Gearbox Reliability Collaborative All-Members Meeting
Golden, Colorado
February 17, 2015

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# Update on Strategic Plan for Wind Plant Reliability

2014

**DOE Wind and Water Power Program**

Carsten Westergaard
Jonathan Keller

**PR-5000-63872**
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

# What is Atmosphere to Electrons (A2e)?

1 ***A technology initiative*** to enable design and deployment of low-cost ***smart wind power plants***

2 ***A novel U.S. Department of Energy (DOE) management construct*** leveraging a diverse expertise and stakeholder groups.



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# How Will Smart Wind Plants Overcome These Challenges?

| Challenges | Smart Wind Plant Objectives[10,11] | A2e LCOE Impact[10,11] |
|---|---|---|
| Wind plant energy losses of 20% or higher | ✓ Increase plant capacity factors from 0.39 to 0.50<br>✓ Reduce losses from 20% to 12% | |
| Major components not meeting 20-year design life | ✓ Extend component/system design life from 20 to 30 years<br>✓ Reduce installed capital costs from 1,615 to 1,454 \$/kilowatt (kW) | **\$65/megawatt-hour (MWh) to \$42/MWh[9,10]**<br>*(39% reduction from 2014 to 2030)* |
| Investment risk has inflated the cost of capital | ✓ Reduce cost of capital from 8.5% to 7.5% for land (larger opportunity for offshore wind) | |
| Inaccurate forecasts cost industry \$300M+/year | ✓ Improve day- and hour-ahead forecast accuracy by 10%–20% | |

*Note: Starting points and trajectories (2014-2030) for A2e objectives and LCOE targets are from the 2014 NREL LCOE Memo to WWPTO, which builds from the Wind Vision study, the 2013 Wind Market Report, and WWPTO LCOE analysis*

# Fiscal Year (FY) 2014 Execution Timeline

Q1 | Q2 | Q3 | Q4 | Q1

**EMC formed**
- *DOE, NREL, SNL, PNNL*

**Selection of seven high-priority research and development (R&D) focus areas and planning groups**

**EMC strategic planning and stakeholder engagement**

**External workshops and strategic plan validation**

**FY15 integrated activity plan development**

**Lab coordination**

**Publish multiyear strategic plan**

**Kickoff and implementation**

National Renewable Energy Laboratory: NREL
Sandia National Laboratories: SNL
Pacific Northwest National Laboratory: PNNL

## Major accomplishments to date

1. **Completed external merit review**
   – External reviewers were quite pleased with A2e's direction towards wind plants
2. **Completed integrated strategic plan**
   – Ready for external merit review in February 2015
3. **Completed many meetings with external stakeholders, both domestic and international, in industry and academia**
   – Topics included: high-fidelity modeling, verification and validation framework development, experimental campaign design, aeroacoustics, advanced controls, reliability, design methods, data archival and portal, performance risk, uncertainty, and finance
4. **Realigned FY15 portfolio to reflect A2e priorities**
   – Capacity to initiate new starts limited by flat funding levels.

# Reliability Planning Group Members

| Name | Organization | Role / competency |
|---|---|---|
| Jonathan Keller | NREL | Planning chair, NREL reliability lead, Gearbox Reliability Collaborative (GRC) lead |
| Carsten Westergaard | SNL/Texas Tech | Planning chair, wind industry experience |
| Ben Karlson | SNL | Lead on national reliability database |
| Shawn Sheng | NREL | Gearbox collaborative lead |
| Josh Paquette | SNL | Blade collaborative lead |
| Rolando Vega | University of Texas at San Antonio | Reliability and industry experience |
| Luiz Cerezo | Electric Power Research Institute | Electrical reliability |
| Bill Erdman | Independent (formerly DNV) | Electrical reliability |
| Ron Grife | EDP Renewables | Owner, performance manager |
| Desiree Johnson and Nick Johansen | Iberdrola | Owner |
| Steve Black | General Electric | Original equipment manufacturer (OEM), manager product service engineering |
| Mark Harral | Group NIRE | Commercial testing |
| Dan Brake | NextEra | Owner |

