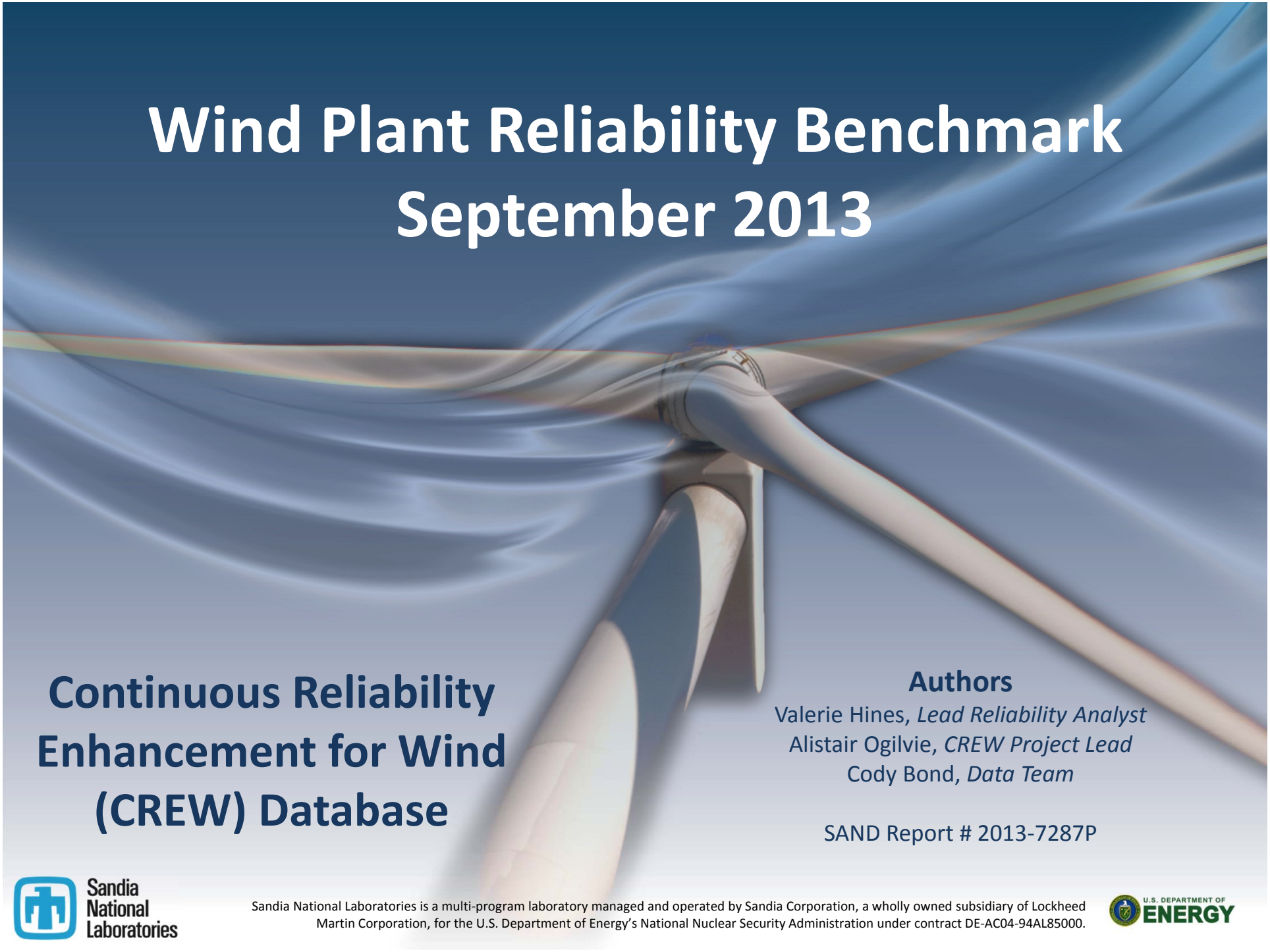
Wind Plant Reliability Benchmark
September 2013



Continuous Reliability Enhancement for Wind (CREW) Database

Authors

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U.S. DEPARTMENT OF ENERGY

Acknowledgements

- This public benchmark report is the third industry report to be issued under the Continuous Reliability Enhancement for Wind (CREW) national database project. The CREW project is guided and funded by the Department of Energy, Energy Efficiency and Renewable Energy program office.
- Sandia National Laboratories would like to acknowledge the contributions of both Strategic Power Systems and the wind plant owner/operators who participated in the development of the CREW database as pilot partners. These partners include enXco Service Corporation, Shell WindEnergy Inc., Xcel Energy, and Wind Capital Group.
- Data gathered from individual partners is proprietary and is only used in an aggregated manner, in order to protect data privacy.

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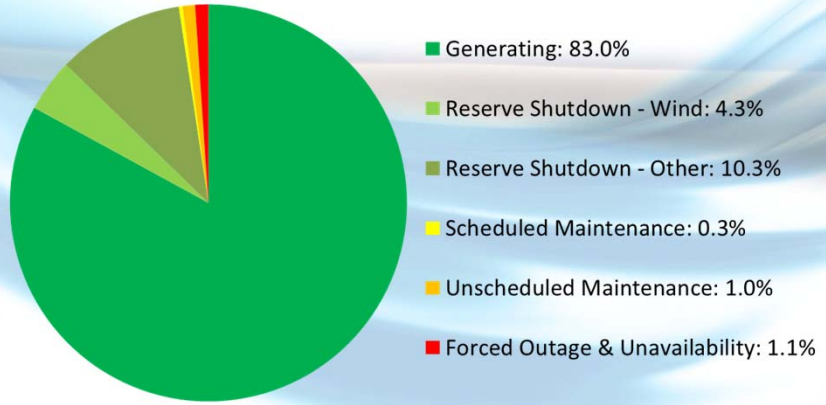
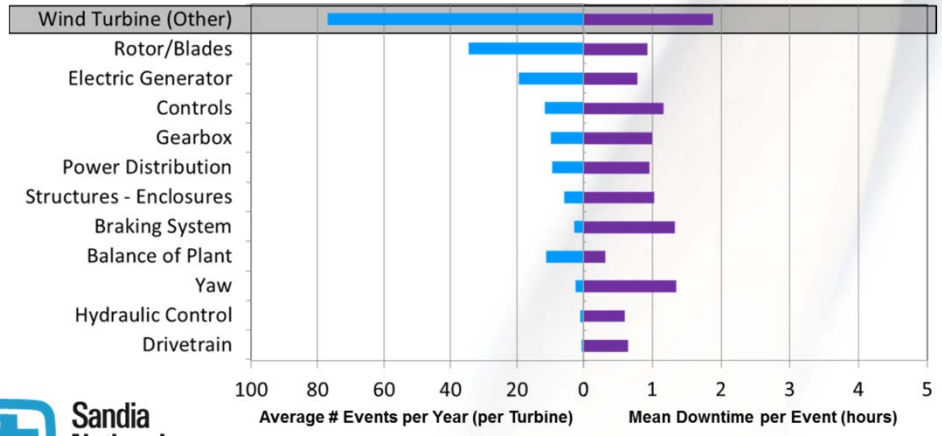
Results at a Glance



