TEST LAB REPORTS TO SUPPORT BANKABLE ENERGY 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

PRESENTATION OVERVIEW

- Motivation for Module Testing
- Module Performance Parameters
- Test Criteria and Uncertainty
- Example 1: Incident Angle Modifier Factor Profile
- Example 2: Initial Light Induced Degradation

MOTIVATION FOR MODULE TESTING

- Publicly-available specifications sheets may be conservative in their representation of module performance

- If warranted, module definitions in PVsyst (PAN files) and loss assumptions may be created/edited to more accurately represent performance

- Test results always inform the analysis, but certain requirements are needed for a P50 adjustment

- Integration of AWST with UL results in:
  - More meaningful module testing
  - More meaningful IE opinions
    - Internal firewall to protect confidentiality of test lab customers (“safe place to fail”)
    - General learning can be shared

MOTIVATION FOR MODULE TESTING

Area of Interest	Independent Engineers	Module Suppliers and Developers
Test Efficacy	Are lab test standards sufficient to capture future field performance?	If current test lab results are not used for bankable energy estimates, what is the value of performance testing?
Sample Size	Do lab test results have lower uncertainty than public spec sheets? • Calibration/precision of measurements and test equipment • Sample size (no. modules, number of measurements per module)	How can testing be optimized to accommodate project schedules? • Some tests require significant chamber time • By the time testing is complete, supply agreements may be final
Relevance	What makes a particular module test relevant? • Related modules with a different in bill of materials? • What constitutes independent module selection?	How can testing be optimized to be more economic? • Testing large sample sizes not financially viable • Are previous tests from similar modules relevant for newer products?

MODULE PERFORMANCE PARAMETERS

Performance Characteristic	Relevant Test Standard(s)
Energy Conversion (I-V Curves)	IEC-61853
Module Quality Adjustment	
Module Mismatch (within Bin)	
Incident Angle Modifier Factor	IEC 61853-2
Spectral Response	IEC 60904-8
Temperature Coefficient of Power	IEC 60891
Initial Light-Induced Degradation	IEC 61215-1 (general), IEC 61215-1-1 (crystalline), IEC 61215-2 (procedure)
Long-Term Degradation	IEC-61853 at project start, after 3-6 months, then every year for first five years
DC Performance Loss	IEC-61853 along with systems-level testing

ACCEPTANCE CRITERIA

Category	Criteria
Test Provider	• Recognized and reputed test laboratory
Standards	• Tested to relevant standard(s)
Relevant Module Definition	• Relevant bill of materials for particular test category • Consistent manufacturing process • Independent "blind" selection

Uncertainty	• Sufficient number of:
	  • Iterations (minimize test error)
	  • Samples (quantify variance)

Reporting	• Sufficient detail to demonstrate adherence to relevant standard(s) • Confirm test instrument calibration • Uncertainty assessment

