SUNPOWER™

THE WORLD'S STANDARD FOR SOLAR™

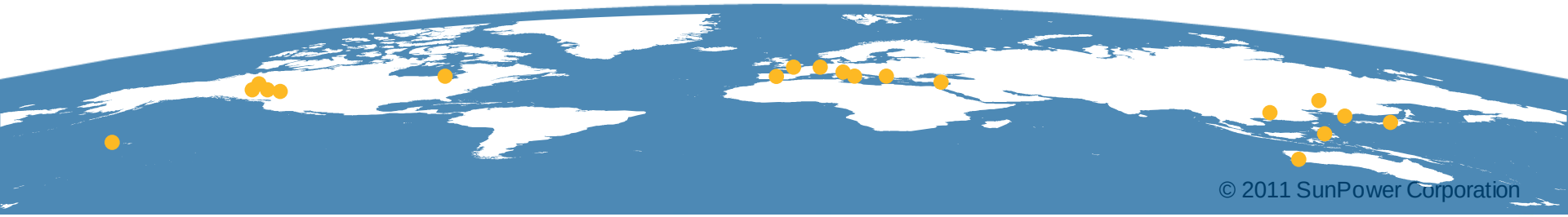
THE JOURNEY OF SUNPOWER TO 20% MODULE EFFICIENCY

Doug Kim, Gabriela Bunea

February 22, 2012

SunPower 2012

- World-leading solar conversion efficiency
- >2 GW solar PV deployed
- Diversified portfolio: roofs to power plants
- More than 180 patents
- 5,000+ employees
- Strategic investment by Total: #11, F500



SunPower Products

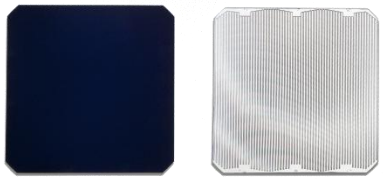
SunPower™ Solar Panels

E18
225W

E19
245W

E20
327W

SunPower Maxeon™
All-Back Contact, High Efficiency Solar Cell



SunPower™ T5 Solar Roof Tile

SunPower™ T0 Tracker

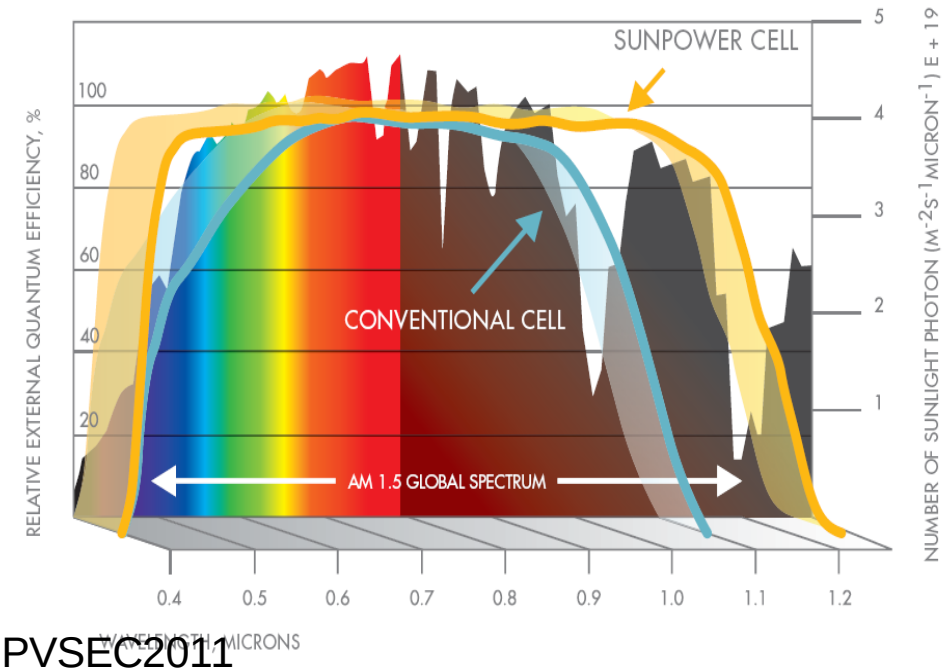
SunPower Oasis

SunPower® C7 Tracker

OUTLINE

- Efficiency Improvement
- Reliability
- High Volume manufacturing
- Conclusion

EFFICIENCY IMPROVEMENT

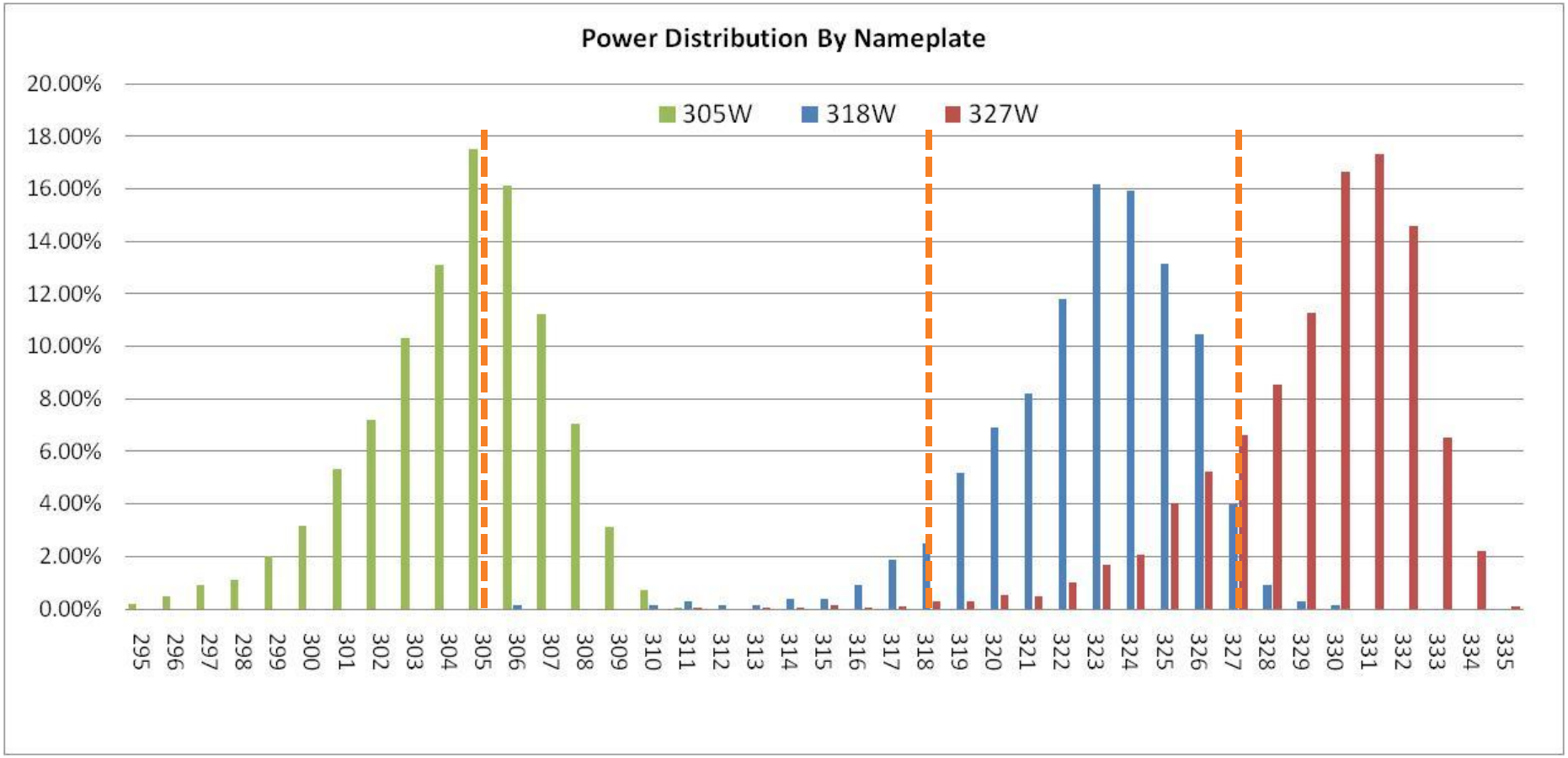


Gabriela Bunea *et al* PVSEC2011

	2007	2009	2011
Module STC Wp	305	318	327
Cell Efficiency (%)	22.4	22.4	22.4
Module Efficiency (%)	18.7	19.7	20.1

