Solar Frontier CIS module

November, 2011
Greg Ashley
About Solar Frontier

- 100% subsidiary of Showa Shell Sekiyu, with 110 years experience in energy
- 30+ years experience in solar
- 1,000+ employees
- Offices in Tokyo, Munich, Santa Clara
- 2010 80 MW production rising to 980 MW from 2011
Solar Frontier History

1974
- Oil crisis sparks joint solar project with Japanese government

1978
- Showa Shell starts PV R&D
- Shell Solar launches R&D

1981
- Technical partnership with Arco Solar

1983
- Started c-Si production

1986
- Co-founded JPEA

1987
- 100 MW production at 1st plant begins
- Showa Shell launched

1988
- Showa Arco Solar

1989
- Showa Arco Solar

1990
- Showa Arco Solar renamed Showa Solar Energy

1993
- Start CIS research funded by NEDO

2003
- Showa Shell Solar

2004
- Shell Solar Japan

2005
- Production at 2nd plant begins; Atsugi R&D Center opens

2006
- Commercial production in Miyazaki Plant 1

2007
- Commitment to CIS production

2010
- New Global Name Solar Frontier

2011
- 1GW Scale launched

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New Factory Opened in February

Full Scale Production started in July, 2011
Solar Frontier's CIS modules do not contain cadmium or lead.
What is CIS?

CIS is a thin-film compound-semiconductor PV consisting of three major elements:

**Cu**  Copper

**In**  Indium

**Se**  Selenium

Sometimes called “ClGS” since portions of *In* are replaced by *Ga*

Crystal structure of CIS (Chalcopyrite structure)

* Partially Ga
** Partially S
## CIS Market Share

**2009**
- Standard Crystalline Si, 8020, 75%
- CdTe, 1019, 10%
- Super Monocrystalline, 653, 6%
- CdTe, 1438, 6%
- CIGS, 166, 2%
- Amorphous Si/Thin film Si, 796, 7%

**2010**
- Standard Crystalline Si, 19768, 83%
- CdTe, 1438, 6%
- CIGS, 426, 2%
- Super Monocrystalline, 920, 4%
- Amorphous Si/Thin film Si, 1349, 5%

### Technology Growth 2009-2010

<table>
<thead>
<tr>
<th>Technology</th>
<th>2009</th>
<th>2010</th>
<th>2010/2009 Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Crystalline Si</td>
<td>8020</td>
<td>19768</td>
<td>246%</td>
</tr>
<tr>
<td>Super Monocrystalline</td>
<td>653</td>
<td>920</td>
<td>141%</td>
</tr>
<tr>
<td>CdTe</td>
<td>1019</td>
<td>1438</td>
<td>141%</td>
</tr>
<tr>
<td>CIGS</td>
<td>166</td>
<td>426</td>
<td>257%</td>
</tr>
<tr>
<td>Amorphous Si/Thin film Si</td>
<td>796</td>
<td>1349</td>
<td>169%</td>
</tr>
<tr>
<td>Total</td>
<td>10654</td>
<td>23901</td>
<td>224%</td>
</tr>
</tbody>
</table>

Source: GTM Research 2010/2011
General View of “Thin Film”

- **Low efficiency:**
  - Commercially available CIS modules have an efficiency over 13% and on track to be greater than 14% (~ c-Si)

- **Thin Film = Frameless:**
  - CIS modules have framed and frameless types available.

- **Polarity Sensitive (Negative grounding required):**
  - Negative grounding is required only for superstrate structure (CdTe, a-Si) where TCO is deposited on cover glass.
  - CIS is not polarity sensitive (substrate structure)

- **Initial degradation (LID):**
  - CIS does not have initial LID as a-Si. On the contrary, CIS has initial output improvement (+5-10%) by light soaking effect.

CIS (or CIGS) is not the same as CdTe or a-Si.
CIS is Thin Film Efficiency Leader

**Best Research-Cell Efficiencies**

<table>
<thead>
<tr>
<th>Company</th>
<th>Area</th>
<th>Efficiency</th>
<th>Announced</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1m²</td>
<td>15.7%</td>
<td>Dec. 2010</td>
</tr>
<tr>
<td>B</td>
<td>0.09m²</td>
<td>17.2%</td>
<td>Mar. 2011</td>
</tr>
<tr>
<td>C</td>
<td>0.754m²</td>
<td>14.7%</td>
<td>Jun. 2011</td>
</tr>
</tbody>
</table>

Source: NREL (National Renewable Energy Laboratory)
World Record Efficiency

- Module efficiency of 17.20% achieved at the Atsugi Research Center on 30 cm X 30 cm module
- Highest thin-film module efficiency in the world

