Lab to Field Predictability of First Solar CdTe Production Modules

NREL PV Module Reliability Workshop (PVMRW), February 24, 2015

Dr. Allan Ward

Director, Module and Systems Reliability

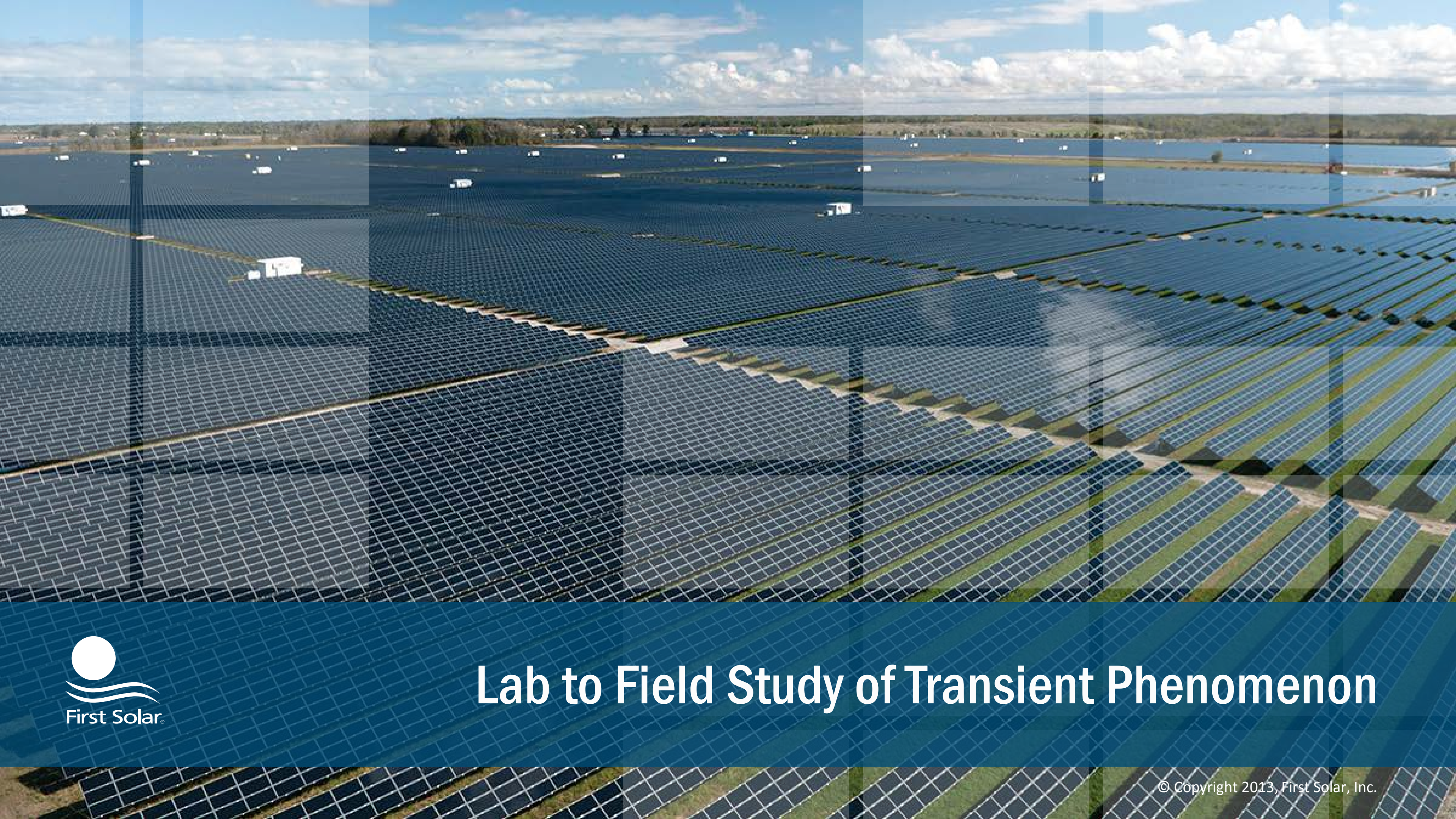
First Solar

Presentation Outline

Presentation Outline: Lab to Field Predictability of First Solar CdTe Production Modules

