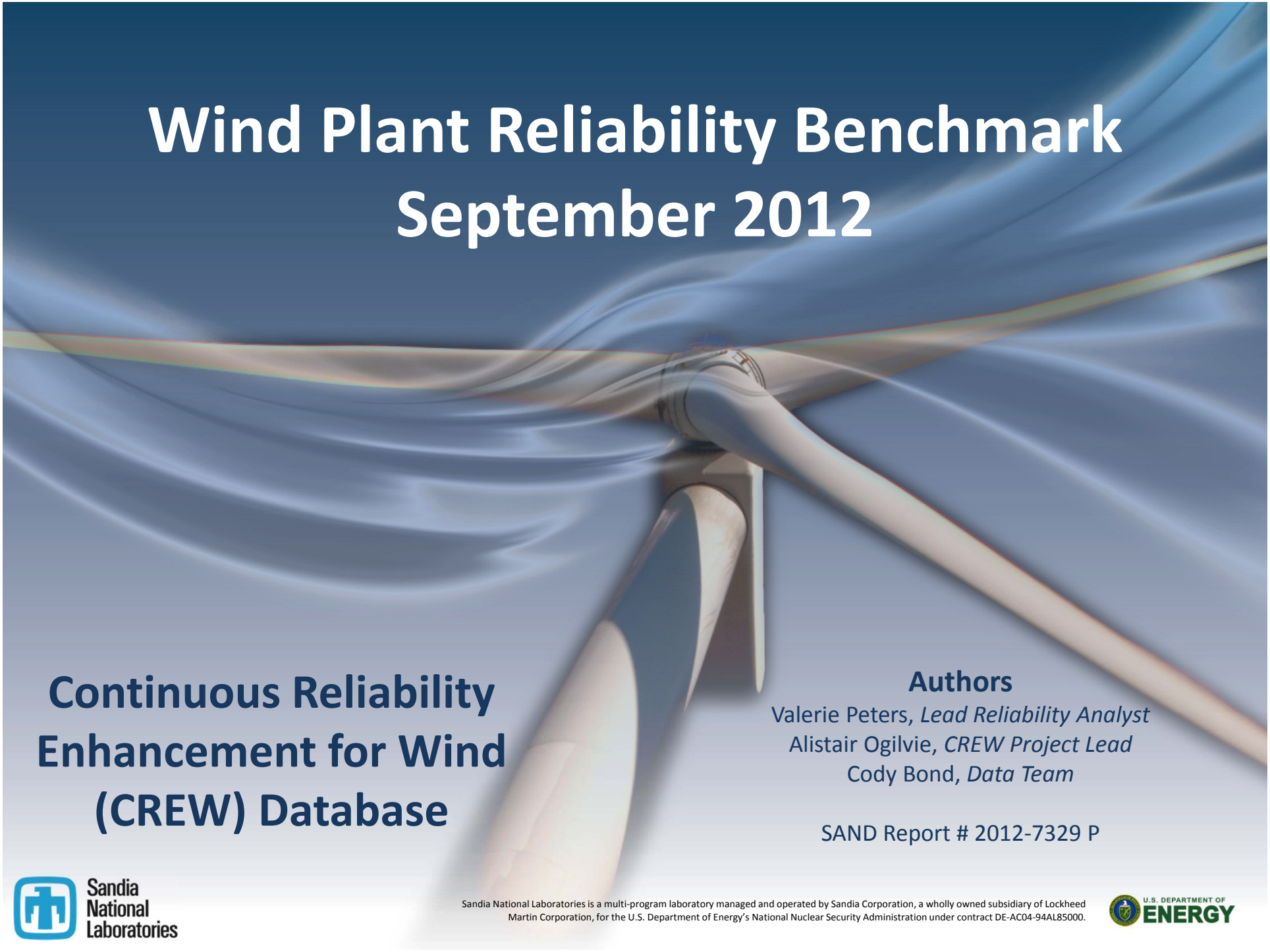
Wind Plant Reliability Benchmark
September 2012



Continuous Reliability Enhancement for Wind (CREW) Database

Authors

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SAND Report # 2012-7329 P

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U.S. DEPARTMENT OF ENERGY

Acknowledgements

- This public benchmark report is the second 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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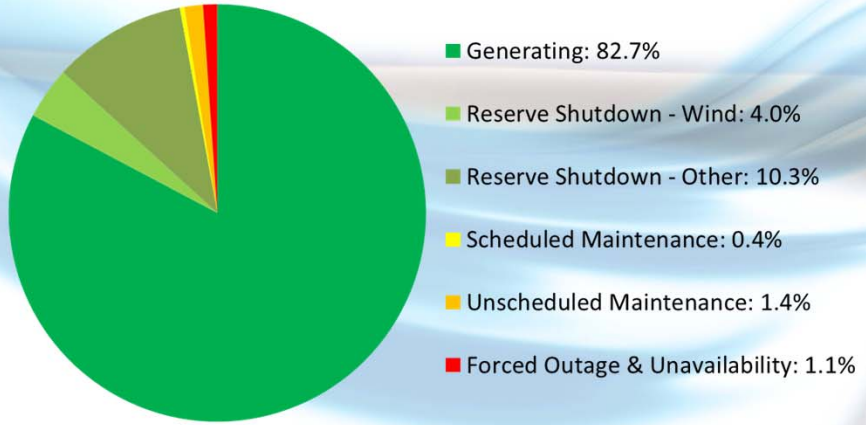
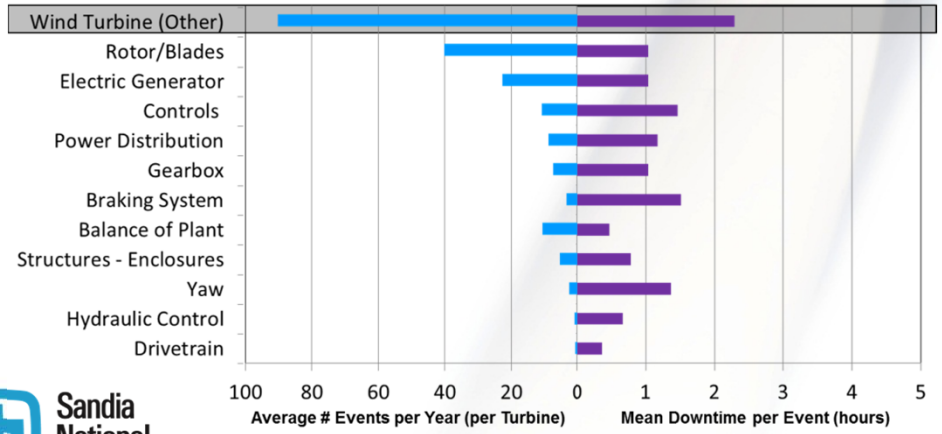
Results at a Glance



