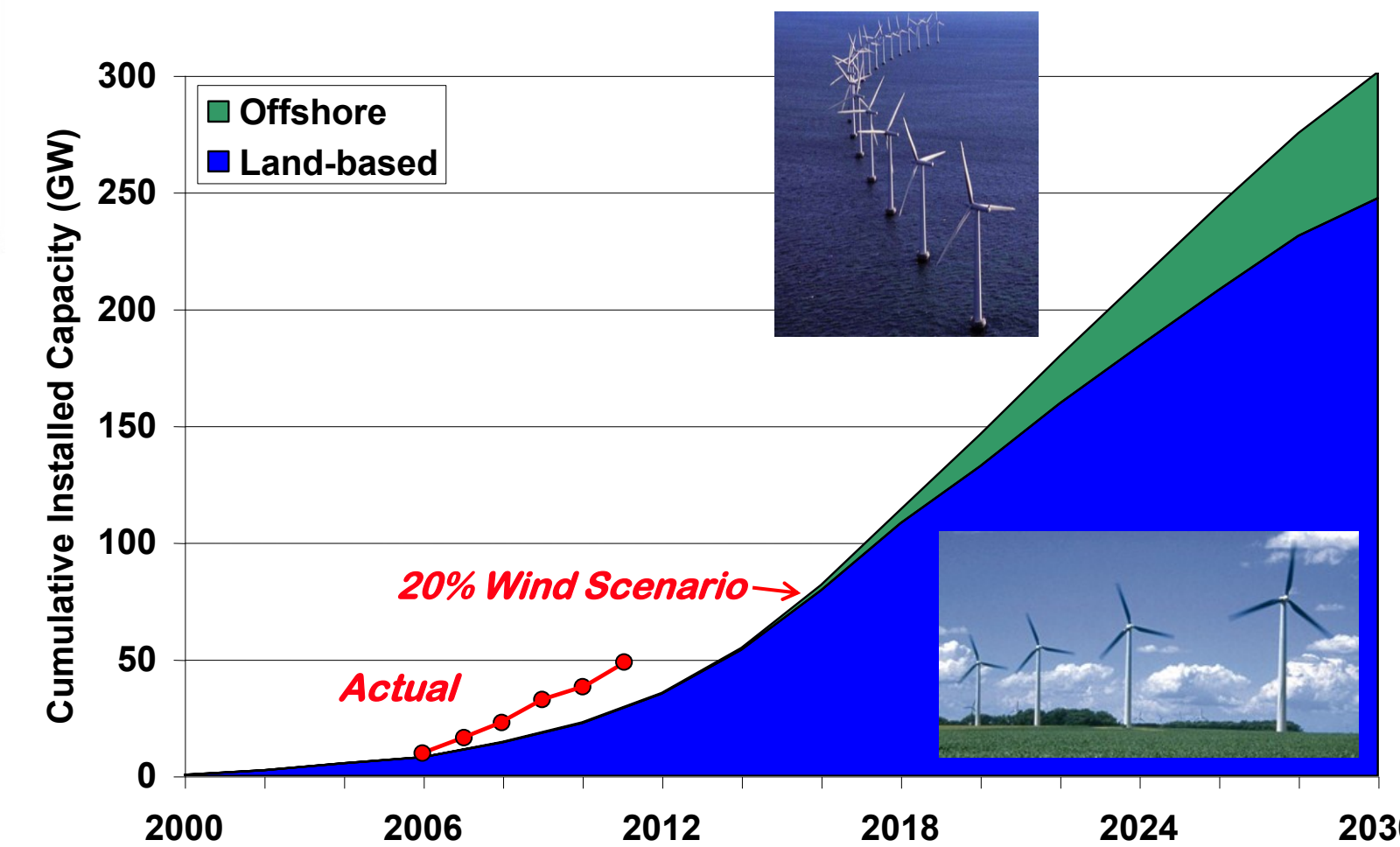


- Tremendous wind potential in the U.S
- Wind provides the lowest-cost source of new renewable power
- With good resource and a PTC, wind can be the lowest cost source of power