- Data represents 327,000 turbine-days
- Key metrics all slightly improved, compared to 2012

	2013 Benchmark	2012 Benchmark
Operational Availability	97.6%	97.0%
Utilization	83.0%	82.7%
Capacity Factor	36.1%	36.0%
MTBE (hrs)	39	36
Mean Downtime (hrs)	1.3	1.6

- Average: 1.6 days of generating before each downtime event
  - Some events automatically reset, others need intervention



- Gearbox not in top 5 systems
  - Benchmarking faults and symptoms, at this point
  - Current emphasis on electronic work orders for wind industry

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Event & SCADA Data Source: SPS ORAPWind

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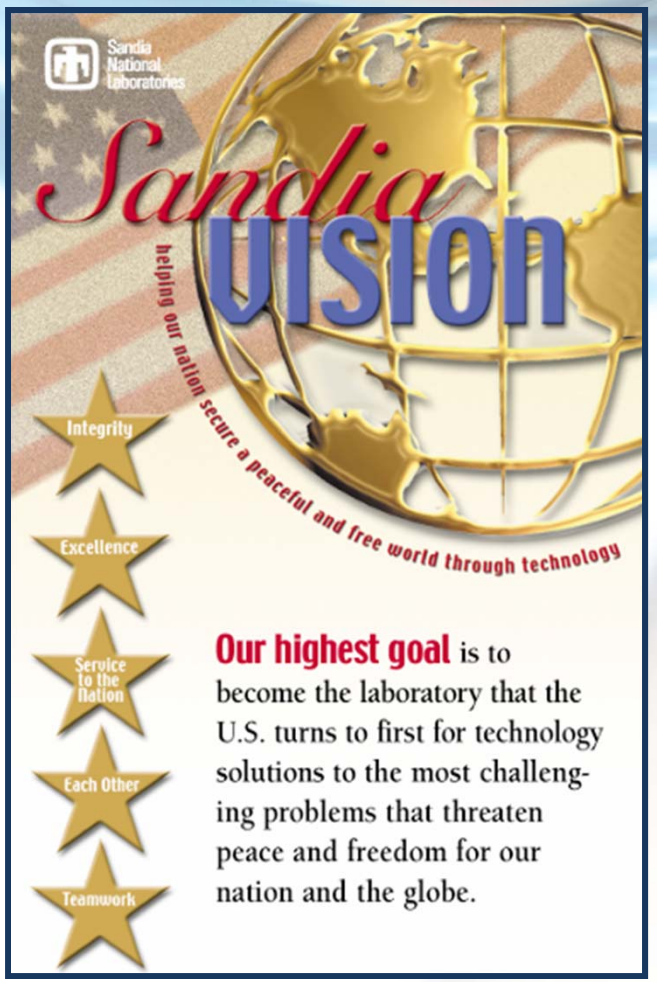
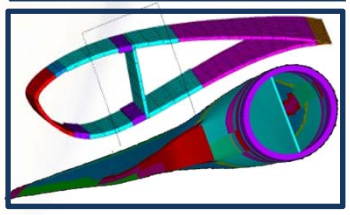
Exceptional Service in the National Interest





Wind Energy Technologies Department

FOCUS

- Industry needs
- Reducing energy cost
- Promoting large-scale deployment of clean, affordable energy

GOALS

- High fidelity modeling
- Blade design to eliminate barriers
- Increased energy capture & improved efficiency
- **Increased system reliability**
- Testing at reduced cost

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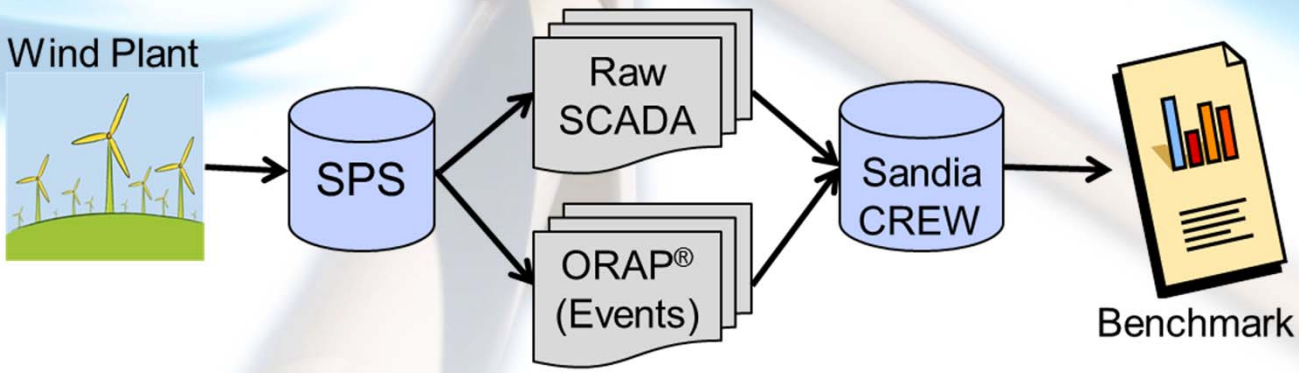
CREW: Continuous Reliability Enhancement for Wind

Goal: Create a national reliability database of wind plant operating data to enable reliability analysis

Method:

Sandia partners with Strategic Power Systems (SPS), whose ORAPWind® software collects real-time data from wind plant partners



Key Objectives:

- **Benchmark reliability performance**
- Track operating performance at a system-to-component level
- Characterize issues and identify technology improvement opportunities
- Protect proprietary information
- Enable operations and maintenance cost reduction
- Increase confidence from financial sector and policy makers

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ORAPWind™ Performance Dashboard

- Cloud based online analysis – 24x7
- RAM and Performance data analysis
- One minute statistical data – everyone else uses 10 minute data
- ORAP® Transformed data
- Fault / Event analysis
- Industry benchmarks
- IEC / IEEE Availability reporting
- NERC GADS reporting
- Data Completeness and Quality monitoring metrics

