2012
Wind Turbine Blade Workshop

June 1, 2012

Continuous Reliability Enhancement for Wind (CREW)

Sandia National Laboratories
Wind Energy Technologies

SAND Report 2012-5010C

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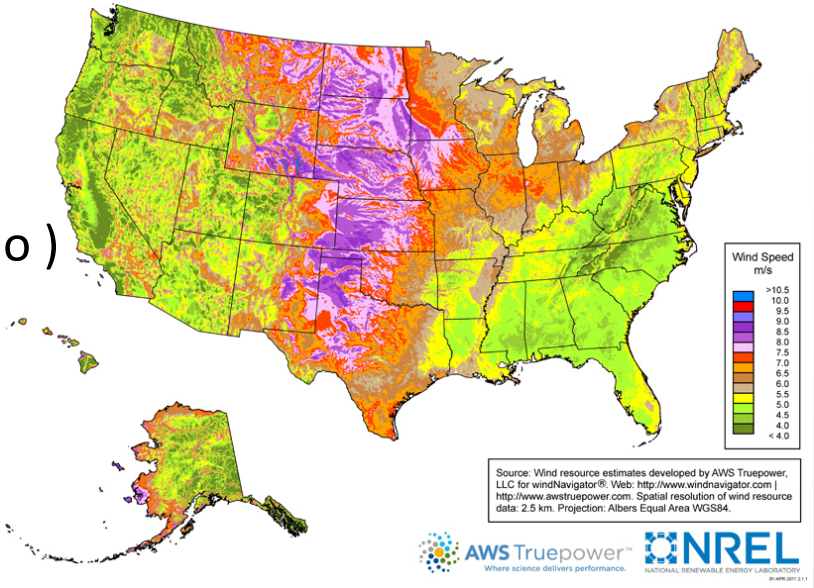
Cost of Energy

- **US wind resources**
  - Total U.S. Utility-Scale Wind Power Capacity
    - Through 1st Quarter of 2012 (AWEA Market Report):
    - ~48.5 GW
  - Potential ~9000 GW
  - 125 GW by 2020
  - 300 GW by 2030 (20% by 2030 Scenario)



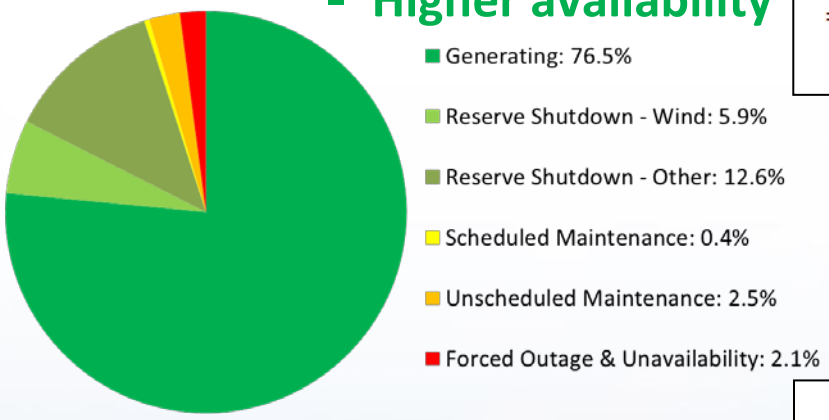
- **Cost Of Energy (COE) by 2020**
  - DOE's Mark Higgins
    - 4.8 cents / kWh (land)
    - 9.3 cents / kWh (offshore)

Two Areas of Impact

- **Technology improvements**
  - Energy capture and conversion – Plant
  - Reduce cost of next gen WTGs
  - Advanced controls
  - Extended useful component life
- **Operations and maintenance (O&M)**
  - Increase Availability
  - Reduce cost
  - Increased component life

Return On Investment

- **Return On Investment (ROI) =** $\frac{(Gain\ from\ investment - Cost\ of\ Investment)}{Cost\ of\ Investment}$
  - Maximize gain
    - **Higher availability**



Equation 10. Operational Availability.

$$Operational\ Availability = \frac{Generating\ Hours + Reserve\ Shutdown\ Wind\ Hours + Reserve\ Shutdown\ Other\ Hours}{Known\ Hours}$$

Utilization (aka Generating Factor)	76.5%
Operational Availability	95.0%

Equation 11. Utilization (i.e., Generating Factor).

$$Utilization = \frac{Generating\ Hours}{Known\ Hours}$$

    - **Better utilization**
  - Reduce costs
    - **Reduce** Unscheduled Maintenance
    - **Minimize** Forced Outages & Unavailability
    - **Targeted** Scheduled Maintenance

Maximize Gain

- **Marketing says "Availability up to 98%"**
  - Downtime of 2% to 5%
    - ~7 to ~18 days per year
- **CREW Benchmark Report says "Availability 95.0%**
  - Downtime of 5%
    - ~18 days per year
- **Rough land-based estimate**
  - Utility size turbines at a 100+ turbine wind plant
    - 1% availability increase = ~$1,000 per turbine per month
    - $1 million per year