* 22.4% is average production efficiency of SunPower ® Gen2 cell technology (85%+ of total cell production.)
* 24.2% is the world record efficiency achieved on SunPower ® Gen 3 cell beta line in Q2 2010

POWER DISTRIBUTION BY NAMEPLATE



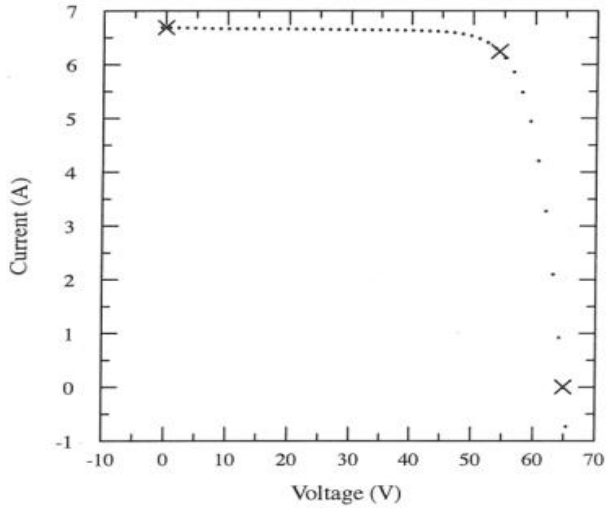
3RD PARTY PERFORMANCE VALIDATION

SunPower
mono-Si module

Device ID: H11P01163763
May 13, 2011 11:15:52 MST
Si Ref. Cell 294278

Device Temperature = 21.7°C
Device Area = 15774.8 cm^2
Irradiance = 1032.0 W/m^2

NREL SOMS IV System Confidential
PV Performance Characterization Team



V_{oc} = 64.90 V
I_{sc} = 6.689 A
Fill Factor = 77.9%
Efficiency = 20.8%

V_{max} = 54.23 V
I_{max} = 6.239 A
P_{max} = 338.3 W

Device Dimensions = 153.9 x 102.5 cm

Air Temperature = 13.7°C, Air Mass = 0.886, POA Sun Angle = 13.3°
Total Irradiance From K&Z CM11 = 1086.4 W/m^2

Irradiance corrected efficiency of 20.1% at 1Sun

SunPower Corporation

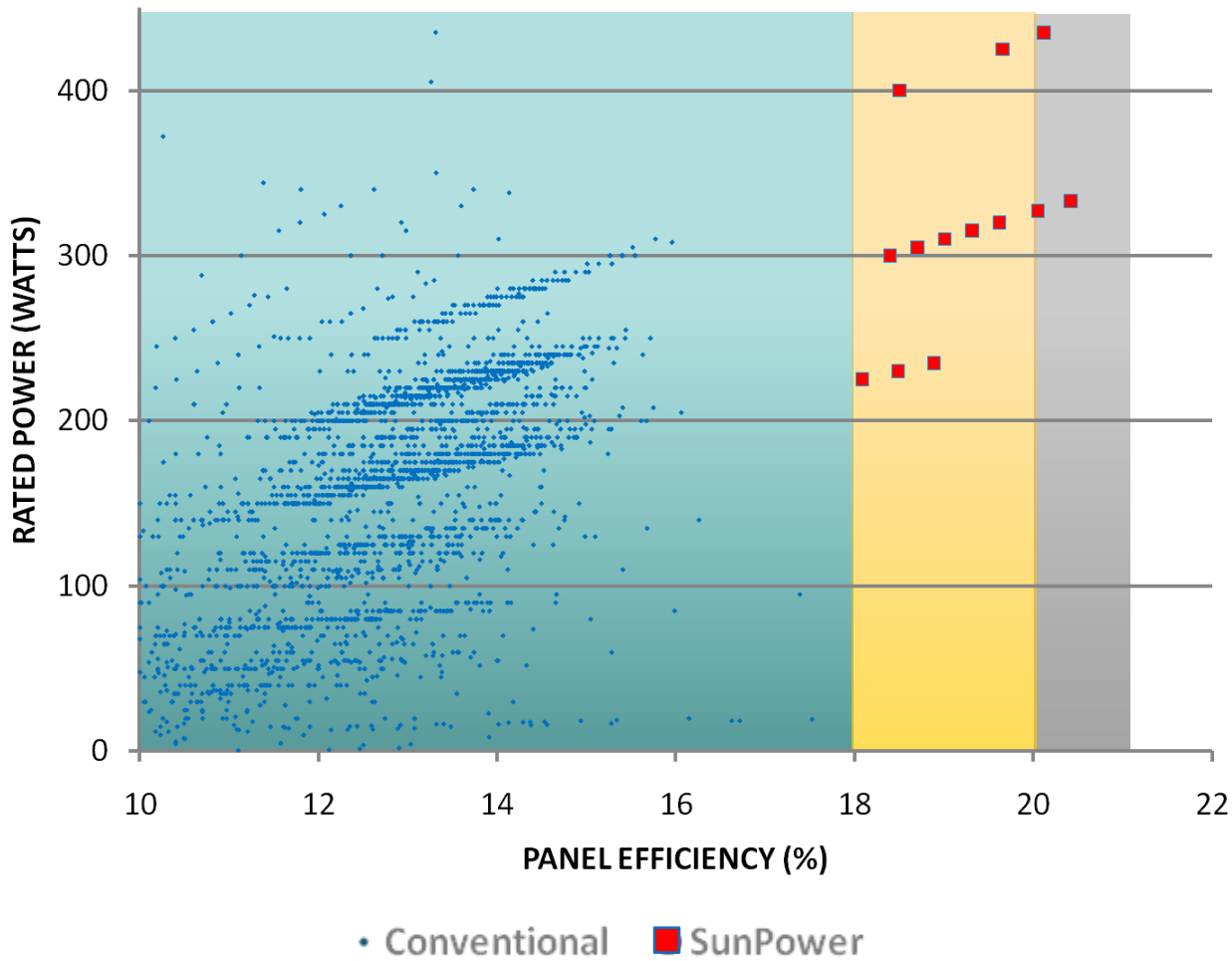
20% Module Efficiency

- E20: New product line launched in 2011
- Module efficiency >20%
- Over 20MW shipped (Sept 2011)