- Average: 1.5 days of generating before each downtime event
  - Some events automatically reset, others need intervention



- Data represents 180,000 turbine-days
- Key metrics all improved, compared to 2011

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

- Gearbox not in top 5 systems
  - Benchmarking faults and symptoms, at this point
  - 2012/2013 emphasis on electronic work orders for wind industry

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Event & SCADA Data Source: SPS ORAPWind

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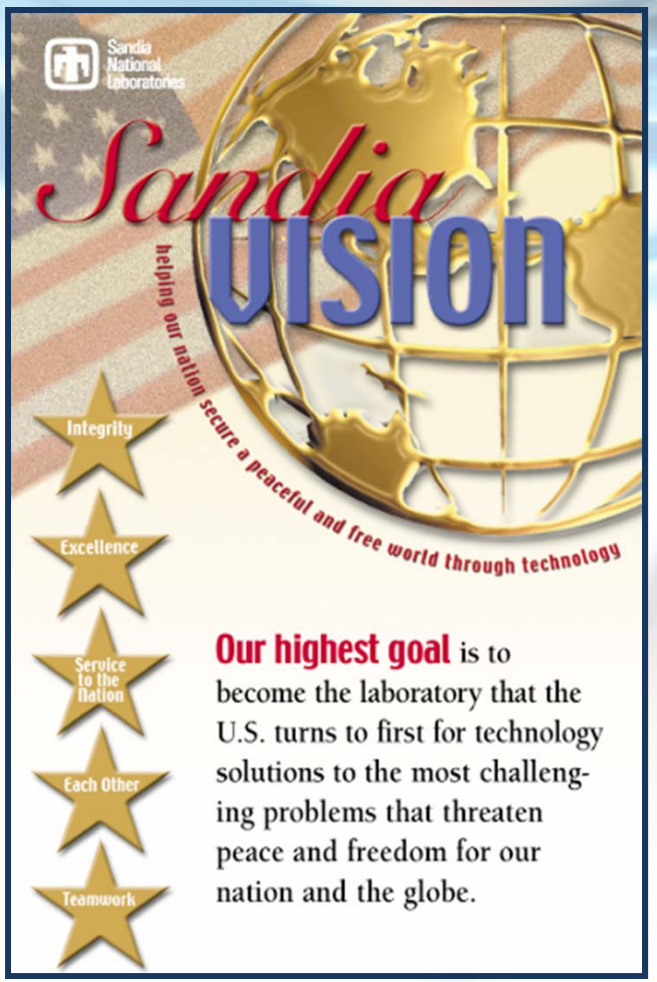
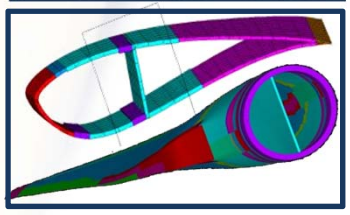
Exceptional Service in the National Interest





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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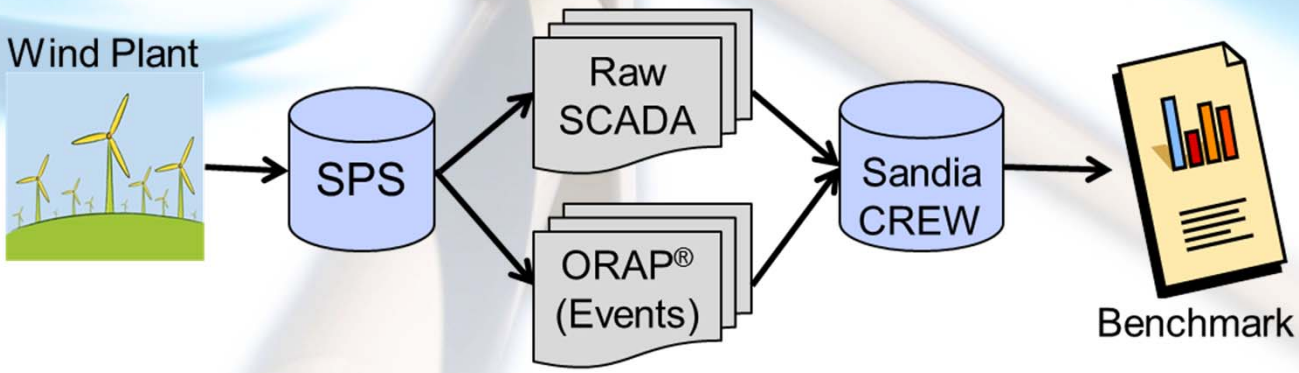
CREW: Continuous Reliability Enhancement for Wind

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

- Results are still “directional”
  - Based heavily on data collected during CREW & ORAPWind® development
  - Database does not yet represent a significant portion of the U.S. wind fleet
- However, data quality & operations breadth from early partners yields a dataset with a useful initial view of the U.S. fleet’s performance

# Plants	10
# Turbines	800-900
# Megawatts	1,300-1,400
# Manufacturers	3
# Turbine Models	6
# Turbine-Days, Known Time	180,000