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency (%)</td>
<td>17.20</td>
</tr>
<tr>
<td>Voc (cell/ V)</td>
<td>0.693</td>
</tr>
<tr>
<td>Jsc (mA/ cm²)</td>
<td>34.60</td>
</tr>
<tr>
<td>Fill Factor</td>
<td>0.716</td>
</tr>
<tr>
<td>Area (cm²)</td>
<td>808</td>
</tr>
</tbody>
</table>

Efficiency: 17.20%

Voc: 693 mV

Jsc: 34.6 mA/cm²

FF: 0.716

Aperture area: 808 cm²

With ARC

30 x 30 cm²-sized submodule
SF155

Dimensions: 49.5 x 38.5 x 1.4 inch
(1,257 x 977 x 35 mm)
Pmax: 155 W
PTC: 140.4 W
Efficiency: 12.6%
Frame: Anodized Aluminum Alloy
1. Proven Technology for Durability
   - Cover glass and backsheet
   - Aluminum frame (less risk of glass damage, mounting flexibility)
   - Wind/Temp/Humidity environmental durability

2. Not Polarity sensitive

Superstrate type (a-Si, CdTe)

- Superstrate glass
- TCO
- a-Si or CdTe
- Encapsulant
- Backside cover (glass)
No Initial LID (Light Induced Degradation)

- CIS output improves after installation due to Light Soaking effect
- The improvement usually ranges between 5-10%.

Source: AIST=(National Institute of) Advanced Industrial Science and Technology, Mr. Otani, 6th Annual Symposium of Research Center for Photovoltaics, Aug 8-9, 2010, Tsukuba, Japan. Using SPI-SUN simulator 1116N
Other Benefits

High performance ratio

- Light Soaking Effect, Broader Spectra Response and Temperature Coefficient increase Performance Ratio

NOTE: Performance ratio PR (%)  
Performance ratio means “the relationship between actual yield and target yield”

\[
\text{Performance ratio PR (\%)} = \frac{\text{Actual output from installed capacity (kWh)}}{\text{Installed Capacity (kW) x } \frac{\text{Actual Radiation (kWh/m}^2\text{)}}{\text{1 sun (1kW/m}^2\text{)}}}
\]

Ecological

- Non-toxic (contains no Cd and uses Pb-free solder)
- Reusable packaging and reduced on-site waste
- Lower overall energy consumption in the manufacturing process (less than 1 year energy payback time)
Thin Film Performs Best

**Figure E-11: Simulated Operating Performance by PV Technology and Location**

Annual Array Gross DC KWh Output per KW Nameplate Capacity

- Phoenix
- Sacramento
- New York
- Seattle

Monocrystalline Si, Multicrystalline Si, Super Monocrystalline Si, Amorphous Si, CdTe, CIGS

Source: NREL Solar Advisory Model, GTM Research

March 18, 2010 / Shyam Mehta Thin Film 2010: Market Outlook to 2015 Executive Summary
Comparison between CIS and c-Si

Array

Atsugi Research Center
1/7/2009~31/10/2010

CIS: 2.25 kW
Poly-Si: 4.20 kW
Mono-Si: 2.10 kW
20° (South East)  Tilt: 20°
Inverter Eff. 94.5%

Output (kWh/kWp)

(kWh/kWp)

Line graph: Performance ratio
Bar graph: amount of power generated (kWh/kWp)

PR(%)
Performance Comparison between CIS and CdTe

Array
- Site: Atsugi Research Center
- Data period: February 2011~June 2011
- CIS: 3.12 kW  CdTe: 3.6 kW
- 0° (South)  Tilt: 20°
- Inverter Eff. 94.5%

Module type
- CIS (Solar Frontier) SF-130 (130W)
- CdTe (75W)

Feb, 2011~ June, 2011

Total Irradiation: 630 kW/m²

PR (%)

96.1%  89.9%

CIS

92.0%  86.6%

CdTe

DCPR

ACPR
Effect of Efficiency

Module Price to keep same kWh cost (14.4% is 100%)

Assumption: 5MW ground mount, fixed BOS $0.75/Wp and area dependent BOS $1.33/Wp
If the module efficiency is only variable (same physical size, same performance ratio etc.)
Importance of Performance Ratio

Module Price to keep same kWh cost (c-Si price is 100%)

- 4.76MW CIS system delivers the same kWh as 5MW c-Si System

Relative Module Price (per Wp) vs Module Efficiency

- +5% PR (+5% kWh)

- c-Si Typical

- 4.76MW CIS system delivers the same kWh as 5MW c-Si System
Actual Data from Arizona

- 12month Total (4/1/2010-3/1/2011) CIS produce over 15% .