- > 327 W / 1.63m^2
- > 433 W / 2.16 m^2

SunPower ® Technology Leadership

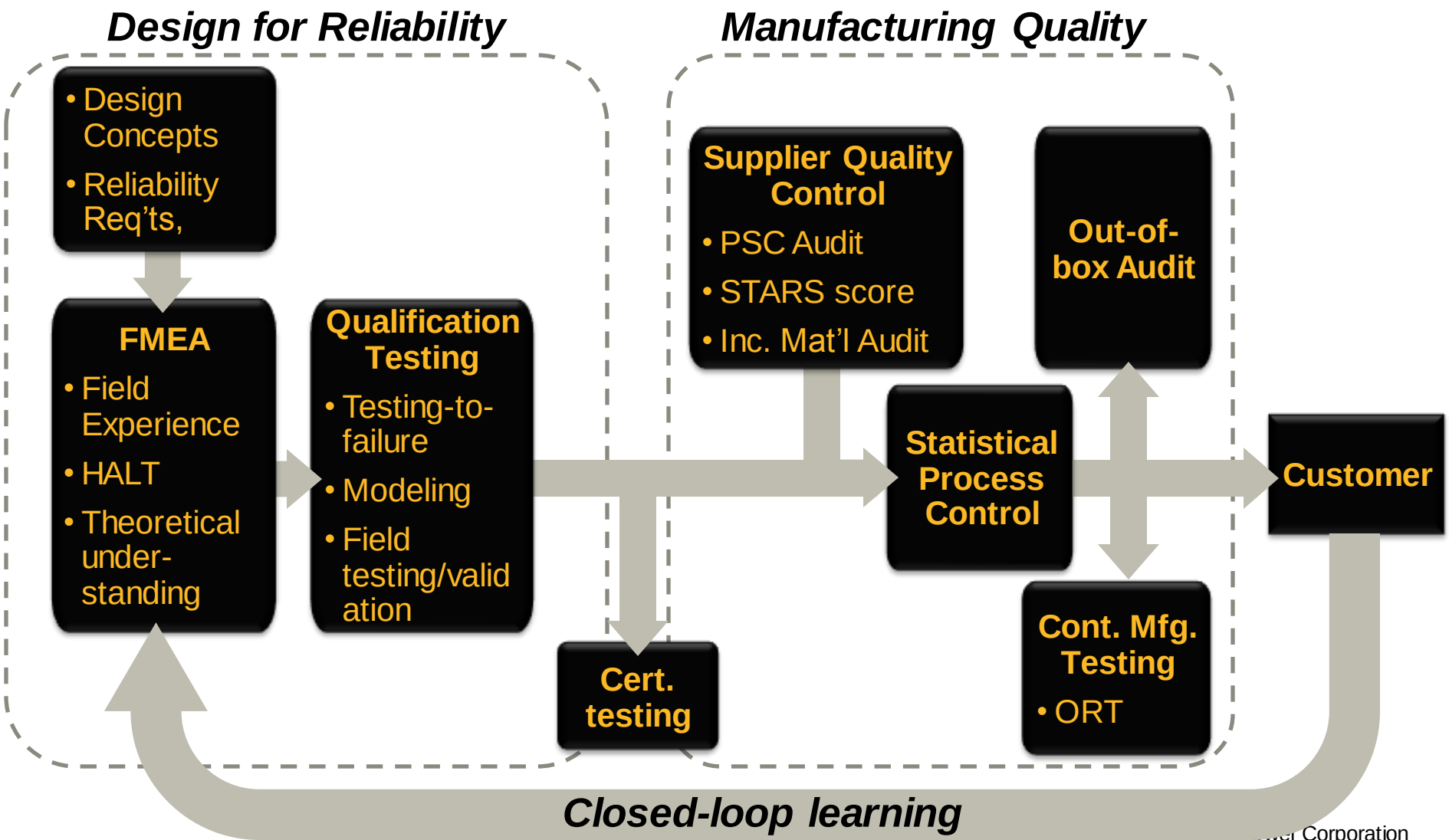
Photon Survey: SunPower® panels are more efficient per rated watt



E20 SERIES

Graph shows SunPower vs. conventional silicon PV
Source: Photon Annual Market Survey, 2010 and SunPower

HIGH RELIABILITY: Overall Process



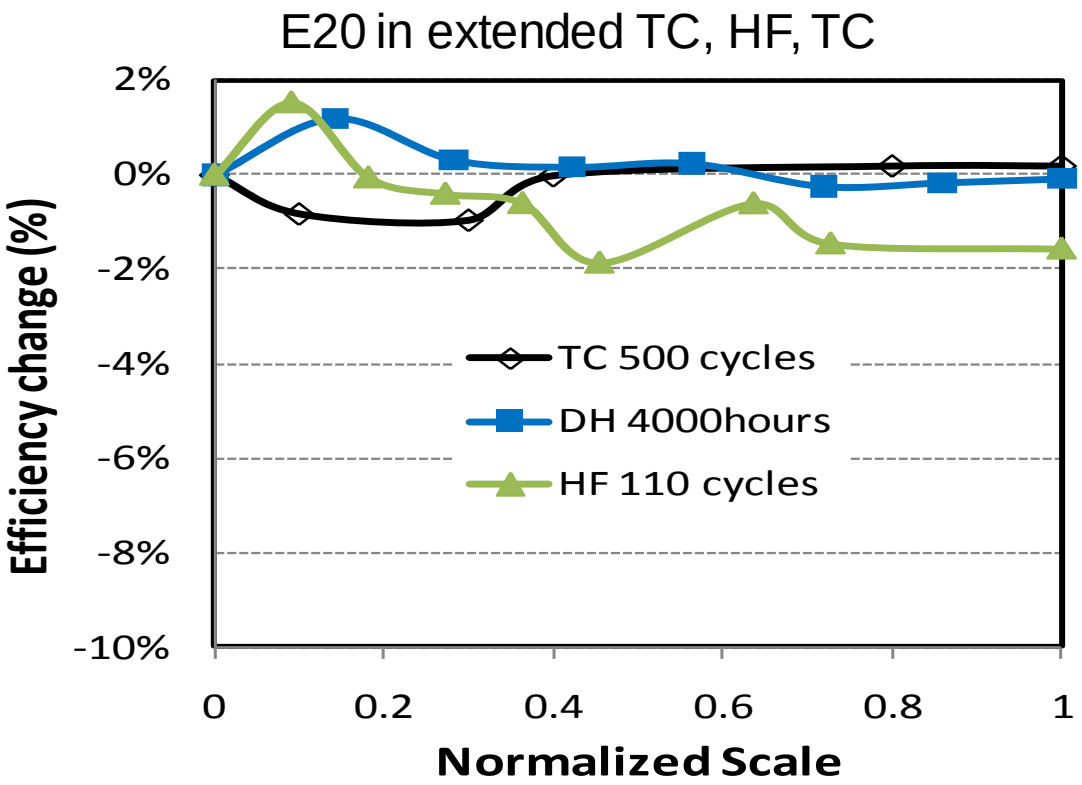
D. DeGraaf et al., "Qualification, Manufacturing, and Reliability Testing Methodologies for Deploying High-Reliability Solar Modules" 25th European Photovoltaic Solar Energy Conference, September 2010, Valencia, Spain

Failure Mode of PV Modules

- Humidity induced
- Mechanical stress induced
- Light induced
- Temperature induced
- Voltage induced