Wind Potential

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



Turbines are Complex Machines

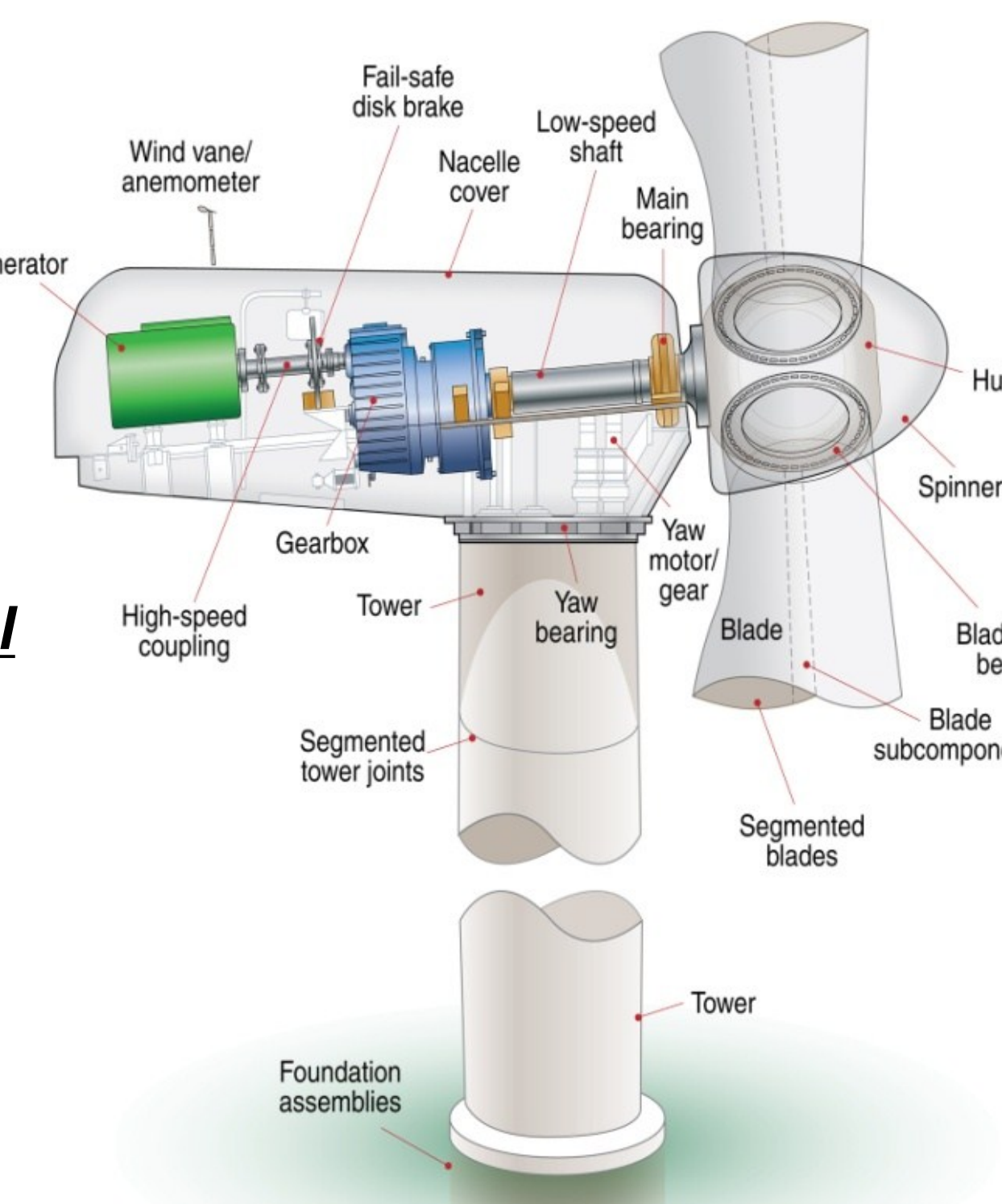


Average Land-based Machine