<table>
<thead>
<tr>
<th>kWp</th>
<th>p-Si (13.44kW)</th>
<th>p-Si (6.4kW)</th>
<th>CIS (9.36kW)</th>
<th>Irradiation (kWh/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>kWh/kWp</td>
<td>1727.6</td>
<td>1745.8</td>
<td>2018.1</td>
<td>2175.1</td>
</tr>
<tr>
<td>DC-PR</td>
<td>79.4</td>
<td>80.8</td>
<td>93.1</td>
<td></td>
</tr>
</tbody>
</table>
**Shadow Tolerance**

- Under partially shaded conditions, the unique patterning of CIS modules keeps the drop of output to a minimum.

![CIS and c-Si Shadow Tolerance Diagram](image)

- There is a partial loss of output but the overall effect is minimum for CIS.
- The module’s output drops significantly under partial shadow for c-Si.

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Energy Payback Time (EPT): the time required for a module to generate the amount of energy spent in its production.

- CIS modules have a faster EPT than conventional silicon.

Source: New Energy and Industrial Technology Development Organization (NEDO)

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Ground mount and rooftop systems

- Kolitzheim, Germany (550 kWp)
- Schwabach, Germany (385 kWp)
- Coalinga, California (1.2 MWp)
- Nissan Motors Headquarters, Japan (40 kWp)
Rooftop Systems

Commercial rooftop, Japan

Commercial rooftop, Italy

Residential rooftop, Germany

Residential rooftop, Australia
## Selected Reference Cases

### Gunkul Megawatt Project, Thailand

<table>
<thead>
<tr>
<th>Date onstream</th>
<th>January 2011</th>
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<tbody>
<tr>
<td>System capacity</td>
<td>3.3 MWp</td>
</tr>
<tr>
<td>Panel type</td>
<td>85 W</td>
</tr>
<tr>
<td>No. of panels</td>
<td>38,688</td>
</tr>
<tr>
<td>Panel angle &amp; orientation</td>
<td>15°, South 0°</td>
</tr>
<tr>
<td>Output Jan. Mar. 2011</td>
<td>1,334,260 kWh</td>
</tr>
<tr>
<td>Estimated CO₂ reduction</td>
<td>715 tonnes</td>
</tr>
</tbody>
</table>

### North Park Project, Saudi Arabia

<table>
<thead>
<tr>
<th>Date onstream</th>
<th>End 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>System capacity</td>
<td>10 MWp</td>
</tr>
<tr>
<td>Panel type</td>
<td>various</td>
</tr>
<tr>
<td>No. of panels</td>
<td>126,000</td>
</tr>
<tr>
<td>Panel angle &amp; orientation</td>
<td>5°, various</td>
</tr>
<tr>
<td>Estimated output</td>
<td>15,000,000 kWh/yr</td>
</tr>
<tr>
<td>Estimated CO₂ reduction</td>
<td>11,000 tonnes/yr</td>
</tr>
</tbody>
</table>

### Almeria Megawatt Project, Spain

<table>
<thead>
<tr>
<th>Date onstream</th>
<th>February 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>System capacity</td>
<td>1 MW</td>
</tr>
<tr>
<td>Panel type</td>
<td>85 W</td>
</tr>
<tr>
<td>No. of panels</td>
<td>11,850</td>
</tr>
<tr>
<td>Panel angle &amp; orientation</td>
<td>25°, South 0°</td>
</tr>
<tr>
<td>Estimated output</td>
<td>1,356,231 kWh/yr</td>
</tr>
<tr>
<td>Estimated CO₂ reduction</td>
<td>529 tonnes</td>
</tr>
</tbody>
</table>

### Yukigunigata Megasolar, Niigata, Japan

<table>
<thead>
<tr>
<th>Date onstream</th>
<th>September 2010</th>
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</thead>
<tbody>
<tr>
<td>System capacity</td>
<td>1 MW</td>
</tr>
<tr>
<td>Panel type</td>
<td>80 W</td>
</tr>
<tr>
<td>No. of panels</td>
<td>12,528</td>
</tr>
<tr>
<td>Panel angle &amp; orientation</td>
<td>20° &amp; 30°, South 0°</td>
</tr>
<tr>
<td>Output Sep.-Nov. 2010</td>
<td>376,586 kWh</td>
</tr>
<tr>
<td>CO₂ reduction</td>
<td>169 tonnes</td>
</tr>
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</table>
Thank You!