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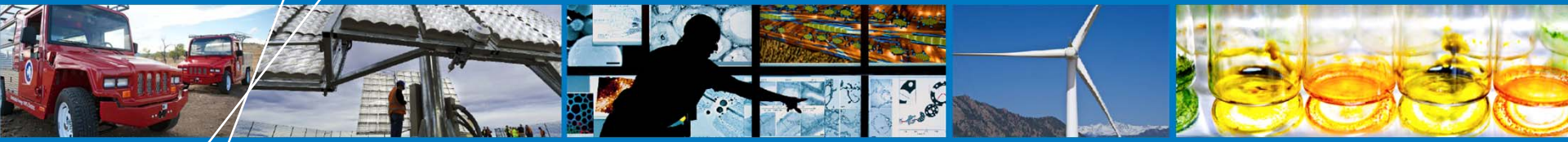
Operations Expenditures: Historical Trends And Continuing Challenges



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Thanks also to our partners at GL Garrad Hassan and DNV KEMA.

Presentation Outline

- **Background**
- **Historical Data**
  - Operations Expenditures
  - System Availability
  - Major Component Replacement Rates
- **Other Market Insights**
- **Challenges**

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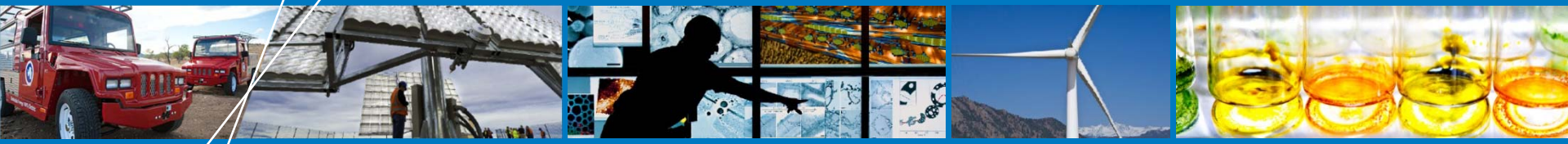

Background

NREL's Interest In Operations Expenditures (OpEx) Data Is Multi-Faceted

- **Minimizing OpEx could increase plant profitability while helping to support a lower cost of energy.**

- **Understanding opportunities for reductions in OpEx requires a baseline level of knowledge of:**
  - OpEx
  - System or Plant Availability
  - Major component replacement rates

- **Publicly available empirical data on the variables listed above are limited in scope and resolution.**

An empirically derived baseline of OpEx and component failures, and experience-based insights into recent trends are useful for R&D decision-making and industry benchmarking.

Data Housed By Project Partners GL Garrad Hassan and DNV KEMA Were Analyzed Independently, with a Focus on Three Metrics

- **Historical OpEx**
- **Historical "plant" or "system" availability**
  - Not to be confused with manufacturer, contractual, or technical availability
- **Major component failure rates and typical repair costs**
  - Blades, gearboxes, generators
  - Sensitivities in failure rates as a result of serial failures were also explored

- **The combined GL Garrad Hassan and DNV KEMA sample represents about 10 GW of operating wind plants**
- **Data shown today represent analysis completed by the respective partners for NREL**

Expert Opinions Were Also Collected

- How have condition monitoring and more advanced turbine designs affected historical OpEx?
- What have been the primary causes of missed OpEx estimates?
- What is the relationship between downtime and OpEx?
- How do trends vary regionally?
- What are the current strategies to service plants and how have these changed over time?
- Have technology perceptions affected financing terms?

Opinions were gathered from within the partner organizations as well as from semi-structured discussions with owner operators

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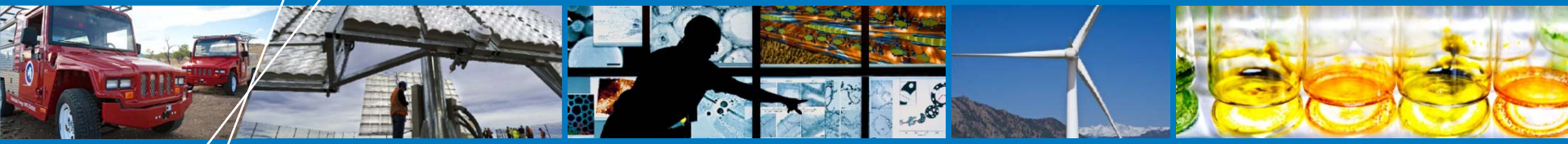