ORAPWind.spsinc.com

Results and Discussion

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Fleet Representation

- CREW represents 2.7% of U.S. turbines
  - 2.4% of Megawatts; 1.9% of plants
- Operations breadth from partners yields a dataset with a useful view of the U.S. fleet's performance
  - Though results may not be fully representative

# Plants	10
# Turbines	800-900
# Megawatts	1,300-1,400
# Manufacturers	3
# Turbine Models	6
# Turbine-Days, Information Available	327,000

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CREW Fleet Metrics

- Key metrics all improved slightly over 2012 values
  - Likely due to a variety of factors, including actual performance improvement and improved data quality
- Operational Availability & Capacity Factors are in alignment with data & anecdotes from operators and OEMs, but higher than other 3rd party benchmarks

	2013 Benchmark	2012 Benchmark	2011 Benchmark
Operational Availability	97.6%	97.0%	94.8%
Utilization	83.0%	82.7%	78.5%
Capacity Factor	36.1%	36.0%	33.4%
MTBE (hrs)	39	36	28
Mean Downtime (hrs)	1.3	1.6	2.5

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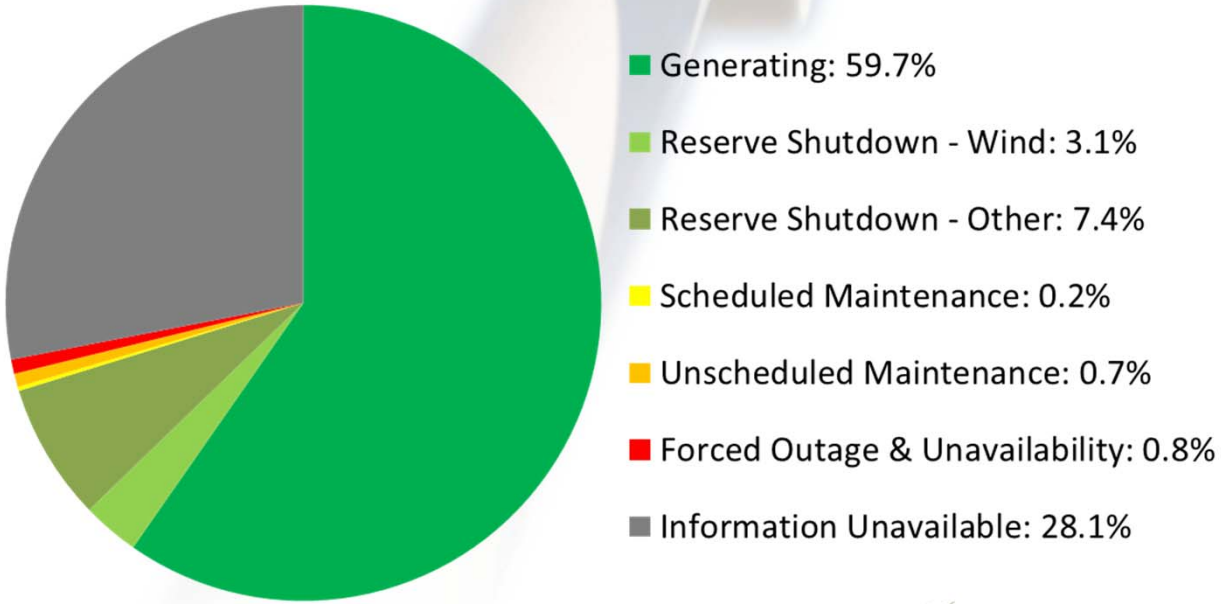
Event & SCADA Data Source: SPS ORAPWind

Availability Time Accounting

- SCADA and data transfer challenges lead to time with Information Unavailable
  - Analysis needs to highlight the common communication and IT issues resulting in missing data
  - CREW, SPS, and plants are actively identifying these industry-wide issues & addressing them where possible



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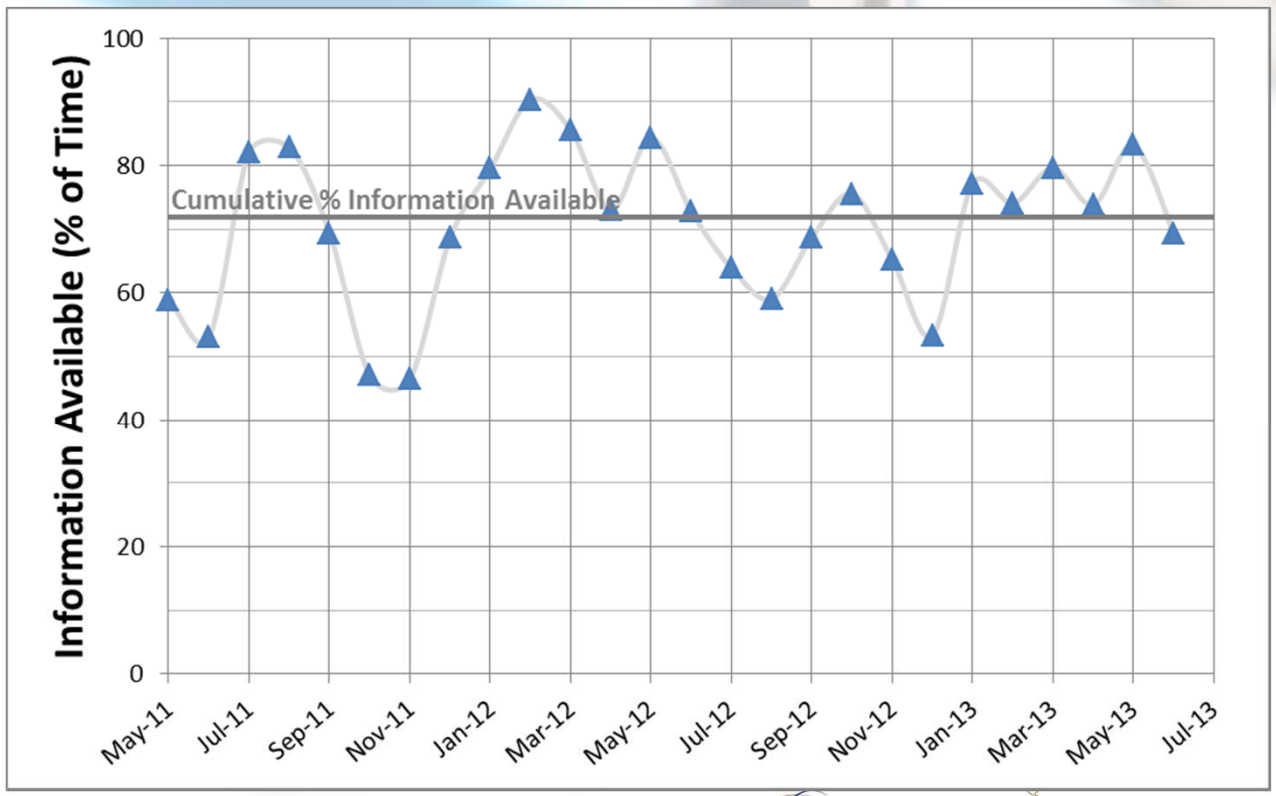
Event & SCADA Data Source: SPS ORAPWind