- Lab to field correlation of transient and steady state behavior in First Solar CdTe thin film PV technology (4.5 years with high quality periodic measurements on simulator compared to light soak on sister plates)
- Lab to field correlation of transient behavior in “Series 3 Black Plus" current high volume product
- Alternate method to predict metastability
- Accelerated coupon analysis of transient behaviors
- Long term lab to field correlation of FS CdTe PV technology (Analysis of field test site modules, MPP for 4.5 and 7 years)


Series 2 Series 3 Series 3 Black +

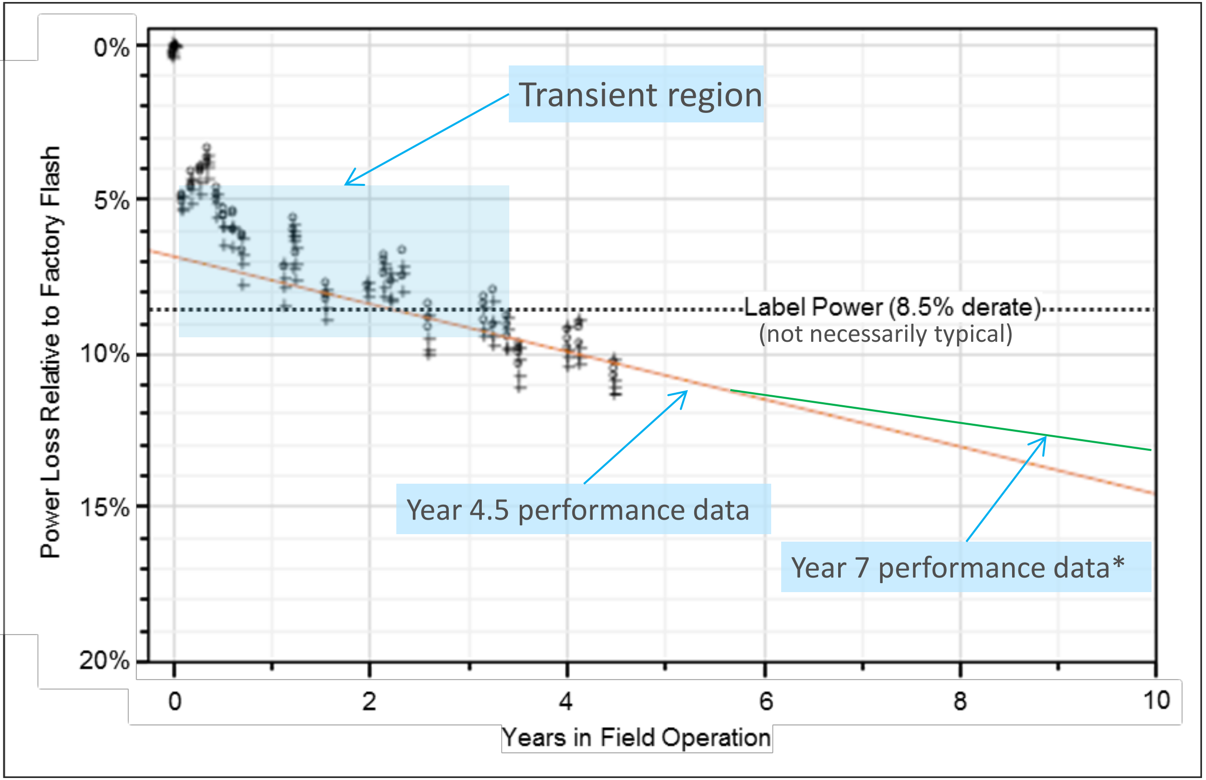


First Solar

Lab to Field Study of Transient Phenomenon

Periodic STC Measurements of Fielded CdTe Modules (Series 3)

- Initial metastability equilibrates trap occupancy to field temperature and bias conditions
- The transient region is greatly influenced by changes in the back contact; the observed damped oscillation is due to the aforementioned metastability behavior and is driven by seasonal temperature changes
- The long term intrinsic cell performance characteristic is believed to change less year over year

