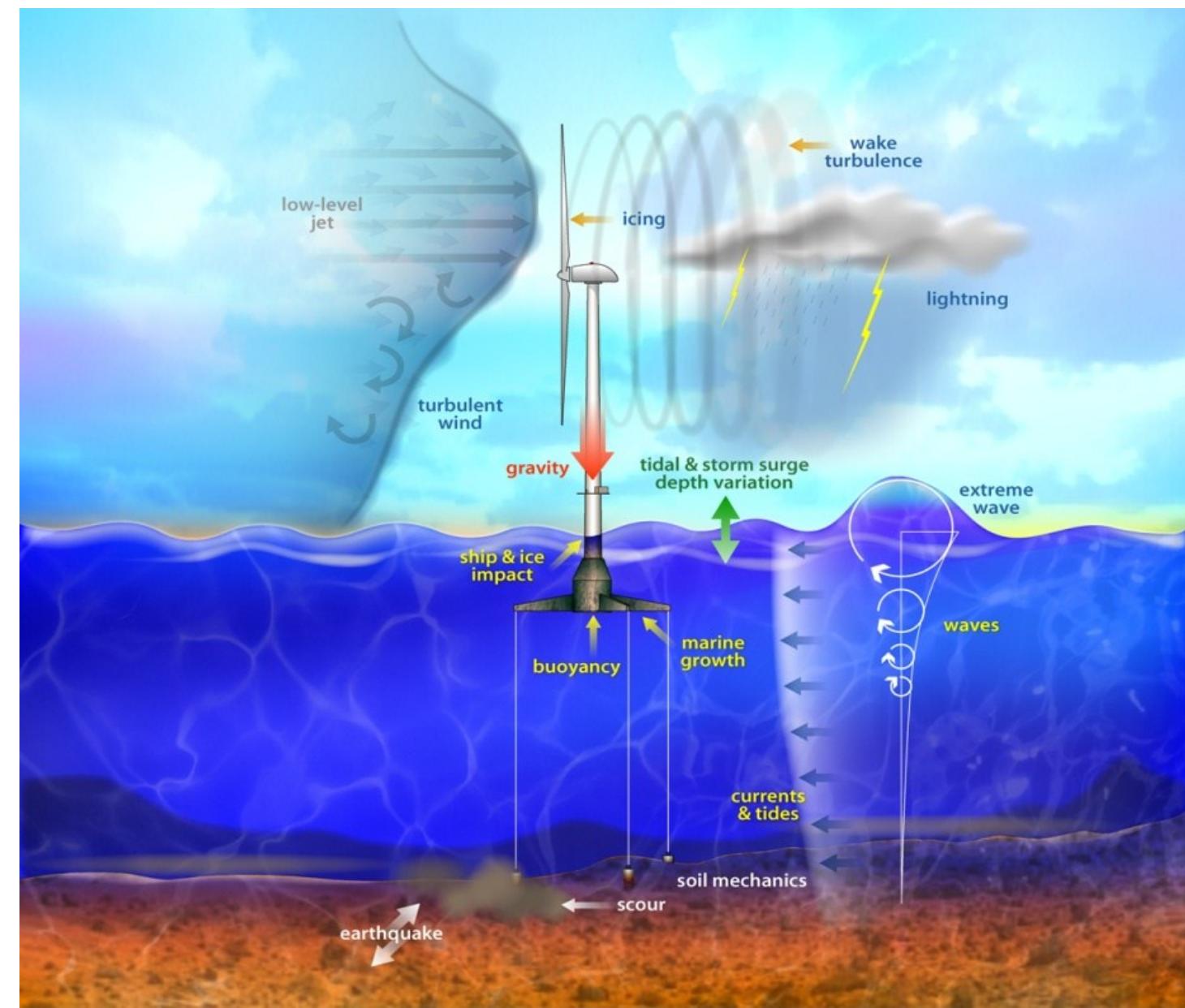
- Rotor / generator speed & torque
- Wind direction
- Wind speed
- Temperature & pressure
- Power quality & production



### Multidisciplinary Design and Control

- Flexible, composite blades
- Multistage gearboxes
- Direct-drive generators
- Complex power electronics
- Interacting subsystems