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CREW Fleet Metrics

- Key metrics all improved over 2011 values
  - Likely due to a variety of factors, including actual performance improvement, presence of all four seasons, 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
  - Also higher than 2011 CREW Benchmark

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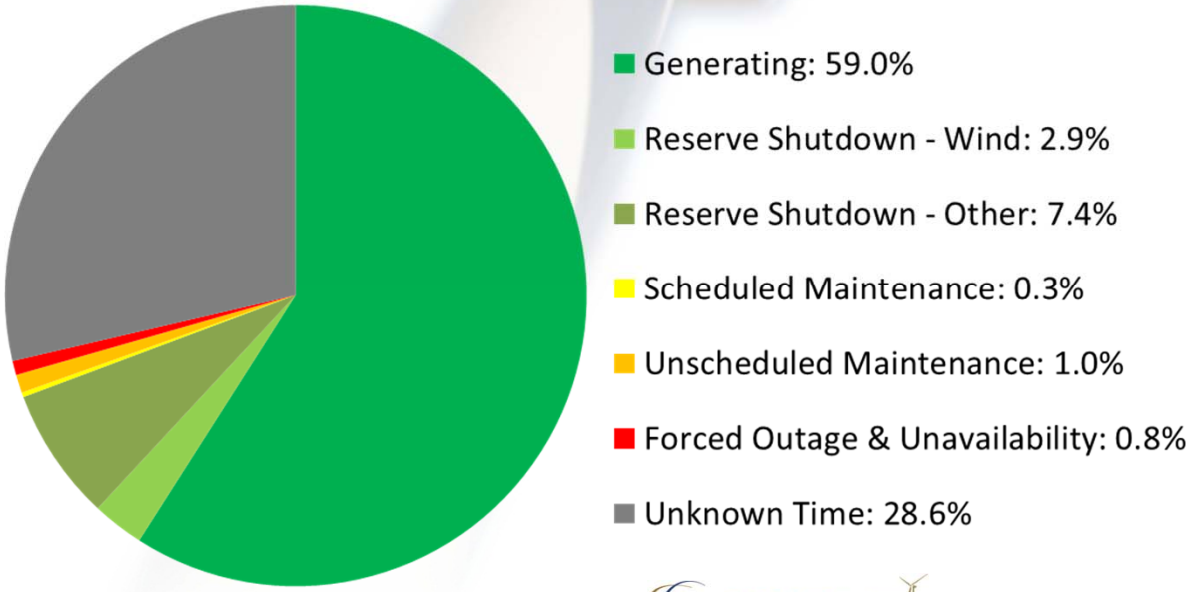
Event & SCADA Data Source: SPS ORAPWind

Availability Time Accounting

- SCADA and data transfer challenges lead to "Unknown Time"
  - 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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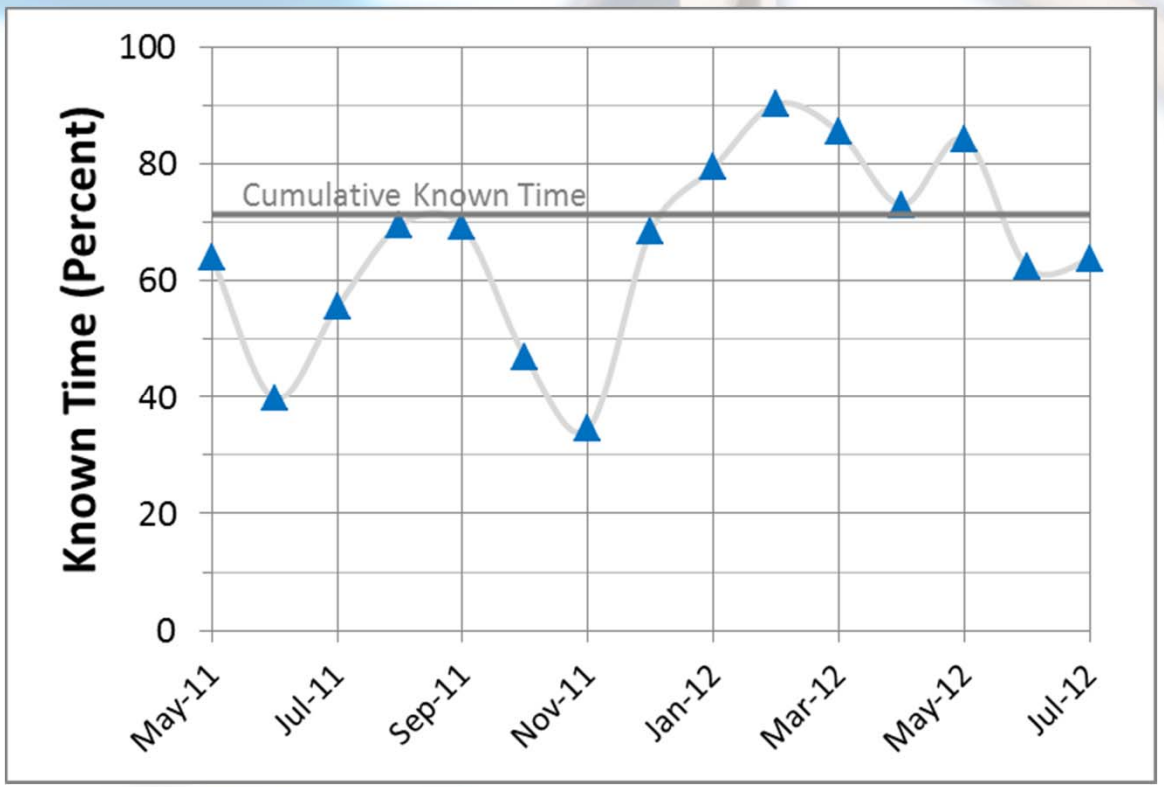
Event & SCADA Data Source: SPS ORAPWind

Improvements in Known Time

- Substantial portion of CREW Unknown Time is attributable to pilot program & beta testing
  - Cumulative Known Time is greater than any month in 2011!