Reduce Cost

- **Reduce costs**
  - Right O&M strategy
    - Minimize Forced Outages & Unavailability
      - Faults and failures
        - Auto resets – what is their contribution?
        - Can they be reduced by scheduled maintenance?
      - Top and bottom performers
        - Low performers
        - Low hanging fruit
    - Targeted scheduled maintenance
      - Wind and weather, personnel availability, specialized equipment
    - Parts inventory that matches your reliability strategy
  - Move from reactive to proactive

Step 1 – Actionable Analysis Results

Based on notional data

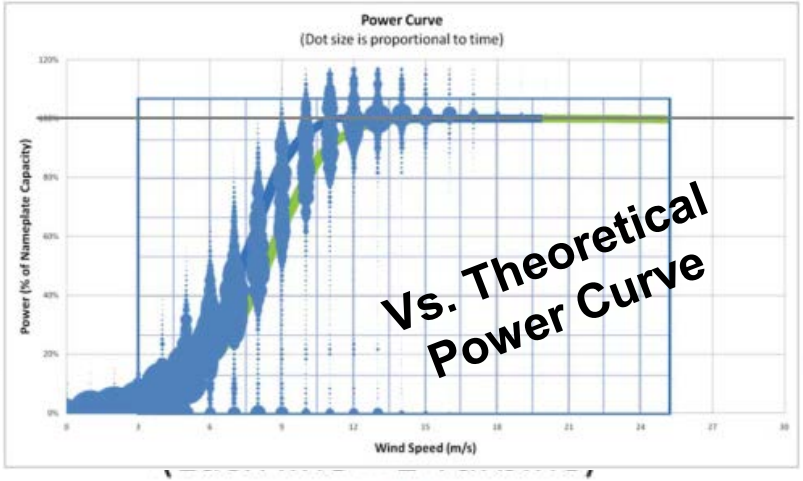
Turbine Summary

Legend: Best Performer | Top 10% | Bottom 10% | Worst Performer

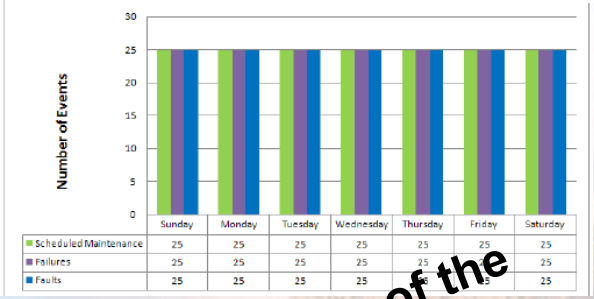
Turbine	Operational Availability	Mean Time Between Events (hrs)	Mean Downtime Per Event (hrs)	Capacity Factor
1	99.00%	20.0	1.00	10.00%
2	98.00%	20.5	1.05	11.00%
3	97.00%	21.0	1.10	12.00%
4	96.00%	21.5	1.15	13.00%
5	95.00%	22.0	1.20	14.00%
6	94.00%	22.5	1.25	15.00%
7	93.00%	23.0	1.30	16.00%
8	92.00%	23.5	1.35	17.00%
9	91.00%	24.0	1.40	18.00%
10	90.00%	24.5	1.45	19.00%
11	89.00%	25.0	[illegible]	20.00%
12	88.00%	25.5	[illegible]	21.00%
13	87.00%	[illegible]	1.60	22.00%
14	86.00%	[illegible]	1.65	23.00%
15	85.00%	27.0	[illegible]	24.00%
16	[illegible]	27.5	1.75	25.00%
17	[illegible]	[illegible]	1.80	26.00%
18	82.00%	[illegible]	1.85	27.00%
19	81.00%	29.0	1.90	28.00%
20	80.00%	29.5	1.95	[illegible]
21	79.00%	30.0	2.00	[illegible]
22	78.00%	30.5	2.05	[illegible]
23	77.00%	31.0	2.10	[illegible]
24	76.00%	31.5	2.15	[illegible]
25	75.00%	32.0	2.20	[illegible]
26	74.00%	32.5	2.25	[illegible]
27	73.00%	33.0	2.30	[illegible]
28	72.00%	33.5	2.35	[illegible]
29	71.00%	34.0	2.40	[illegible]
30	70.00%	34.5	2.45	[illegible]