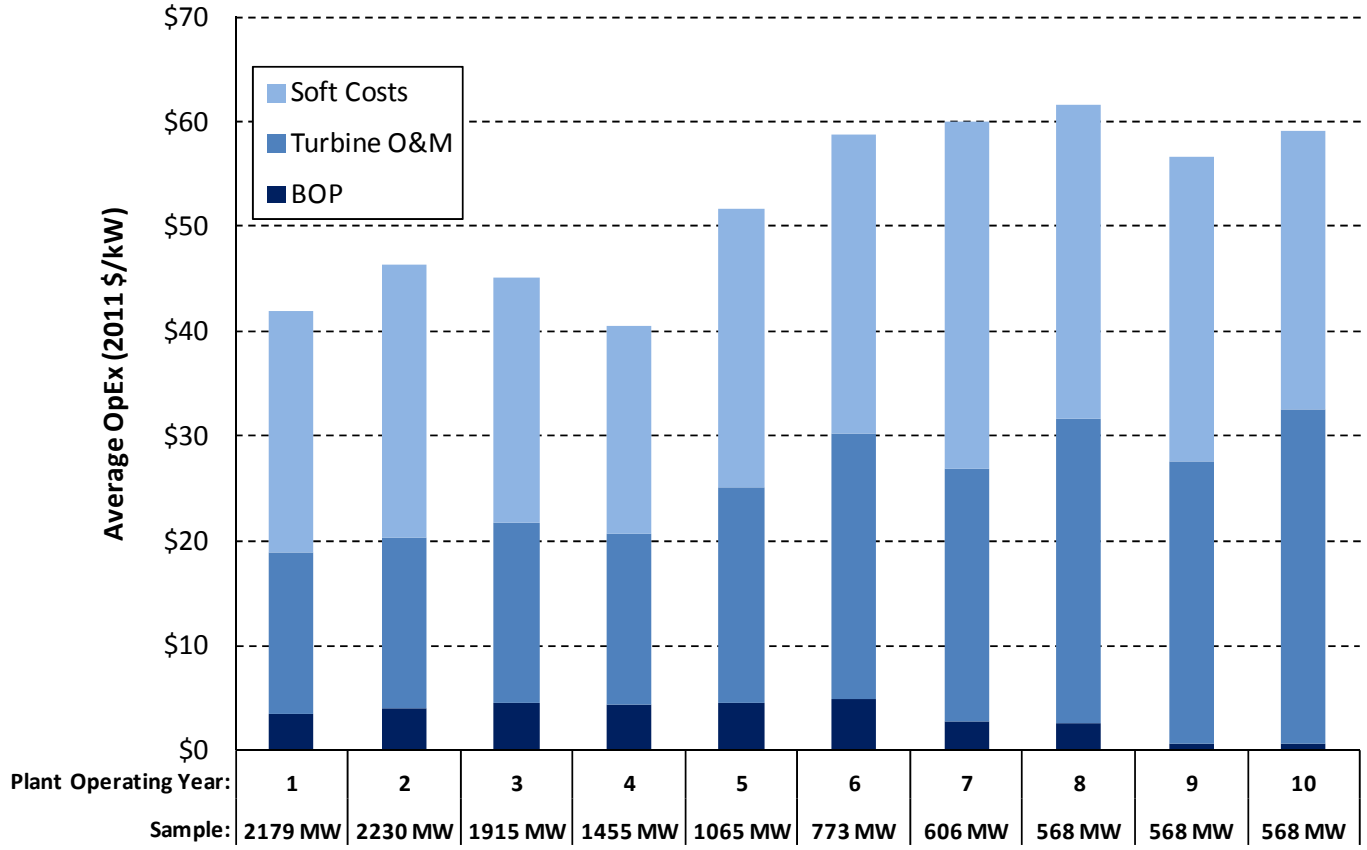
Historical Operations Expenditures, System Availability, And Replacements