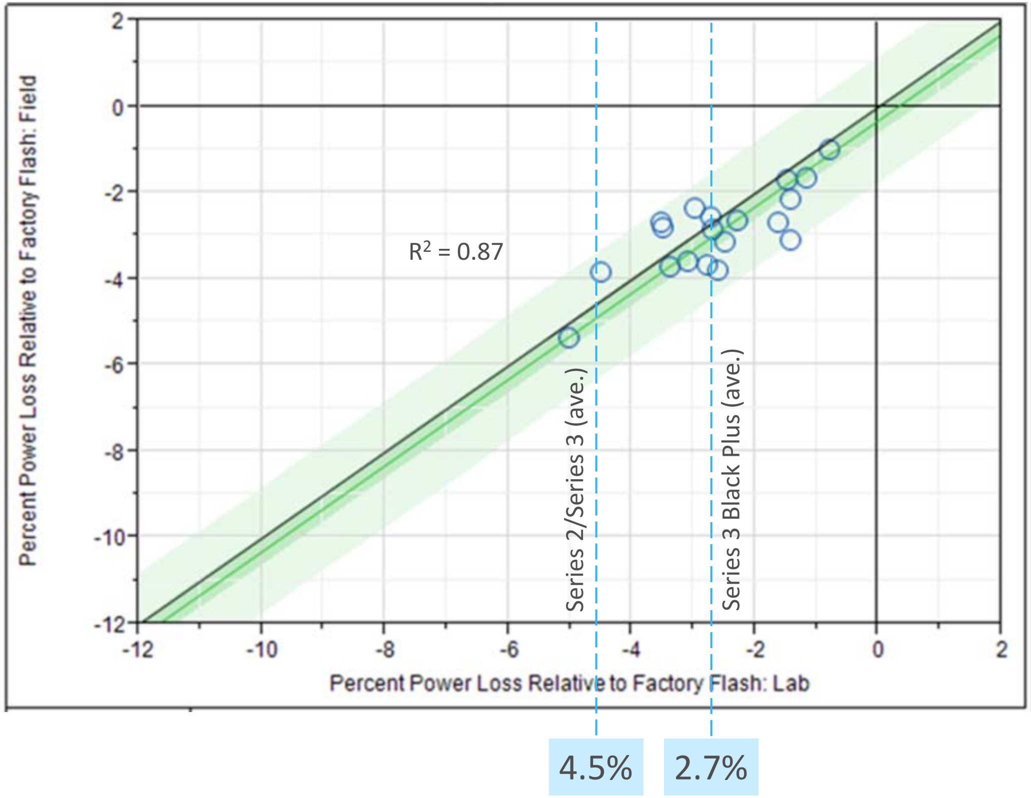


*Year data is also Series 3 from a different location (shown later in this presentation)

First Solar.

