• Webcast: centrotherm’s “grid parity factory”

February 4th, 2009
Agenda

- **Basics, background, motivation:**
  Dr. Wolfgang Herbst, Market & Technology Research

- **Technology, costs, perspectives:**
  Dr. Peter Fath, CTO

- **Questions & Answers:**
  Dr. Peter Fath, CTO
  Dr. Wolfgang Herbst, Market & Technology Research
  Dr. Wolfgang Jooß, Director Technology Integrated Factories
  Franz-Josef Feilmeier, GP Solar Module Technology
centrotherm photovoltaics: Understanding and generating the market

**centrotherm photovoltaics at a glance**

- Technology and equipment supplier for PV industry
- Leading market player of turnkey crystalline solar cell production lines

<table>
<thead>
<tr>
<th>Business divisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>► Silicon</td>
</tr>
<tr>
<td>► Solar cell</td>
</tr>
<tr>
<td>► Thin film</td>
</tr>
<tr>
<td>► Semiconductor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technology &amp; Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Services</td>
</tr>
<tr>
<td>Key equipment</td>
</tr>
<tr>
<td>Turnkey lines</td>
</tr>
<tr>
<td>Turnkey production plants</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Key Figures</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
</tr>
<tr>
<td>Employees:</td>
</tr>
<tr>
<td>Sales:</td>
</tr>
<tr>
<td>EBIT:</td>
</tr>
</tbody>
</table>

* Including CTTS integration
## Company structure

**centrotherm photovoltaics AG**

**Solar Device manufacturing technologies for crystalline & Thin-Film**
Turnkey Production - Key Equipment - Process Technology - Project Management - Facility Design

<table>
<thead>
<tr>
<th>Silicon</th>
<th>Solar Cell</th>
<th>Thin-Film</th>
<th>Semiconductors / Microelectronics</th>
</tr>
</thead>
<tbody>
<tr>
<td>centrotherm SiTec GmbH</td>
<td>centrotherm thermal solutions GmbH &amp; Co. KG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Michael Glatt Maschinenbau GmbH</td>
<td>centrotherm PV Technology GmbH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FHR Anlagenbau GmbH</td>
<td>GP Solar GmbH / GP Inspect GmbH</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Value Chain of Photovoltaics

silicon

ingot / wafer

solar cell

solar module

photovoltaic system

Value chain of crystalline silicon based photovoltaics technology
centrotherm’s competences and business activities within the PV value chain:

<table>
<thead>
<tr>
<th></th>
<th>Silicon</th>
<th>ingot/wafer</th>
<th>cell</th>
<th>module</th>
<th>thin film PV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>turnkey</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>process / device technology</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>key equipment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
"Non-subsidized Market" Generation by Reducing PV System Cost

PV market development

When and at what PV system price?
- Off-grid markets
- Utility grid parity
- Customer grid parity

PV competitiveness against household electricity prices?

Calculation using assumptions:
- 20 years depreciation
- 1% operating cost
- 4% interest rate
- Output degradation 0.5%/a
- Different conditions for
  - Local irradiation level
  - Electricity prices
“Customer retail price” grid parity @ 3 €/Wp

Grid parity in near future

- Installed System Price 3 €/Wp
- Grid Parity
- Germany
- Italy
- France
- Portugal
- Spain
- Greece
- India
- Hawaii
- Australia
- California
- Texas
- Sun Irradiation [kWh/m²/year]
- Average household electricity price

- € / kWh
- 0,40
- 0,35
- 0,30
- 0,25
- 0,20
- 0,15
- 0,10
- 0,05
- 0,00
- 700
- 800
- 900
- 1000
- 1100
- 1200
- 1300
- 1400
- 1500
- 1600
- 1700
- 1800
- 1900
- 2000
- 2100
- 2200
"Customer retail price" grid parity @ 2,50 €/Wp

Grid parity in near future

Installed System Price 2.50 € / Wp

Germany
France
Italy
Spain
Portugal
Hawaii
Australia
California
Texas
India
Greece

Average household electricity price

Sun Irradiation [kWh/m²/year]
How to Achieve PV System Price < 3 €/W_p?

Estimate of maximum module manufacturing cost to achieve PV system price of < 3 €/W_p

- Installation profit 0,27 €/W_p
- Labour cost 0,10 €/W_p
- Inverter 0,25 €/W_p
- Supporting structure, cables 0,20 €/W_p
- Module trading 0,10 €/W_p
- Margin 25%, 0,51 €/W_p
- Overhead 10%, 0,14 €/W_p
- Manufacturing cost 1,40 €/W_p

Target: module manufacturing cost < 1,40 €/W_p
Achieving Grid Parity by an Integrated Fabrication

Cost advantages of integrated fabrication:

- Reduced cost due to enhanced overall product yield (e.g. omission of long distance shipment of wafers and cells)
- Fast feedback loops and significant optimization potential over the entire value chain results in better product quality and yield
- Reduced overhead cost (QC, purchasing, sales …)
- Reduced working capital
- No long term purchasing contracts and down payments
- Fast response to changes in the market (along complete value chain)
Integrated Factory: Overview