Table 2: Turbine Summary Statistics

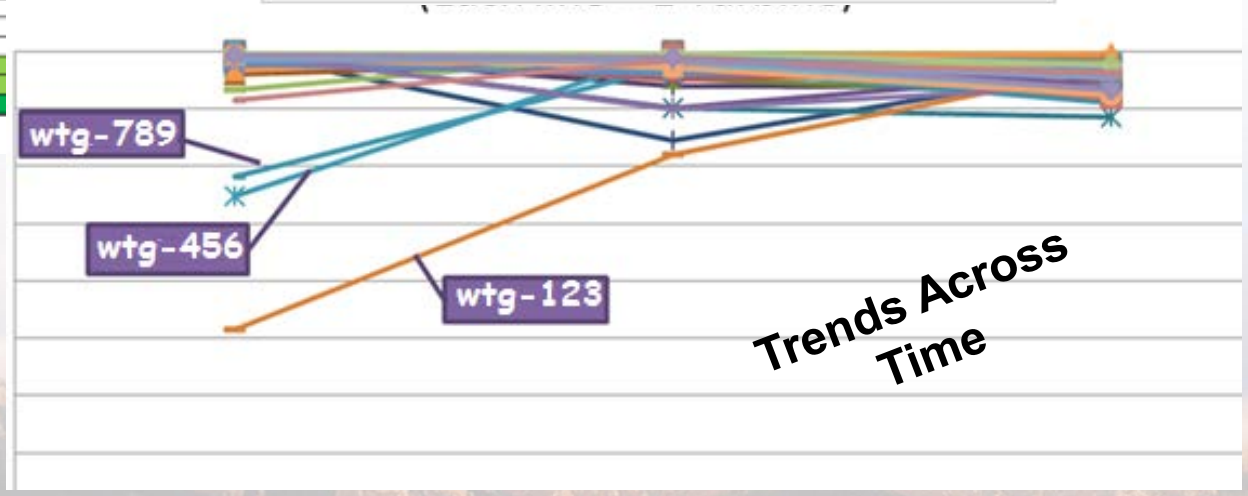
Top & Bottom Performers



Vs. Theoretical Power Curve



Days of the Week



Trends Across Time

Step 2 - Data Needs

Inputs: Data from Plants

- SCADA tags: Wind, power, etc.
- SCADA tags: Faults, alarms, etc.
- Met tower tags: Wind speed & direction, pressure, etc.
- Work Orders
- Financials, etc.

The Magic

- Performance
- Complete Downtime Accounting
- Root Cause Analysis
- Turbine, Plant, and Environmental Status

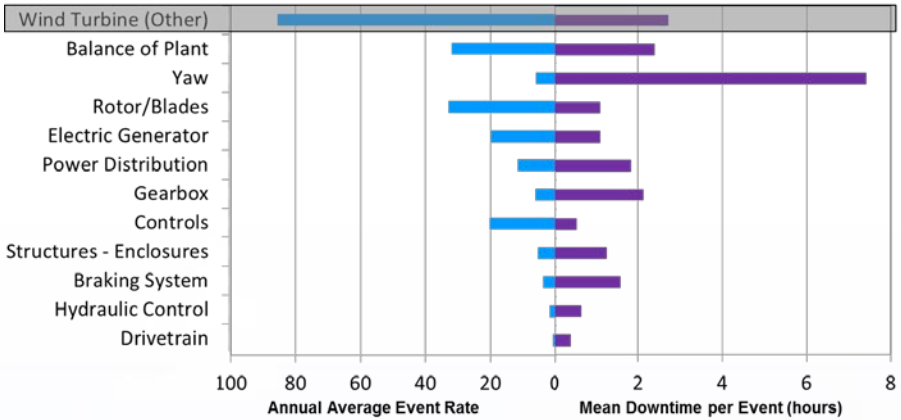
Step 1 - Outputs: Reliability Analysis

- **Metrics & Trends:** Availability, Utilization, DT, Capacity Factor, …
- **Time Allocation:** Status, by equipment AND environmental state
- **Paretos:** Biggest contributors to poor performance and variable performance
- **Other Analysis** (parts tracking)

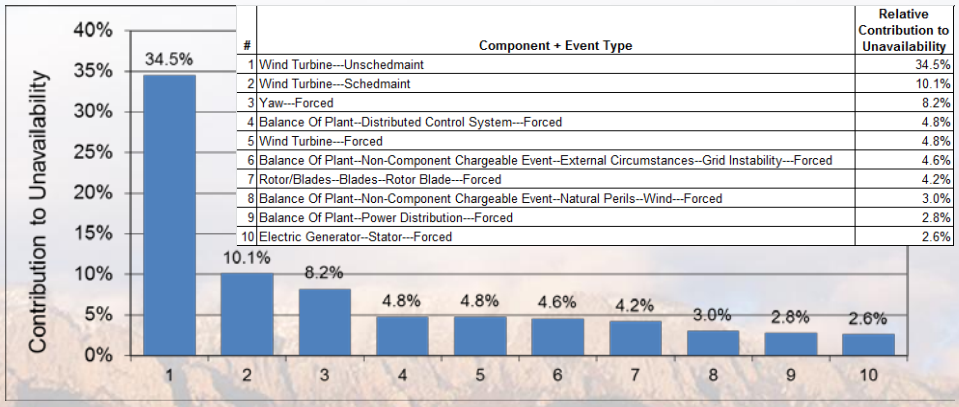
All of the above, by turbine and by plant

