LESSONS LEARNED FROM OPERATIONAL ENERGY DATA TO INFORM PRE-CONSTRUCTION ESTIMATES

AWS TRUEPOWER

100+
Countries where UL customers are located

FORECAST PROVIDER for
60+ GW
of renewable energy projects

Investor/Owner's Engineer on
450+
wind & solar projects*

*since 2012

ADVISED
90%
of the industry's top **PROJECT DEVELOPERS** and **PLANT OWNERS**

500+ **UL Renewable Energy Experts**

200,000+ MW
Total renewable energy megawatts (MW) assessed

35 years
Continuous renewable energy consulting experience

GLOBAL PRESENCE

143+
Countries with office locations

500+
Renewable energy experts

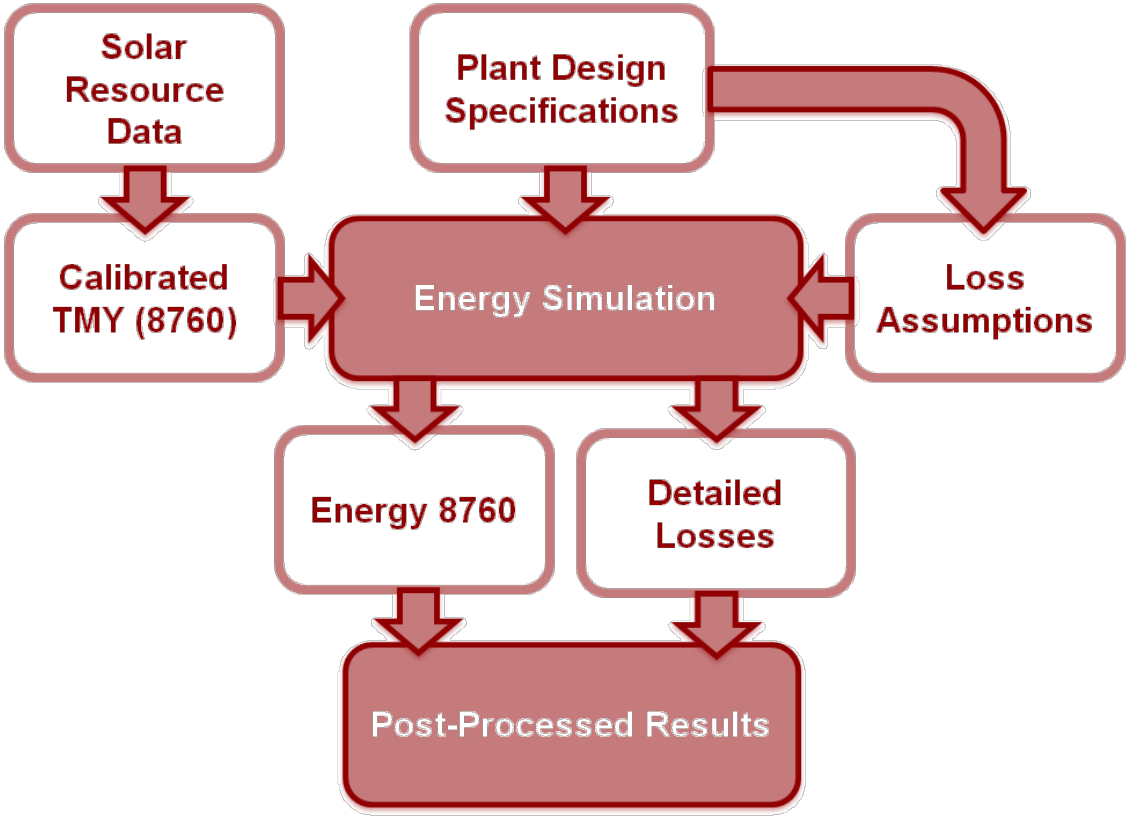
● Key Locations

INTRODUCTION

- Review of operational projects
- Evaluation of:
  - Availability
  - Performance Ratio
  - Net Capacity Factor
  - Degradation
- Key Takeaways to inform pre-construction assumptions

ENERGY PRODUCTION ESTIMATES

- Loss factors inputs calibrated to plant design and site-specific conditions.
- PVSYST used for simulation.
- Results post-processed to address operational and long term loss factors.



DATA STATISTICS

- Projects from multiple data sources**:**
  - Supervisory Control and Data Acquisition (SCADA)
  - U.S. Energy Information Administration (EIA)
  - Operational energy production reviews (OEPR) based on Monthly Operational Reports (MORs)

- Detailed project information was not always available.