Key figures of integrated fabrication in Canada and Germany

Module manufacturing cost

1,26 < 1,40 €/W_p possible

Example: Grid Parity factory in Germany/Canada

- Integrated factory consisting of 5 single factories using state of the art technology available today
  - Poly Si (TCS / "Siemens"): 2,500 t/a
  - Multi ingot: 2,270 t/a
  - Multi wafer: 97 million wafer /a
  - Cell: 361 MW_p/a
  - Module: 347 MW_p/a

- Calculated scenario includes poly silicon factory using lower electricity costs in Canada + wafer, cell & module production in Germany

- CAPEX 718 Mio € (accuracy +/- 10%)

Module manufacturing cost

<table>
<thead>
<tr>
<th>Canada</th>
<th>Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>Ingot</td>
</tr>
<tr>
<td>0,21€/W_p</td>
<td>0,14 €/W_p</td>
</tr>
</tbody>
</table>

1,26 €/W_p

* Accuracy of all figures +/- 10%
## Assumptions for Cost Calculations

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poly-Si</td>
<td>Material usage</td>
<td>1.6 t MG-Si / t Poly-Si</td>
</tr>
<tr>
<td>Multi Ingot</td>
<td>Material yield*</td>
<td>91%</td>
</tr>
<tr>
<td>Wafer</td>
<td>Wafer thickness</td>
<td>180 µm</td>
</tr>
<tr>
<td></td>
<td>Kerf loss</td>
<td>185 µm</td>
</tr>
<tr>
<td></td>
<td>Material yield*</td>
<td>94%</td>
</tr>
<tr>
<td>Solar Cell</td>
<td>Efficiency</td>
<td>15.8%</td>
</tr>
<tr>
<td></td>
<td>Production yield</td>
<td>96%</td>
</tr>
<tr>
<td>Solar Module</td>
<td>Encapsulation loss</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>Production yield</td>
<td>99%</td>
</tr>
<tr>
<td>Depreciation</td>
<td>Building/Facility</td>
<td>15 years</td>
</tr>
<tr>
<td></td>
<td>Equipment/Technology</td>
<td>5 years (wafer, cell, module)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7/10 years (ingot/poly-Si)</td>
</tr>
<tr>
<td>Electricity</td>
<td>Price per kWh</td>
<td>0.028/0.08€ Canada/Germany</td>
</tr>
<tr>
<td>Labour costs</td>
<td>Management</td>
<td>110.000 €/a</td>
</tr>
<tr>
<td></td>
<td>Engineers/Technicians</td>
<td>65.000 €/a</td>
</tr>
<tr>
<td></td>
<td>Operators</td>
<td>39.000 €/a</td>
</tr>
</tbody>
</table>

* includes recycling
**Integrated Factory: Polysilicon Production Plant**

- **TCS / Siemens technology**
- **18 Siemens type deposition reactors**
- **Capacity 2.500 t/a**
- **80.000 m²**
- **Production cost 28,5 €/kg (0,21 €/Wp)**

Key figures of 2.500 t Poly-Si production in Canada

- **Equipment:** 227,0 Mio.€
- **Building:** 85,0 Mio.€
- **Production goods:**
  - MG Si 1,60 t/t Poly-Si
  - HCl 0,48 t/t Poly-Si
- **Running Cost:**
  - Electr. 165 kWh/kg
  - Utilities 1,6 €/kg
- **Workforce:** 239 persons

**Total Costs:** 71 Mio. €/a

- **Labour Costs 17%**
- **Depreciation Equipment/Technology 31%**
- **Running Costs 32%**
- **Depreciation Building & Facility 8%**
- **Production Goods 12%**
Integrated Factory: Ingot Manufacturing

- Crystallization of ingots and bricking
- 28,000 m²
- 53 Crystallization furnaces
- Capacity 2,270 t ingots / a
- Production costs 20,7 €/kg (0,14 €/Wp)

Total Costs: 47 Mio. €/a

- Equipment: 80,5 Mio. €
- Building: 16,0 Mio. €
- Production goods: Crucibles 2,2 pcs./t
- Running Cost: Electr. 25,9 kWh/kg, Utilities 1,10 €/kg
- Workforce: 358 persons
Sawing of bricks to wafer
- 18,500 m²
- 55 wafer saws
- Production of 97 Mio. wafer / a
- Wafer thickness 180 µm
- Production costs 0,63 €/wafer (0,18 €/Wₚ)

Total Costs: 61 Mio. €/a

- Equipment: 76,8 Mio. €
- Building: 13,0 Mio. €
- Production goods: Slurry, Wire
- Running Cost:
  - Electr. 0,20 kWh/Wₚ
  - Utilities 0,023 €/Wₚ
  - Transport. 0,005 €/Wₚ
- Workforce: 198 persons

**Production Goods Costs:**
- Slurry: 27%
- Wire: 25%
- Electricity: 32%
- Transport: 15%
- Labour: 15%
- Depreciation Building & Facility: 1%
- Depreciation Equipment/Technology: 25%
- Production Goods: 27%