Improvements in Information Available

- Information Available improved over 2012 Benchmark
  - Higher overall average AND less month-to-month variability

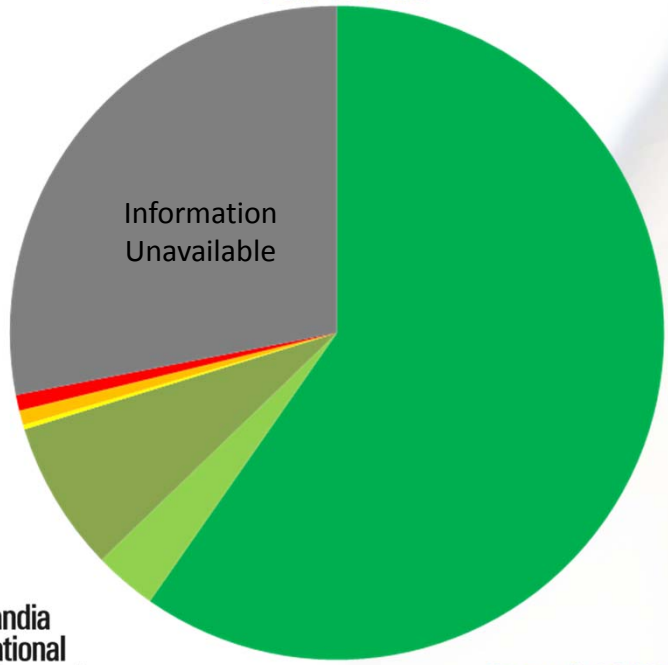


Event & SCADA Data Source: SPS ORAPWind

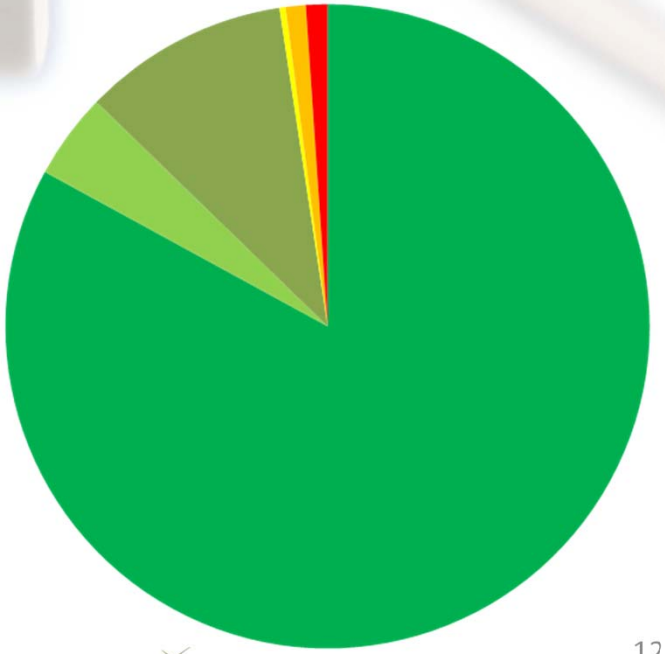
Focusing on What is Known

- Did not assume turbine's status
  - Essentially treated this time as if it never existed
- In addition to understanding impact of Information Unavailable, also explore after removing this time

All Data



Information Available



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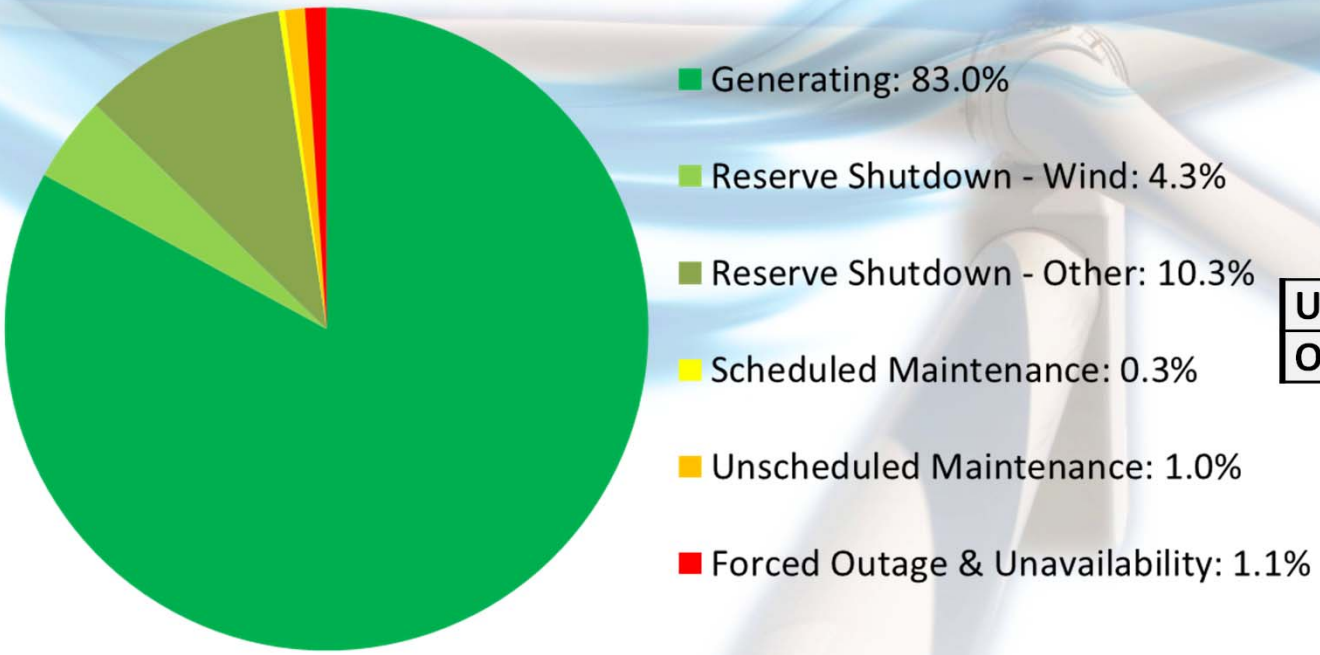
Event & SCADA Data Source: SPS ORAPWind