- AWST removed data from startup periods or that appeared erroneous or unrealistic.

- Primary data set: SCADA

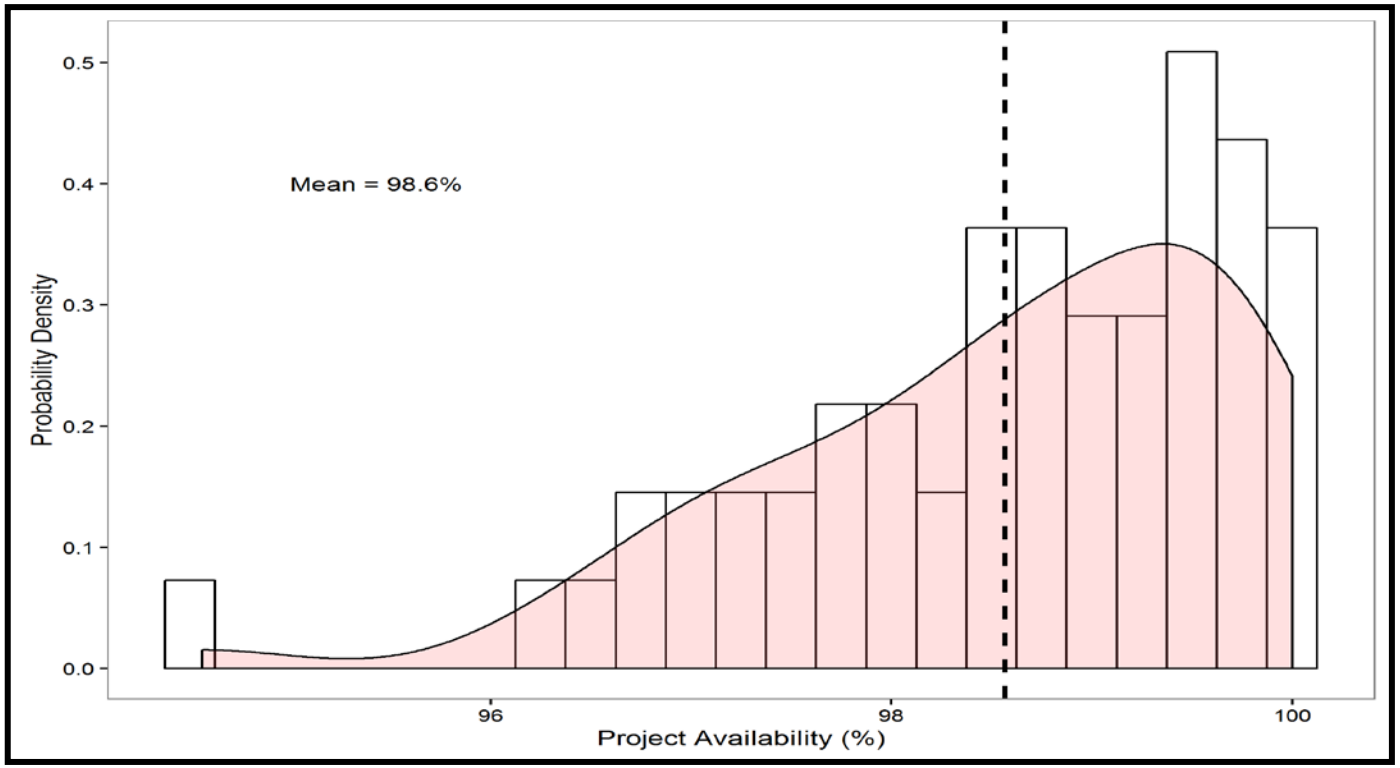
- EIA and OEPR data used to inform understanding from SCADA results

DATA STATISTICS

Parameter	SCADA	EIA
Number of Projects	55	41
Average Nameplate Capacity (MW_{AC})	34	29
Average Period-of-Record (years)	2.4	4.2
Total Number of Years Represented	100	172
Tracking - Fixed Tilt	91% - 9%	49% - 51%‡
Crystalline - Thin Film - Mixed	65% - 29% - 5%	67% - 33% - 0%‡
DC-AC Ratio Average	1.31	-
Availability Average	98.6%	-
AC Capacity Factor Average	29.5%	24.2%
Performance Ratio Average	76.4%	-
‡Calculated from projects where data were available.		