CONTRIBUTORS TO TEST UNCERTAINTY

Measurement Accuracy

- Equipment accuracy
- Calibration

Environmental Factors

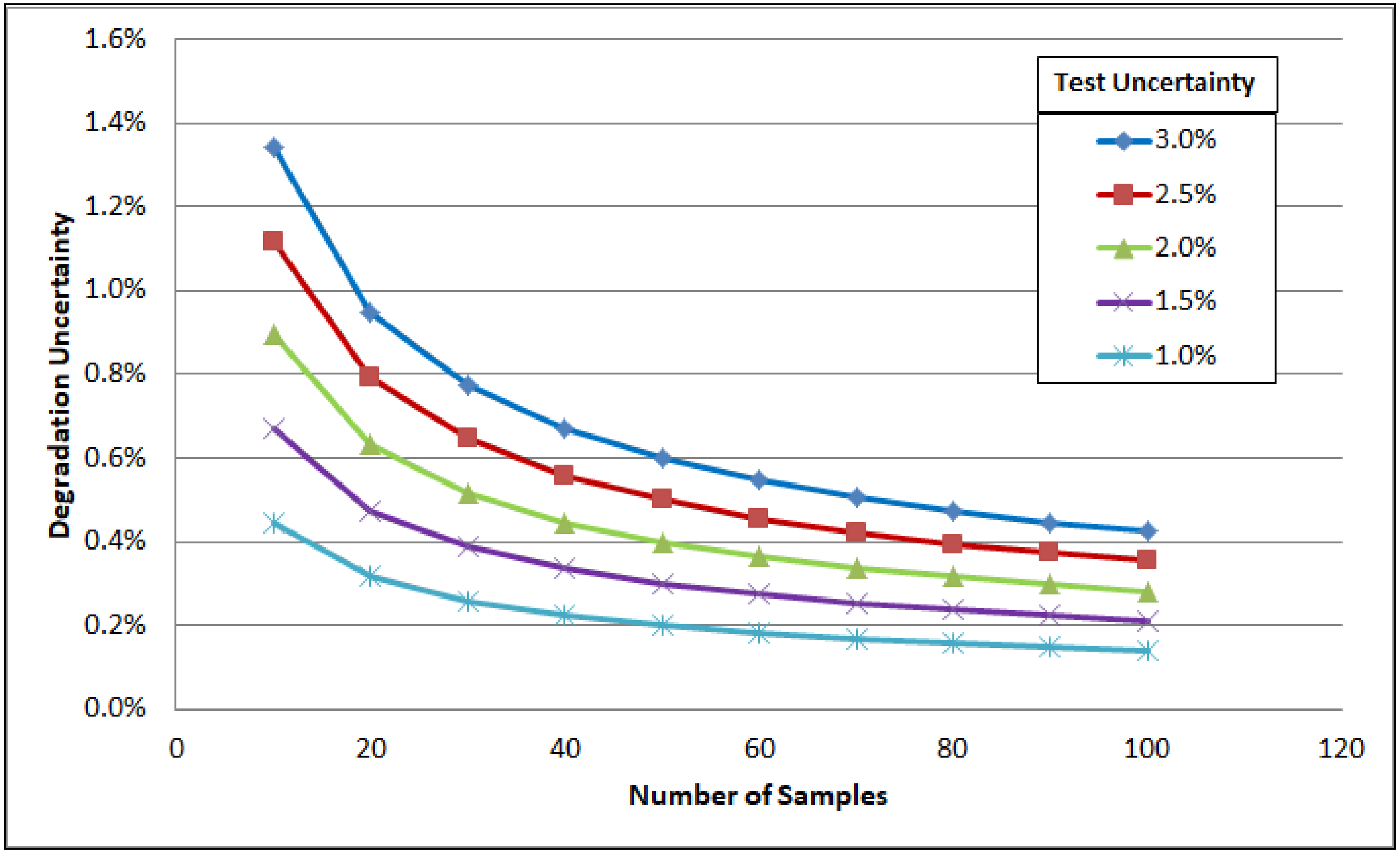
- Outdoor testing
- Indoor testing

Test Error

- Module variation
- Test protocols
- Human operator error
- Reporting accuracy

SAMPLE SIZE AND UNCERTAINTY

- Number of iterations helps reduce test error
- Number of samples helps reduce variance
- Where's the sweet spot?