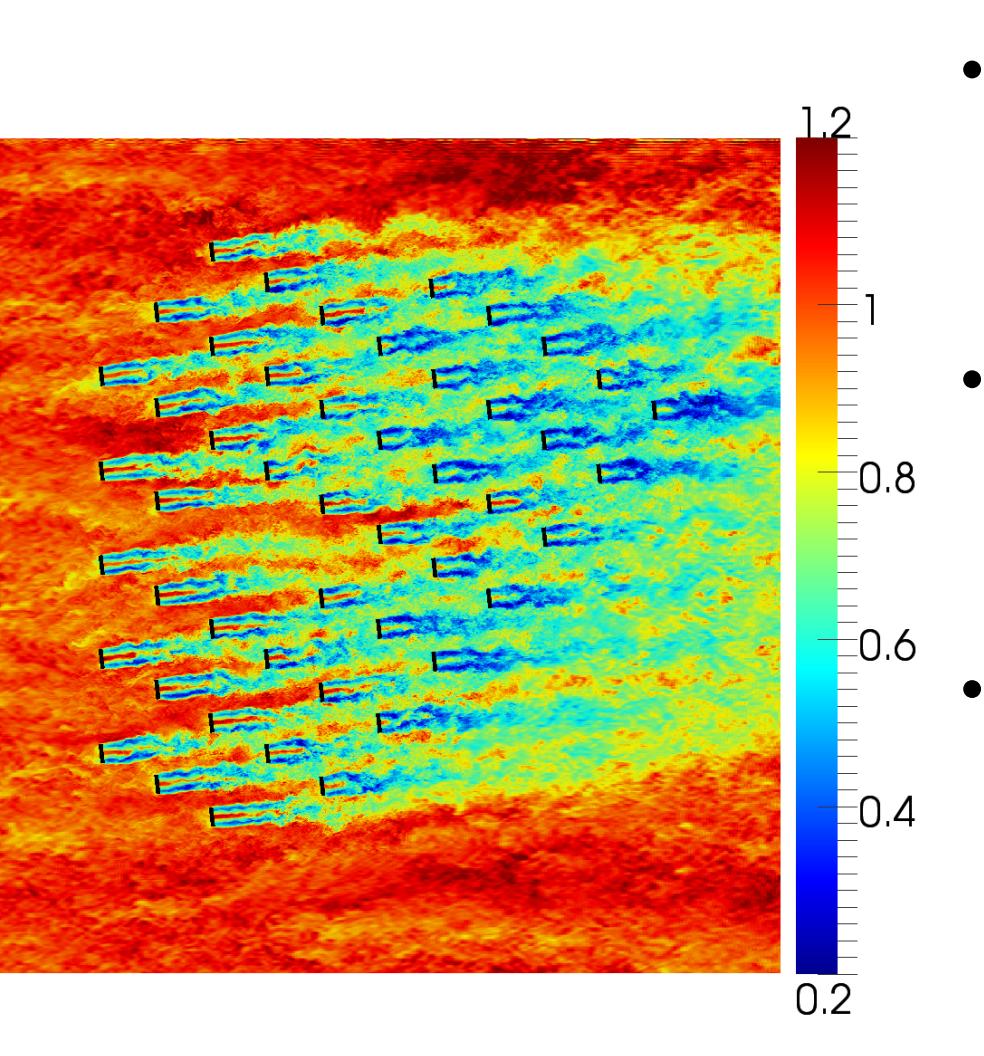




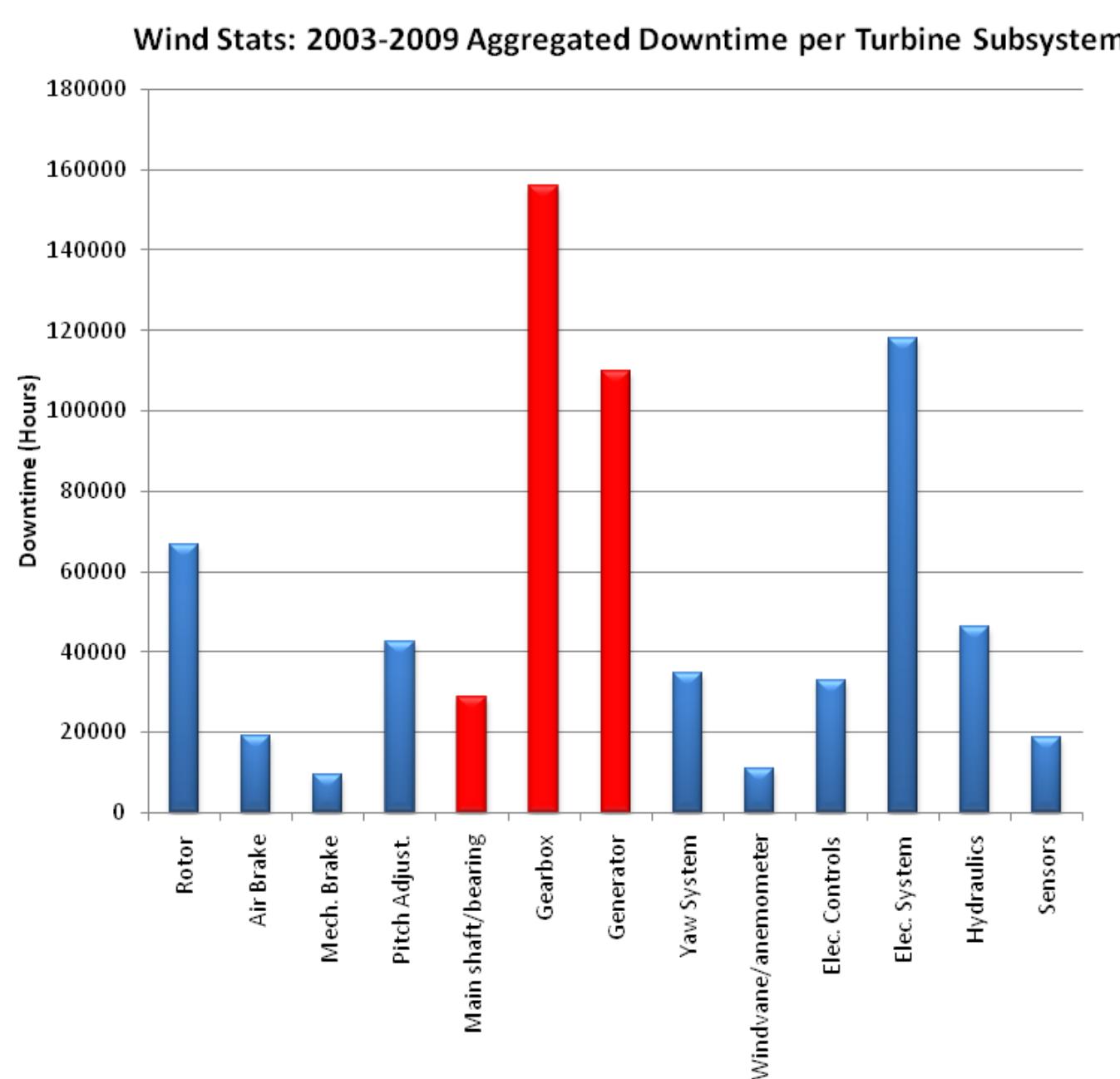
- Enormous size and scale of turbines require innovation to permit continued growth in size
- Wind turbines installed in arrays experience reduced power production and increased fatigue loads
- Turbines required for 20+ years of lifespan
- Issues with grid interconnection, operation with increasing amount of variable generation
- Barriers to deployment: wildlife, radar, permitting, land-use conflicts
- Extreme coastal and offshore environments require remote sensing
- Plummeting natural gas prices