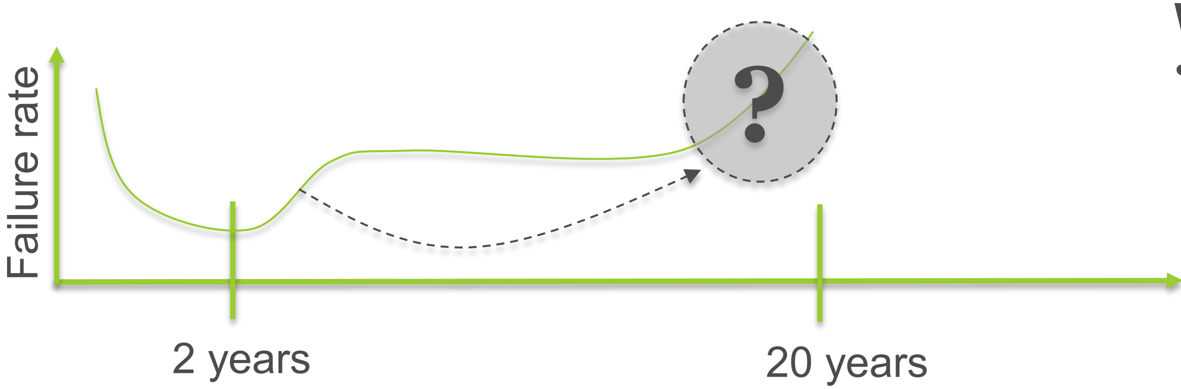
# Why is Wind Plant Reliability Important for an R&D Program?

- Reliability is a fundamental discipline that affects all aspects of LCOE:
  - Operational expenditure (OpEx) costs – scheduled and unscheduled
  - Financing – through lack of reliability and subsequent uncertainty
  - Annual energy production (AEP) – through unavailability
  - Capital expenditure (CapEx) costs – through overdesign/underdesign and testing
- The potential:
  - O&M is estimated to be 25% of revenue for land-based wind
  - U.S. wind O&M is a $1.6B-$3B market on its way to become a $5B market
  - Direct CapEx improvement potential is currently unknown
- The opportunity:
  - Aggregated data over larger volumes and cross-sections will reduce uncertainty and fill in knowledge gaps not otherwise available for the individual
  - Support an industry supply chain as it is changing towards more standardization (similar to the car/aerospace hybrid industry) and new products
  - Need for smart fleet management tools supporting an evolving O&M industry.

# The Life of Components in a Wind Plant

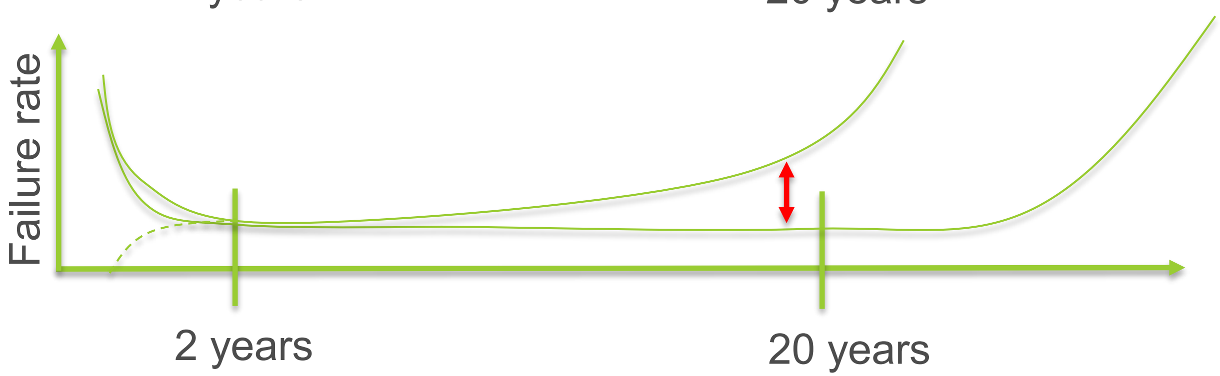

**The expectation:**

- Infant mortality
- Random failures at constant rate
- Opportunity for life extension




**What we fear:**

- "Black swan" events shorten life and prevent future opportunity




**What we could achieve:**

- Monitor and quantify remaining life
- Reduce quantifiable uncertainty by understanding failure and events.