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

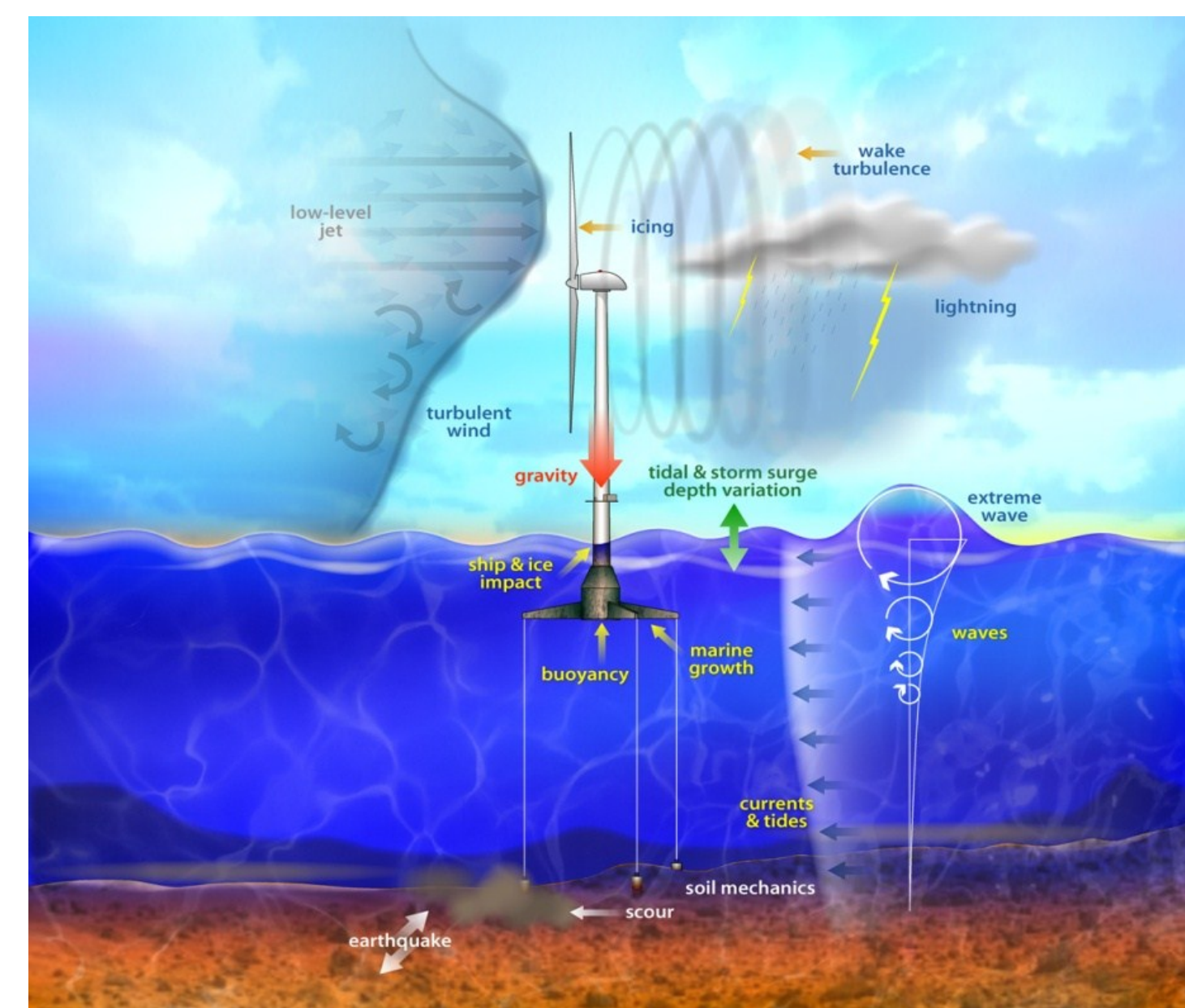
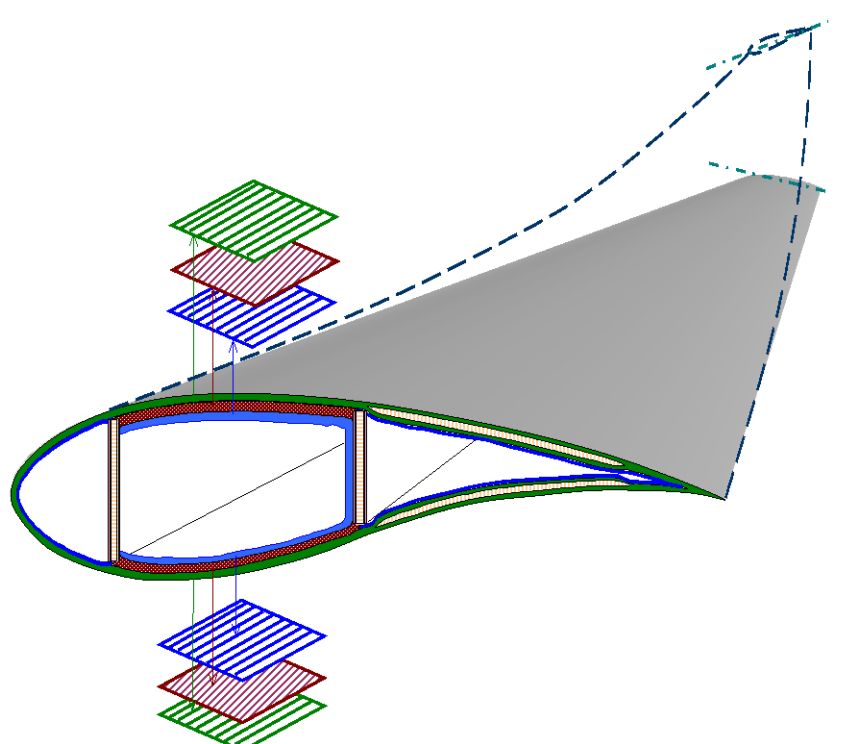
Typical Sensors on Commercial Turbines