### Challenges

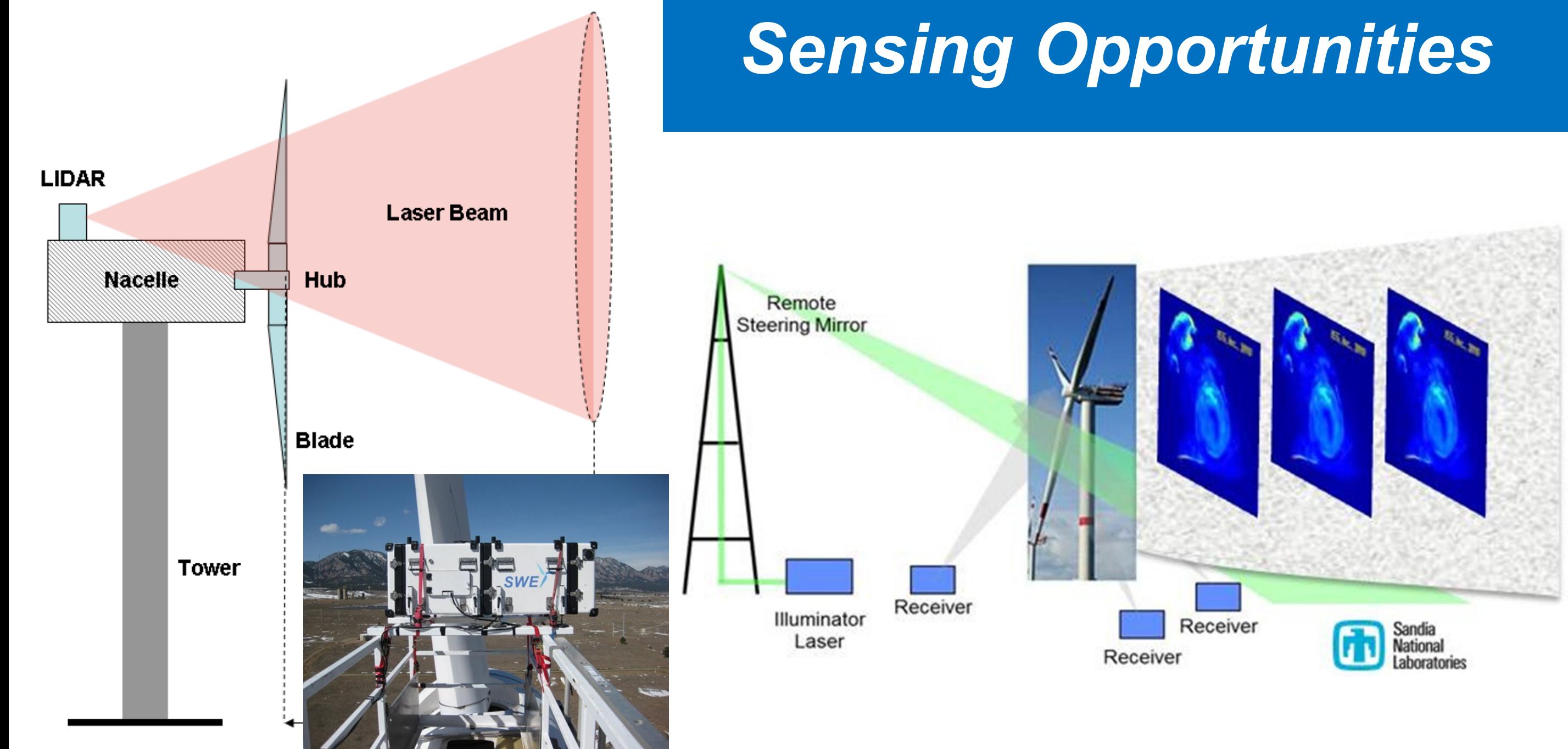




- Premature component failures lead to reduced turbine availability and increased cost of energy
- Turbine performance and availability improvement through robust, reliable and cost effective sensors
- Performance optimization of wind plant presents an opportunity for sensor networks
- Offshore wind deployment requires tremendous attention to demonstrating high-reliability, availability and maintainability, for which sensing plays a critical role