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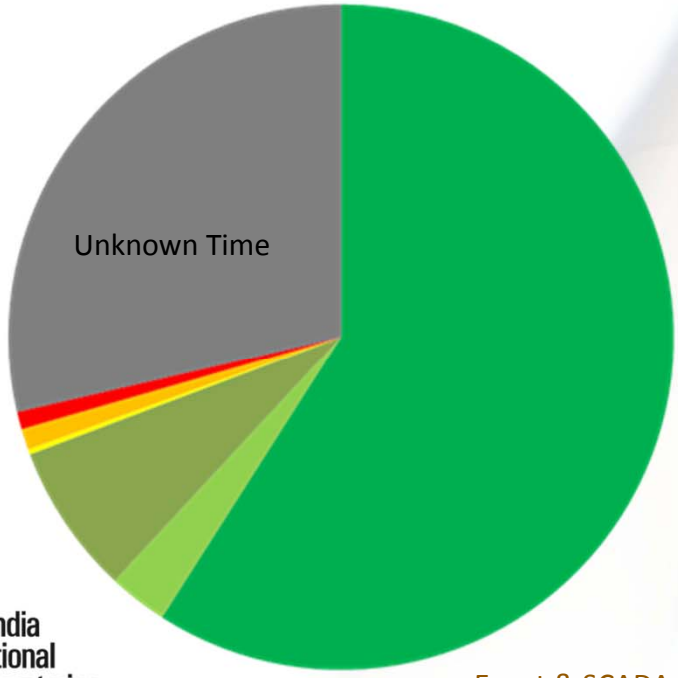
Event & SCADA Data Source: SPS ORAPWind

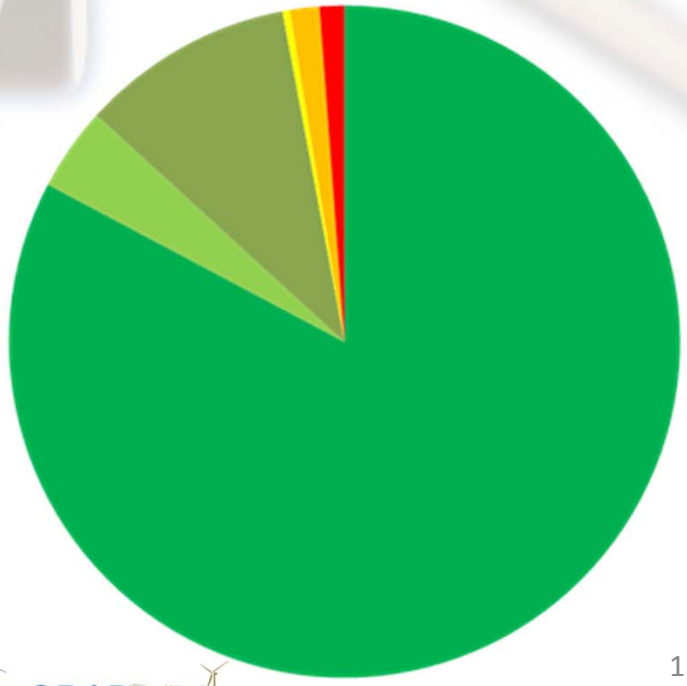
Focusing on What is Known

- In addition to understanding Unknown Time impact, also explore results after this time is removed
  - Essentially treated as if it never existed; did not assume turbine's status

All Data



Unknown Time Removed



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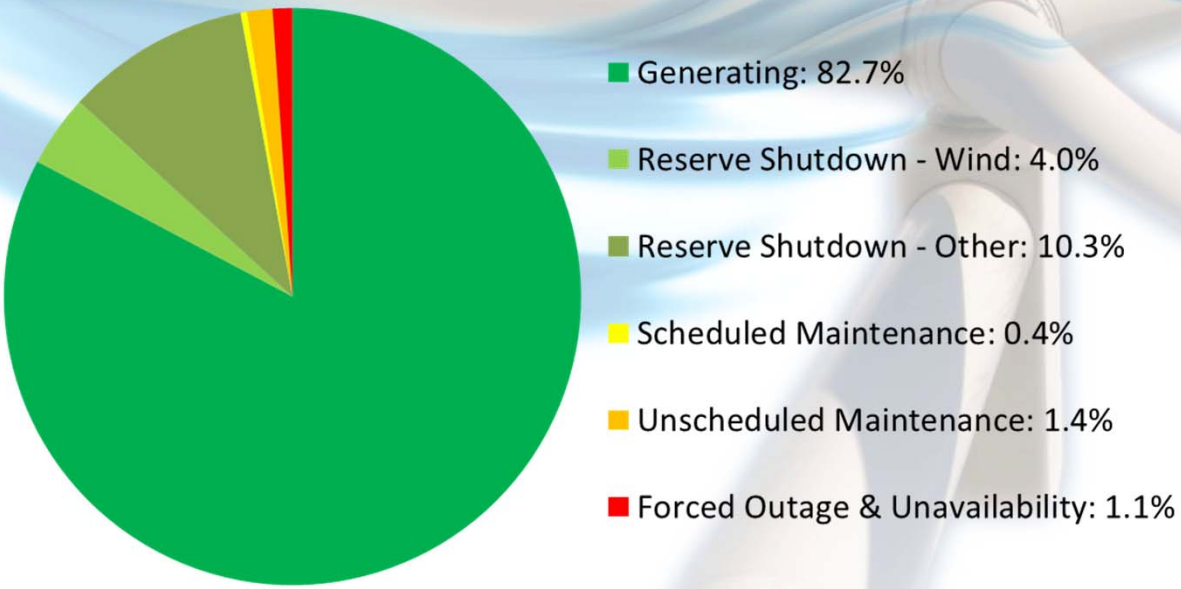
Event & SCADA Data Source: SPS ORAPWind

