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 (ROI) = \( \frac{\text{Gain from investment} - \text{Cost of Investment}}{\text{Cost of Investment}} \)

- **Maximize gain**
  - **Higher availability**
    - 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%

- **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 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

Vs. Theoretical Power Curve

Trends Across Time

Days of the Week
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
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

Event & SCADA Data Source: ORAP® for Wind
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
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 yet 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
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
Generating Factor = Generating

Operational Availability = Generating + Reserve Shutdown Wind + Reserve Shutdown Other

Can calculate other metrics of interest from these categories

Example: Technical Availability =
\[
\frac{\text{Generating} + \text{Reserve Shutdown Wind} + \text{Reserve Shutdown Other}}{\text{Generating} + \text{Reserve Shutdown Wind} + \text{Reserve Shutdown Other} + \text{Unscheduled Maintenance} + \text{Forced Outage & Unavailability}}
\]
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
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

Top Unavailability Contributors
Component + Event Type

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