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# Environmentally Induced Reliability Events

| Failure induced by | Component | Annual failure rate of repairable items (number is relative to all component repairs) | Fraction of fleet which that will experience major replacement in lifetime (20 years) |
|---|---|---|---|
| Lightning<br>35 days/year | Blade | 3% | 4% |
| | Other | High? | ? |
| Ice | Blade | ? | ? |
| | Other | Some, but low$ | Some, but low$ |
| Erosion | Blade | High | Almost none |
| | Other | None | None |
| Extreme wind with/without vibration | Blade | ? | 6% |
| | Other | ? | Unknown |
| Corrosion and surface degradation | Blade | ? | ? |
| | Other | ? | ? |
| Miscellaneous | Blade | ? | 4% |

The data on environmental is not quantified at this stage and are fleet average. I.e. icing is a regional effect

# Focus Area Description and Vision

Aggregating data over larger volumes and cross sections will reduce uncertainty and fill in knowledge gaps not otherwise possible for the individual. Fundamental knowledge gaps relating to reliability exist all the way from the wind plant aerodynamics level to the part microstructure level. Although the wind industry has improved tremendously over the past two decades, there is a need to support the supply chain as it changes towards more standardization to achieve a vehicle or aerospace style of reliability. Existing design standards no longer support the growing wind industry at the plant level and do not enable effective risk management at any level. The role of DOE is to identify opportunities that can reduce existing uncertainty and preempt future uncertainty for owner/operators.

The vision of the Wind Plant Reliability focus area is:

**Reliable delivery of electricity and significantly reduced costs by increasing inherent reliability and reducing remaining useful life uncertainty.**

# Work Package #1

**Continuously validate assumptions in interaction with industry**.

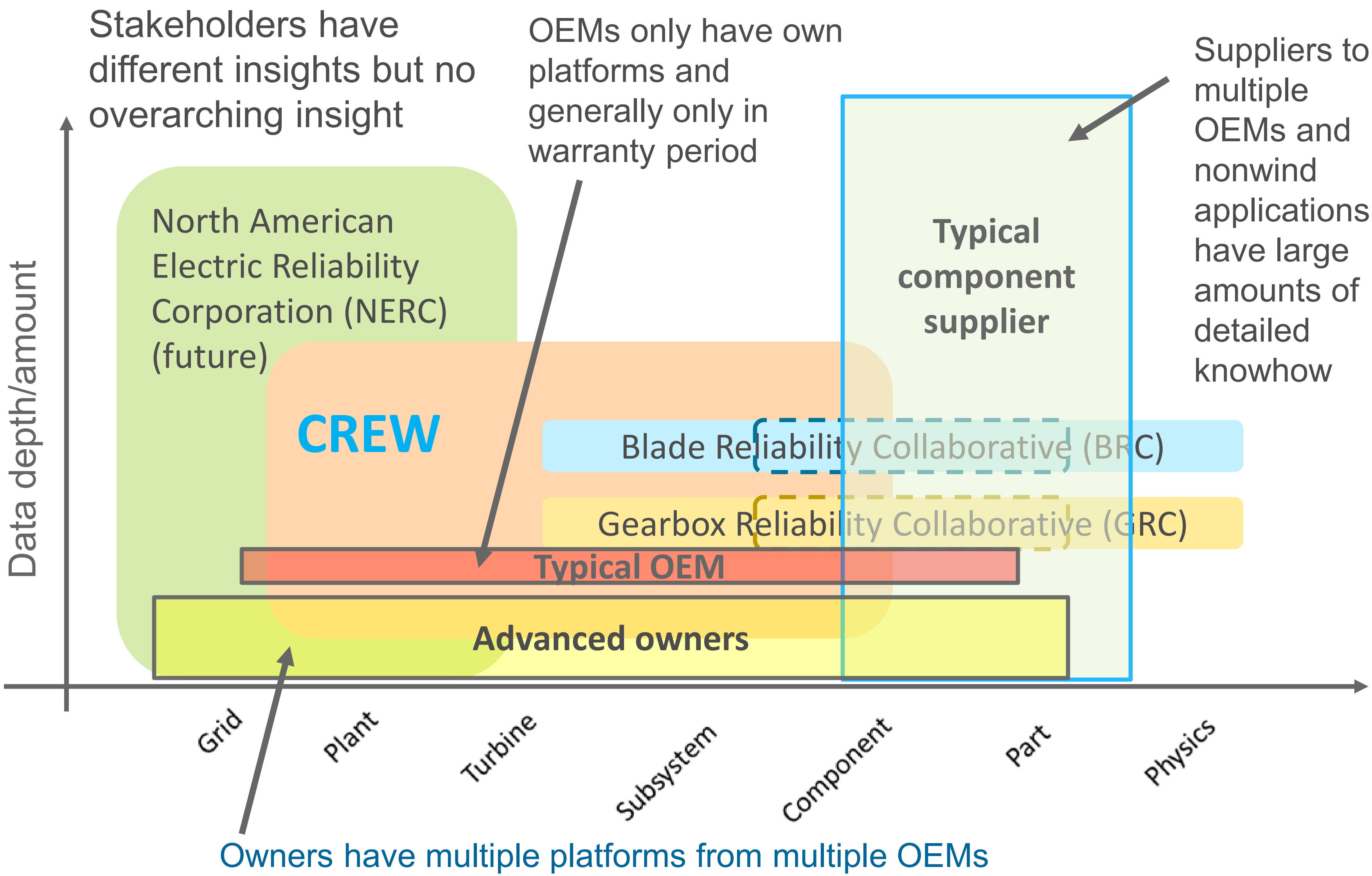
The reliability collaboratives (RCs) have been proven effective and are highly valued by industry.