Increase Component Life

- **Reliability**
  - Frequency AND Duration



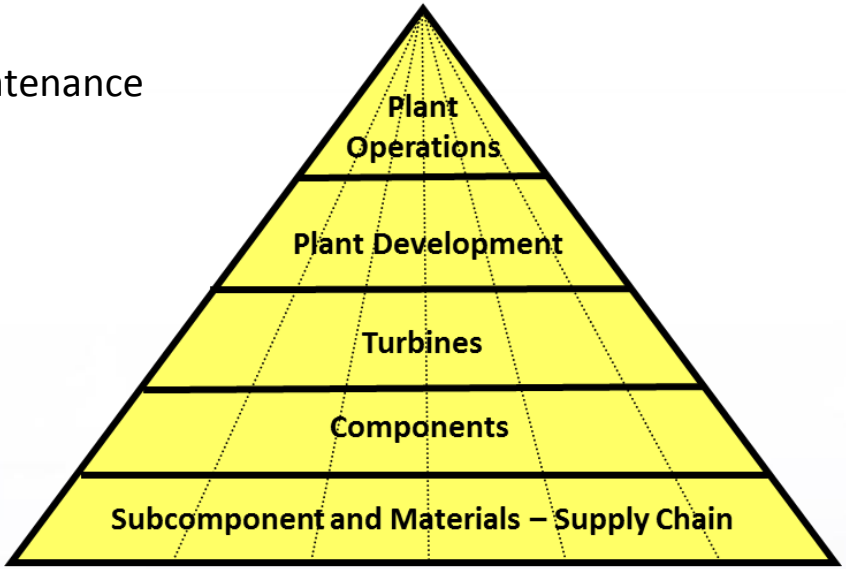
- **Top Unavailability Contributors**
  - Component + Event Type



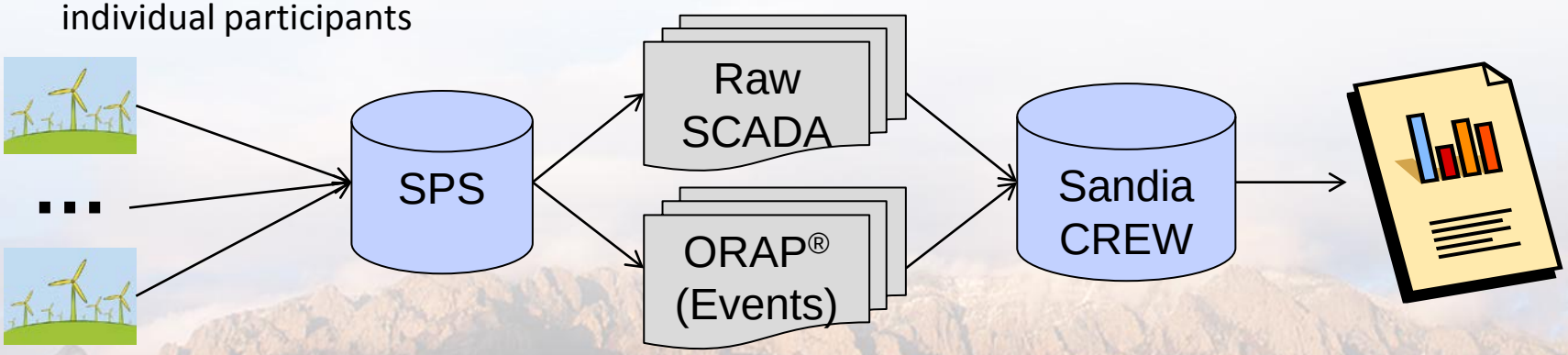
#	Component + Event Type	Relative Contribution to Unavailability
1	Wind Turbine---Unschedmaint	34.5%
2	Wind Turbine---Schedmaint	10.1%
3	Yaw---Forced	8.2%
4	Balance Of Plant--Distributed Control System---Forced	4.8%
5	Wind Turbine---Forced	4.8%
6	Balance Of Plant--Non-Component Chargeable Event--External Circumstances--Grid Instability---Forced	4.6%
7	Rotor/Blades--Blades--Rotor Blade---Forced	4.2%
8	Balance Of Plant--Non-Component Chargeable Event--Natural Perils--Wind---Forced	3.0%
9	Balance Of Plant--Power Distribution---Forced	2.8%
10	Electric Generator--Stator---Forced	2.6%

CREW Benchmark Approach

- Establish national reliability database
  - Benchmark U.S. wind turbine operations and maintenance (O&M) experience
- Provide regular public-domain reporting
  - Calculate aggregated fleet reliability data metrics
  - Provide specific failure sources and frequencies
  - Enable comparison of a plant or fleet against the benchmark
- Data from individual participants is proprietary
  - Data only used in reporting when it can be sufficiently aggregated or masked to protect individual participants