Extended IEC61215 Tests

- No humidity degradation
- No thermal degradation



Reliability significantly exceeds the industry standards

D. Kim et al, 26th European Photovoltaic Solar Energy Conference, September 2011,Hamburg

Reliability of the E20 module starts from the cell architecture

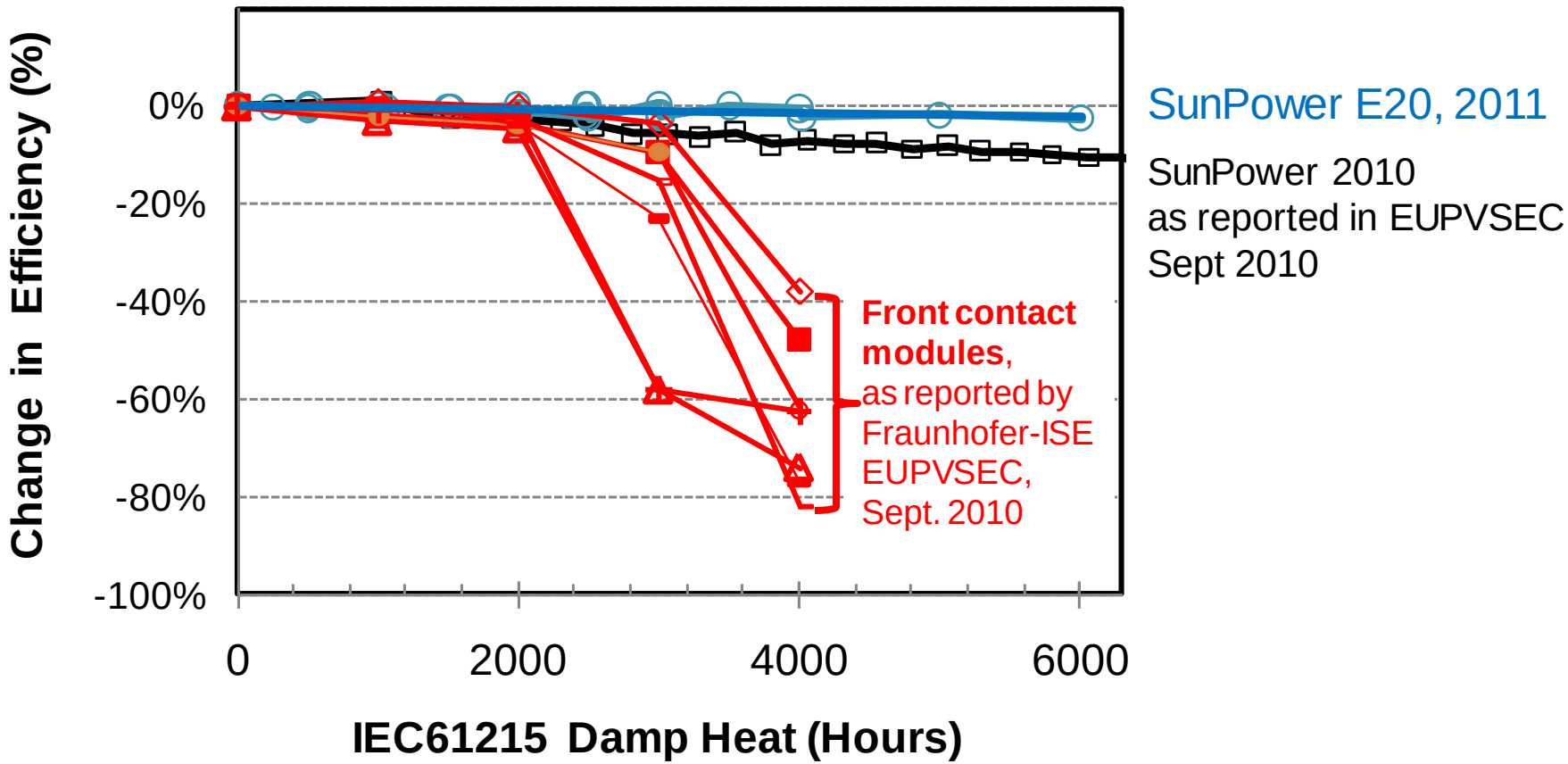
- All back-contact cell design
  - Front with no metal: corrosion free
  - Back with excellent corrosion resistance and humidity resistance
  - Thick metal fingers provide mechanical strength / integrity
  - Uniform non-damaging reverse break-down due to cell design

All-Back Side Contacts

Front Side (no gridlines)

Low corrosion susceptibility

- Robust cell and module design: No front metal & humidity resistant back



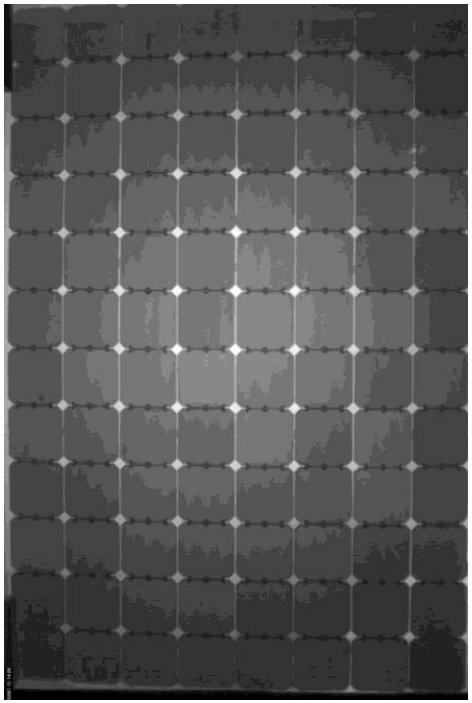
Mechanical integrity: another reliability advantage of back-contact cell

SunPower cell is held together by the metal on the back

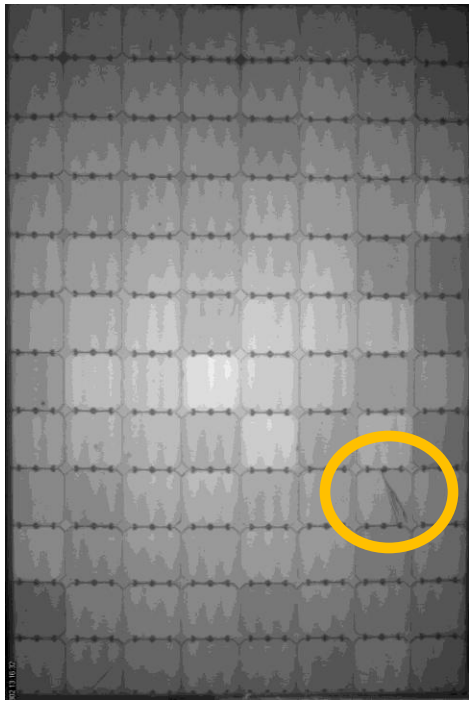
IEC Static loading test (2400Pa) on module

No power loss even with Some cracks

Before

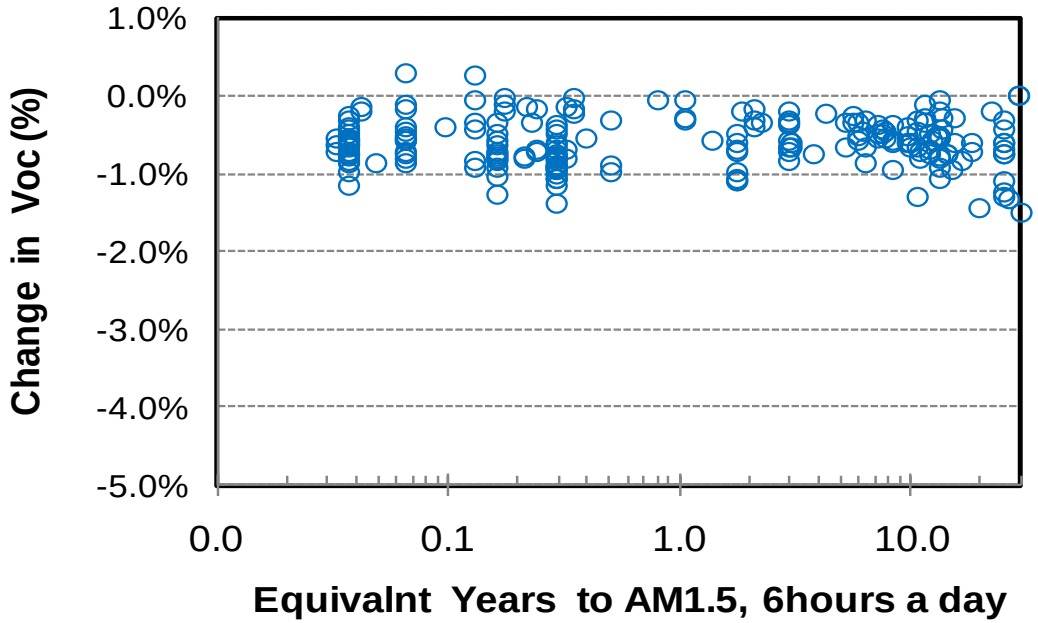


After



Robust cell design for UV stability

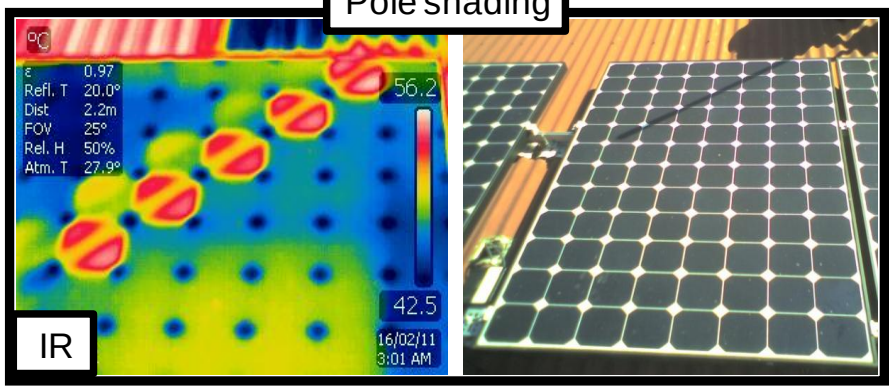
- Front surface of the cell designed for long-term outdoor exposure