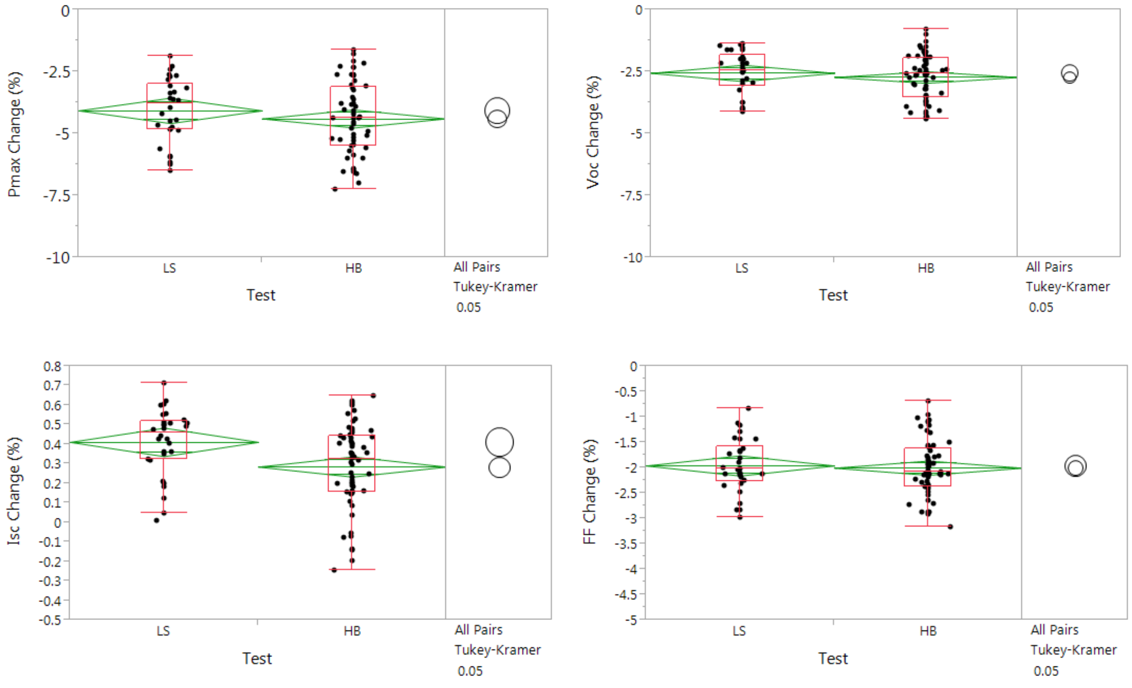
Lab-to-Field Metastability Correlation

- For a given temperature, the initial metastability change in the field is very predictable from lab measurements; the correlation plot shows sister modules exposed to equivalent cell temperatures in the lab and in the field
- Since the metastable point responds to temperature change with a time constant on the order of a few days, an average value for field temperature is sufficient to predict power loss from metastability effects

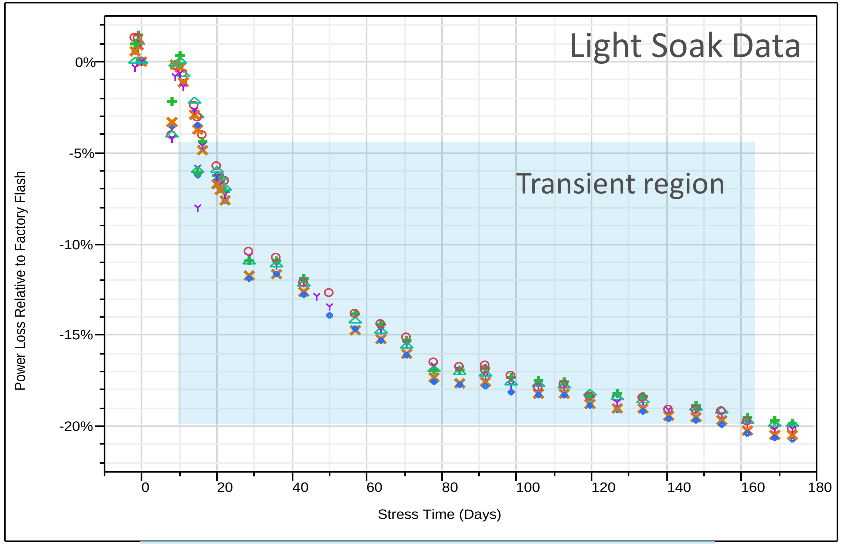


Lab-to-Field Metastability Correlation (Alternate Method)

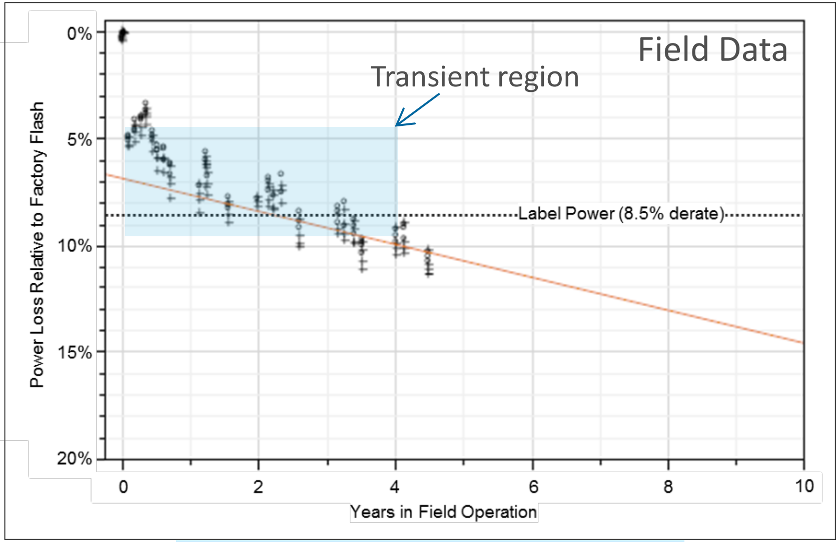
- It is not necessary to use light soak to predict metastable field behavior for First Solar CdTe modules
- These data show that effectively the same result is obtained using heat and bias (HB) stressing or traditional light soak (LS) testing
- This alternate method is conducive to increased sample throughput (important for reducing design cycle time and supporting high volume manufacturing) and lower capital and operational testing costs