Reliability Improves from the bottom up



Event & SCADA Data Source: ORAP® for Wind

Challenges

- **Gather and Protect Proprietary Data**
  - Sandia history, NDAs, aggregation
- **Multiple Plants, Multiple Technologies**
  - Numerous implementations of WTG and SCADA
- **Data Volume**
  - Huge amounts
- **Fully Accounting For All Time**
  - Data completeness and quality
- **Capturing Adequate Detail**
  - **Work orders** are key to root cause

Image Source: http://wind-turbine.tripod.com/id13.html

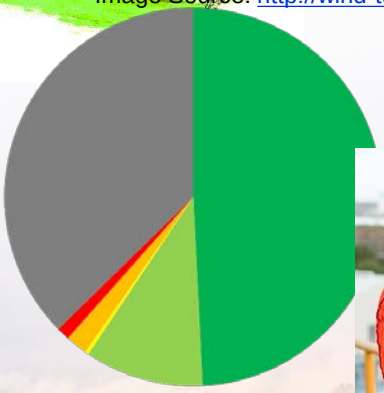


Image Source: http://resortdata.com

CREW - Current Partnership

SPS

ORAPWind

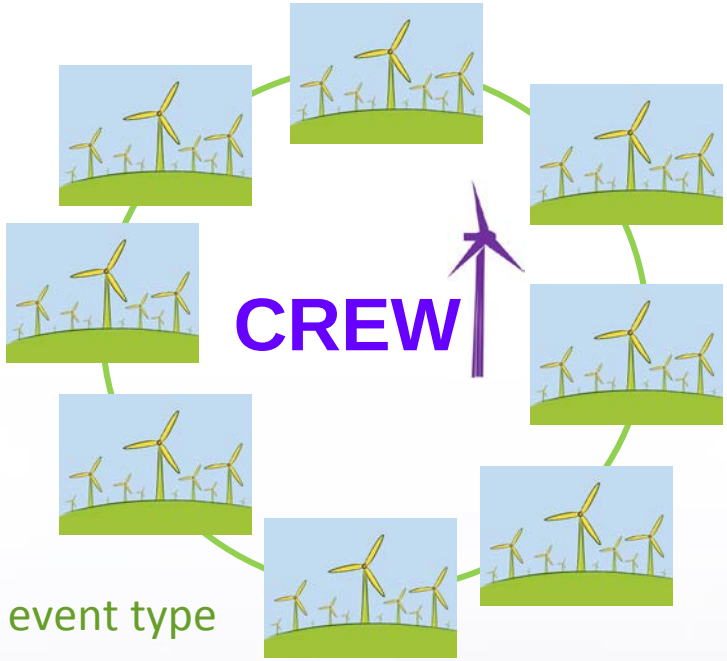
enXco
An EDF EN Company

Xcel Energy®
RESPONSIBLE BY NATURE™

Wind Capital Group
Bringing Wind Energy Home®

Sandia National Laboratories

Methodology: Aggregation



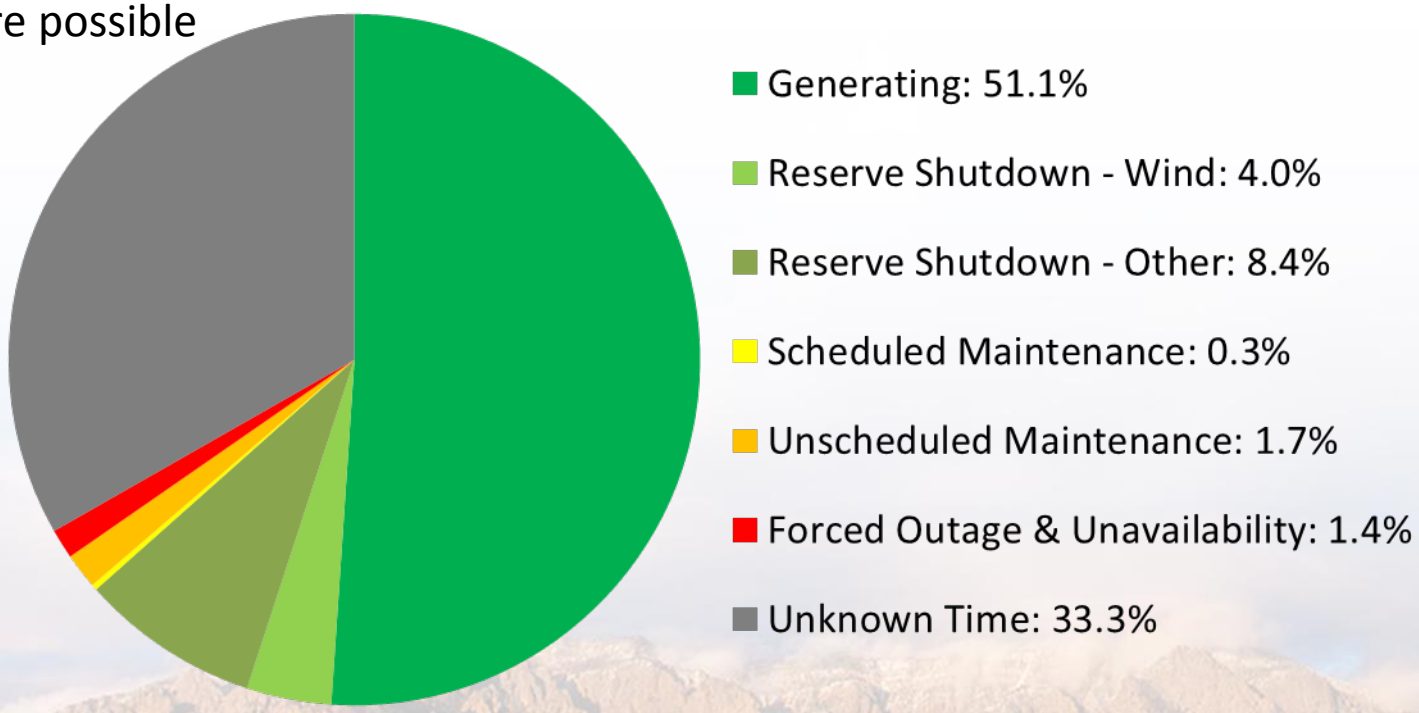
- **Gather statistically appropriate sample**
  - Sufficient data (duration, breadth) to aggregate without violating anonymity
  - Goal: Accurately represent U.S. fleet through an appropriately-sized sample
- **Create individual plant models, by summarizing ORAP® for Wind events into:**
  - Event frequency & duration for each component + event type
  - Time accounting, based on summing hours across turbines
- **Aggregate results from plant models**
  - Event frequency & duration: weight plant model results by turbine-days