Critical Caveats

- **Datasets studied are not comprehensive and data quality varies by project and across time.**
- **Data are skewed toward recent builds because that's when the capacity has come on line; however, these projects only offer 1-3 years of operating data.**
- **Operating data beyond 5 years are sparse and may not be fully representative of industry experience.**

Results may be sensitive to the dataset considered

Data from DNV KEMA for Projects Commissioned Through 2009 Suggest OpEx Initially of $40-$50/kW and Increasing Over Time



Data Source: DNV KEMA

Note: Sample does not contain data for projects commissioned after 2009

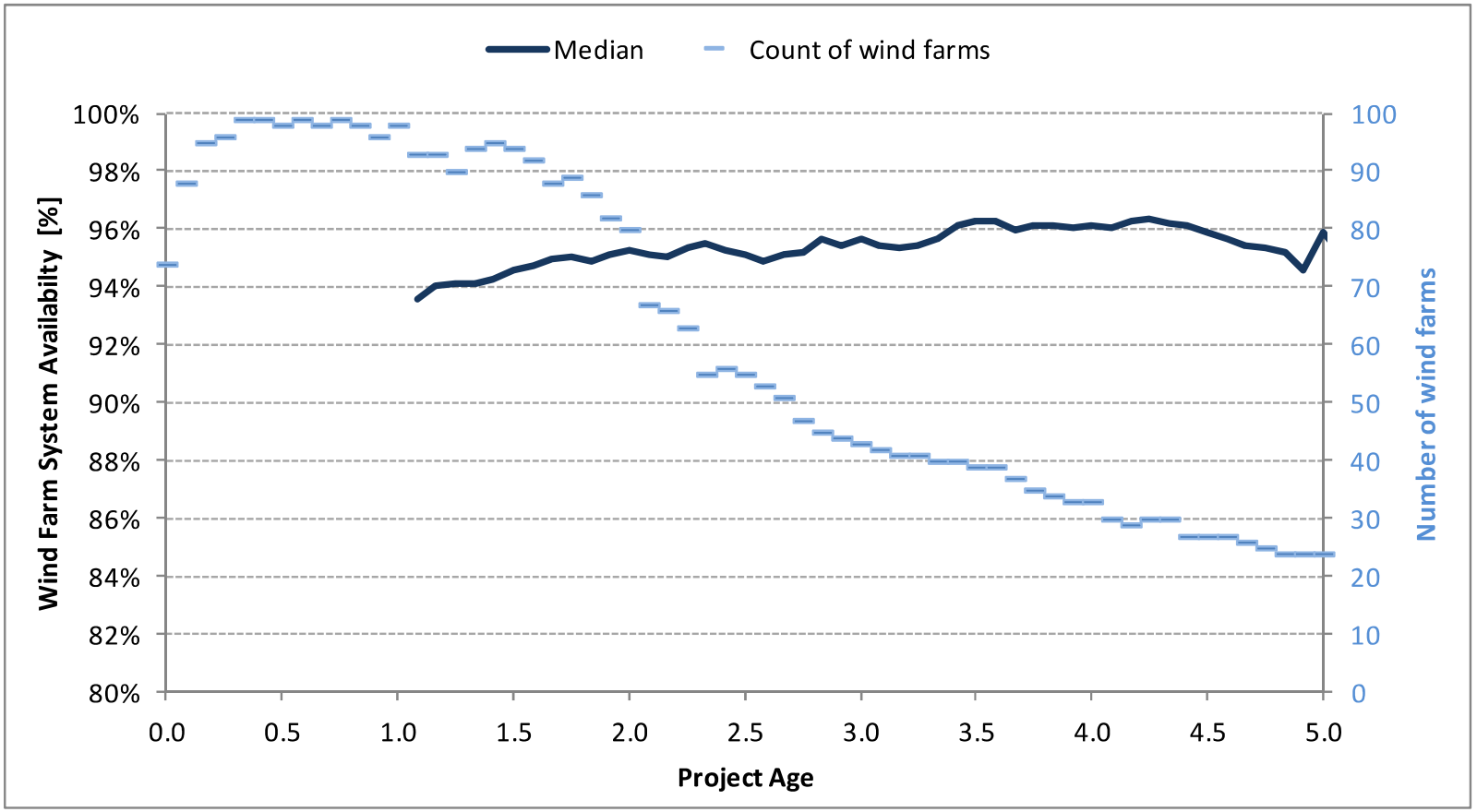
- **Increases are primarily attributed to unscheduled maintenance and increases in soft costs (e.g., audit compliance, system operator fees, other fees, royalty payments)**
- **Preliminary analysis of additional data and including more recent projects suggests this trend is sensitive to servicing agreement terms as well as regional competition**