Availability Time Accounting

Information Available



Utilization	83.0%
Operational Availability	97.6%

- Utilization = Generating
- Operational Availability
  = Generating + Reserve Shutdown Wind + Reserve Shutdown Other
- Can calculate other metrics of interest from these categories
  - Example: Technical Availability
    = (Generating + Reserve Shutdown Wind + Reserve Shutdown Other)
    /(100%-Scheduled Maintenance)

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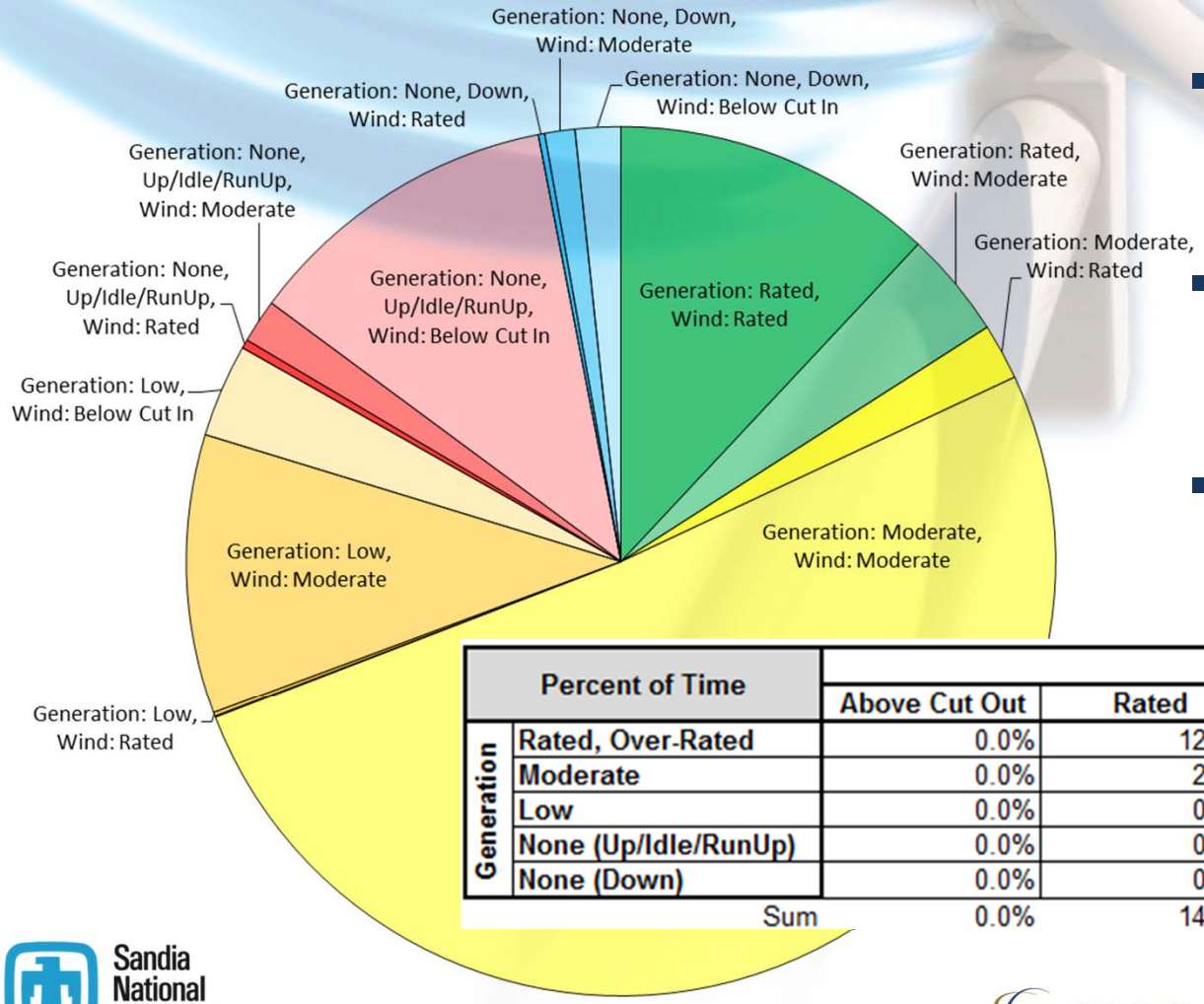
Event & SCADA Data Source: SPS ORAPWind

Wind Speed & Generation Time Accounting

Information Available

- Categories show what the turbine is doing and what the wind is doing
- Incorporates Environmental Impact (Wind Speed) on Turbine (Generation)



- 3.3% of the time, the wind is good but the turbines are not ready
- 56% of downtime happens when wind is below Cut In
- Rated generation (90%+) 16% of the time

Percent of Time		Wind				
		Above Cut Out	Rated	Moderate	Below Cut In	Sum
Generation	Rated, Over-Rated	0.0%	12.0%	4.0%	0.0%	15.9%
	Moderate	0.0%	2.1%	51.1%	0.0%	53.2%
	Low	0.0%	0.1%	10.4%	3.5%	14.0%
	None (Up/Idle/RunUp)	0.0%	0.3%	1.6%	11.8%	13.8%
	None (Down)	0.0%	0.2%	1.1%	1.7%	3.0%
	Sum	0.0%	14.8%	68.2%	17.0%	100.0%

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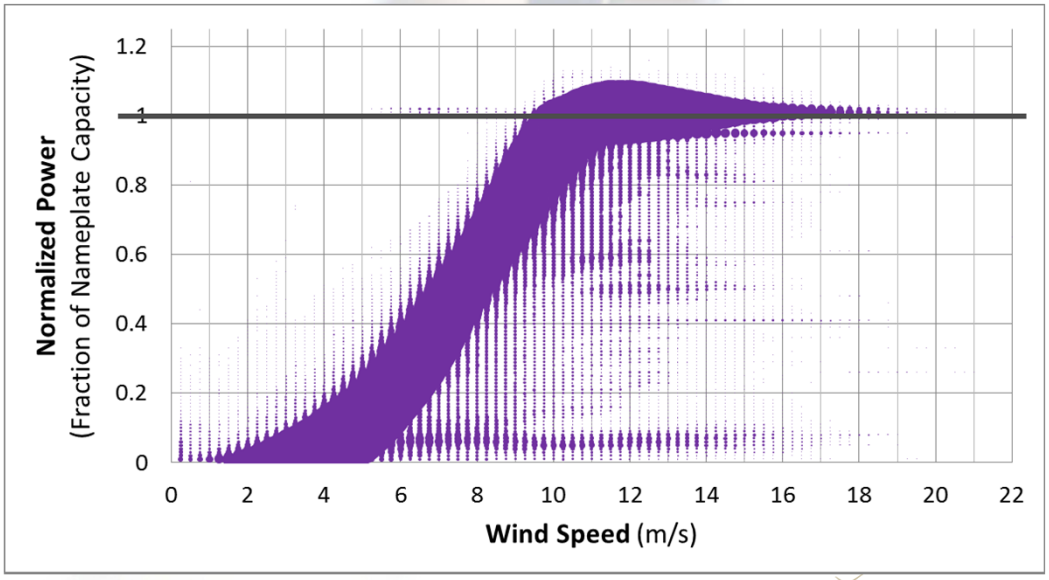
Event & SCADA Data Source: SPS ORAPWind