Availability Time Accounting

Only Known Time



Utilization (aka Generating Factor)	82.7%
Operational Availability	97.0%

- 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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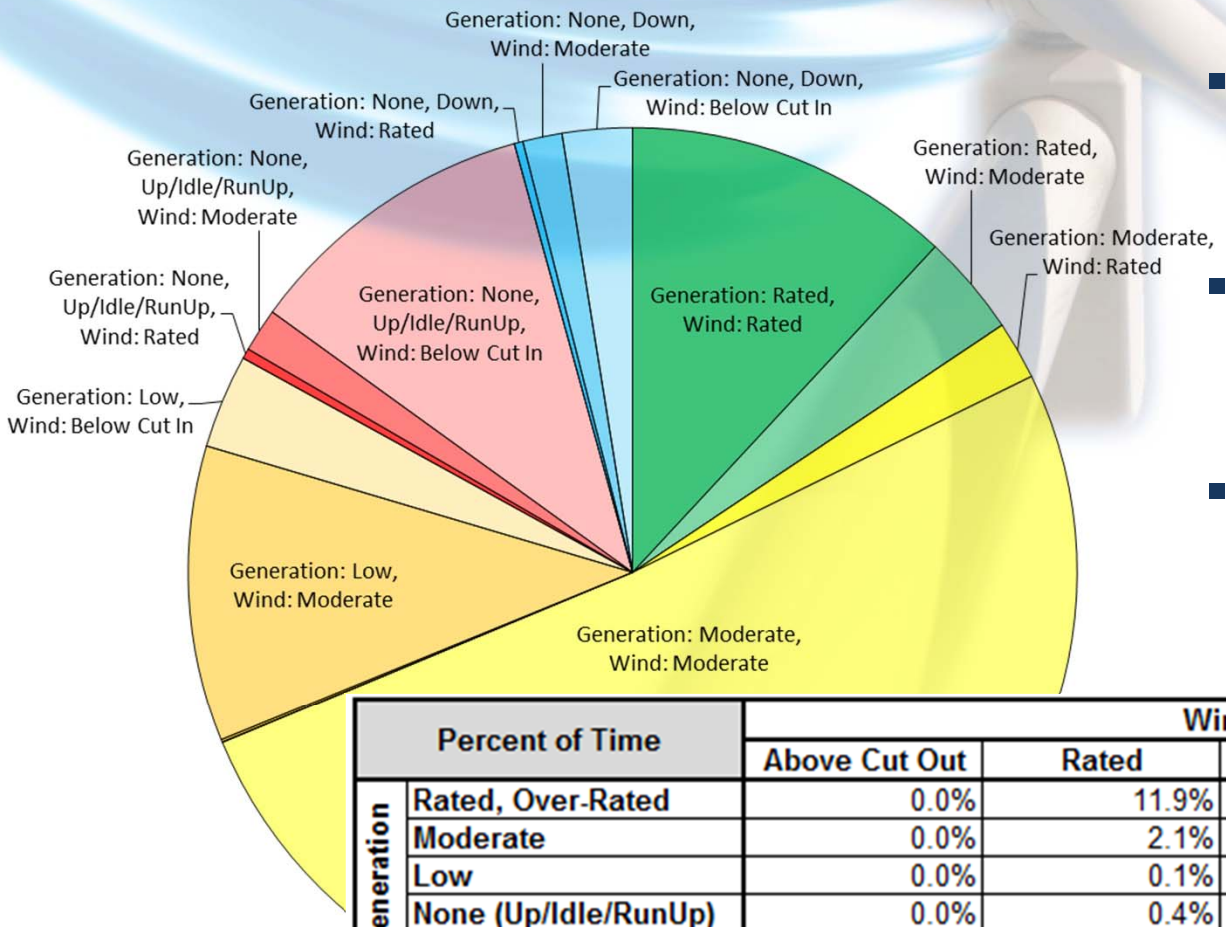
Event & SCADA Data Source: SPS ORAPWind

Wind Speed & Generation Time Accounting

Only Known Time

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



- 3.7% of the time, the wind is good but the turbines are not ready
- 60% of downtime happens when wind is below Cut In
- Rated generation (90%+) 15.6% of the time

Percent of Time		Wind				
		Above Cut Out	Rated	Moderate	Below Cut In	Sum
Generation	Rated, Over-Rated	0.0%	11.9%	3.7%	0.0%	15.6%
	Moderate	0.0%	2.1%	51.0%	0.0%	53.1%
	Low	0.0%	0.1%	10.8%	3.4%	14.3%
	None (Up/Idle/RunUp)	0.0%	0.4%	1.6%	10.8%	12.7%
	None (Down)	0.0%	0.3%	1.4%	2.5%	4.3%
	Sum	0.0%	14.8%	68.5%	16.7%	100.0%

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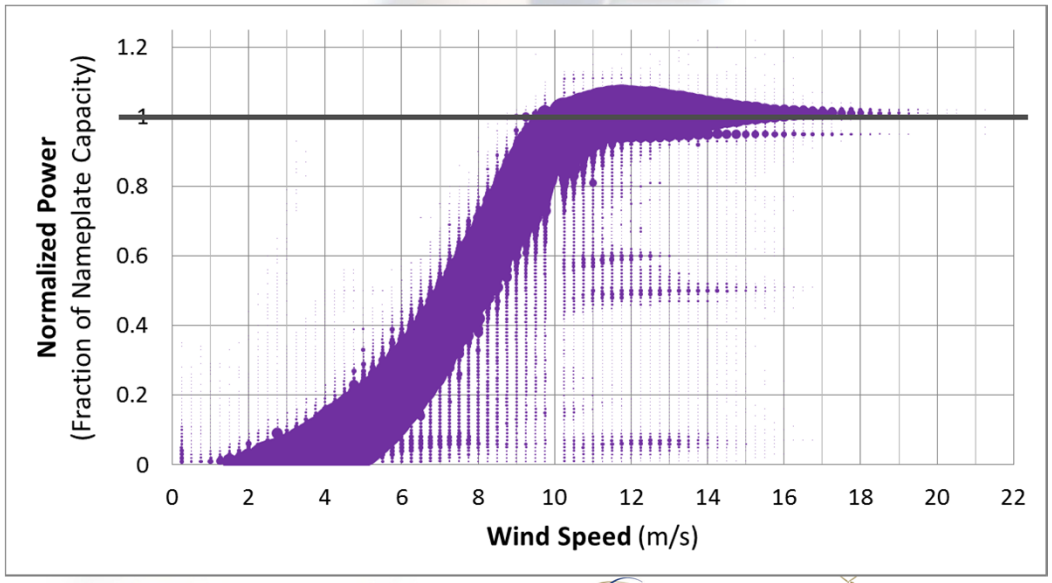
Event & SCADA Data Source: SPS ORAPWind