    - Greater impact from plants with: large number of turbines, longer data history
  - Time Accounting: sum turbine hours from plant models
    - Naturally provides greater impact from large plants & plants with longer data history

Fleet Representation

- **Results here are considered "directional"**
  - 1st CREW public benchmark + initial updates
  - Based on data collected during development phase
- **Database does not <u>yet</u> represent a significant portion of the U.S. wind turbine fleet**
  - *Premature to consider results here fully "actionable"*
  - Data represents 85,000 turbine-days for analysis
- **Early partners helped create useful initial view of U.S. fleet's operational and reliability performance**

Availability Time Accounting

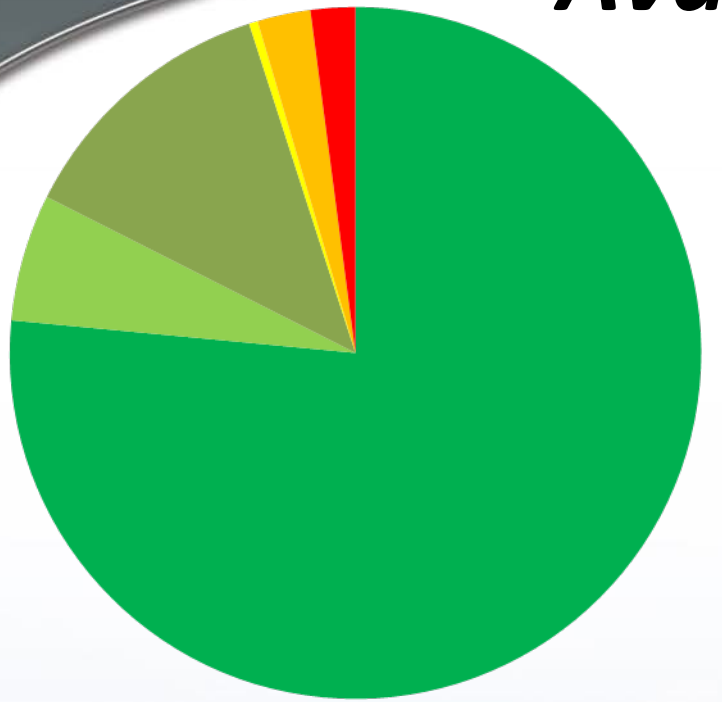
- **SCADA and data transfer challenges lead to "Unknown Time"**
  - Availability analysis needs to highlight the common communication and IT issues resulting in missing data*
  - CREW team is actively identifying these industry-wide issues & addressing them where possible



*Substantial portion of Unknown Time is attributable to pilot program & associated beta testing

Event & SCADA Data Source: ORAP® for Wind

Availability Time Accounting



- Generating: 76.5%
- Reserve Shutdown - Wind: 5.9%
- Reserve Shutdown - Other: 12.6%
- Scheduled Maintenance: 0.4%
- Unscheduled Maintenance: 2.5%
- Forced Outage & Unavailability: 2.1%