They provide organization that industry needs, driven by laboratory technology leadership and fundamental research delivered by the resulting separate WPs investigating common issues without breaching proprietary considerations in the areas of rotors, drivetrains, actuators, and electrical delivery systems.

They will be supported by benchmarking against aggregated data to select research objectives and develop requirements for standards.

From a national perspective, benchmarks will continue to drive reliability transparency and the success of the industry. This WP will drive prioritization of the other WPs and deliver a national database and benchmark for owners.

# Benchmarking and Analysis



# Work Package #2

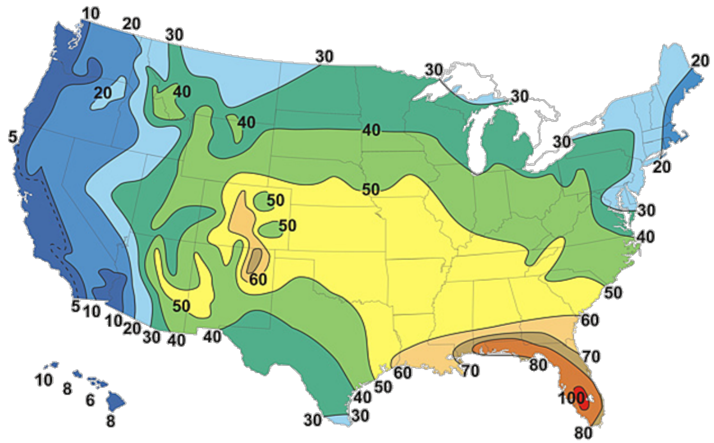
**Define the external challenge and its impact.**

Environmental conditions have a large impact on reliability. In the design and siting phases, they are dealt with through the standards and siting exercises assuming relatively generic conditions.

There may be regional understanding of lightning, icing, erosion, extreme winds, and corrosion, but no linkage to the actual consequences that are important to insurance providers, owners, designers, and eventually design standards. This WP will characterize the effects of U.S.-specific weather events on reliability.

# Lightning: Regional Risk Variation

- International Electrotechnical Commission (IEC) Technical Report (TR) 61400-24:2002
  - Based on data from 2,800 “small turbines” in northern European Union (<15 days) and inner Germany (<35 days of thunderstorms)
  - Annual failure rate 0.4% to 1.4%
- United States has 5 to 100 days of thunderstorms, 0.3% to 5%
- Midwest has ~55 days with an annual failure rate up to 3%




- Subconclusion:
  - Fleet average without considering regional exposure is fairly meaningless
  - A well document standard for normalization combined with a national fleet average could improve our understanding
  - Many U.S. owners have more accumulated experience than what the IEC standard is based upon.

