PV Technologies

State of the Art

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Renewable Energy Unit
• Solar Energy Conversion to Electricity
• Solar Potential
• Photovoltaic Technologies
• Conclusions
Solar Energy Conversion

Fuels

- $\text{C}_2\text{O}$
- Sugar
- $\text{H}_2\text{O}$
- $\text{O}_2$

Photosynthesis

Electricity

- $\text{O}_2$ → $\text{H}_2$
- $\text{H}_2\text{O}$

Semiconductor/Liquid Junctions

e.g. Photovoltaics

Courtesy: N. Lewis, CalTec
CSP: Concentrated Solar Thermal Power

- Generation of Steam with Solar Power and then conversion with Steam Turbine to Electricity
- Possibility of Co-Generation with fossil fuel
- Possibility of Heat Storage for extended operation

PV: Photovoltaics

- Direct conversion of solar power into electricity
- No moving parts
- Electricity has to be stored or converted into a storable medium, e.g. pumped water storage, Hydrogen
PV: PhotoVoltaics

Electron Hole(+) Electron (-)
Negative Semiconductor P-N Junction Positive Semiconductor

Source: Sharp Corp.
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PV electricity potential

Yearly sum of Global Irradiation (kWh/m²)

Yearly sum of Solar Electricity generated by 1kWp system (kWh/kWp) optimally-inclined modules
Electricity Market Prices in Southern Italy and Solar Irradiation

Electricity market prices (IPEX by Gestore Mercato Elettrico: bars; €/MWh) versus global irradiance (HelioClim-2: red line; W/m²)

Unweighted Prices November 2007
Unweighted Prices November 2004
Average Daily Irradiation November

Unweighted Prices June 2008
Unweighted Prices June 2004
Average Daily Irradiation June
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Manufacturing of Silicon Solar Cells and Modules

- Polykristallines Silizium
- Phosphor-Diffusion
- Verketten
- Tiegelziehprozeß
- Laminieren
- Besäumen
- Rahnung
- Scheiben sägen
- Solarzelle
- Solarmodul

Renewable Energy
Ribbon Silicon

- Molten silicon
- String ribbons
- Silicon feed

- Renewable Energy
Different Thin Film Technologies

- SnO$_2$
- a-Si
- a-SiGe
- Glass Substrate
- metal
- Transparent
- CdS thin-film
- CdTe
- Glass Substrate
- Carbon
- As
- ZnO
- CIGS Absorber
- Mo
- Glass Substrate
- Zn(O,S,OH) Buffer
- CIGSS Surface Layer
- Ag
- ITO
- Top cell
- Bottom cell
- poly-Si
- a-Si
- Back reflector
- Glass substrate
- Series-hole
- Via-hole
- Metal electrode
- Film Substrate
- Back electrode
Multi-junction Technologies

Projected real-world efficiencies at 500 suns:

- GaInP: 1.8 eV - 39% in production
- GaAs: 1.4 eV
- Ge: 0.7 eV
- New: 1.25 eV
- GaAs: 1.4 eV
- New: 1.0 eV
- Ge: 0.7 eV

Future generation technology.
Multi-junction Technologies

Contact

Top Cell

GaAs n-type
AlInP n-type
GaInP n-type
GaInP p-type
AlGaInP p-type

Middle Cell

GaAs n-type
GaAs p-type
GaInP p-type

Bottom Cell

GaAs n-type
Ge n-type
Ge p-type
Concentration Technologies

Renewable Energy
Amonix High Concentration System .................. 8.8 kWh/kW
Single axis tracking flat plate ...................... 7.2 kWh/kW
Fixed flat plate ...................................... 5.0 kWh/kW

Best Research-Cell Efficiencies

Multijunction Concentrators
- Three-junction (2-terminal, monolithic)
- Two-junction (2-terminal, monolithic)

Single-Junction GaAs
- Single crystal
- Concentrator
- Thin film

Crystalline Si Cells
- Single crystal
- Multicrystalline
- Thick Si film

Thin-Film Technologies
- Cu(In,Ga)Se₂
- CdTe
- Amorphous Si:H (stabilized)
- Nano-, micro-, poly-Si
- Multijunction polycrystalline

Emerging PV
- Dye-sensitized cells
- Organic cells (various technologies)

Source: Bolko von Roedern and Harin S. Ullal, NREL, 2008
# Efficiency of Solar Modules