Utilization (aka Generating Factor)	76.5%
Operational Availability	95.0%

- **Generating Factor** = Generating
- **Operational Availability**

  = Generating + Reserve Shutdown Wind + Reserve Shutdown Other
- Can calculate other metrics of interest from these categories

  Example: Technical Availability =

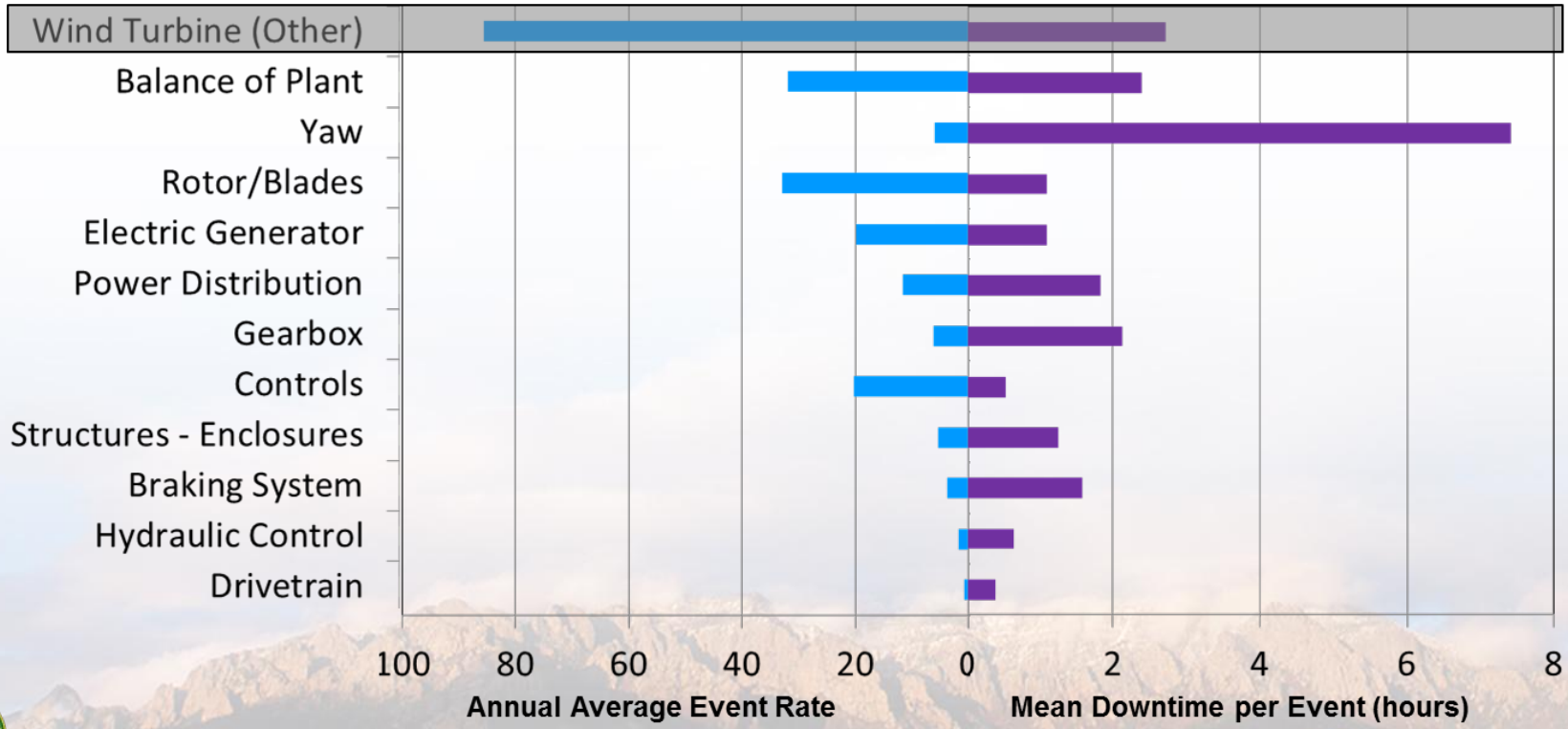
  (Generating + Reserve Shutdown Wind + Reserve Shutdown Other) /

  (Generating + Reserve Shutdown Wind + Reserve Shutdown Other + Unscheduled Maintenance + Forced Outage & Unavailability)