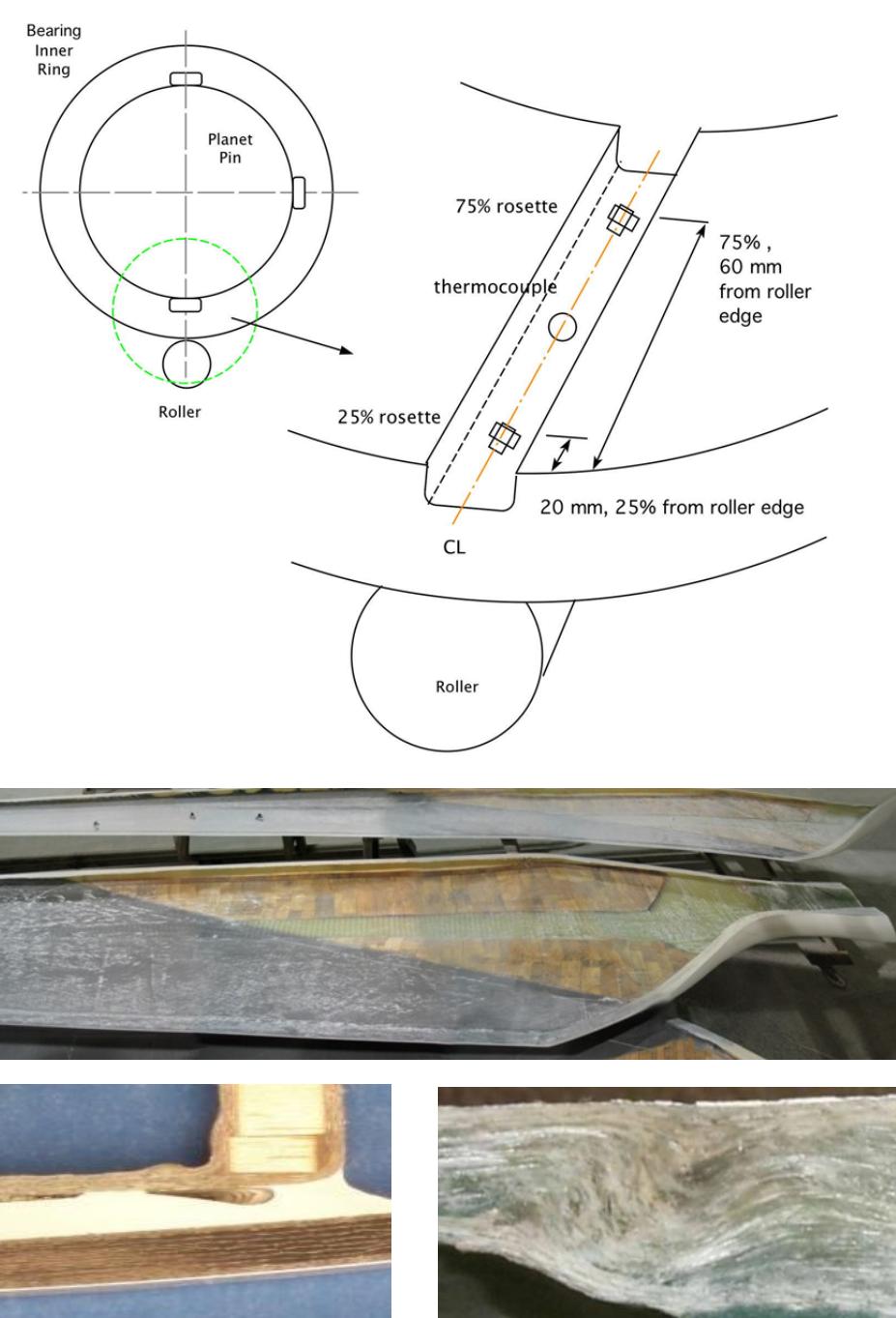


### Sensing Opportunities



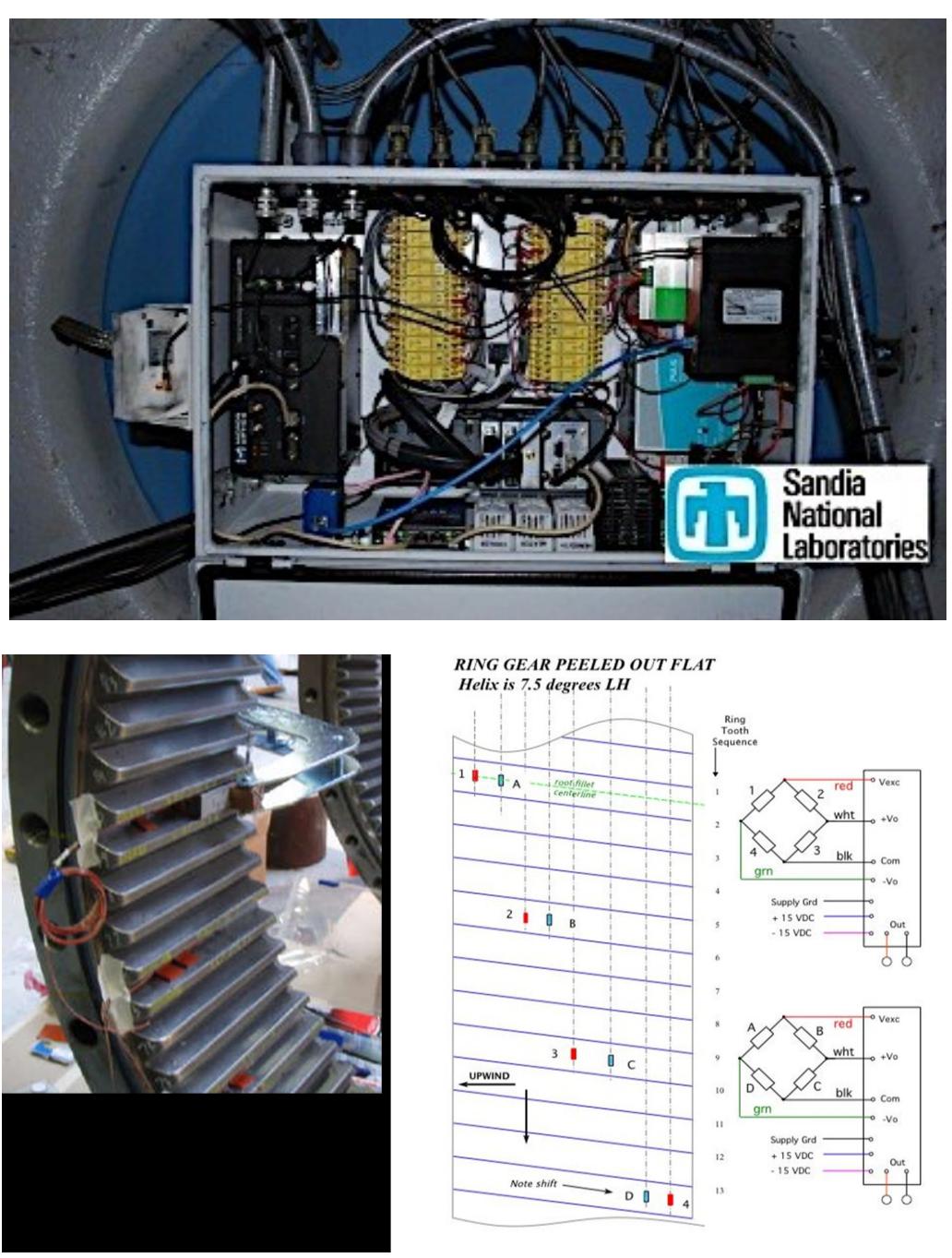
#### Advanced Sensing and Control Needs

- Measuring and understanding inflow – enable forward looking real-time control to mitigate fatigue and extreme loads
- Understanding array interactions – opportunity to reduce production loss from wake interaction by 40%