Sources: NOAA.gov, Cannata 2014, Coffery 2014, Nissam 2013, LM Wind power



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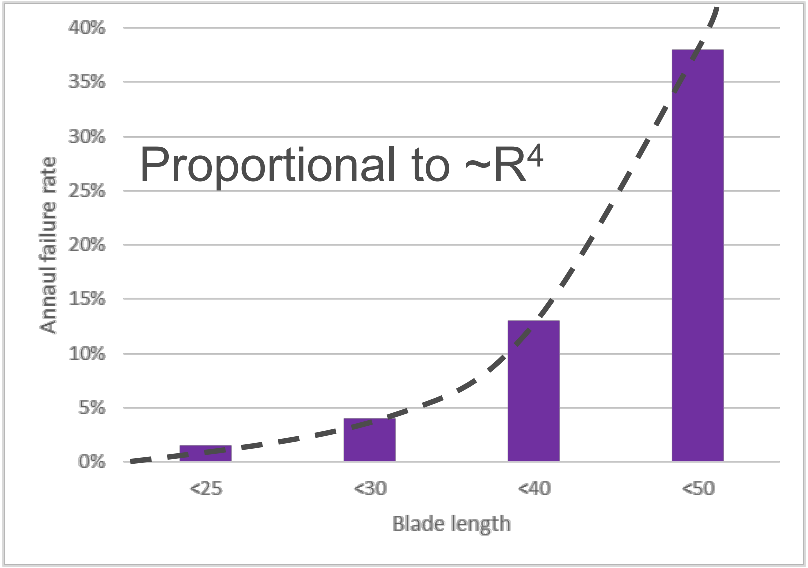
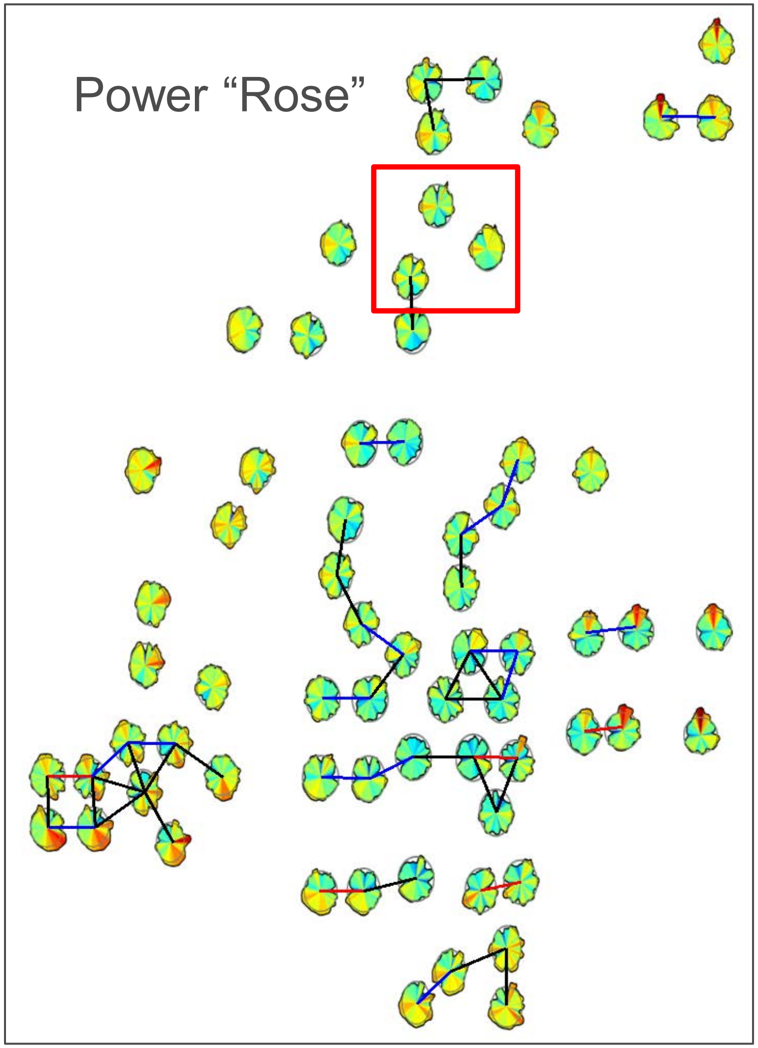
# Lightning: Technology Bias and Size Bias