EXAMPLE 1: INCIDENT ANGLE MODIFIER FACTOR

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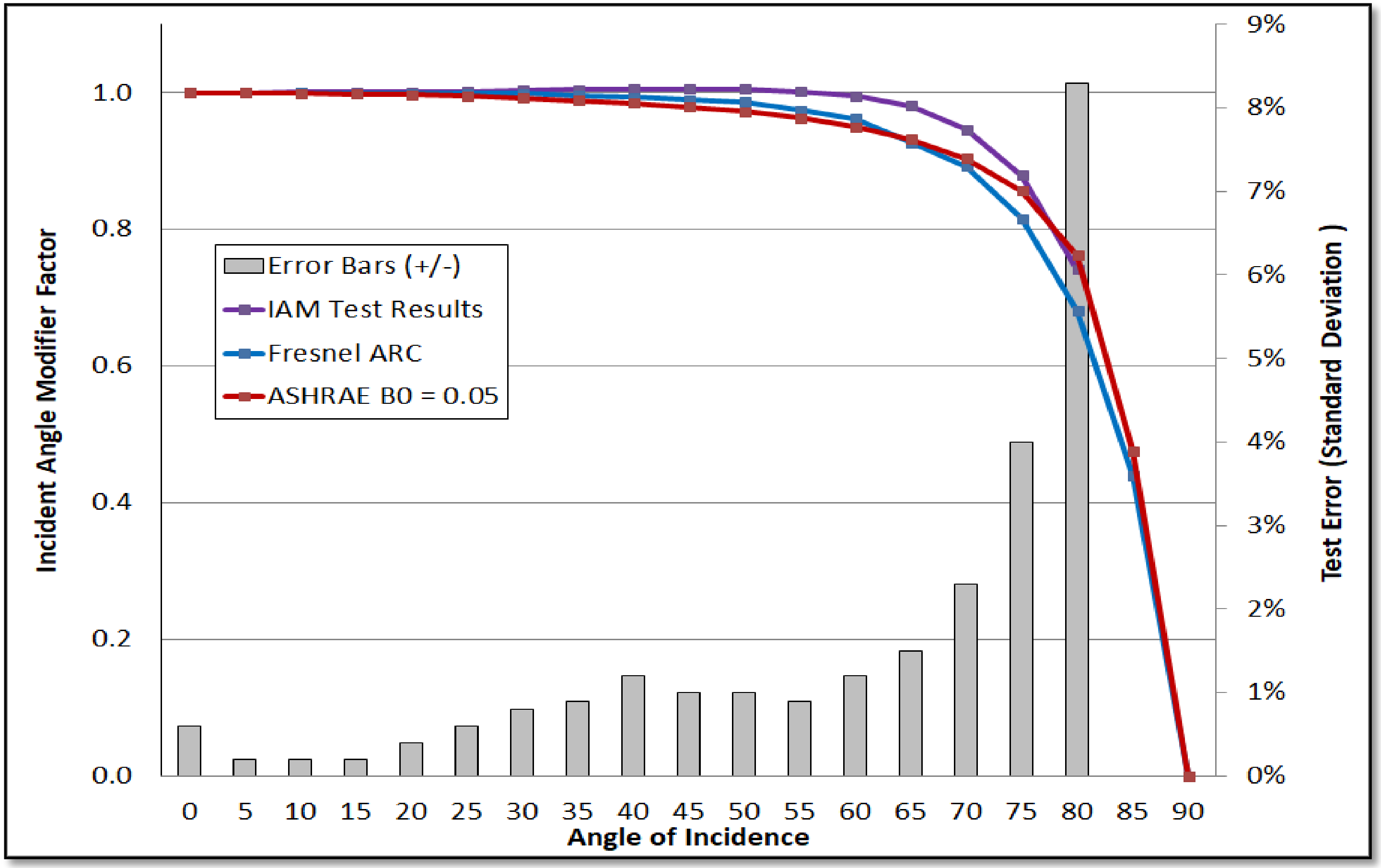
- Outdoor testing introduces environmental error (albedo and diffuse sunlight)
- Uncertainty increases with angle of incidence: most critical part of profile
- Higher latitude sites stand to experience greatest potential energy gain



IAM FACTOR: CONTRIBUTORS TO TEST UNCERTAINTY

Measurement Accuracy

- Pyranometer accuracy
- Calibration, instrument soiling, angularity
- Power measurement accuracy

Environmental Factors

- Temperature, irradiance, wind fluctuations
- Albedo and diffuse (esp. outdoor tests)
- Non-collimated light (indoor tests)