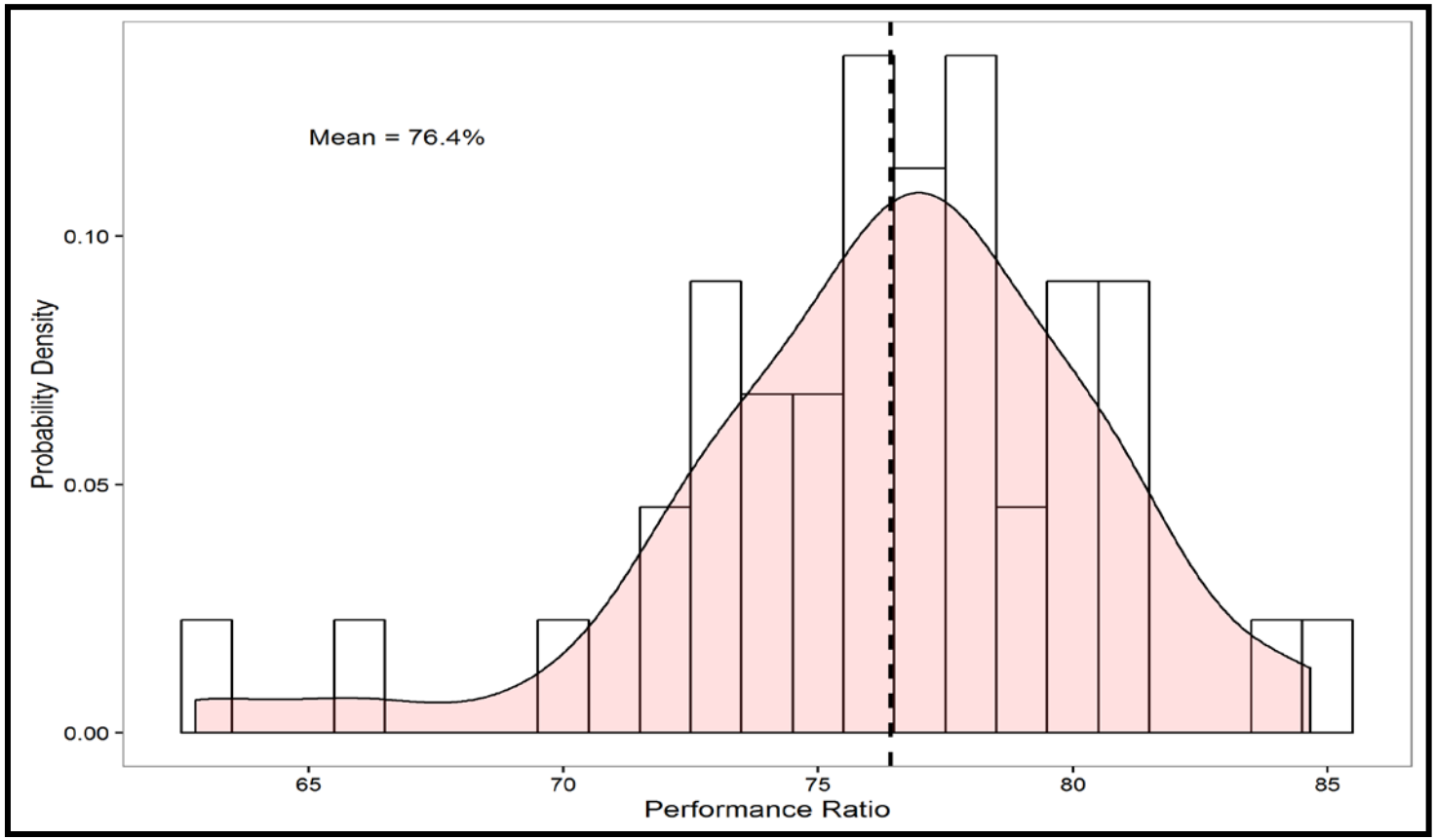
AVAILABILITY OF INVERTERS

- Average of 98.6% (pre-construction estimate is usually ~99%)
- 31% of projects below 98% availability, non-normal distribution with low tail
- Standard deviation (annual): 1.2% (100 years)
- Standard deviation (monthly): 5.6% (1000+ months)
- Tracking vs. fixed-tilt: within 0.1% of each other