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 0.185% of the time (16.2 hours/turbine/year)



Event & SCADA Data Source: SPS ORAPWind

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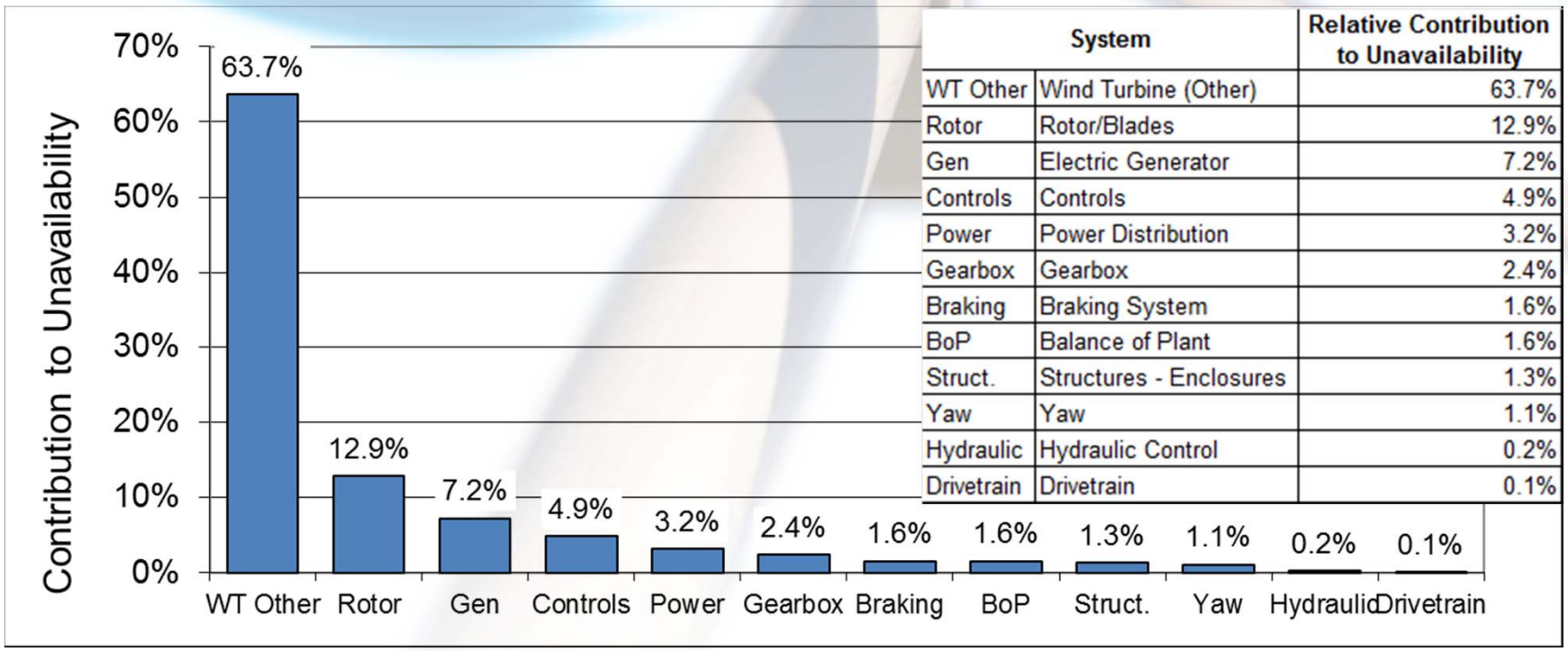
Unavailability Contributors: Systems

- **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 63.7%, from 71.7% in 2011



System		Relative Contribution to Unavailability
WT Other	Wind Turbine (Other)	63.7%
Rotor	Rotor/Blades	12.9%
Gen	Electric Generator	7.2%
Controls	Controls	4.9%
Power	Power Distribution	3.2%
Gearbox	Gearbox	2.4%
Braking	Braking System	1.6%
BoP	Balance of Plant	1.6%
Struct.	Structures - Enclosures	1.3%
Yaw	Yaw	1.1%
Hydraulic	Hydraulic Control	0.2%
Drivetrain	Drivetrain	0.1%