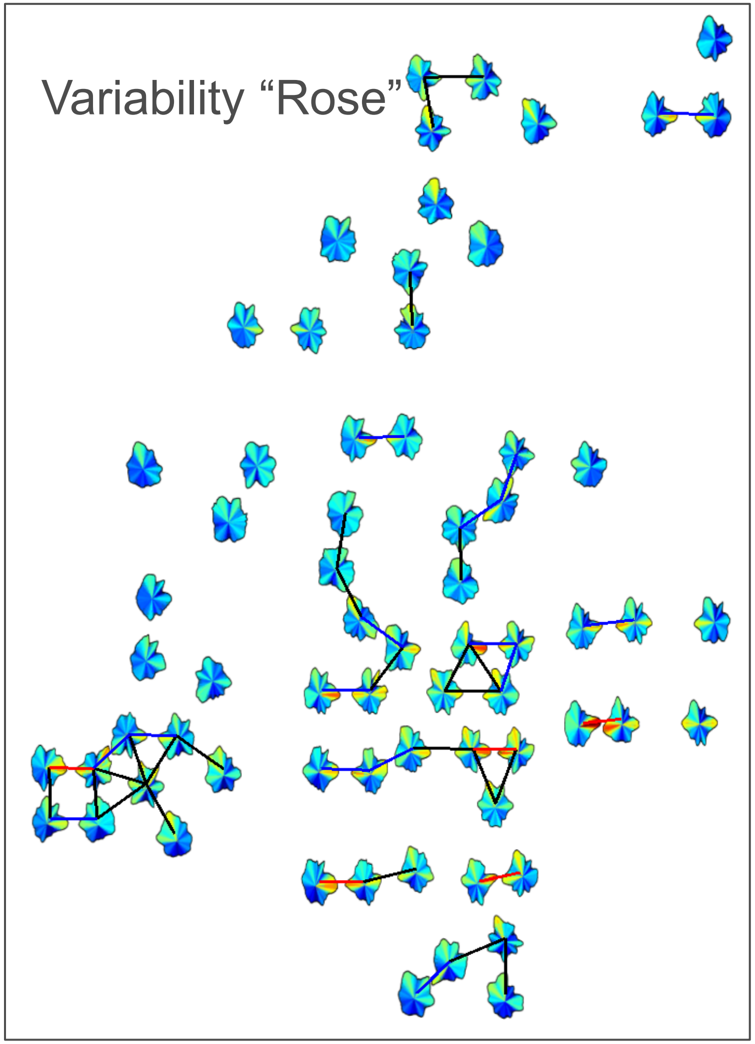
- Lightning risk, according to IEC TR 61400-24 and ported from building code, suggest risk is proportional to height squared, including landscape topology
- Experience shows much higher height dependency (~$R^4$)
- On the flip side, improved lightning protection systems are reported to have as much as tenfold improvement
- Subconclusion: Historical fleet average will not predict the future without significant considerations to technology and size correction.




Sources: Cannata 2014, Coffery 2014, Green 2014, LM Wind power

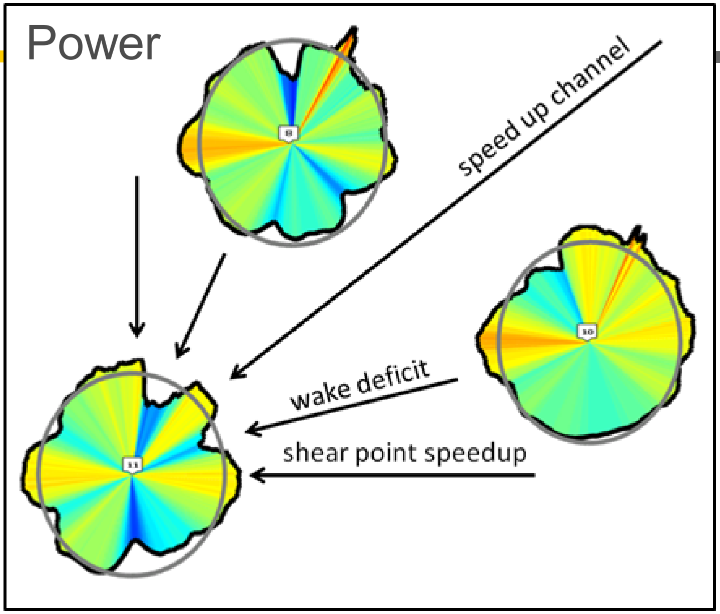
# Directional Analysis of System Control and Data Acquisition (SCADA) Data