- Imbalance and vibration sensing – mitigate drivetrain fatigue loads
- Active rotor load control sensors – improve performance and reduce fatigue
- Structural health monitoring and prognostics – minimize maintenance and replacement costs



#### Advanced Data Acquisition and Sensors

- Ruggedized, marine environments
- Wireless, mixed signal content (analog, digital)
- Lighting and outage protection
- Fiber optics – temperature, strain, pressure
- Embedded sensor – smart subsystem and structure
- Remote inspection and NDE



#### SNL Sensored Rotors

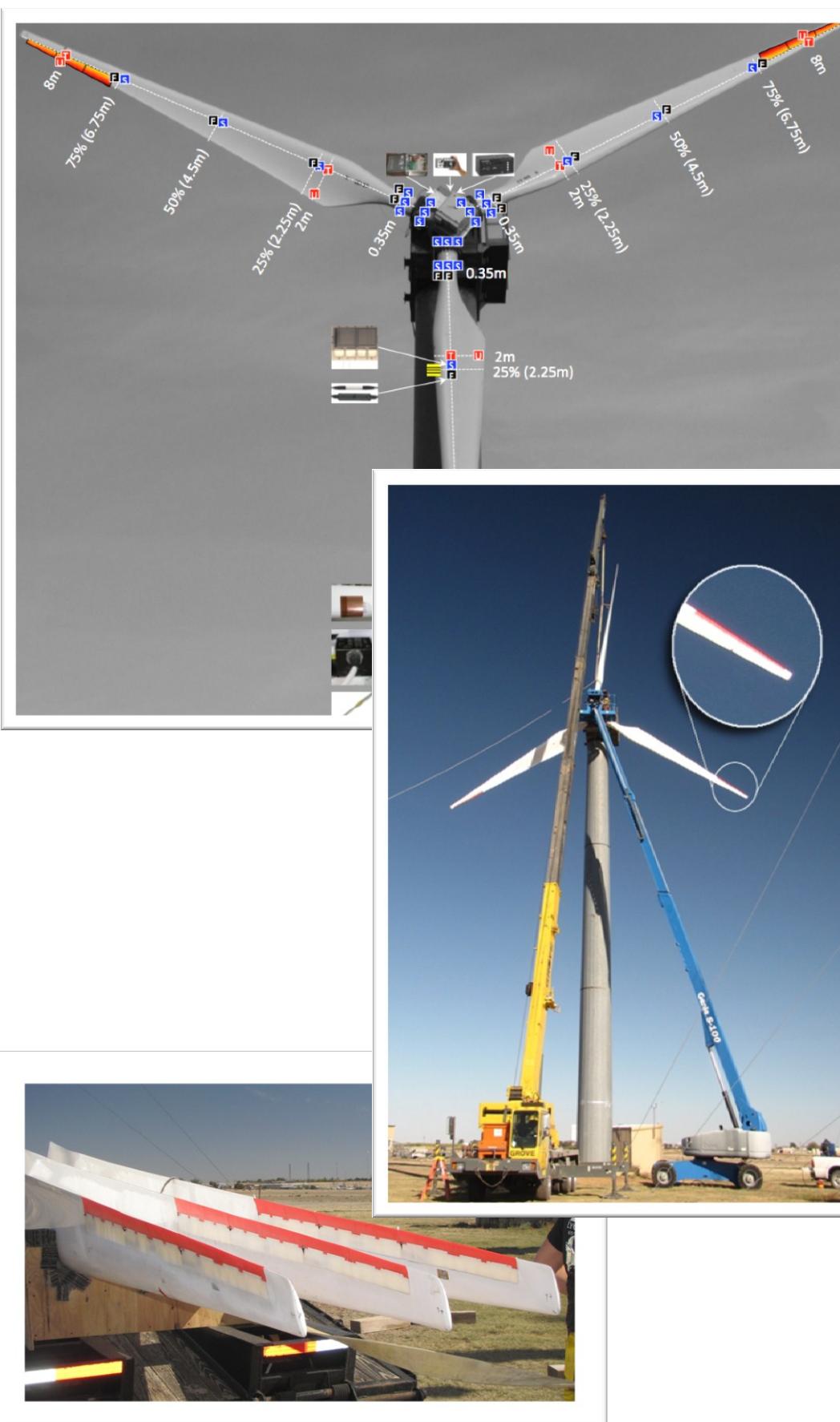
- Array of sensors tested to accelerated 20-year life on blade
- Manufacturing process for embedded sensors developed
- Sensor reliability improvement