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



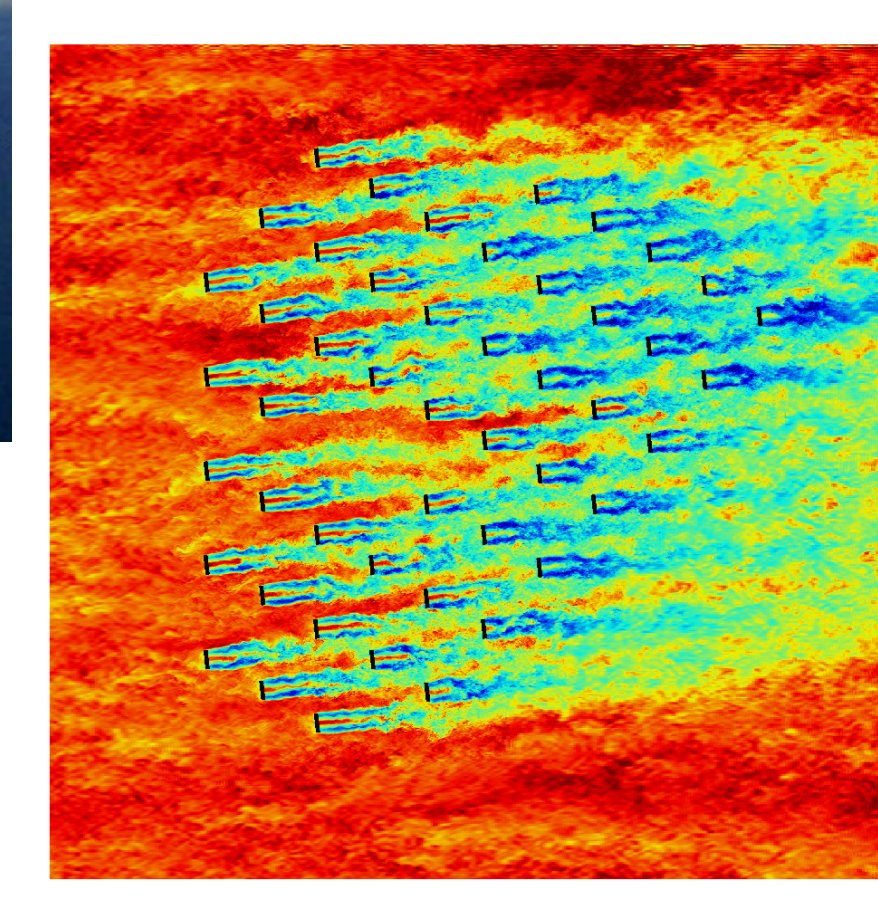
Multidisciplinary Design and Control

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

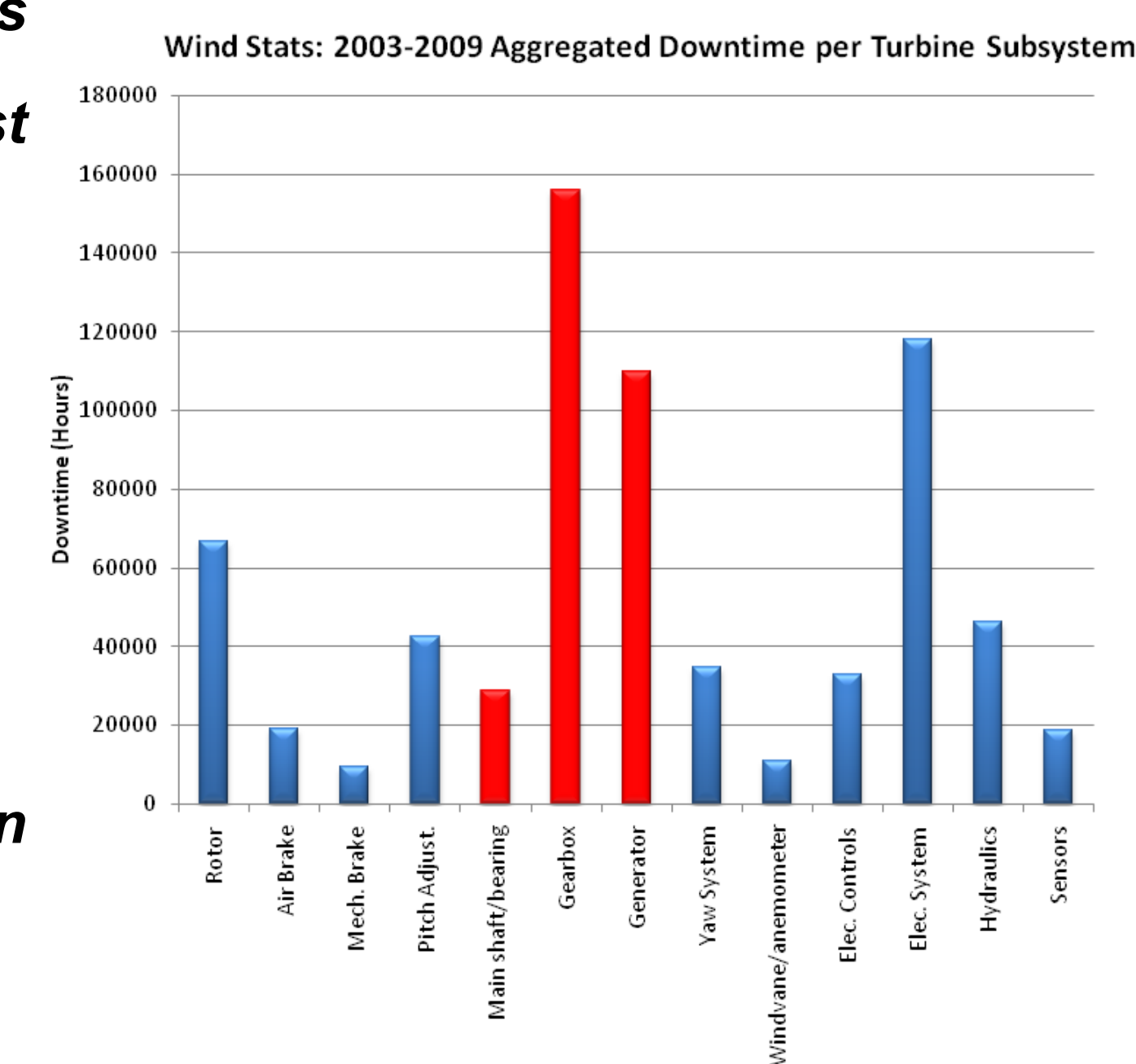


- Enormous size and scale of turbines require innovation to permit continued growth in size
- Wind turbines installed in arrays experience reduced power production and increased fatigue loads
- Turbines required for 20+ years of lifespan
- Issues with grid interconnection, operation with increasing amount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