Test Error

- Module variation
- Test angle accuracy
- Test protocols
- Reporting accuracy

CRITERIA: INCIDENT ANGLE MODIFIER FACTOR

Category	DRAFT Criteria
Test Provider	• Recognized and reputed test laboratory
Standards and Test Requirements	• Protocols of IEC 61853-2, and • 10° intervals as a minimum, 5° intervals strongly preferred between 60°-90° AOI • Indoor testing preferred, as this lowers uncertainty and prevents positive bias

Relevant Module Definition	• Independent/random selection of test samples
	• Provenance control of modules from production through testing
	• Same series and product line, OR
	• Signed statement from manufacturer indicating:
	  • Same type of glass
	  • Same manufacturing process

Uncertainty	• At least three modules, tested separately or together (sample size) • At least three measurements for every angular interval (reduce/quantify test error)

Reporting	• Demonstration of testing to IEC 61853-2, showing work
	• Numerical reporting of uncertainty for each measurement interval, including
	  • Calibration of all sensors (meteorological, flash tester, flash reference module)
	  • Uncertainty of temperature correction/adjustment (if relevant)
	  • Assessment of human error

EXAMPLE 1: IAM FACTOR OBSERVATIONS

- Opportunities:
  - Impact on P50 can be 0-1.5% depending on latitude and configuration
  - Relevant module for testing is flexible
  - Adjustments to reporting are easily achievable (uncertainty)

- Challenges:
  - Uncertainty is highest in most critical part of the profile
  - Indoor tests are preferred, but still not perfect