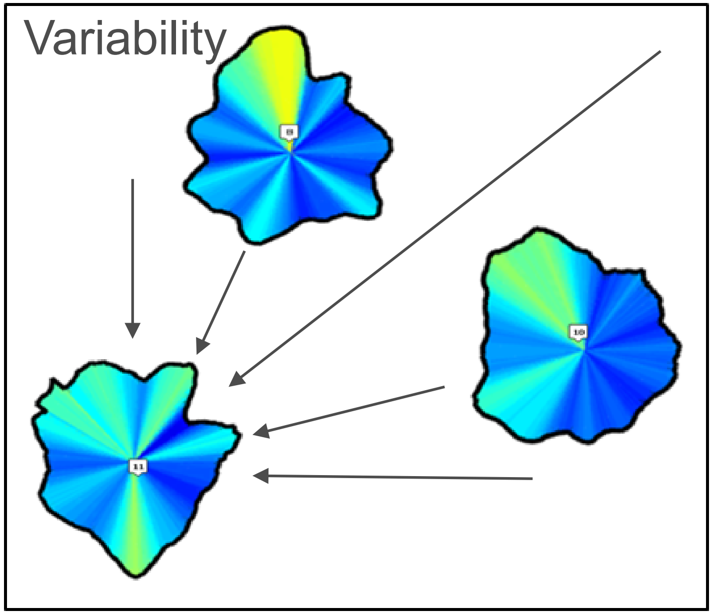


# Operational Quantification

- Observation: High power extraction relative to average performance occurs with low variance
- If low variance equals low rates of fatigue and wear, then low rates of failure should be observed as a function of direction
- Working hypothesis: Direction plays a major role and is a simple way to quantify power and reliability
- Can we link data mining of SCADA and apply a simple metric for reliability?



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# Work Package #3

**Perform research to increase inherent reliability.**

The major activities in the rotor and drivetrain are an outgrowth of existing DOE research. In contrast, major activities in power conversion and grid interconnection are a result of industry feedback.

Each technical work package contains testing and modeling activities as directed by the reliability collaboratives and benchmarking and is focused on delivering the data and knowledge for the supply chain to increase the inherent, or baseline, reliability of components, the wind turbines, and the plant connection to the electrical grid.

# 1.5-MW Testing and Modeling

- Measurements and tests
  - Main shaft (input) and high-speed shaft (reaction) torque and bending loads
  - No need for component (gear tooth or bearing race) instrumentation
    - Models predict component stresses accurately, *given the loads*
  - Rotor, tower, meteorological tower, and SCADA data to characterize turbine operational state
  - Actual controller action can differ widely from design assumptions
  - A 2.5-MW dynamometer, DOE 1.5-MW turbine, and controllable grid interface are stepping stones to field tests
- Analysis and modeling
  - Process loads to characterize design load cases and transients
    - A2e reference load distribution
  - Develop and model generic drivetrain to explore design deficiencies.