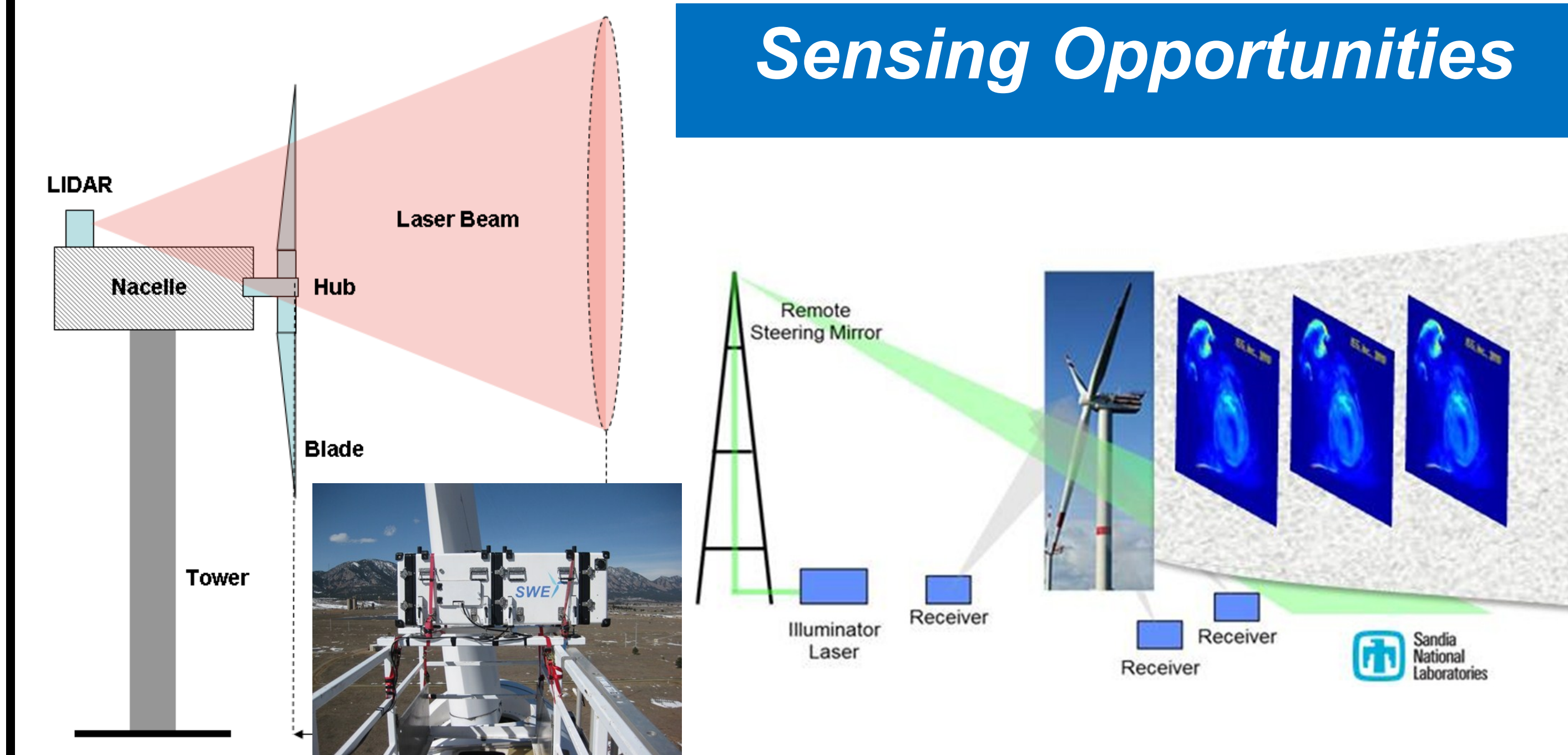
Challenges



- 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

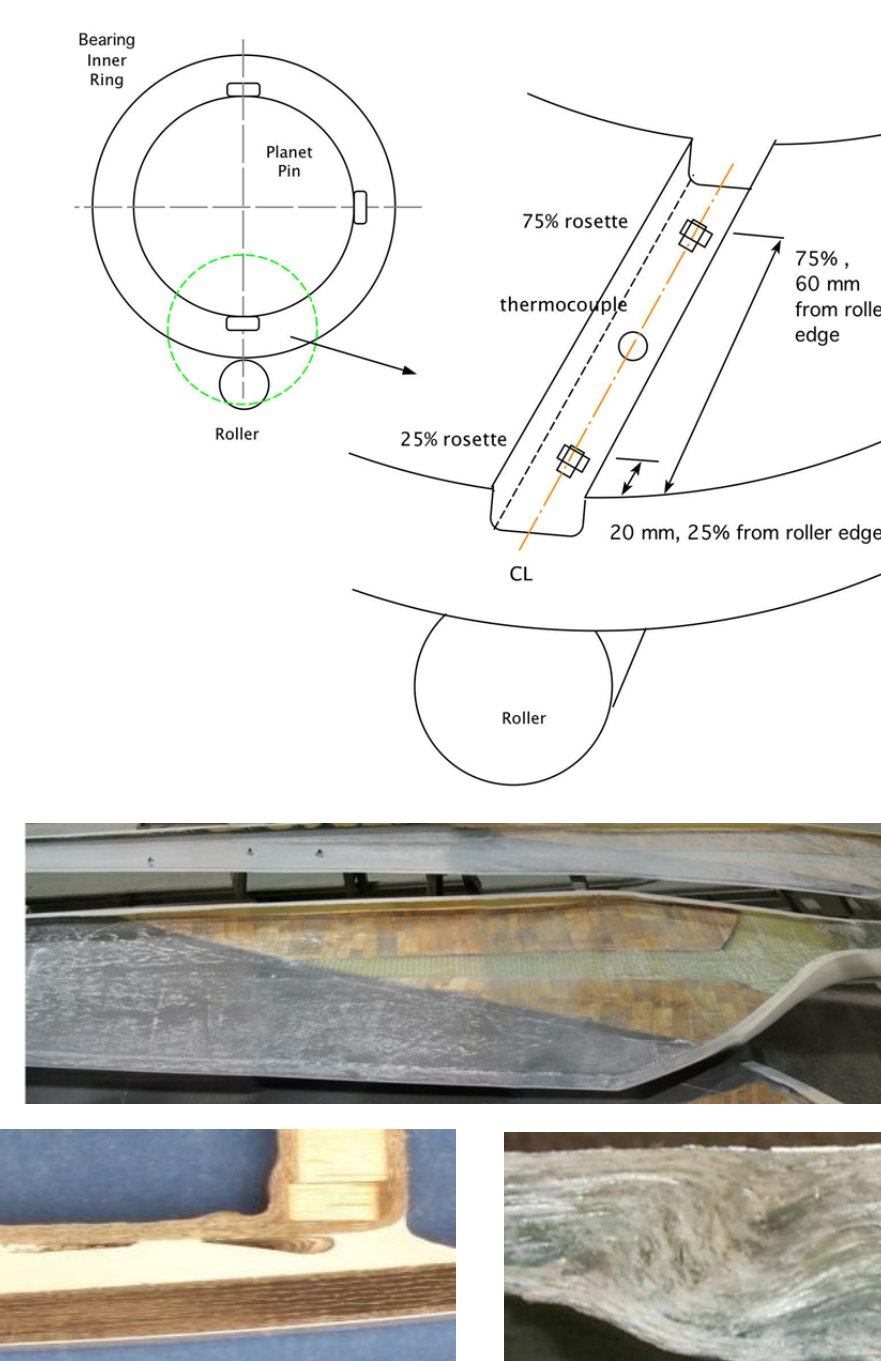


Sensing Opportunities