GL Garrad Hassan's Sample Shows Turbine O&M Expenditures Increasing for More Recent Projects

Data Source: GL Garrad Hassan

Potential OpEx reductions resulting from enhanced turbine reliability may be offset by deployment of more complex equipment or operations across a broader array of wind regimes; sample size, servicing agreement details, and market forces also affect the trends.

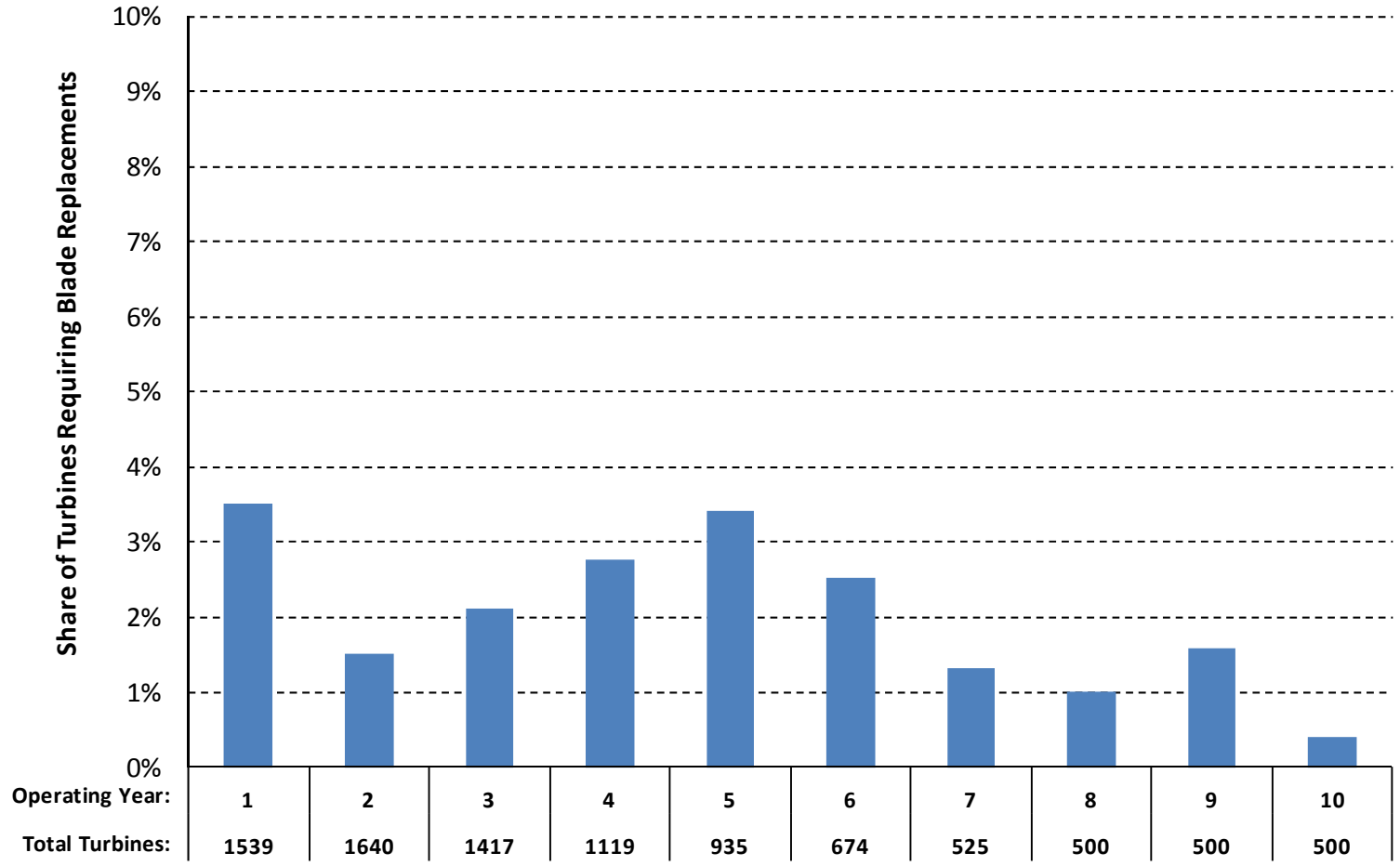
When Adjusting for Curtailment, System Availability Appears Stable At About 95% Through At Least Year Five