<table>
<thead>
<tr>
<th>Eff. (%)</th>
<th>Module</th>
<th>T.coeff (%P/°C)</th>
<th>Technology</th>
<th>c/c-ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.3</td>
<td>SunPower 315</td>
<td>-0.38</td>
<td>FZ-Si, ‘point contact’</td>
<td>78%</td>
</tr>
<tr>
<td>17.4</td>
<td>Sanyo HIP-205BAE</td>
<td>-0.30</td>
<td>CZ-Si, ‘HIT’</td>
<td>70%</td>
</tr>
<tr>
<td>15.1</td>
<td>BP7190</td>
<td>-0.5</td>
<td>CZ-Si, ‘PERL’</td>
<td>61%</td>
</tr>
<tr>
<td>14.2</td>
<td>Kyocera KC200GT</td>
<td>Only for Voc</td>
<td>MC-Si</td>
<td>70%</td>
</tr>
<tr>
<td>14.2</td>
<td>SolarWorld SW 185</td>
<td>Only for Voc</td>
<td>CZ-Si</td>
<td>70%</td>
</tr>
<tr>
<td>13.4</td>
<td>SolarWorld SW 225</td>
<td>Only for Voc</td>
<td>MC-Si,</td>
<td>70%</td>
</tr>
<tr>
<td>13.4</td>
<td>Suntech STP 260S-24V/b</td>
<td>Only for Voc</td>
<td>MC-Si,</td>
<td>66%</td>
</tr>
<tr>
<td>13.3</td>
<td>Sharp ND-216-U1</td>
<td>not given</td>
<td>MC-Si</td>
<td>66%</td>
</tr>
<tr>
<td>11.0</td>
<td>WürthSol. 11007/80</td>
<td>-0.36</td>
<td>CIGS</td>
<td>55%</td>
</tr>
<tr>
<td>10.4</td>
<td>First Solar FS-275</td>
<td>-0.25</td>
<td>CdTe</td>
<td>63%</td>
</tr>
<tr>
<td>8.5</td>
<td>Sharp NA-901-WP</td>
<td>-0.24%/C</td>
<td>a-Si/nc-Si</td>
<td>70%</td>
</tr>
<tr>
<td>6.3</td>
<td>Mitsubishi H. MA100 T2</td>
<td>-0.2</td>
<td>a-Si (1-j)</td>
<td>66%</td>
</tr>
<tr>
<td>6.3</td>
<td>Uni Solar PVL-136</td>
<td>(-0.21)</td>
<td>a-Si (3-j)</td>
<td>52%</td>
</tr>
<tr>
<td>6.3</td>
<td>Kaneka T-SC</td>
<td>Not given</td>
<td>a-Si (1-j)</td>
<td>66%</td>
</tr>
</tbody>
</table>

Source: Bolko von Roedern and Harin S. Ullal, NREL, 2008
### Possible Efficiencies of Thin Films

<table>
<thead>
<tr>
<th>Technology</th>
<th>Future commercial performance</th>
<th>Relative Performance (s.p. Si =1)</th>
<th>Relative-cost/relative-performance (50% thin film cost advantage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon (non-stand)</td>
<td>19.8%</td>
<td>1.18</td>
<td>0.85 (competitive)</td>
</tr>
<tr>
<td>Silicon (standard)</td>
<td>17.0%</td>
<td>1.00</td>
<td>1.00 (reference)</td>
</tr>
<tr>
<td>CIS</td>
<td>15.9%</td>
<td>0.94</td>
<td>0.53 (highly competitive)</td>
</tr>
<tr>
<td>CdTe</td>
<td>13.2%</td>
<td>0.78</td>
<td>0.64 (highly competitive)</td>
</tr>
<tr>
<td>a-Si (1-j)</td>
<td>8.0%</td>
<td>0.47</td>
<td>1.06 (about the same)</td>
</tr>
<tr>
<td>a-Si (3-j) (or a-Si/nc-Si)</td>
<td>9.7%</td>
<td>0.57</td>
<td>0.88 (competitive)</td>
</tr>
</tbody>
</table>

Source: Bolko von Roedern and Harin S. Ullal, NREL, 2008
Which Efficiency for Which Cost

1: Crystalline Silicon

2: Thin Films

3: Beyond Horizon

Glass

Courtesy: M. Green, UNSW

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Conclusions

😊 Photovoltaic Electricity in Europe and the Mediterranean region is already very attractive, notably in peak load times

😊 High PV potential still untapped Southern Europe and the Mediterranean region

😊 A range of technologies is available, which is important to have no showstoppers

😊 Future Research and Development work is necessary to provide technology solutions

😊 Markets have to be developed further to provide the necessary growth for further cost reduction
Thank you for your attention!