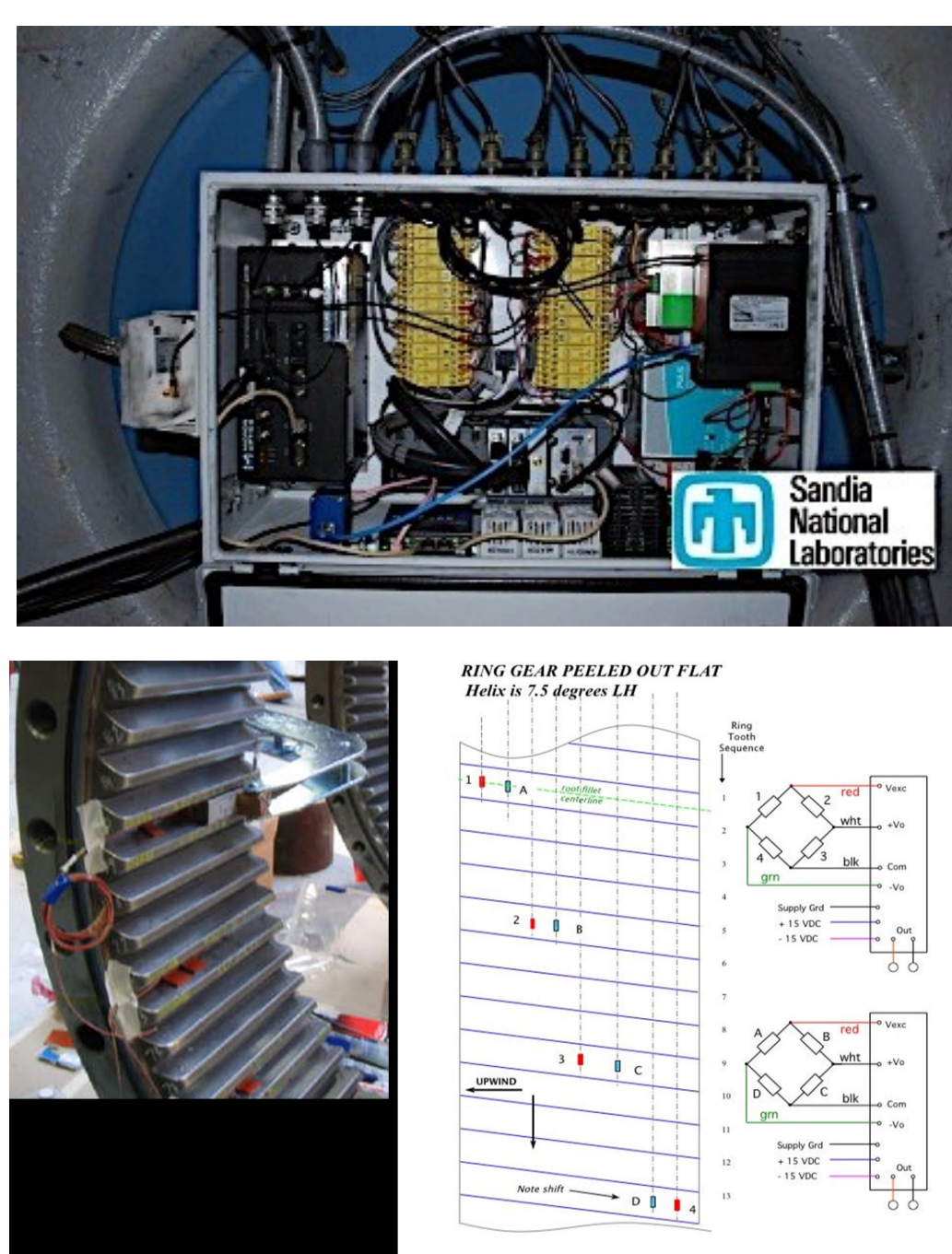
Advanced Sensing and Control Needs

- 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

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