Lab-to-Field Transient Power Loss Correlation (Series 3)



Average light soak cell temperature = 58°C

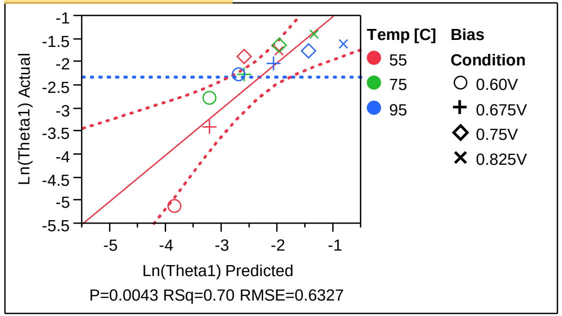


Average field cell temperature = 21°C

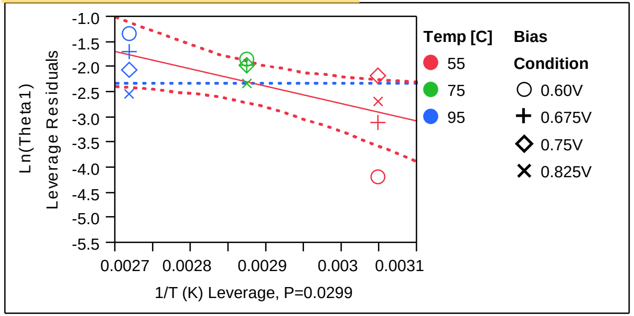
- Transient region activation energy for the magnitude of power loss is approximately 0.3eV, with an additional 5% bias acceleration factor, resulting in a total acceleration factor of approximately 4; this loss is non-recoverable (not a metastability); slide 8 will compare this to coupon results
- Transient region activation energy for the magnitude of the time constant is approximately 0.67eV, resulting in an acceleration factor of approximately 20); slide 9 will compare this to coupon results

Lab-to-Field Transient Power Loss Acceleration Factors (Series 3)

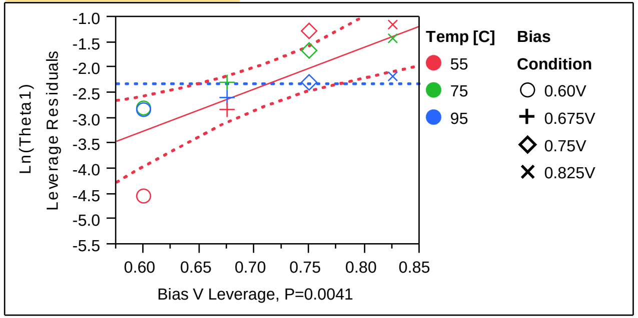
Actual vs Predicted



Leverage Plot (1/Temperature)



Leverage Plot (Bias)

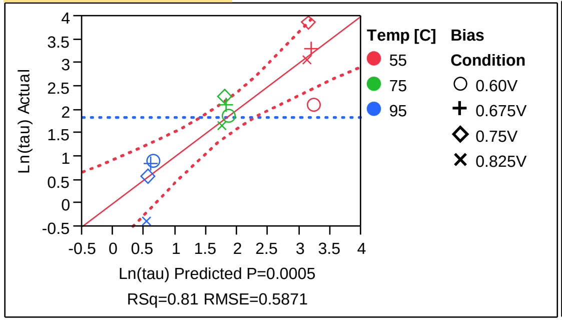


- The activation energy for the magnitude of the transient power loss (denoted as ‘theta 1’ in the plots) as calculated from lab coupon data is 0.3eV, which is consistent with the aforementioned field observations indicating 0.3eV
- The magnitude of the transient power loss has a small dependence on bias (about 5% for a temperate climate)