Source: GL Garrad Hassan

When factoring in curtailment, sample-wide system availability is about 93% (after year 2); minimization of plant downtime may at some point require consideration of power system policy and planning.

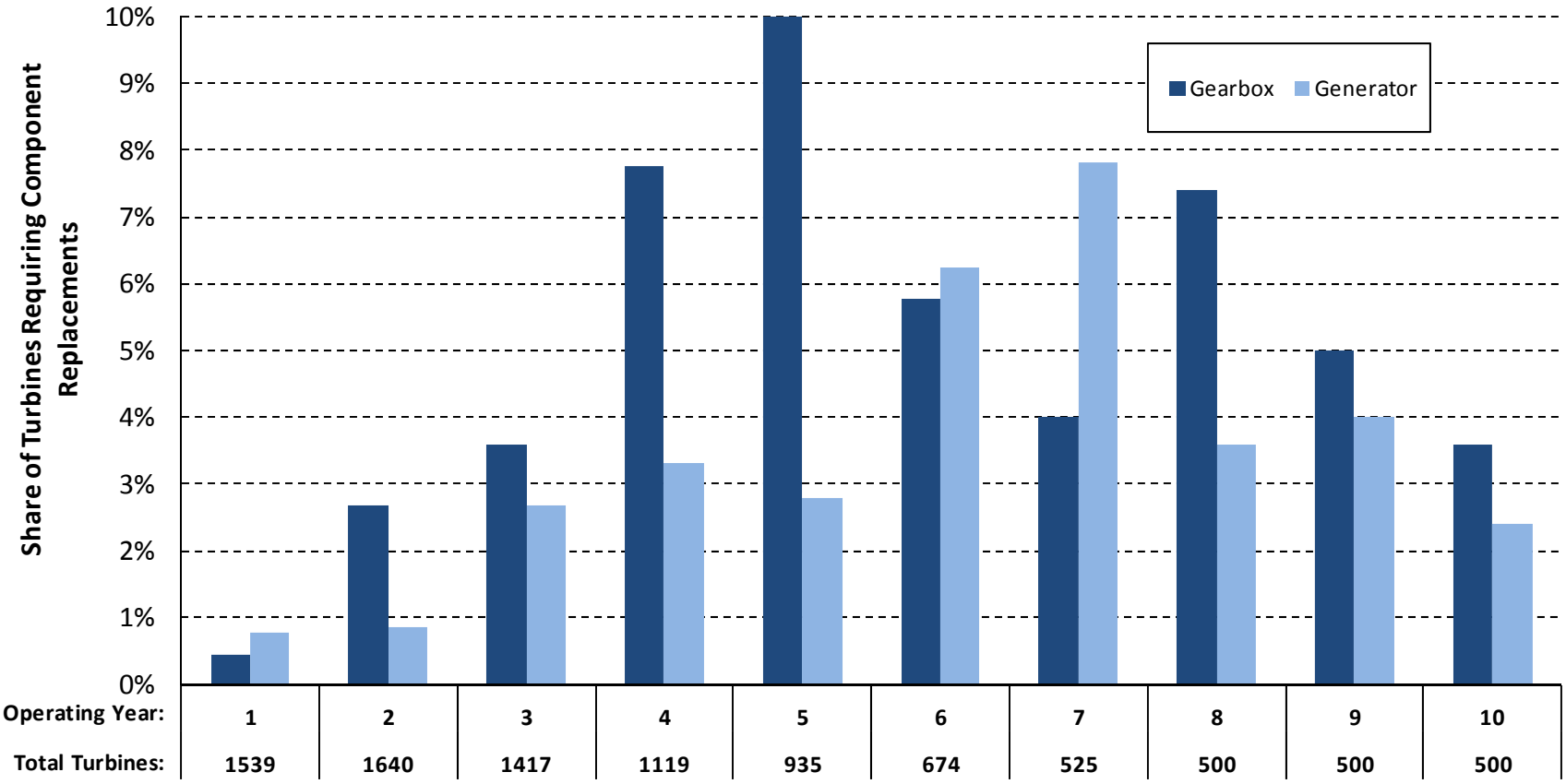
Annually, 1% - 3% of Turbines Require Blade Replacements with Spikes In Years 1 and 5