#### SNL SMART Rotor

- World's first active load control rotor validated with embedded synchronized fiber optic, accelerometer, and aerodynamic sensor array
- Structural health and prognostic control for offshore wind demonstrated

#### SNL Blade Reliability Collaborative

- Blade defect and damage database
- Inspection validation
- Effect of defect evaluation



Jonathan R. White  
Wind & Water Power Technologies, Sandia National Laboratories  
jonwhit@sandia.gov  
505-284-5400

### DOE Laboratory Projects and Capabilities

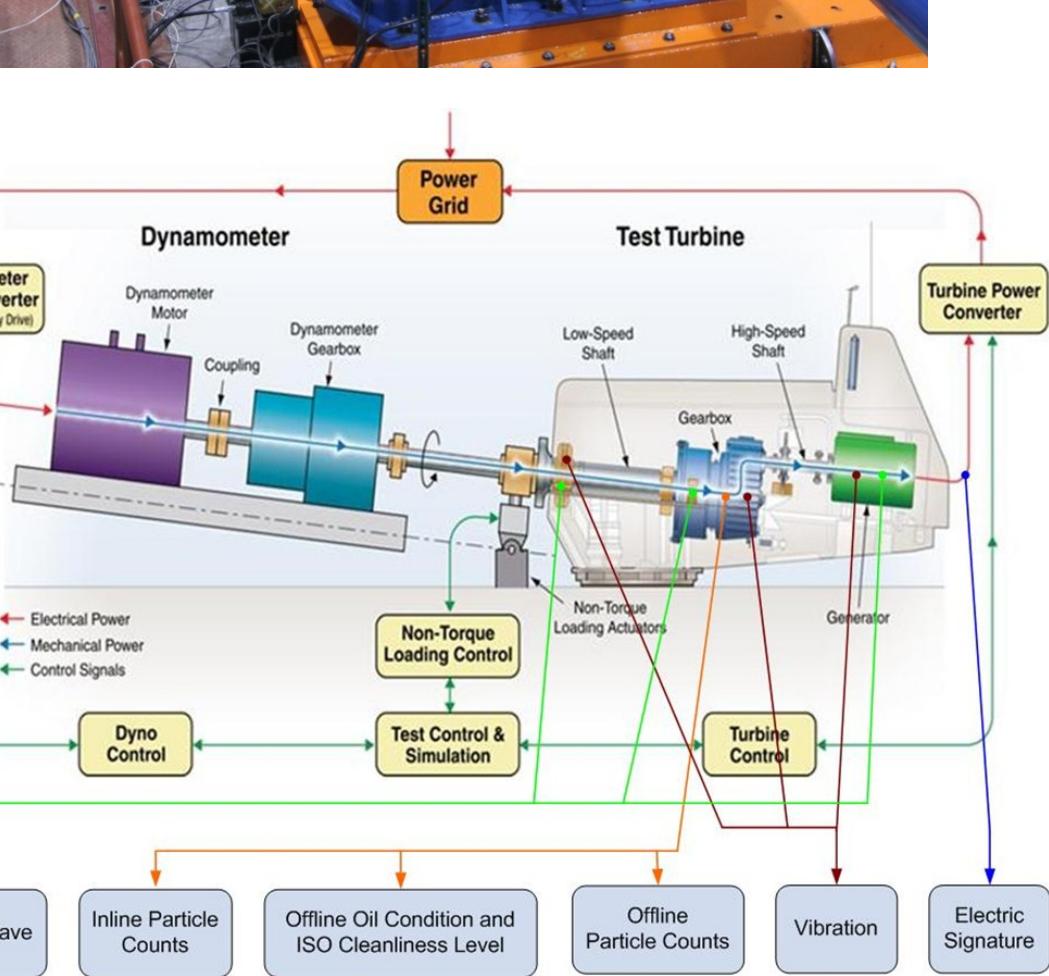
#### NREL Gearbox Reliability Collaborative

- Collaborative R&D with industry
- Generic drivetrain – identify and investigate “representative” test gearboxes
- Testing - model validation, load characterization, detailed gearbox responses