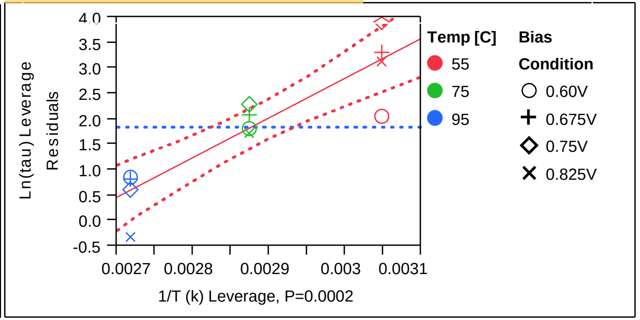
First Solar.

Lab-to-Field Transient Power Loss Acceleration Factors (Series 3)

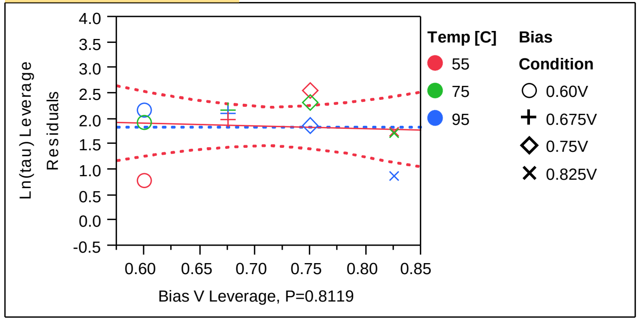
Actual vs Predicted



Leverage Plot (1/Temperature)



Leverage Plot (Bias)



- The activation energy for the time constant (denoted as 'tau' in the plots) as calculated from lab coupon data is 0.67eV, which is consistent with the aforementioned field observations indicating 0.67eV
- The time constant has a weak dependence on bias, thus simplifying lab to field predictions

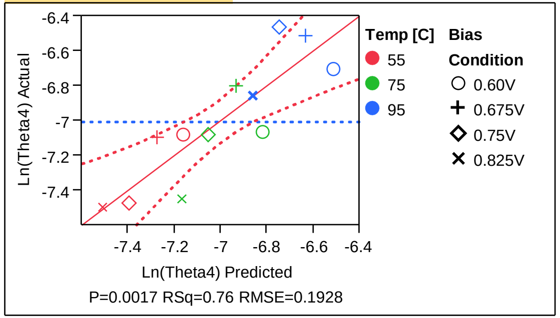
First Solar.

First Solar.

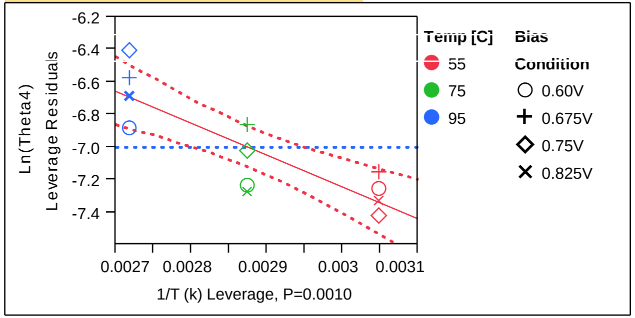
Long term performance characterization

Lab-based Long Term Power Loss Acceleration Factors (Series 3)

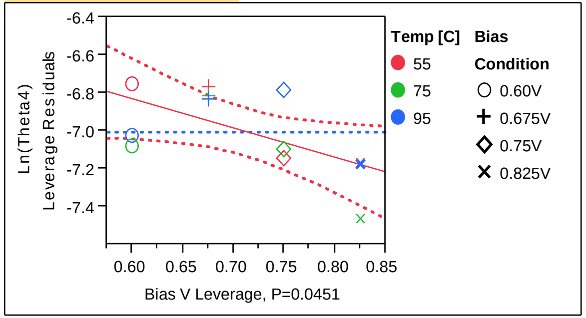
Actual vs Predicted



Leverage Plot (1/Temperature)



Leverage Plot (Bias)



- The activation energy for the slope of the long term reliability characteristic as calculated from lab coupon data is 0.17eV
- The long term slope has a weak dependence on bias, thus simplifying lab to field predictions

First Solar.