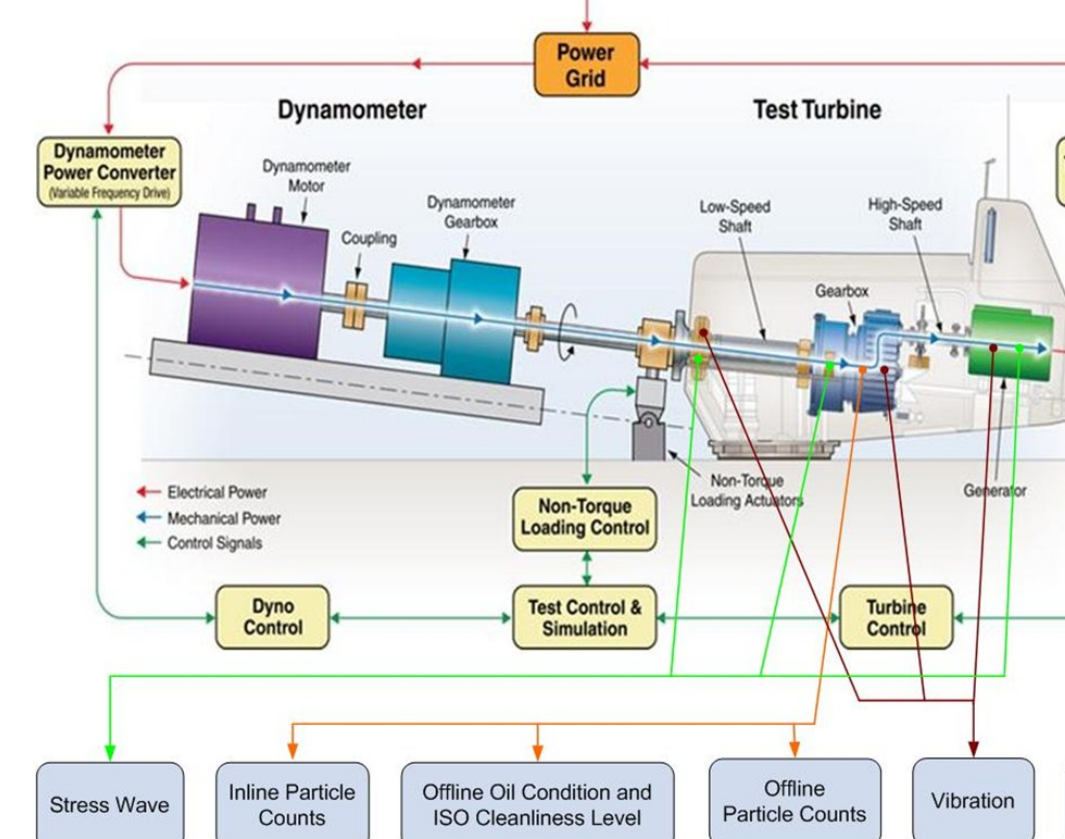
DOE Laboratory Projects and Capabilities

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