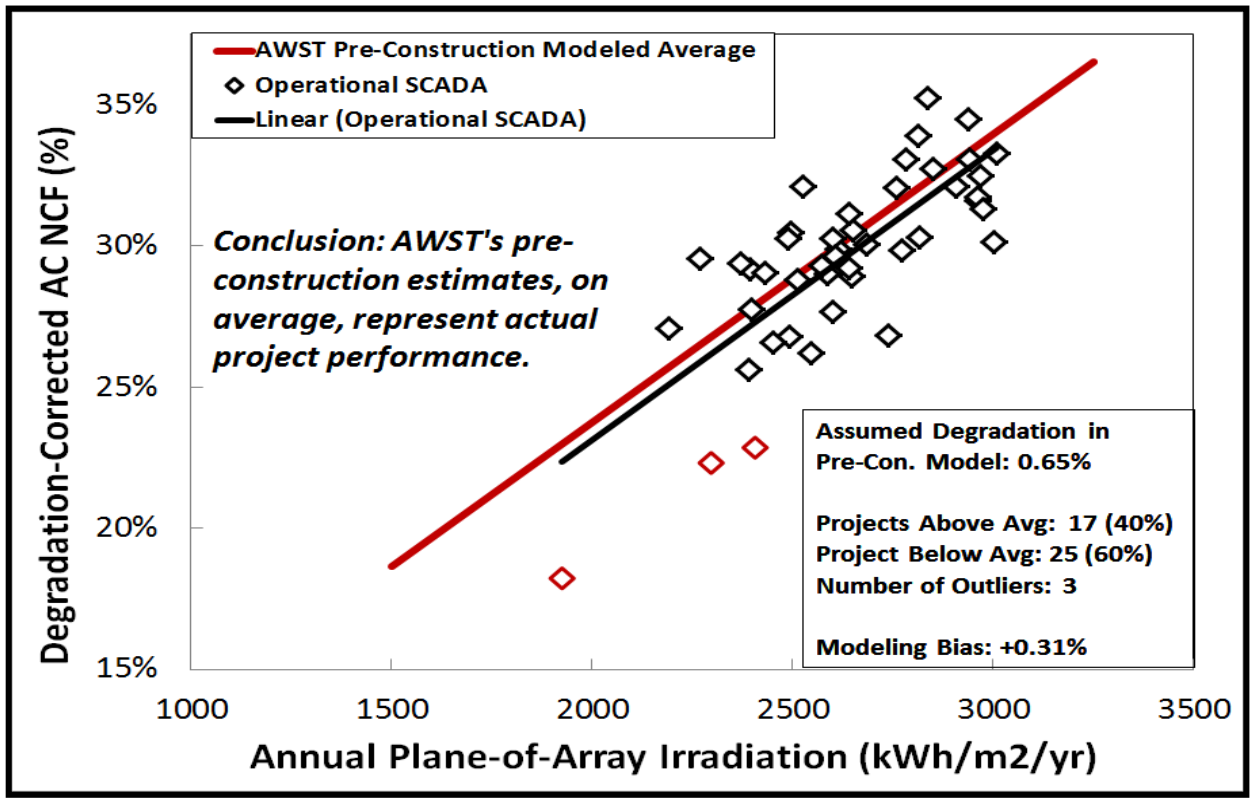
PERFORMANCE RATIO

- PR = Net Energy / Gross Energy = 1 – combined loss
- Gross Energy calculated from plane-of-array irradiance (POA) in SCADA
- Mean = 76.4%, about 3% lower than typical pre-con PRs (77-81%).
- Outliers suggest equipment performance or maintenance issues at two sites