SCADA faults tend to indicate symptom, not necessarily root cause

Event & SCADA Data Source: SPS ORAPWind

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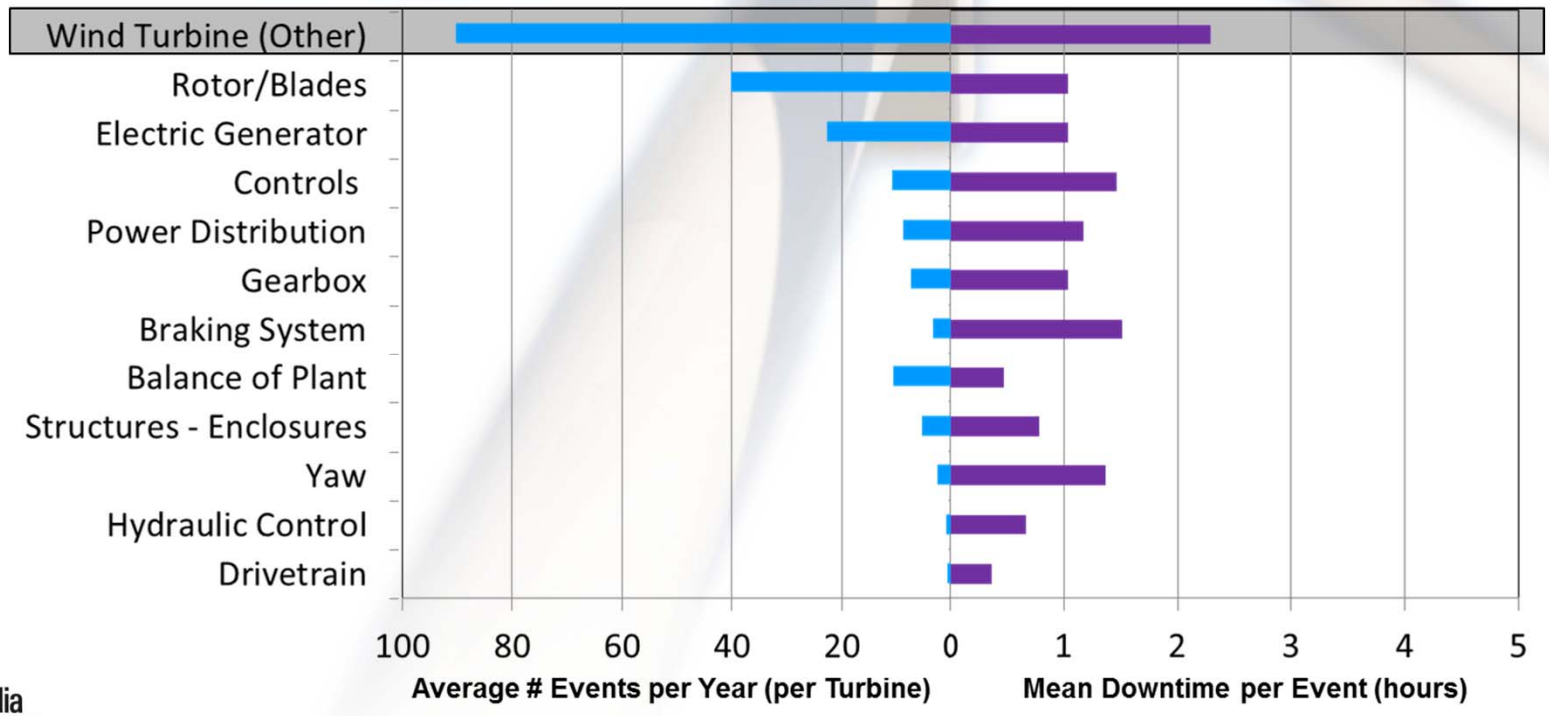
Event Frequency vs. Downtime

- 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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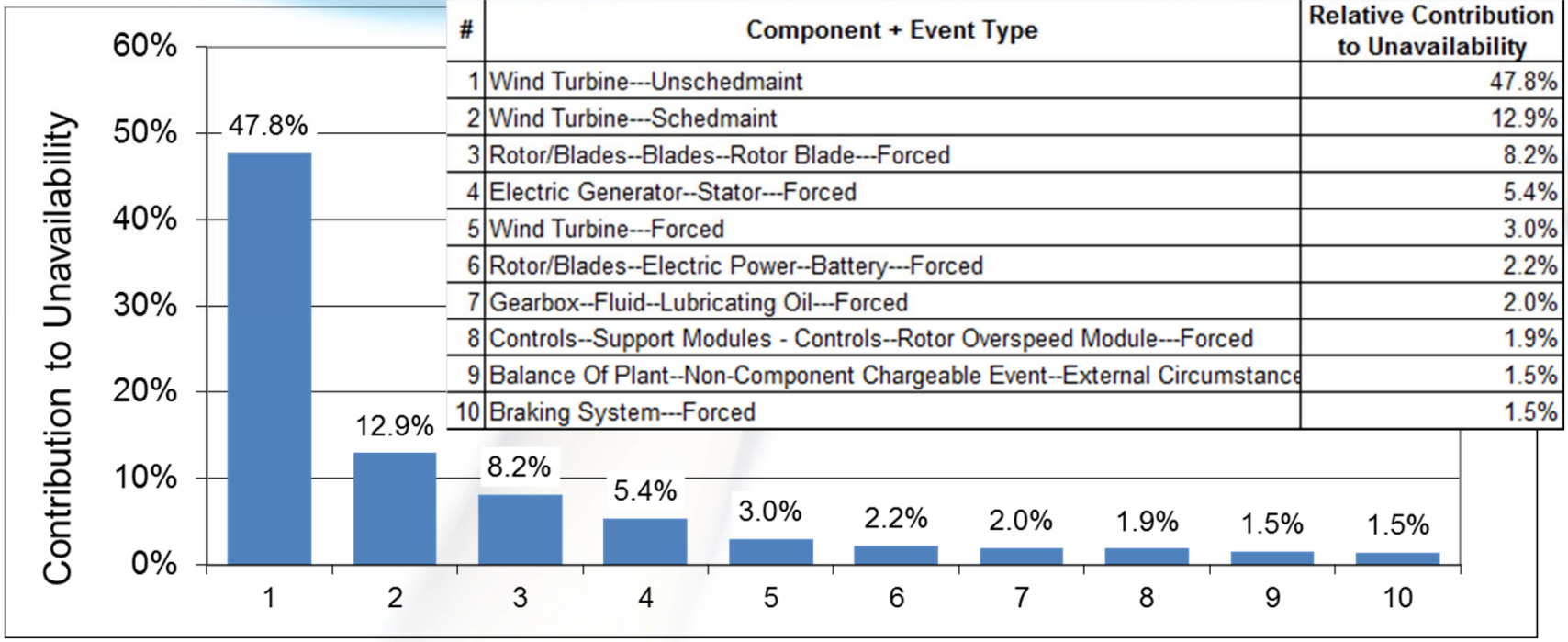
Event & SCADA Data Source: SPS ORAPWind