EXAMPLE 2: INITIAL LIGHT-INDUCED DEGRADATION

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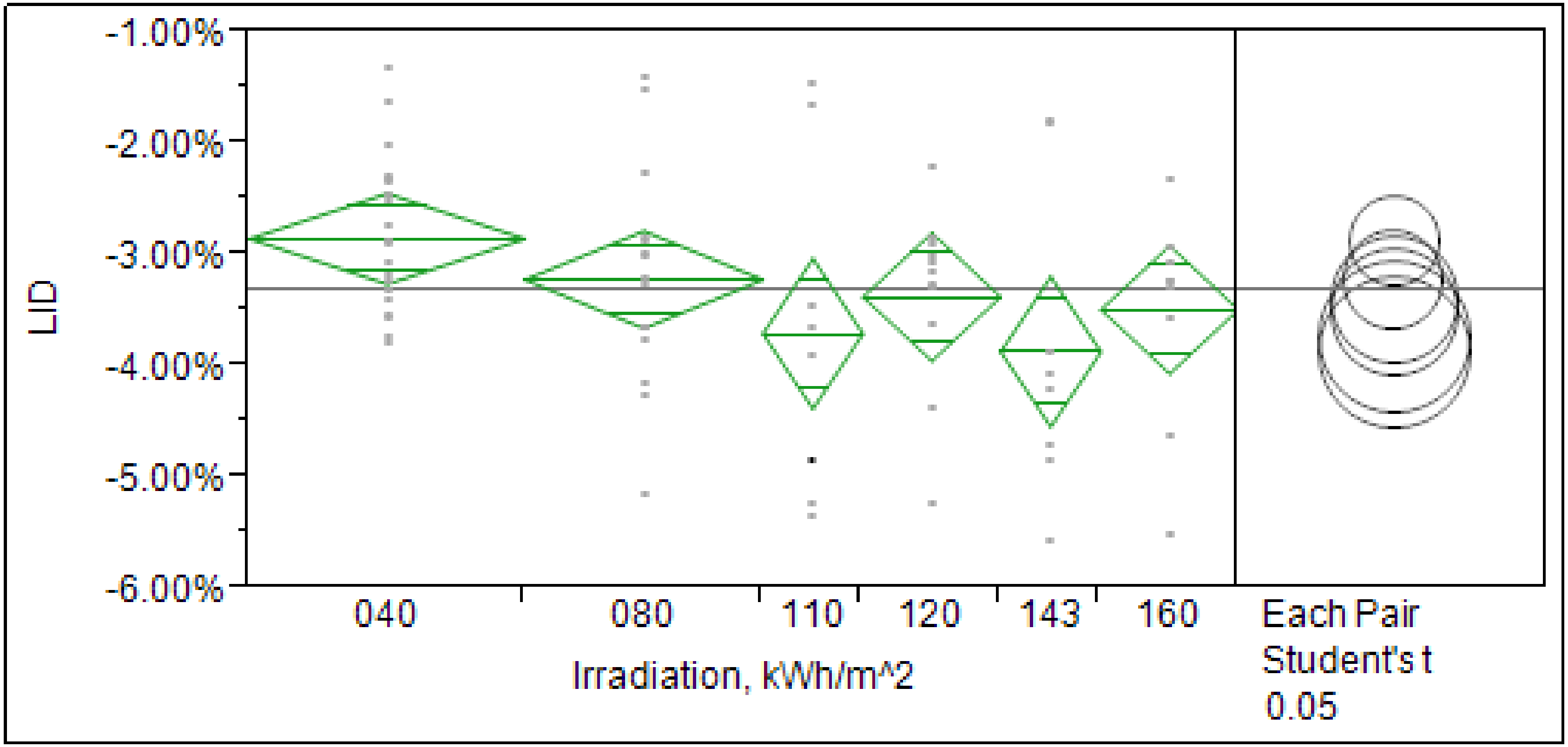
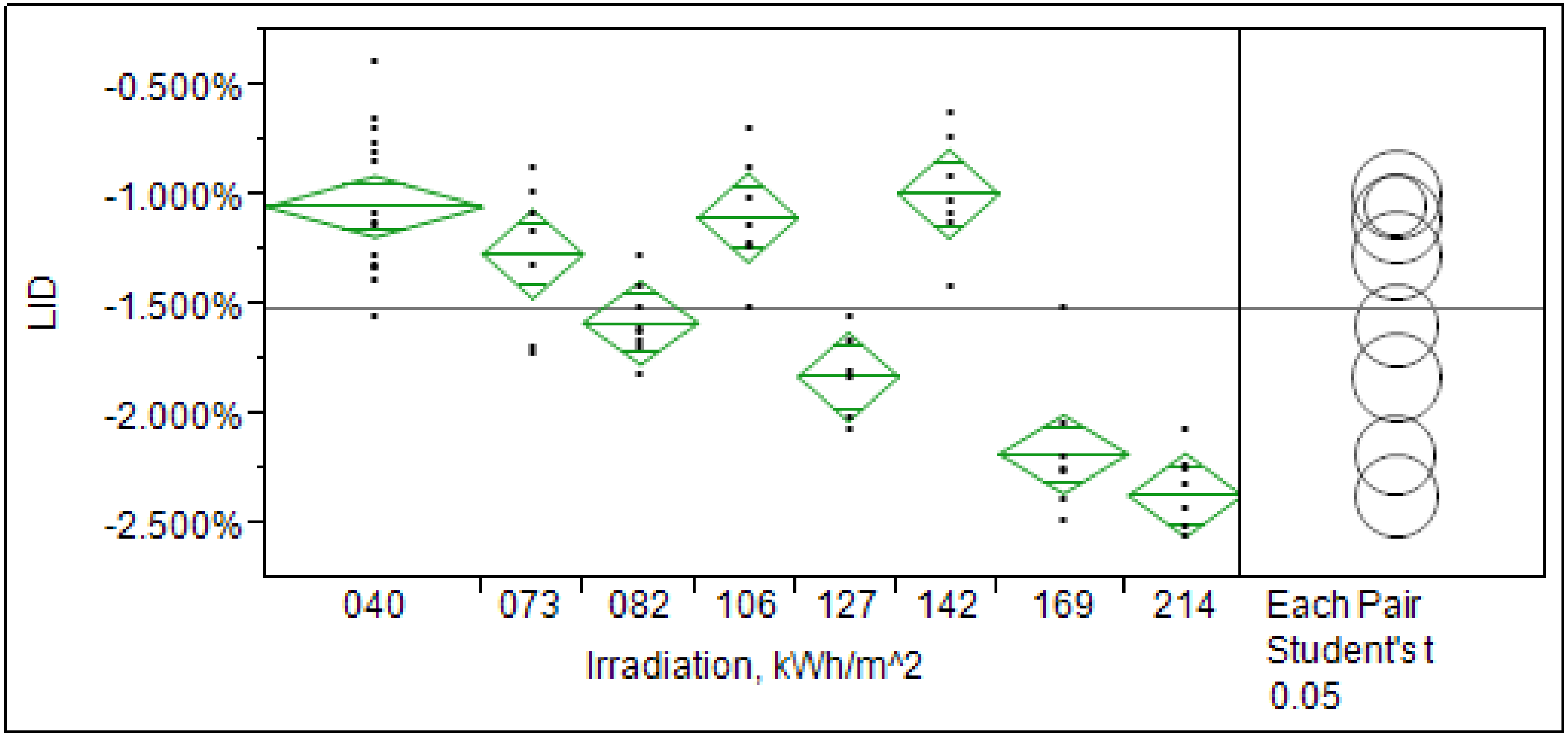
MANUFACTURER A