Power Curve

- Real-world variability
- Under performance
  - Below and right of main curve (“paint drips”)
  - Examples include ramp up/down, true performance issues, intentional setting changes (e.g., decrease noise or extend the life of a failing part)
- Over-performance
  - Above thick gray line
  - Generation (10 minute average) above 1.02 times nameplate capacity 0.54% of the time (47 hours/turbine/year); up from 2012 Benchmark



Event & SCADA Data Source: SPS ORAPWind

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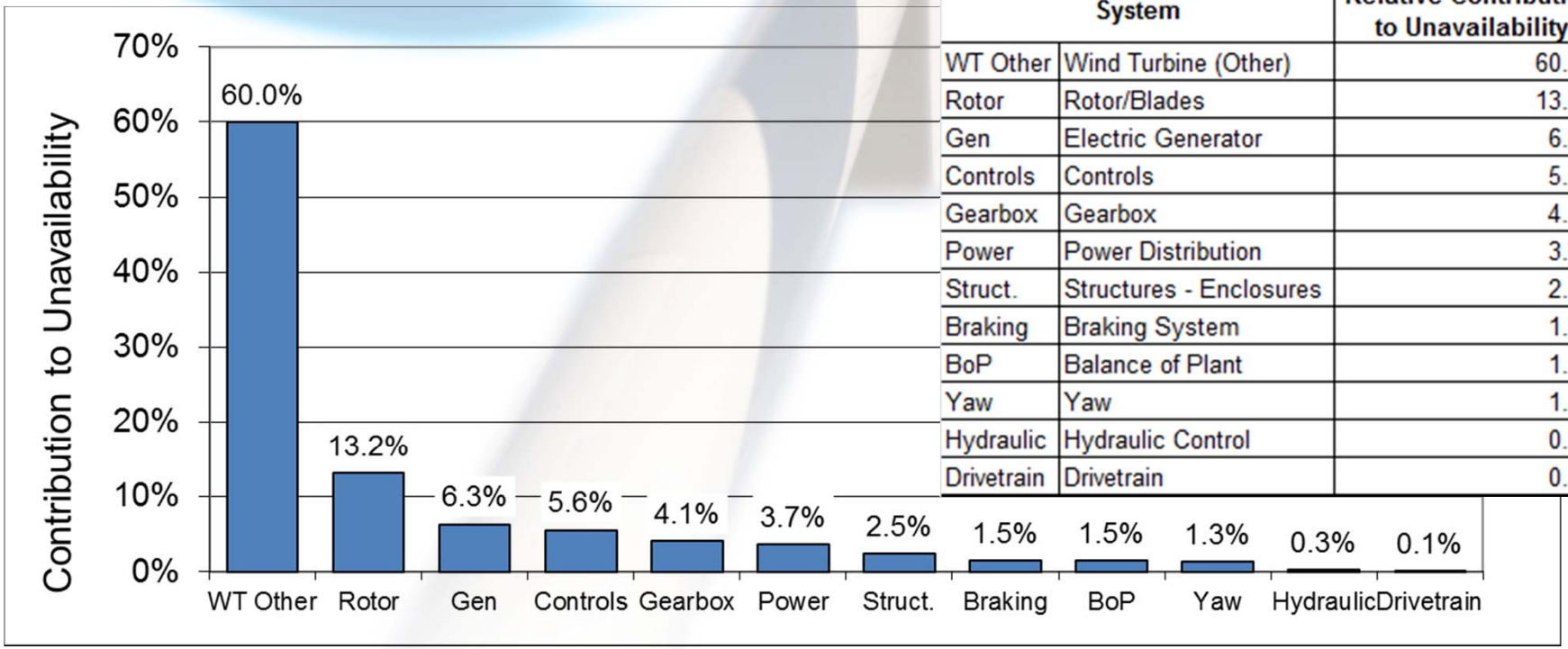
Unavailability Contributors: Systems

- **Unavailability**: combined impact of event frequency (how often) and downtime (how long)
- Dominated by "Wind Turbine (Other)" events
  - Mainly when technician has turbine in maintenance/repair mode
  - Down to 60%, from a high of 71.7% in 2011



System		Relative Contribution to Unavailability
WT Other	Wind Turbine (Other)	60.0%
Rotor	Rotor/Blades	13.2%
Gen	Electric Generator	6.3%
Controls	Controls	5.6%
Gearbox	Gearbox	4.1%
Power	Power Distribution	3.7%
Struct.	Structures - Enclosures	2.5%
Braking	Braking System	1.5%
BoP	Balance of Plant	1.5%
Yaw	Yaw	1.3%
Hydraulic	Hydraulic Control	0.3%
Drivetrain	Drivetrain	0.1%