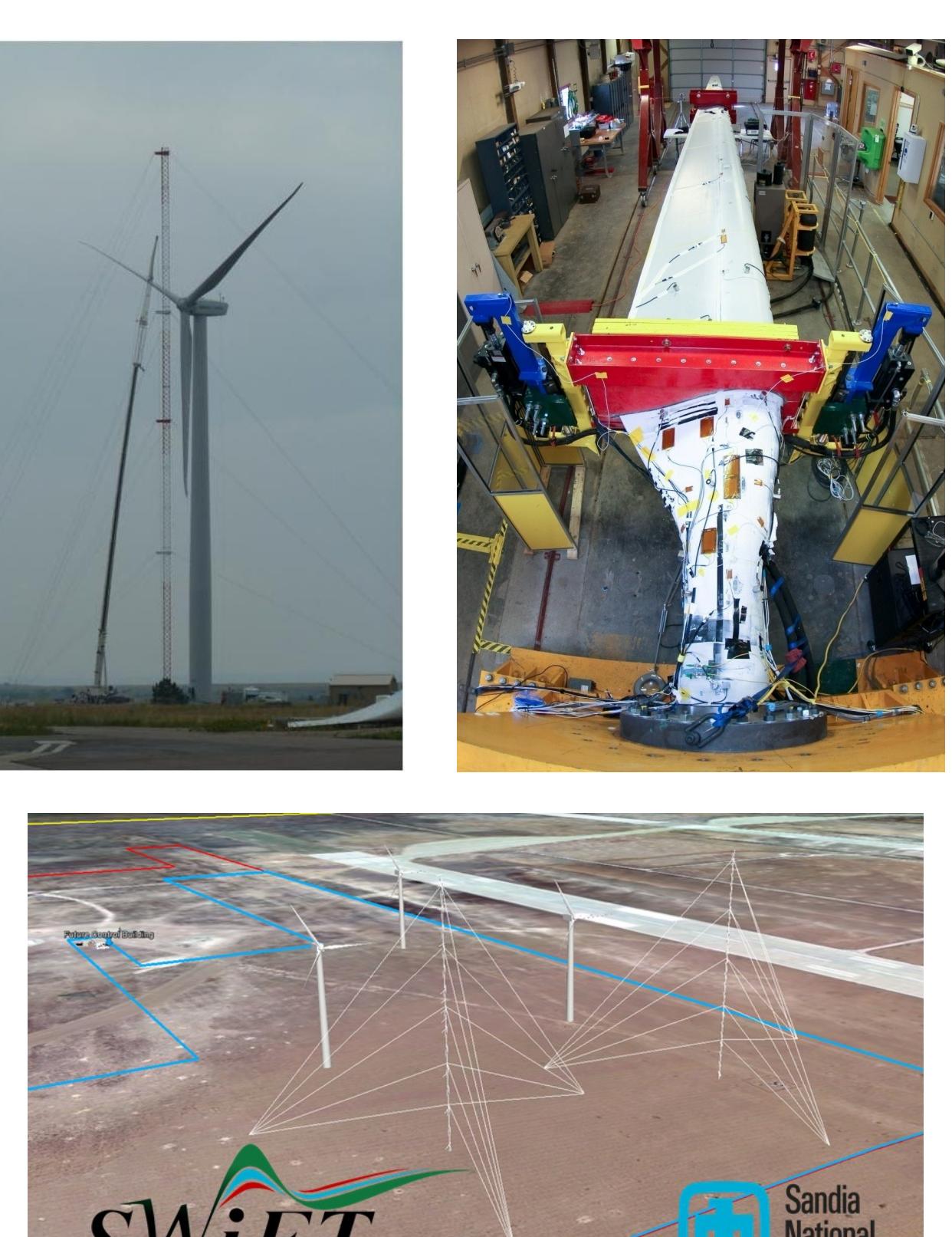
#### NREL Drivetrain Condition Monitoring

- Investigate use of various monitoring techniques to improve turbine availability – no single technique is a solution for all possible failure modes
- Vibration analysis algorithms need improvements
- Sensors and DAS cost needs to be dramatically reduced



#### NREL and SNL Capabilities

- Computer simulation tools
- Structural mechanics and dynamics testing of components and full-systems
- Advanced control design, simulation, and demonstration
- Wind plant aerodynamics simulation and testing facilities
- Cost modeling and analysis
- Environmental impact assessment
- Nondestructive evaluation and inspection
- Component and full-scale fatigue test facilities
  - Accredited testing to international standards
  - Full-scale drivetrain testing
  - Full-scale blade testing
- Testing of novel sensing techniques on single turbine and in wind plant



Scott Hughes and Shuangwen (Shawn) Sheng  
NREL – National Wind Technology Center  
Scott.Hughes, Shuangwen.Sheng@nrel.gov  
303-384-7054, 7106

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