Lab-to-Field Long Term Performance Assessment Challenge

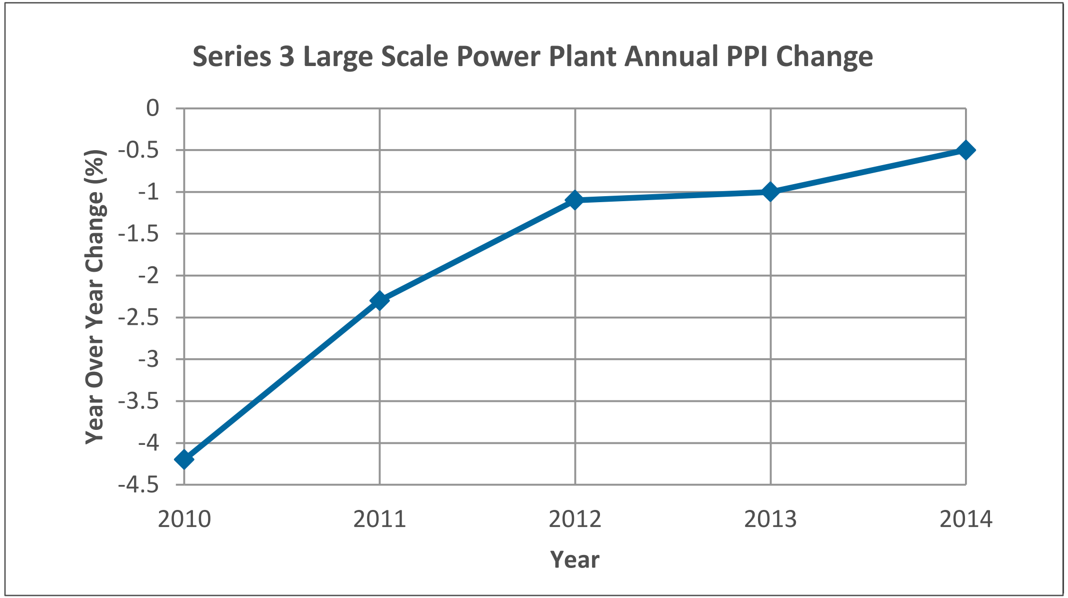
- Long term power changes are too small to measure precisely in the field due to various sources of noise (soiling, BoS component changes, etc.)

- Due to the small acceleration factor for long term modeling, sample conditioning would require very long stress durations

- Therefore, samples were retrieved from the field and studied with 3-temperature tests

Long Term Cell Performance

- Activation Energy is estimated to be 0.07eV +/- 0.07, with a 95% confidence that it is less than 0.3eV, consistent with the aforementioned lab result of 0.17eV
- Even with a non-zero, low value activation energy (<0.2eV), the implication is that hot spots should not affect intrinsic cell reliability significantly so long as they are less than 105C peak temperature (approximately 50C above nominal cell temperature in the desert summer)
- At the power plant level, the annual output appears to stabilize over time, consistent with a gradual reduction in the rate of change



Summary

- Lab to field correlation of transient and steady state behavior in First Solar CdTe thin film PV technology was presented using:
  - modules from a temperate climate field test site operated at MPP for 4.5 years
  - modules from a desert climate field test site operated at MPP for 7 years
  - determination of thermal and bias acceleration factors for the magnitude and time constants of all three phases of reliability behavior
- Field metastability can be predicted with high confidence from lab stress tests
- A successful alternate method to predict field metastability was presented
- Accelerated coupon analysis of transient behaviors is consistent with field observations
- The rate of performance change of the intrinsic cell in the field is expected to be less than 0.8%/year after year 6, with an activation energy likely to be less than 0.2eV

First Solar®