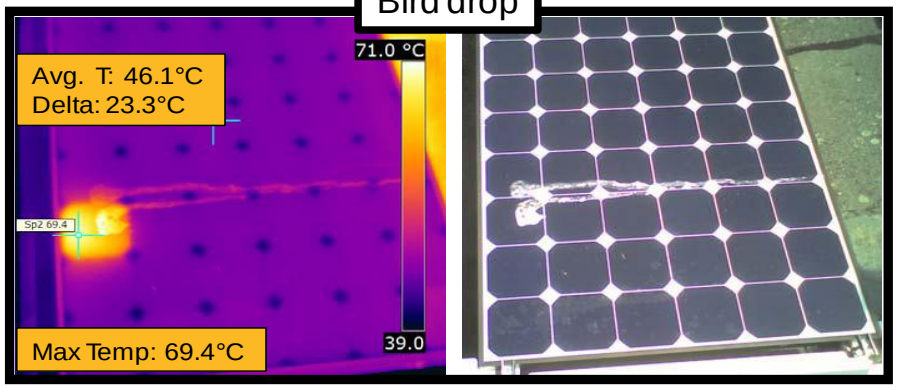
Individual points represent one sample from various tests:
Coupon or modules in outdoor, QUV, highly accelerated UV test

Shading / Hot cell

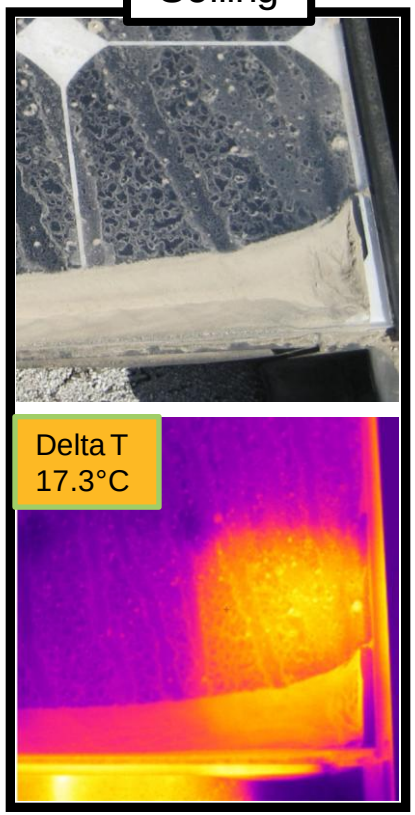
Pole shading



Bird drop



Soiling

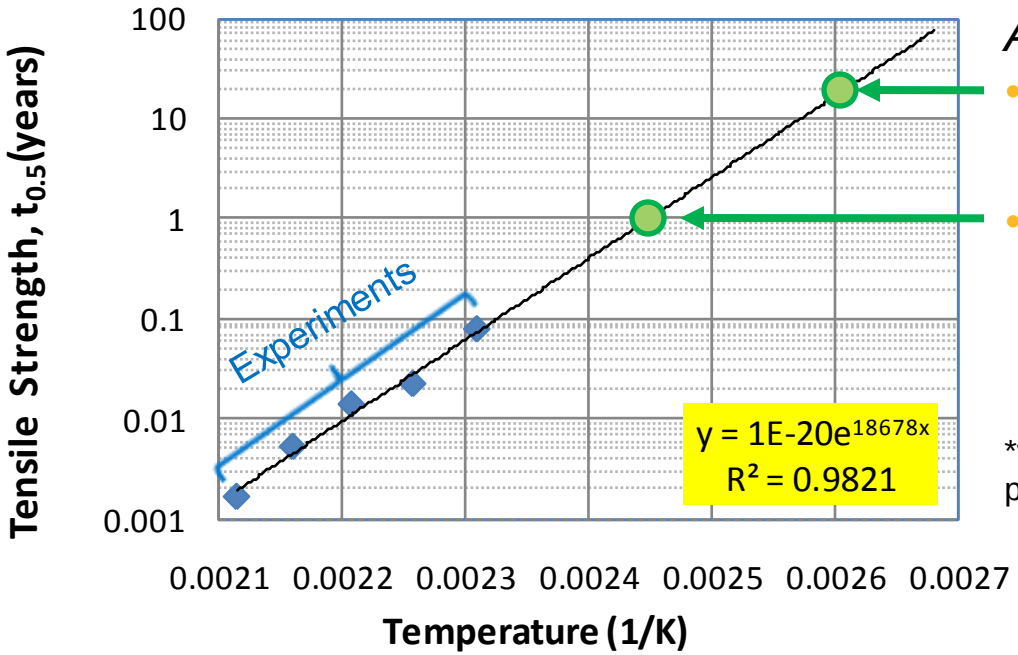


Hot cells are expected to exist in the field

Module should be reliable under hot cell condition for years

Thermal stability of backsheet

- Criteria for backsheet cracking on hot cells: *External stress > Mechanical strength*
- Conservative criteria: *External stress = 45MPa (50% of initial tensile strength)*



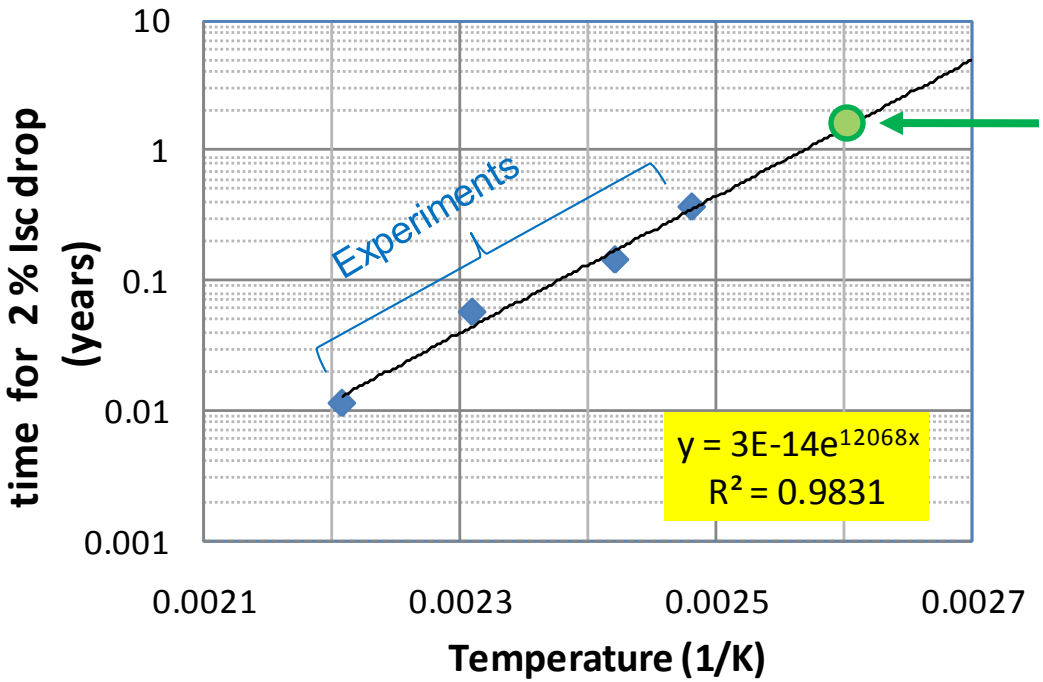
Arrhenius plot predicts

- mechanical failure after 21years of continuous use at 110°C
- RTI* of 135°C

*well agrees with literature data on RTI of polyethylene terephthalate

Thermal stability of encapsulant

- Highly Accelerated Lifetime Test (HALT): 130°C-180°C oven soak
- Encapsulant in E20 module is expected to show no significant degradation in full shading conditions