SCADA faults tend to indicate symptom, not necessarily root cause

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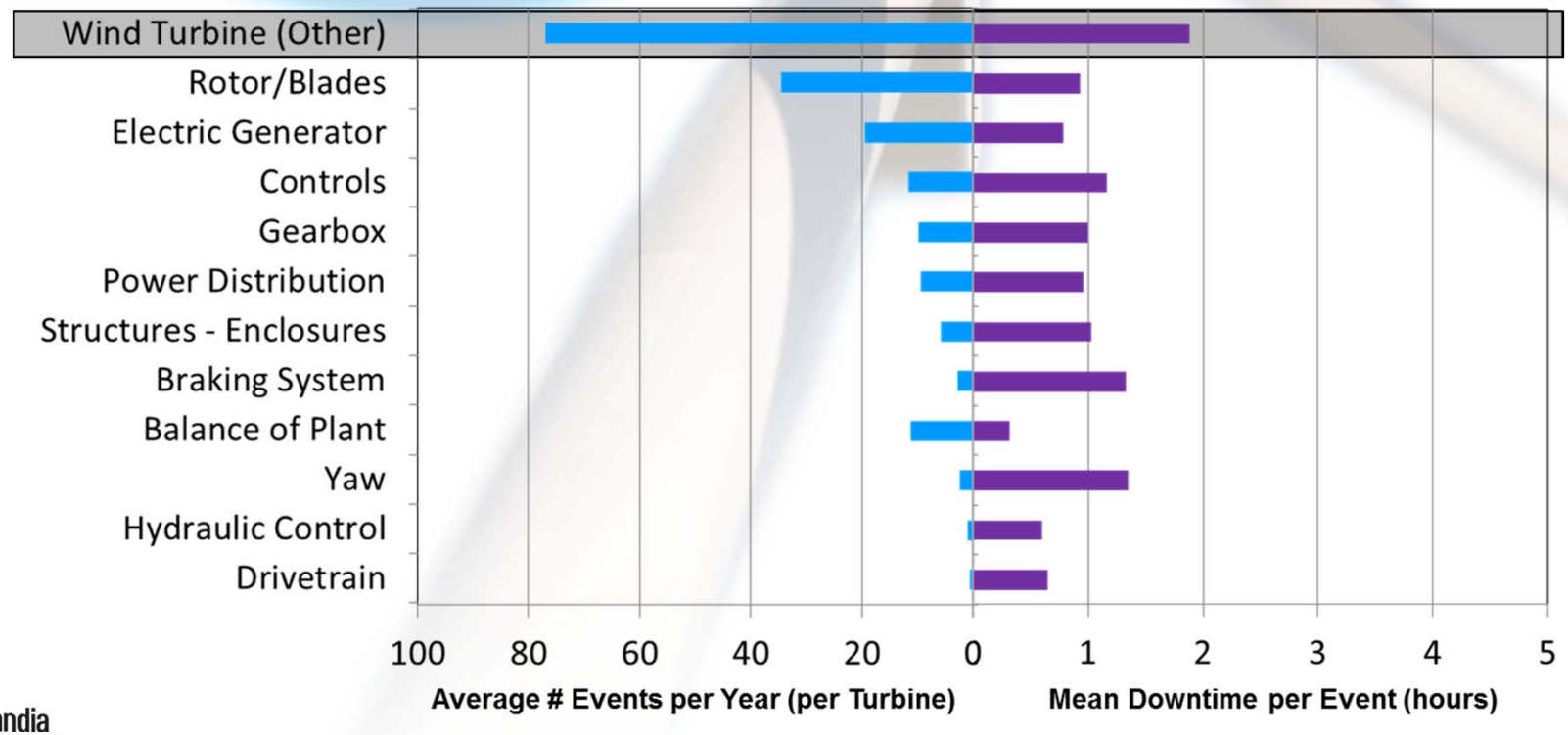
Event & SCADA Data Source: SPS ORAPWind

Event Frequency vs. Downtime

- Sorted by Unavailability Contribution
- Aside from “Wind Turbine (Other)”, Rotor/Blades & Generator have most frequent events
- Relatively little variability in mean downtime



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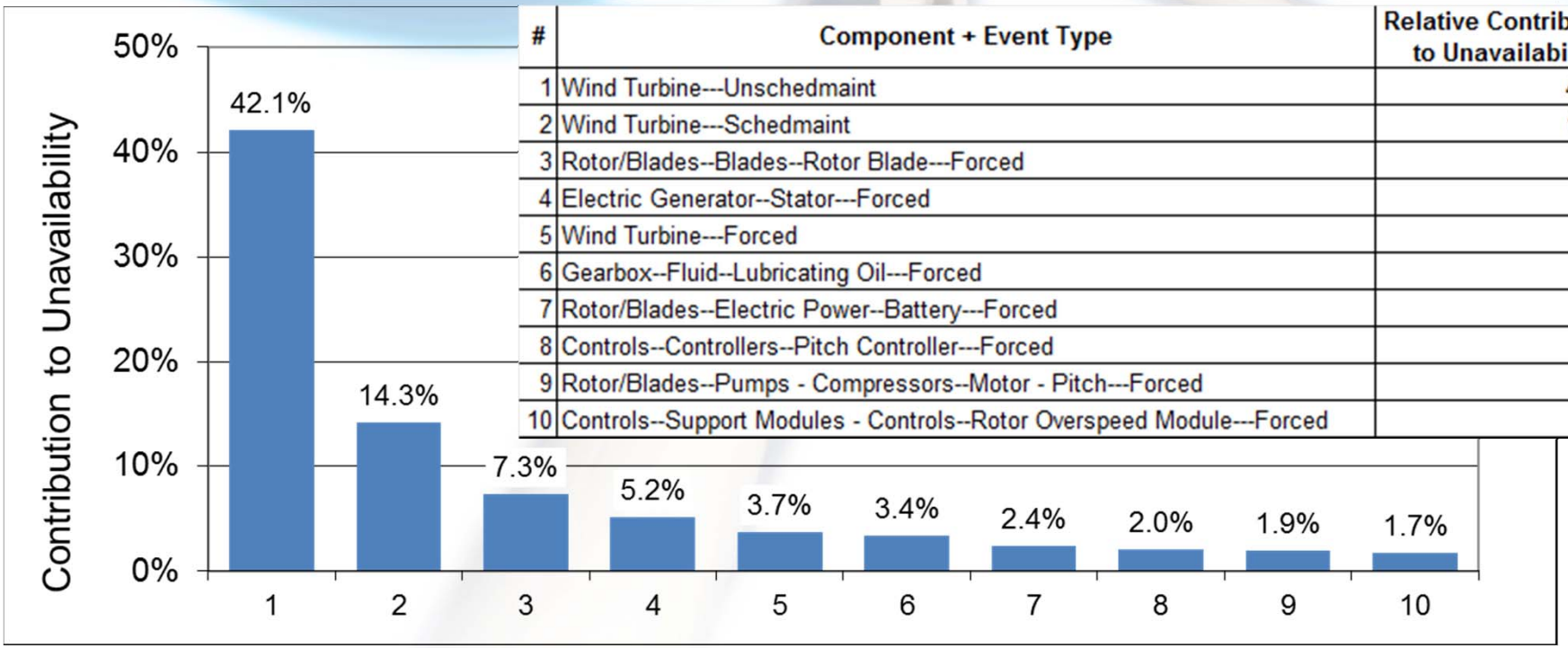
Event & SCADA Data Source: SPS ORAPWind

Unavailability Contributors: Components + Event Types

- Dominated by general events, but their influence is lessening
  - "Wind Turbine" accounts for 60% of unavailability
  - Unscheduled & Scheduled Maintenance: technician has turbine in maintenance/repair mode
    - Work Orders are critical for establishing root cause