Event & SCADA Data Source: ORAP® for Wind

Event Frequency vs. Downtime

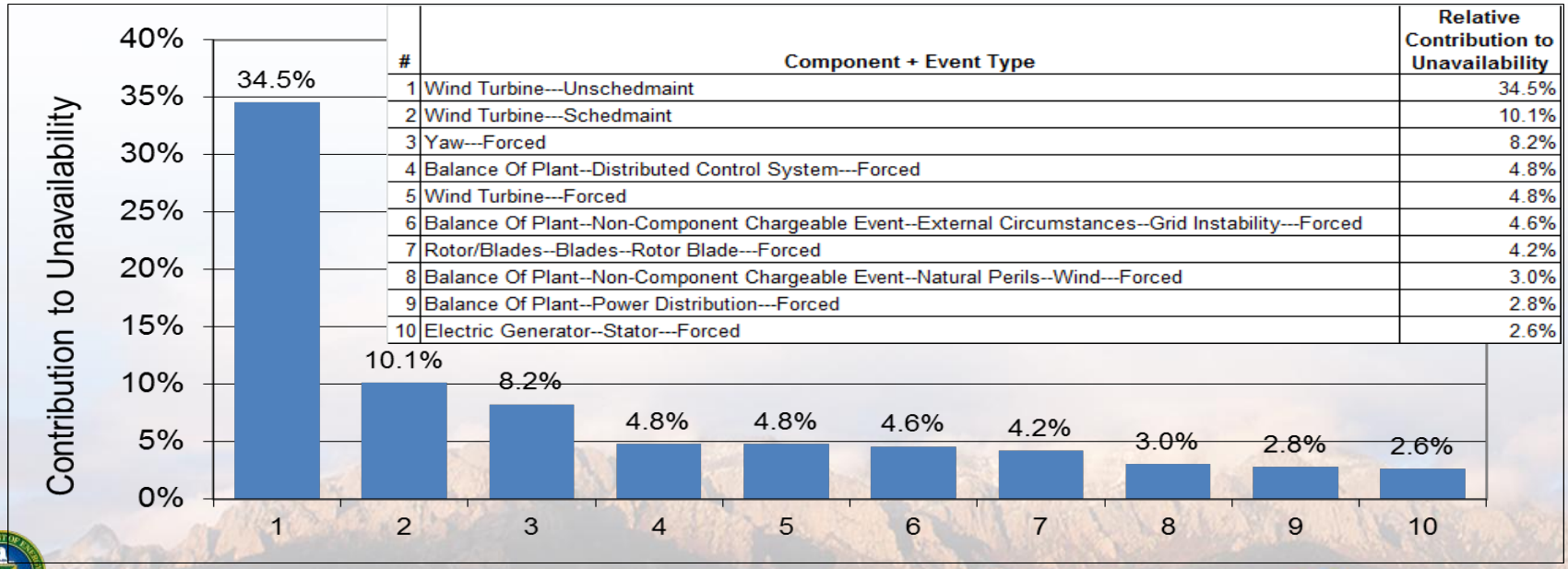
- **Sorted by Unavailability Contribution**
- **Balance of Plant, Rotor/Blades have most frequent events**
  - Aside from "Wind Turbine (Other)"
- **Lengthy, but infrequent, Yaw events have largest downtime**



Event & SCADA Data Source: ORAP® for Wind

Top Unavailability Contributors
Component + Event Type

- **Dominated by general events**
  - Wind Turbine (Other): 3 of top 5; just under 50% of unavailability
  - Work Orders are critical for filling in these blanks about true root cause



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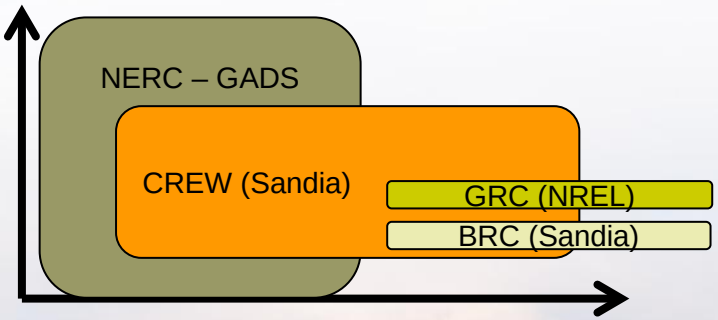
Actionable Analysis Into Results

- **Wind Industry - Benchmark Reliability Information**
  - Benchmarking – What's the standard?
  - Benchmarking – How do I compare?

"The benchmark is a phenomenal tool to allow the wind industry to assess itself and work to achieve improvements, resulting in the industry moving forward to higher profitability"
- Wind Industry Performance Engineer

Additional Results

- **Department of Energy (DOE)**
  - "State of the industry"
  - Strategic allocation of research funds
  - Technical Improvement Opportunities – GRC and BRC



- **DATA DRIVEN ACTIONS !!**

Benchmark Report

- **The full benchmark can be accessed at http://energy.sandia.gov/crewbenchmark**

- **Archive of Wind Turbine Reliability publications**
  energy.sandia.gov/?page_id=3057#WPR

- **Fall 2012 benchmark: increased depth & breadth**
  - Longer time periods, more plants, more variety
  - Larger section of fleet
    - More and varied operating data will help accurately represent U.S. fleet
    - All U.S. wind plant owners, operators, and OEMs are invited to participate