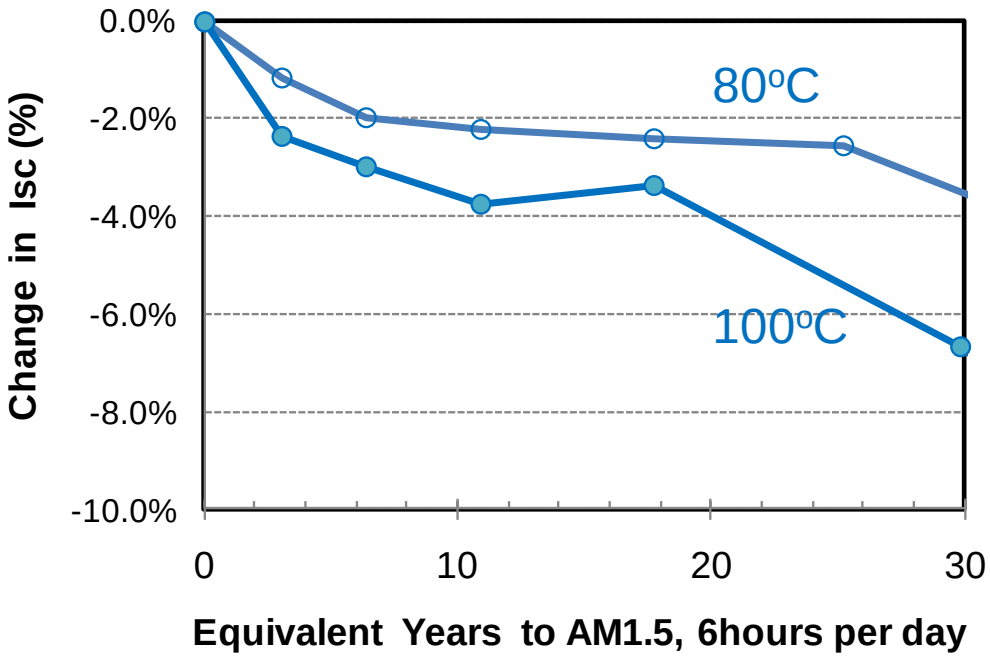
Arrhenius plot predicts

- 2% I_{sc} drop after 1.7 year continuous use* at 110°C / full shading

(* 7-10 field years)

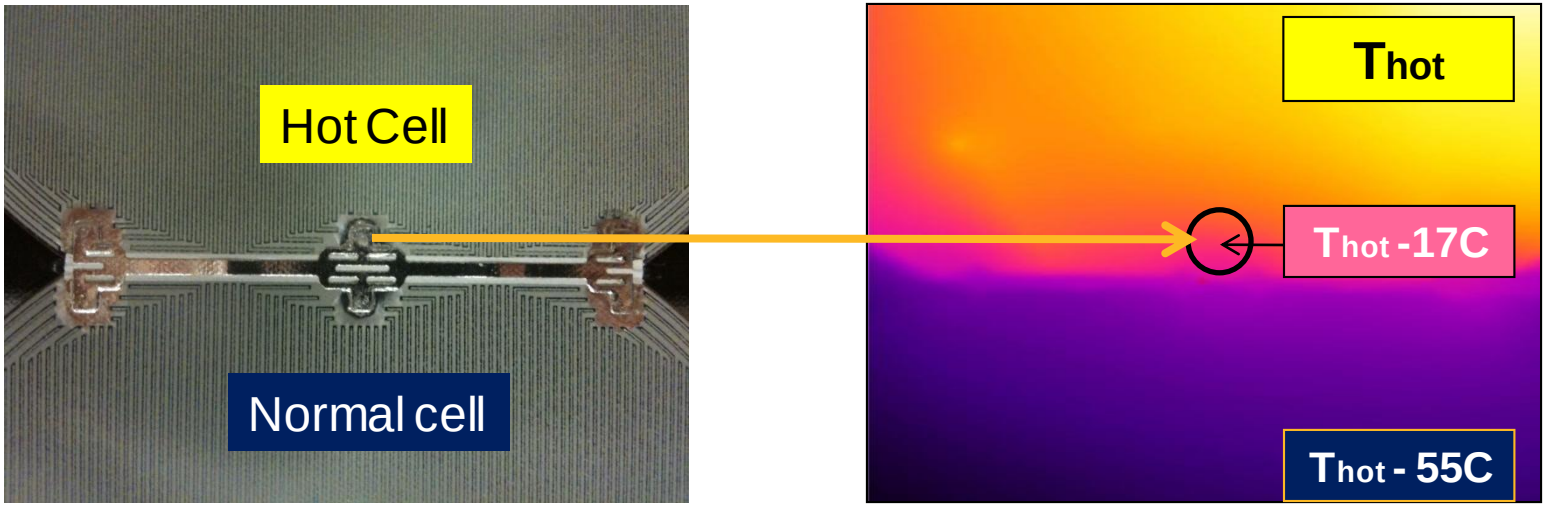
Thermal / UV stability of encapsulant

- HALT: *high intensity UV / high temperature*
- Encapsulant in E20 module is expected to show only marginal color change after 25 years



Extra safety factor on solder joint

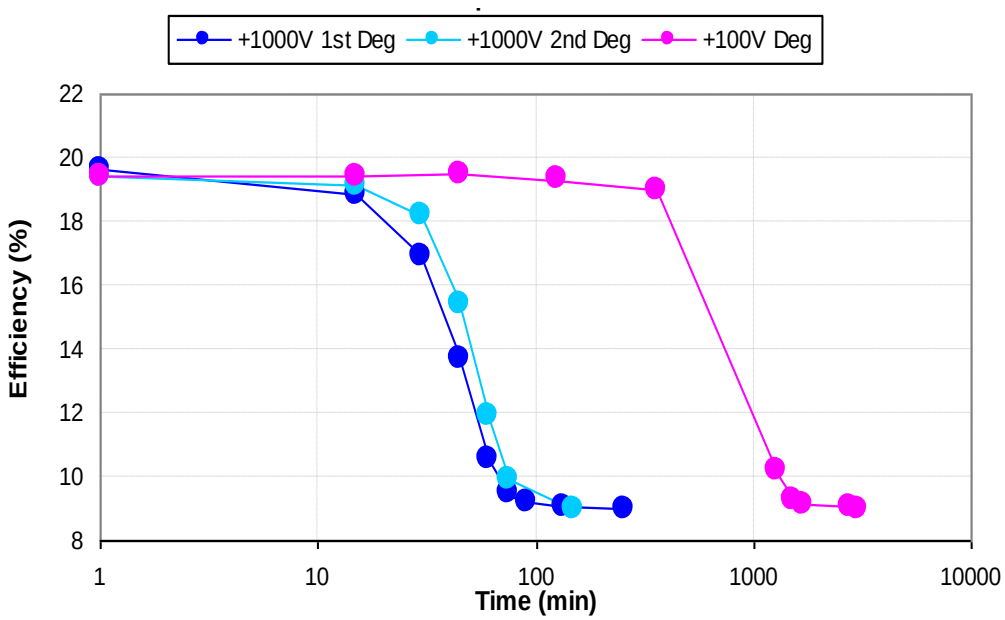
- TC cycles (-40°C to 90°C)
  - No degradation after 2200 cycles -D. DeGraaff, et al, EUPVSEC, 2010.
- Hot cell condition in the field
  - High mass interconnect conducts heat from a hot cell to neighboring cold cells
  - Lowered solder joint temperature provides extra safety margin