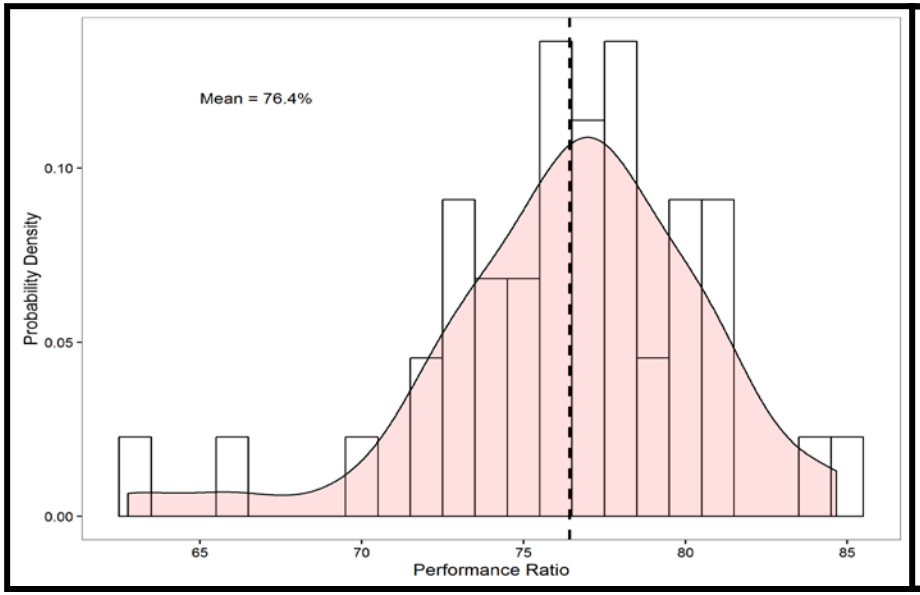
NET AC CAPACITY FACTOR AND PERFORMANCE

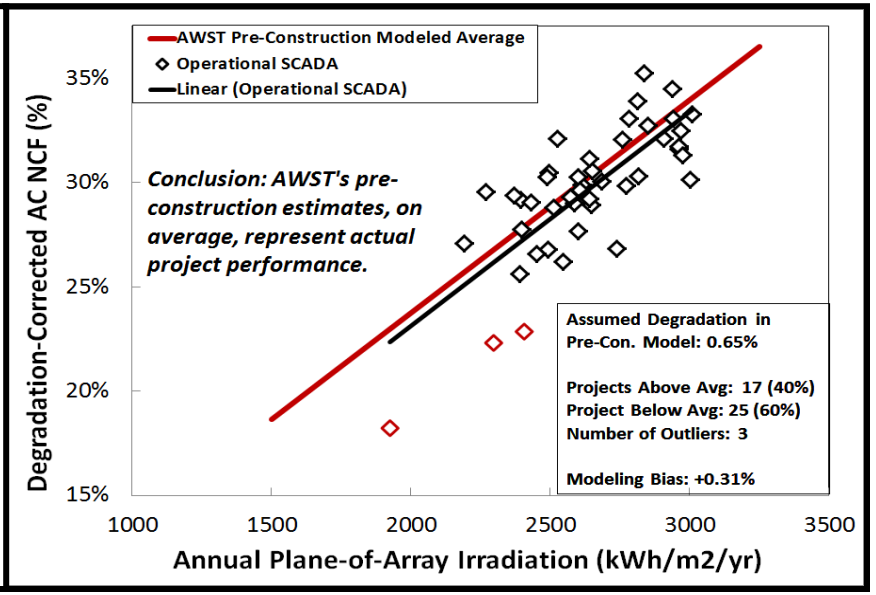
- Monthly energy totals adjusted to first-year values using a typical modeled degradation rate of 0.65% per year.
- Net capacity factor (NCF) calculated from reported MW_{AC}
- Presented as a function of reported POA
- Compared to typical pre-construction relationship between POA and NCF