Data Source: DNV KEMA

- **Blade replacements in years 1 and 2 are typically the result of manufacturing defects or damage that occurs during transport and construction.**
- **On average, about 2% of turbines per year (through 10 years of operations) require blade replacements; lightning strikes are the most commonly noted cause of failure.**

More Turbines Require Gearbox and Generator Replacements, Particularly in Years 4-6



Data Source: DNV KEMA

- **Average gearbox failure rate over 10 years of operations is estimated at 5%.**
- **The average generator failure rate is somewhat lower and over 10 years of operations is estimated at 3.5%.**
- **Serial failures were observed to have a noteworthy effect on gearbox and generator failure rates, potentially skewing the results.**

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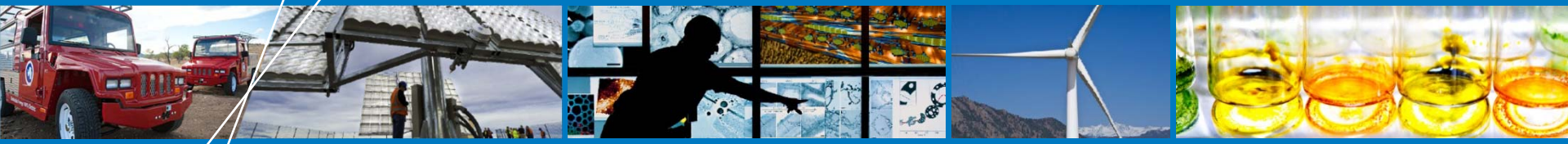

Other Market Insights

Unscheduled Maintenance Remains a Significant Source of Uncertainty for the Industry

- **Failure rates and unscheduled maintenance are the principal drivers of uncertainty around OpEx estimates.**
  - Gearbox replacements can approach $500k including crane costs; generator and blade replacements are typically less costly, but still non-trivial.
- **There is no clear link between downtime and OpEx expenditures.**
  - This may be a function of data limitations rather than the absence of an actual correlation.
- **The value of condition monitoring is not yet fully understood.**
  - Condition monitoring is generally seen as useful even though perspectives on costs savings remain varied.
  - Some operators cite logistics, parts availability, and preventative maintenance as more critical.

Competition and Risk Management Are Expected to Continue to Influence OpEx and Servicing Strategies

- **Regional competition and clustering are correlated with OpEx (i.e., more competition and a higher concentration of plants results in lower OpEx).**
  - Market share can also play a role.

- **Proper management of risk has a direct impact on financing terms.**
  - New products and more competition among providers allows owners to choose the service and terms that match their risk appetite.

- **Servicing and OpEx management strategies have evolved in the last decade; continued evolution entails:**
  - More sophisticated electronic reporting and better documentation
  - Consideration of regional climate, turbulence, and shear in cost models

Challenges

- **The absence of standardized reporting throughout the industry makes comparisons across operations-related datasets very difficult.**

- **Limited data for older projects make conclusions for plants operating in the 7-10 year timeframe more tentative.**
  - The time required to gather years of operational data will continue to make it difficult to understand how technological developments affect OpEx.

- **Operations servicing remains dynamic and may create continued data and reporting challenges in the future.**

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