Lab test, no wind

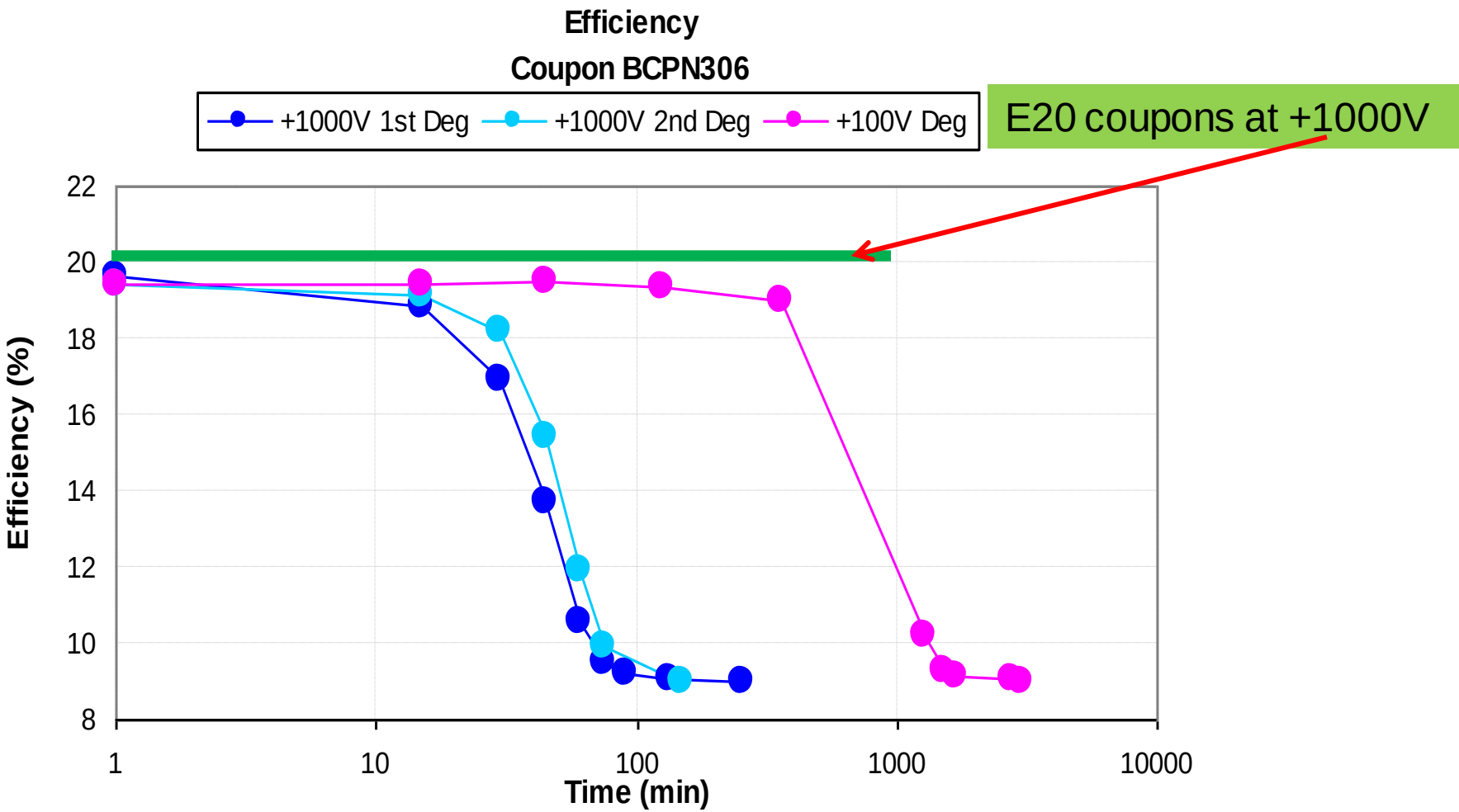
VOLTAGE INDUCED DEGRADATION

- Irreversible [2,3]
- Reversible: polarization [1,2] : SunPower Modules



[1] R. Swanson et al., "The surface polarization effect in high-efficiency silicon solar cells", 15th PVSEC, Shanghai, China, 2005
[2] J. Berghold et al., "Potential Induced Degradation of solar cells and panels" 25th European Photovoltaic Solar Energy Conference, September 2010, Valencia, Spain
[3] P. Hacke *et al.*, "Characterization of Multicrystalline Silicon Modules with System Bias Voltage Applied in Damp Heat" 25th European Photovoltaic Solar Energy Conference, September 2010, Valencia, Spain

POLARIZATION RATE



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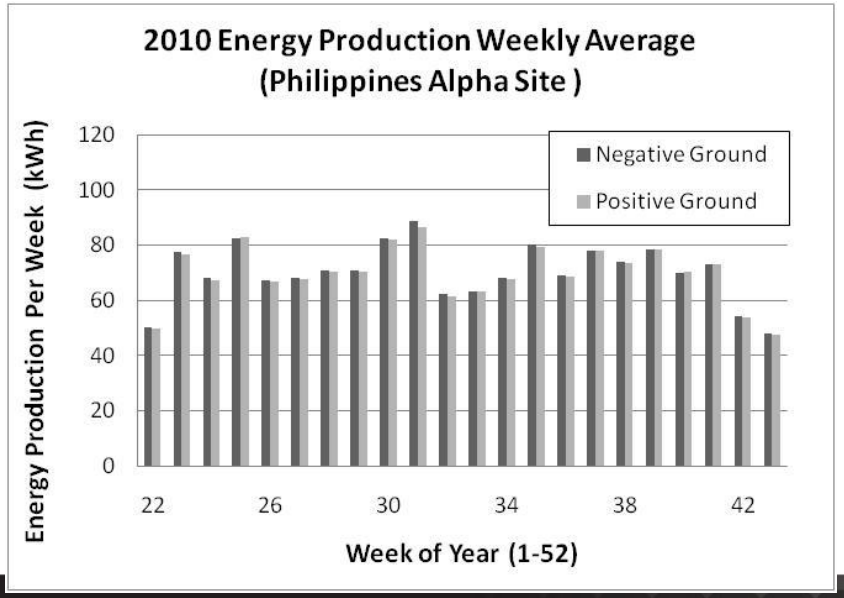
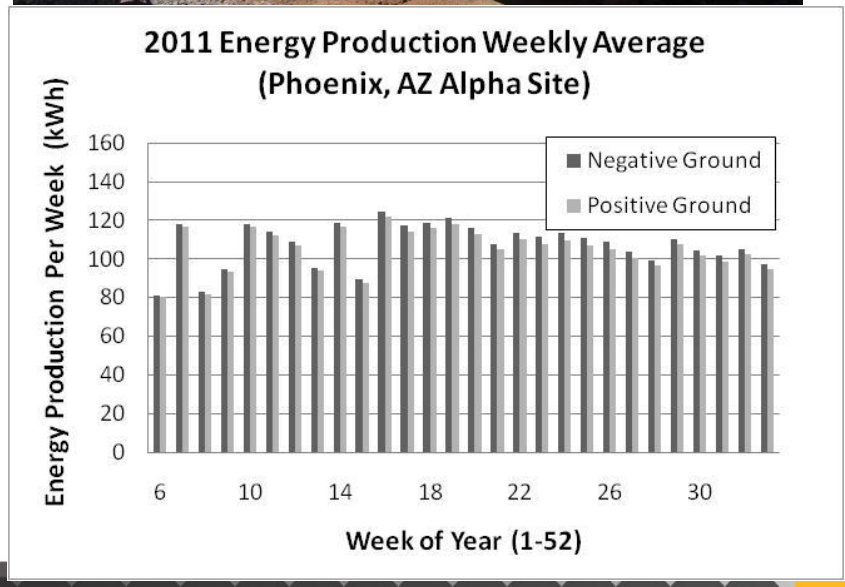
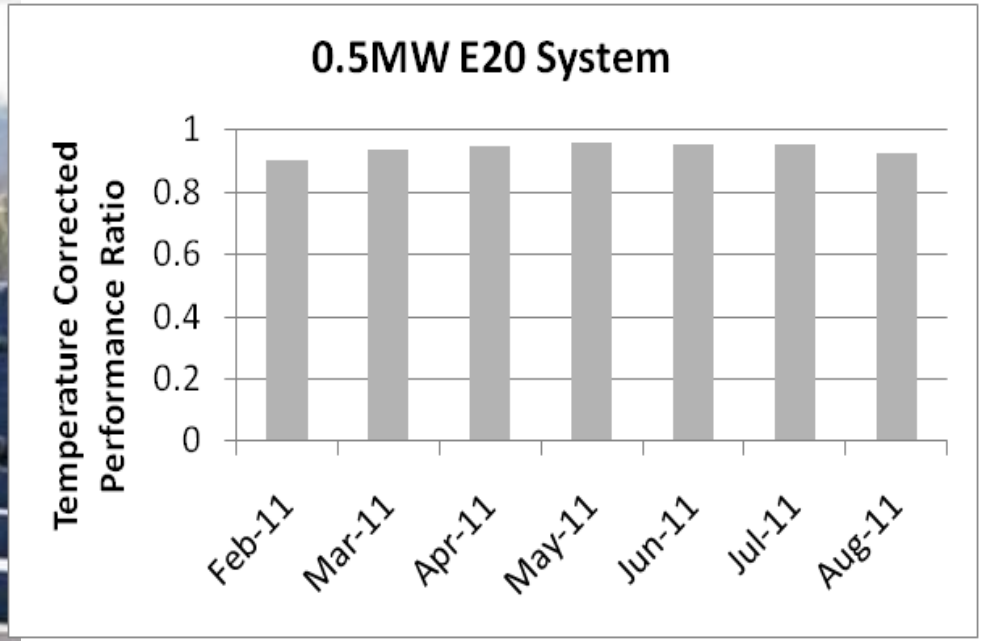
RESULTS: Field Alpha Test 1, 2