NET AC CAPACITY FACTOR AND PERFORMANCE

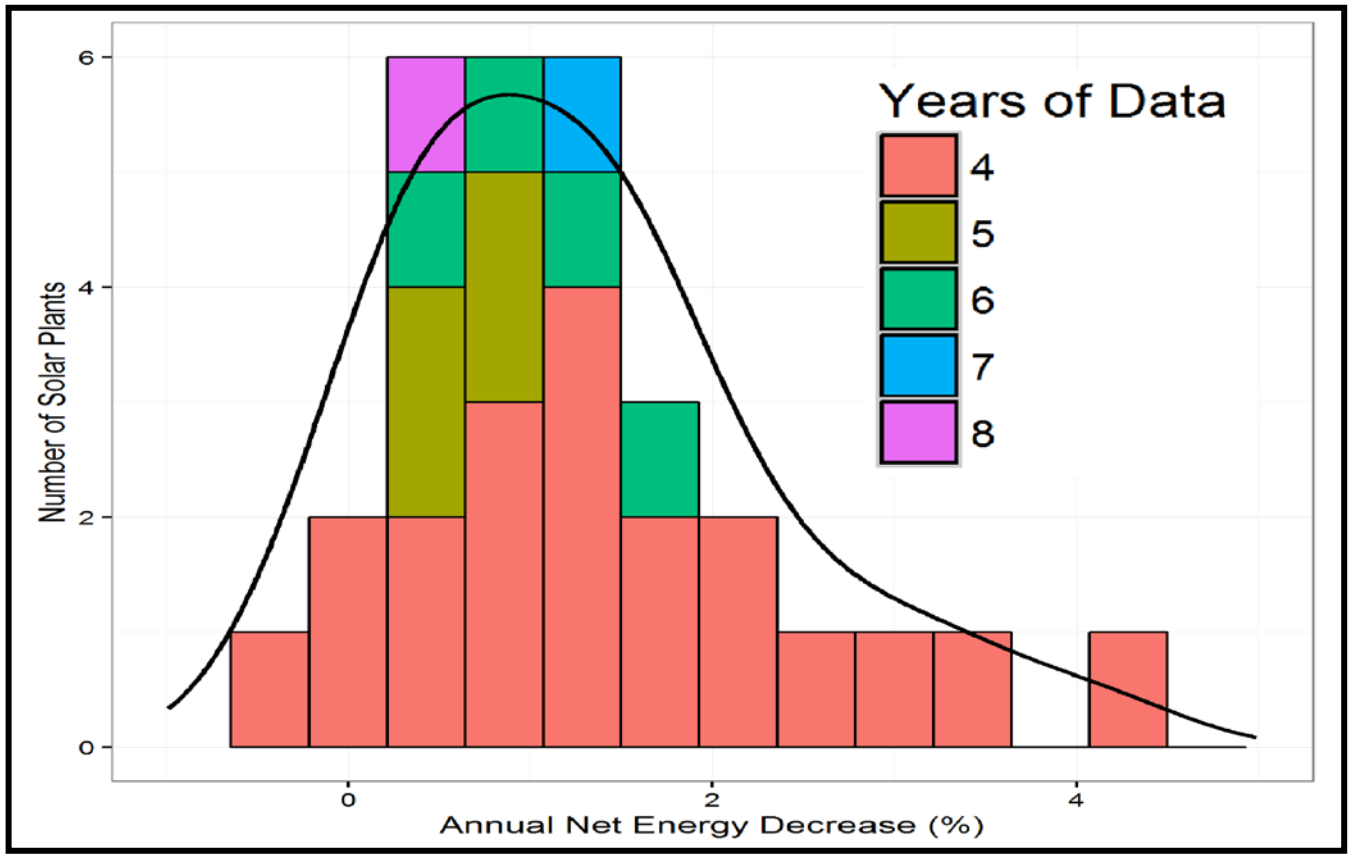
- Operational performance is within 0.3% of AWST's estimates (on average)
- Standard deviation of 2.1% from the regression line, somewhat influenced by configuration-specific factors not considered for operational relationship (equipment/technology, DC-AC ratio)
- AC over-sizing may compensate for the ~3% difference between pre-construction and operational PRs
- Outliers by 5-10% below regression (despite high availability) have poor PRs, suggesting equipment underperformance or poor O&M activities





DEGRADATION

- Degradation calculated as percent energy decrease after irradiance correction
- Projects with only four years of data showed a greater range of degradation rates due to a shorter assessment period.
- Early-year degradation rates are more uncertain, making them difficult to predict and analyze.
- System degradation rates may be greater than material-only impact



OEPR ANALYSIS

Approximately 50 Operational projects:

- Desert Southwest
- Canada
- South America
- India

Findings:

- Perceived underperformance sometimes due to optimistic PRs from some IEs (2% underperformance, or 2% over-prediction?)
- Key loss areas overlooked:
  - DC array performance loss (0.5-1.5%)
  - String-level mismatch (0.5%)
  - Snow loss under-prediction (up to 5-10%)
  - Plant operation of curtailment on string, inverter, or plant level
- Availability for well-maintained projects: 98-99%
- Annual degradation (system level) influenced by unresolved DC system failures

CONCLUSIONS

- Availability is within ~1% of pre-construction estimates
- AWST's pre-construction estimates align well with operational experience; however:
  - Pre-construction performance ratios may be 2-3% optimistic
  - Some modelers overlook DC factors, leading to ~2% over-prediction
- Degradation:
  - Is difficult to estimate until year 5
  - Exceeds material-only degradation estimates (despite inverter limitation loss reclamation)
- Pre-construction estimates can be improved by considering:
  - Undetected/unmitigated/unaccounted-for DC array issues
  - O&M service consistency/quality
  - Snow loss underprediction in certain climates
  - Long-term degradation on a system-level, accounting for:
    - Mismatch increase
    - Unresolved DC array issues



THANK YOU FOR YOUR TIME

Peter Johnson
peter.johnson@ul.com | 1.518.213.0044 x1048