- Larger variability than expected
- Stabilization occurred at 100 kWh/m^2 (about 20 days)

EXAMPLE 2: INITIAL LIGHT-INDUCED DEGRADATION

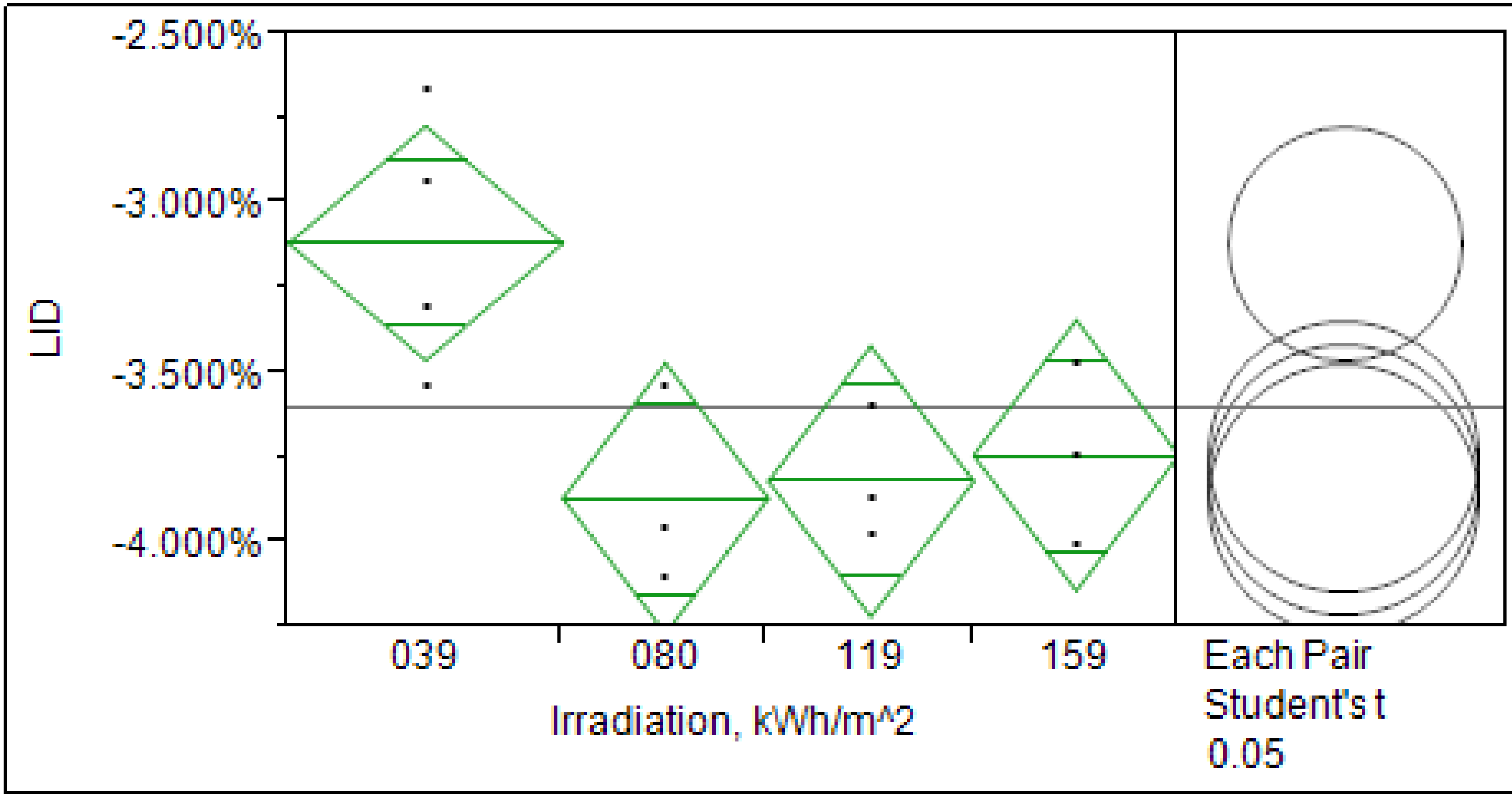
MANUFACTURER B



- In this location, stabilization was not achieved even after 200 kWh/m^2
- Another sample group in another location did stabilize

EXAMPLE 2: INITIAL LIGHT-INDUCED DEGRADATION

MANUFACTURER C



- Stabilization achieved by 80 kWh/m^2 (about 15 days)
- Gradual return, but final value difficult to determine (site specific)

CRITERIA: INITIAL LIGHT INDUCED DEGRADATION

Category	DRAFT Criteria
Test Provider	• Recognized and reputed test laboratory
Standards and Test Reuirements	• IEC 61215-1 (general), IEC 61215-1-1 (crystalline), IEC 61215-2 (procedure) • Test to stabilization: Pmax within 1% for three successive measurements using 25 kWh/m^2 bins
Relevant Module Definition	• Independent/random selection of test samples • Provenance control of modules from production through testing • Same series and product line required
Uncertainty	• At least twenty-module sample size • Assessment of uncertainty required (tools, operator, variance)

Reporting	• Demonstration of testing to standards, showing work
	• Numerical reporting of test uncertainty for each measurement interval, including
	    • Calibration of all sensors (meteorological, flash tester, flash reference module)
	    • Uncertainty of temperature correction/adjustment
	    • Assessment of human error (operator, exposure time, etc.)

EXAMPLE 2: ILID OBSERVATIONS

- Opportunities:
  - Quick stabilization suggests more confidence ILID assumption
  - Consistent results → reduction in ILID uncertainty

- Challenge: universality of test results for P50 adjustment
  - Relevant module is exact same bill of materials
  - Variation within a sample set, from batch to batch
  - ILID rate and magnitude are impacted by environment

CONCLUSIONS: LAB TEST REPORTS

General Observations for Energy Modeling

- Lab performance tests always inform pre-construction energy estimates
- In some cases, additional test/reporting requirements add value
- There is a tradeoff between uncertainty reduction and cost/schedule

Incident Angle Modifier Factor

- Reporting on test uncertainty is an easy win (+)
- Uncertainty is highest in most critical part of the profile (-)

Initial Light-Induced Degradation

- Universality of test results for P50 adjustment? (-)
- If results are consistent → reduction in ILID uncertainty (+)

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