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

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OUTLINE

- Efficiency Improvement
- Reliability
- High Volume manufacturing
- Conclusion
# EFFICIENCY IMPROVEMENT

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**Gabriela Bunea et al PVSEC2011**

<table>
<thead>
<tr>
<th></th>
<th>2007</th>
<th>2009</th>
<th>2011</th>
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<tbody>
<tr>
<td>Module STC Wp</td>
<td>305</td>
<td>318</td>
<td>327</td>
</tr>
<tr>
<td>Cell Efficiency (%)</td>
<td>22.4</td>
<td>22.4</td>
<td>22.4</td>
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<tr>
<td>Module Efficiency (%)</td>
<td>18.7</td>
<td>19.7</td>
<td>20.1</td>
</tr>
</tbody>
</table>

* 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

Power Distribution By Nameplate

© 2011 SunPower Corporation

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3rd Party Performance Validation

SunPower
mono-Si module

Device ID: H11P01163763
Device Temperature = 21.7°C
May 13, 2011 11:15:52 MST
Device Area = 15774.8 cm²
Si Ref. Cell 294278
Irradiance = 1032.0 W/m²

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

Device Dimensions = 153.9 x 102.5 cm

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

Air Temperature = 13.7°C, Air Mass = 0.886, POA Sun Angle = 13.3°
Total Irradiance From K&Z CM11 = 1086.4 W/m²

Irradiance corrected efficiency of 20.1% at 1Sun
20% Module Efficiency

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

- > 327 W / 1.63m²
- > 433 W / 2.16 m²
SunPower® Technology Leadership

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

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

**Design for Reliability**
- Design Concepts
- Reliability Req’ts,
- FMEA
  - Field Experience
  - HALT
  - Theoretical understanding
- Qualification Testing
  - Testing-to-failure
  - Modeling
  - Field testing/valid ation
- Cert. testing

**Manufacturing Quality**
- Supplier Quality Control
  - PSC Audit
  - STARS score
  - Inc. Mat’l Audit
- Out-of-box Audit
- Statistical Process Control
  - Cont. Mfg. Testing
    - ORT
- Customer

**Closed-loop learning**

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

![Diagram of E20 module showing all-back side contacts and front side (no gridlines)]
Low corrosion susceptibility

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

![Graph showing change in efficiency over IEC61215 Damp Heat (Hours)]

- Front contact modules, as reported by Fraunhofer-ISE EUPVSEC, Sept. 2010

- SunPower 2010 as reported in EUPVSEC Sept 2010

SunPower E20, 2011
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

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 21 years 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)

- 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

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Polarization Rate

Efficiency
Coupon BCPN306

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RESULTS: Field Alpha Test 1, 2

2010 Energy Production Weekly Average
(Philippines Alpha Site)

2011 Energy Production Weekly Average
(Phoenix, AZ Alpha Site)
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

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

Positive Power Tolerance

GUINNESS WORLD RECORDS

Industry-leading Warranty

Advanced Module Design

Compatible With Transformer-less Inverters

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)

Quantiles

<table>
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<tr>
<th>Percentile</th>
<th>Value</th>
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<tbody>
<tr>
<td>100.0%</td>
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Normal(330.625, 4.6335)
SunPower Extending Efficiency Advantage

- SunPower Gen 1
- SunPower Gen 2

Solar Cell Efficiency (%)

Thin films:
- a-Si: Amorphous Silicon
- CIGS: Copper Indium Gallium DiSelenide
- CdTe: Cadmium Telluride

Average production efficiency