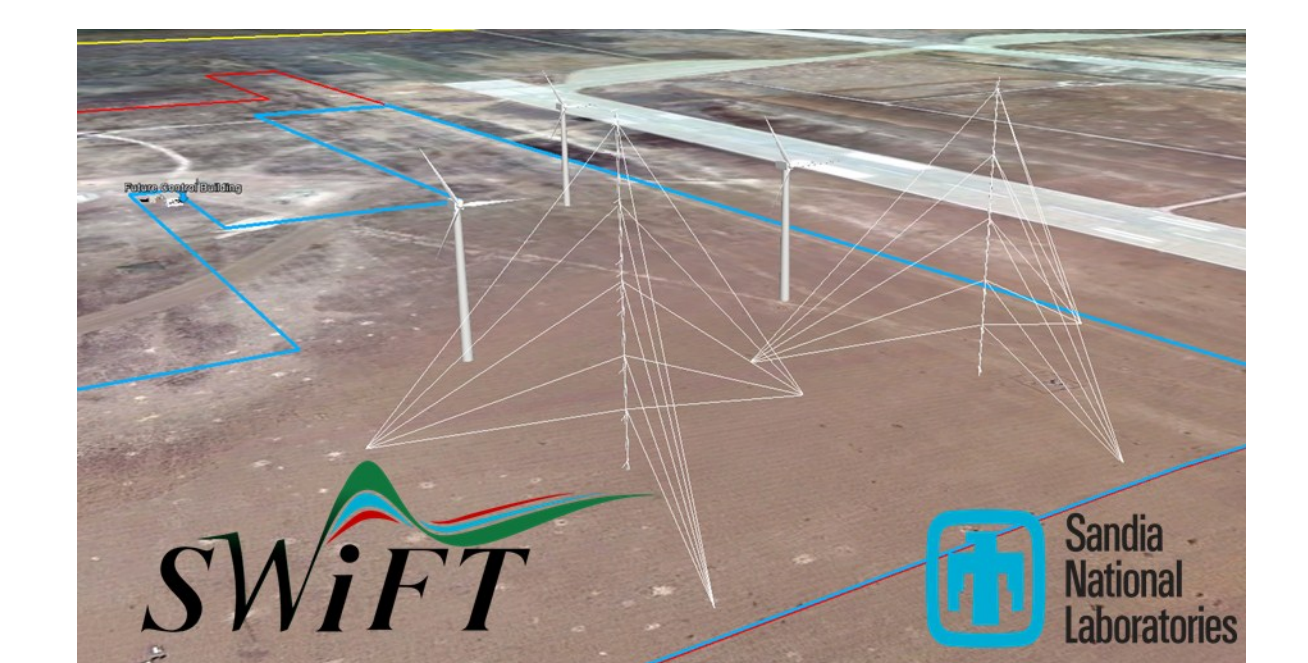
NREL Drivetrain Condition Monitoring

- 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



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