RESULTS: Beta test 1



No polarization after 8 months in field

VOLTAGE INDUCED DEGRADATION

- Reversible: polarization [1,2]
- Irreversible [2,3]

SunPower 20% module efficiency platform addresses the polarization effect and enables mounting in negative grounding and use of transformer-less inverters

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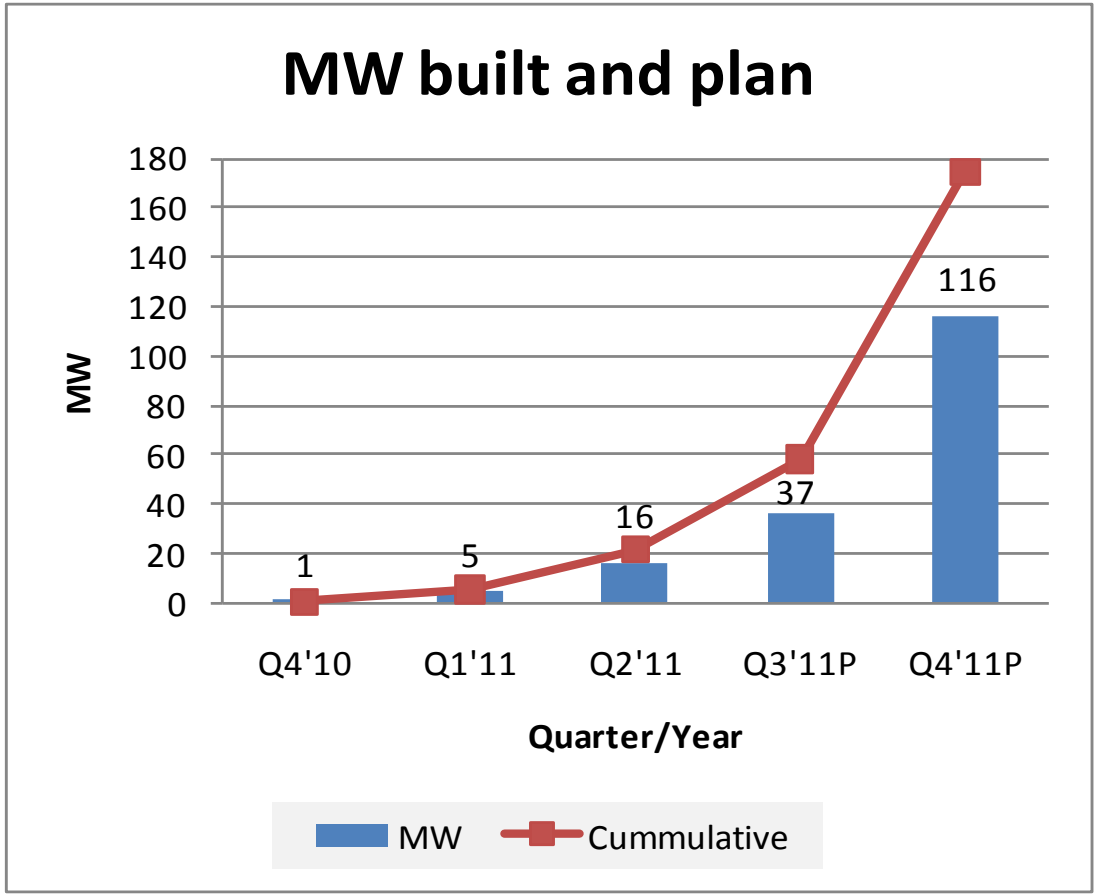
Field Tests

- Alpha sites (2-3 KW scale)
  - Philippines: Hot / humid
  - Arizona, US: Hot / dry
- Beta sites (0.5-10 MW scale)
  - New Jersey, US
  - Delaware, US
  - Italy
- Main observation
  - No infant failures
  - No UV, humidity, temperature induced degradation
  - No potential induced degradation with negative grounding / positive grounding

RAMP PLAN (September 2011)

Total MW produced to date since product released to manufacturing in Q4 2010 and current ramp plan for 2011



CONCLUSIONS

We have reported on high volume manufacturing of the industry's first commercially available 20% efficiency modules.

- Achieved through improvements in module design and optimization of cell to module conversion losses
- The modules are polarization free hence compatible with transform-less inverters, negative or positive grounding
- The new platform reliability significantly exceeds the industry norm and also is improved compared to current SunPower product
- These advancements represent the new technology platform for volume manufacturing of SunPower modules.

INTRODUCING THE SUNPOWER® E20 SOLAR PANEL

The first module in the world to reach 20% efficiency

Conclusions

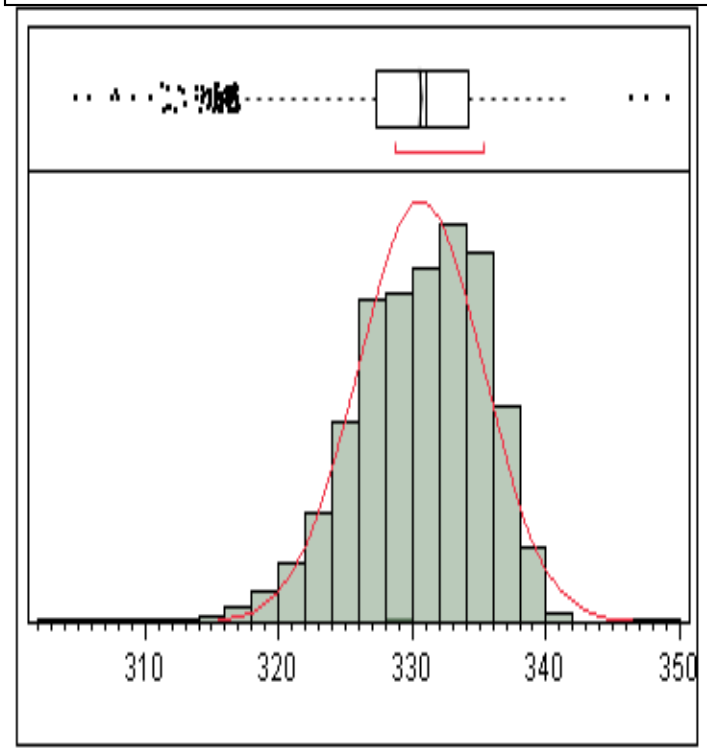
- 20% efficiency modules are produced in large commercial scale
- Years of reliability studies on E20 modules have been conducted
  - Highly accelerated life testing, test-to-failure, standard IEC, outdoor
- E20 module demonstrates robust reliability and durability in:
  - Humidity
  - UV
  - Temperature
  - High voltage (+ / - grounding)

THE WORLD'S STANDARD FOR SOLAR™

Highest Efficiency | Highest Reliability | Guaranteed Performance

HIGH VOLUME MANUFACTURING: 20% Efficiency Module

Measured Power (STC)



Normal(330.625,4.6335)

Quantiles

100.0%	maximum	349.15
99.5%		339.53
97.5%		338.27
90.0%		336.32
75.0%	quartile	334.22
50.0%	median	331.02
25.0%	quartile	327.36
10.0%		324.49
2.5%		320.75
0.5%		317.74
0.0%	minimum	302.15

The Competitive Landscape