# Work Package #4

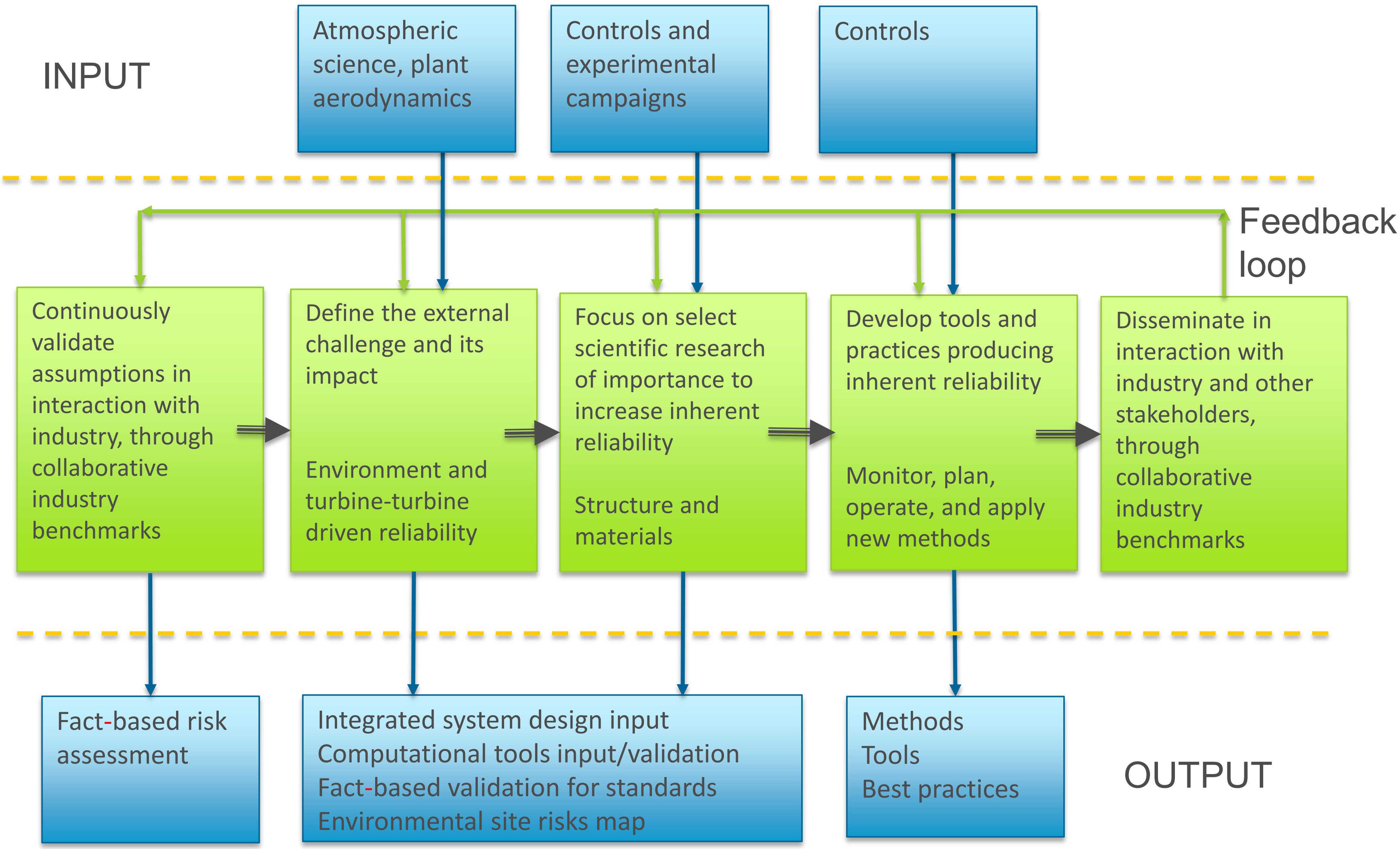
**Develop tools and practices producing inherent reliability.**

Scheduled and reactive maintenance require significant effort. There is a lack of accurate diagnostic and prognostic capabilities in the wind industry; however, these capabilities are critical for optimized O&M strategies and reduced O&M costs.

State-of-the-art operations centers at OEMs have increased the availability of wind plants to 98%–99% by intense monitoring, immediate responses, and sophisticated escalation procedures. The costs have risen, however, and proactive practices are only in their infancy stage.

This WP will deliver methodologies and analysis capabilities to move from reactive to proactive maintenance, starting with obtaining metrics for major component severity damage levels to quantify remaining useful life.

# Work Package and Focus Area Interactions



# Attribution

This work was supported by the U.S. Department of Energy under Contract No. DE-AC36-08GO28308 with the National Renewable Energy Laboratory. Funding for the work was provided by the DOE Office of Energy Efficiency and Renewable Energy, Wind and Water Power Technologies Office.



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