Unavailability Contributors: Components + Event Types

- Dominated by general events
  - "Wind Turbine" (Other) 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	47.8%
2	Wind Turbine---Schedmaint	12.9%
3	Rotor/Blades--Blades--Rotor Blade---Forced	8.2%
4	Electric Generator--Stator---Forced	5.4%
5	Wind Turbine---Forced	3.0%
6	Rotor/Blades--Electric Power--Battery---Forced	2.2%
7	Gearbox--Fluid--Lubricating Oil---Forced	2.0%
8	Controls--Support Modules - Controls--Rotor Overspeed Module---Forced	1.9%
9	Balance Of Plant--Non-Component Chargeable Event--External Circumstance	1.5%
10	Braking System---Forced	1.5%

SCADA faults tend to indicate symptom, not necessarily root cause

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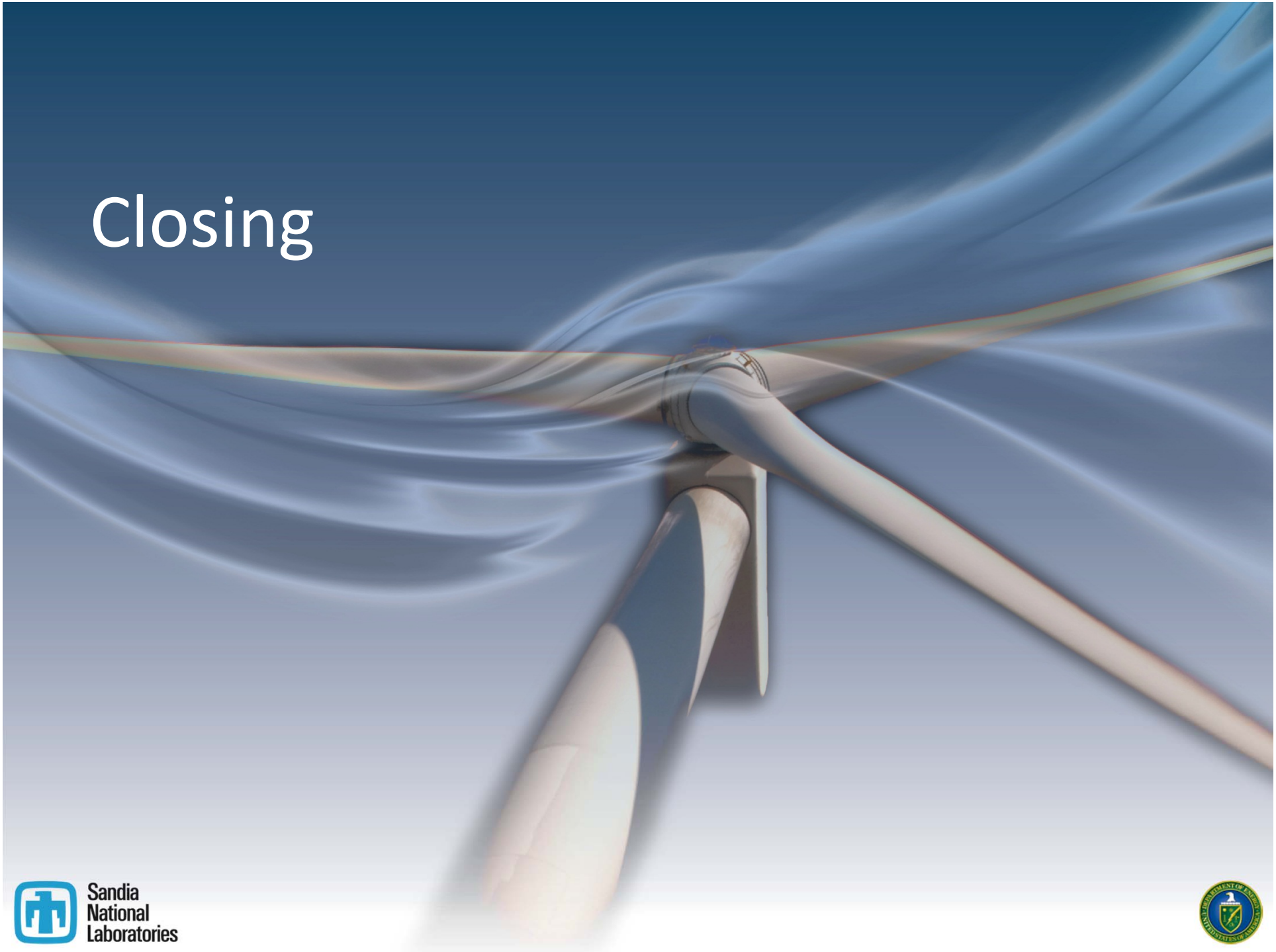
Event & SCADA Data Source: SPS ORAPWind

Closing



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Observations

- Average turbine at the average plant: actively generates power for 1.5 days between downtime events
  - Average downtime event lasts 1.6 hours
  - Maintenance/repair events (technician at turbine) occur every 1.6 weeks, on average
    - Substantial maintainability implications, if this translates to offshore
- Generally good alignment between other sources and CREW
  - 2012 CREW benchmark is a little closer to data and anecdotes from operators and OEMs, than third parties or the 2011 benchmark
- Excluding "Wind Turbine (Other)", top three system-level contributors to unavailability:
    - Rotor/Blades
    - Electric Generator
    - Controls
  - Gearbox notably absent - likely due to SCADA's limited insight into major repairs
  - Work Order information is critical to "filling in the blanks" about downtime event root cause (vs. control system symptoms)

Accessing More Information

- The companion technical report on the 2012 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.

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