#	Component + Event Type	Relative Contribution to Unavailability
1	Wind Turbine---Unschedmaint	42.1%
2	Wind Turbine---Schedmaint	14.3%
3	Rotor/Blades--Blades--Rotor Blade---Forced	7.3%
4	Electric Generator--Stator---Forced	5.2%
5	Wind Turbine---Forced	3.7%
6	Gearbox--Fluid--Lubricating Oil---Forced	3.4%
7	Rotor/Blades--Electric Power--Battery---Forced	2.4%
8	Controls--Controllers--Pitch Controller---Forced	2.0%
9	Rotor/Blades--Pumps - Compressors--Motor - Pitch---Forced	1.9%
10	Controls--Support Modules - Controls--Rotor Overspeed Module---Forced	1.7%

SCADA faults tend to indicate symptom, not necessarily root cause

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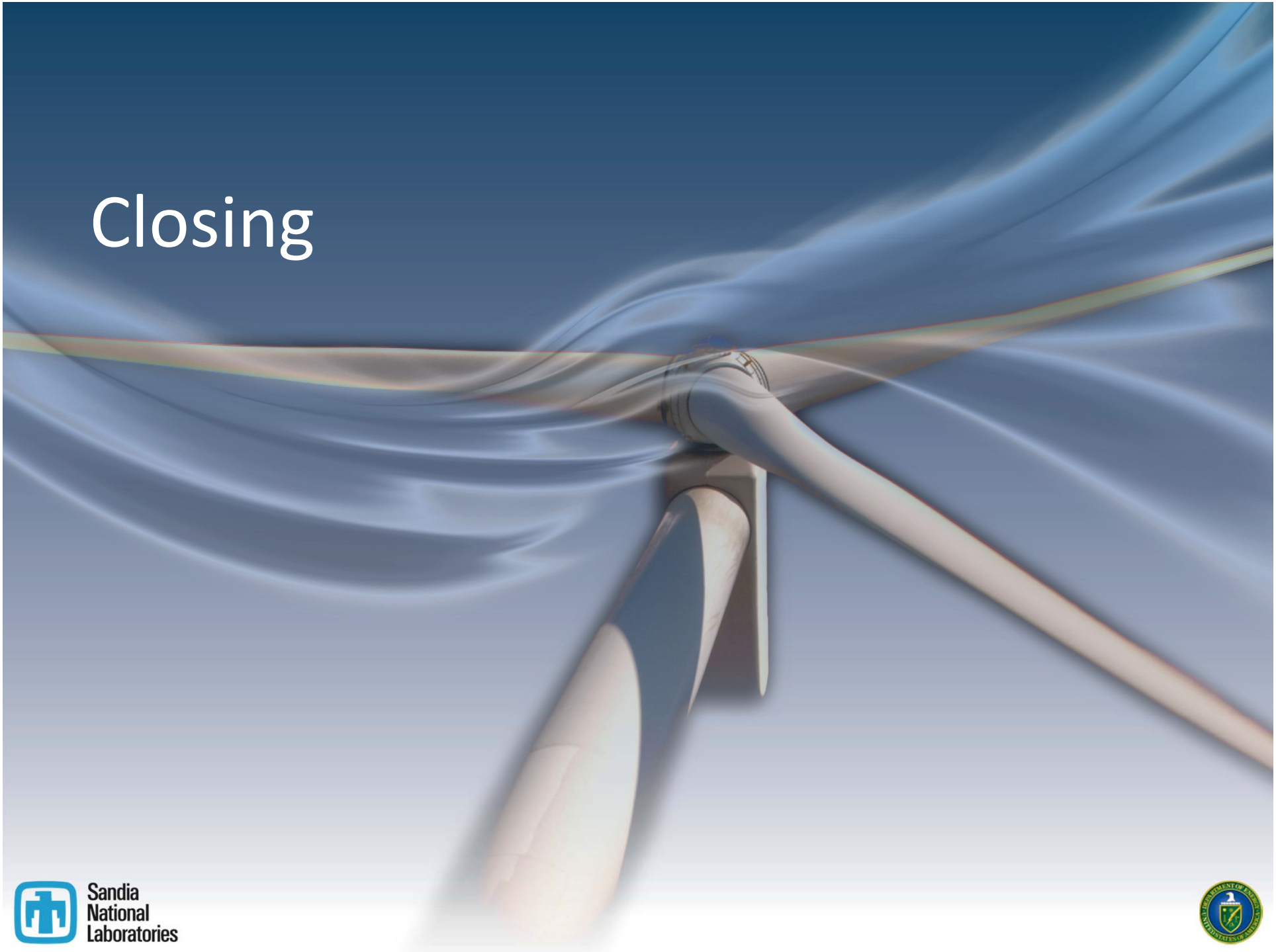
Event & SCADA Data Source: SPS ORAPWind

Closing



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Observations

- Analysis Results Are Stabilizing
  - Operational Availability, Utilization, and Capacity Factor each increased by less than 1% (compared to 2012 Benchmark)
  - Top 3 system-level unavailability contributors were identical to 2012
    - 8 of top 10 component-level contributors were identical, too
  - Results stabilization, combined with industry alignment on key metrics, provides a foundation for industry representation
- Electronic Work Orders
  - Work Order information is critical to understanding a complete reliability picture, including component-level root cause insights
    - Gearbox still absent from top 3 system-level unavailability contributors; likely due to SCADA's limited insight into major repairs
- Event Frequency
  - Scheduled and Unscheduled Maintenance Events occur, on average, every 1.9 weeks for each turbine
  - Because the events are based on SCADA data, there are many short duration and nearly back-to-back events
    - These Maintenance events occur every 3.8 weeks, if only counting events that last at least 1.5 hours and are at least 4 hours apart

Accessing More Information

- The companion technical report on the 2013 Benchmark can be found at http://energy.sandia.gov/crewbenchmark
- Sandia keeps an archive of our past wind plant reliability publications at http://energy.sandia.gov/?page_id=3057#WPR

- All U.S. wind plant owners, operators and OEM's are invited to participate. Please contact:

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- The data in the CREW database is proprietary to our partners. We are not able to disclose non-aggregated data.
  - Due to a large volume of requests and limited funding, Sandia is not able to provide customized subsets of aggregated data outside the Department of Energy's Energy Efficiency and Renewable Energy program.
  - Strategic Power Systems, our corporate partner in this effort, may be able to assist with more information about wind plant reliability. For more information, please contact SPS' Jim Thomas.