**Total Costs Breakdown:**
- Equipment: 25%
- Building & Facility: 1%
- Production Goods: 27%
- Running Costs: 32%
- Labour Costs: 15%
- Depreciation Equipment/Technology: 25%
**Integrated Factory: Solar Cell Manufacturing**

- 7 centrotherm solar cell turnkey lines (>50MW_p each)
- 18.000 m²
- Efficiency 15.8% on multi wafer
- Production of 361 MW_p / a
- Production costs 1,02 €/wafer (0,28 €/W_p)

**Total Costs: 96 Mio. €/a**

- **Equipment:** 110,0 Mio.€
- **Building:** 16,3 Mio.€
- **Production goods:**
  - Paste front 0,047 g/W_p
  - Paste rear Ag 0,042 g/W_p
  - Paste rear Al 0,42 g/W_p
- **Running Cost:**
  - Electr. 0,21 kWh/W_p
  - Utilities 0,024 €/W_p
- **Workforce:** 323 persons

**Cell**
- Depriciation Equipment/ Technology 23%
- Running Costs 18%
- Production Goods 41%
- Labour Costs 17%
- Depreciation Building & Facility 1%
Integrated Factory: Solar Module Manufacturing

- Module design:
  - 60 cells per module, 220 W<sub>p</sub>
  - glass / backsheet laminate
  - framed
- 20 lamination lines
- 20,000 m²
- Production 347 MW<sub>p</sub> / a
- Production cost 98 €/module (0,45 €/W<sub>p</sub>)

**Total Costs: 157 Mio. €/a**

- Equipment: 73,5 Mio.€
- Building: 20,0 Mio.€
- Production goods:
  - Glass 1,6 m²/module
  - EVA 3,2 m²/module
  - Backsheet 1,6 m²/module
  - Frame 5,2 m/module
  - Junction box 1 pcs/module
- Running Cost: Utilities 0,025 €/W<sub>p</sub>
- Workforce: 305 persons
CAPEX and key figures of integrated fabrication

Integrated factory: Summary CAPEX

Further figures

<table>
<thead>
<tr>
<th></th>
<th>Capacity</th>
<th>Machinery</th>
<th>Building &amp; Infrastructure</th>
<th>Workforce</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poly-Si</td>
<td>2.500 t</td>
<td>227 Mio. €</td>
<td>85 Mio. €</td>
<td>239</td>
</tr>
<tr>
<td>Multi Ingot</td>
<td>2.270 t</td>
<td>80 Mio. €</td>
<td>16 Mio. €</td>
<td>358</td>
</tr>
<tr>
<td>Wafer</td>
<td>374 MW</td>
<td>77 Mio. €</td>
<td>13 Mio. €</td>
<td>198</td>
</tr>
<tr>
<td>Solar Cell</td>
<td>361 MW</td>
<td>110 Mio. €</td>
<td>16 Mio. €</td>
<td>323</td>
</tr>
<tr>
<td>Solar Module</td>
<td>347 MW</td>
<td>74 Mio. €</td>
<td>20 Mio. €</td>
<td>305</td>
</tr>
<tr>
<td>Total</td>
<td>568 Mio. €</td>
<td>150 Mio. €</td>
<td></td>
<td>1423</td>
</tr>
</tbody>
</table>
Integrated Factory: Different Production Location

Production costs for three different locations:
- Canada/Germany
- USA
- China.

Major differences are the price of electricity and labour.

<table>
<thead>
<tr>
<th>Location</th>
<th>Module</th>
<th>Cell</th>
<th>Wafer</th>
<th>Multi Ingot</th>
<th>Poly-Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada / Germany</td>
<td>0.45</td>
<td>0.28</td>
<td>0.18</td>
<td>0.14</td>
<td>0.21</td>
</tr>
<tr>
<td>USA</td>
<td>0.45</td>
<td>0.26</td>
<td>0.16</td>
<td>0.14</td>
<td>0.22</td>
</tr>
<tr>
<td>China</td>
<td>0.41</td>
<td>0.23</td>
<td>0.14</td>
<td>0.10</td>
<td>0.19</td>
</tr>
</tbody>
</table>

€/Wp

- 0.20 0.40 0.60 0.80 1.00 1.20 1.40

Canada / Germany  USA  China
• Customer base:
  – Existing companies of PV value chain:
    ▪ Cell company: integration to module production, later backward integration
    ▪ Poly-Si company: integration to ingot and wafer production, later further forward integration
  – New entrants:
    ▪ Companies from different industries: switch to PV as a promising industry
    ▪ Institutional investors: high ROI expectations

• Customer needs:
  – Only one supplier for equipment and technology
  – Turn-key (for new entrants)

• Realization scenarios:
  – Main scenario I: Fast market presence with small cell and module factory, later integration and extension of cell/module capacity; existing factories source material from external suppliers and switch to own production as soon as possible
  – Main scenario II: Realization of Poly-Si factory and ramp-up of further factories accordingly; existing factories feed further factories along the value chain
Smart integrated factory:
• Processes at the interface between the different factories are merged leading to a truly integrated factory

Major factors for cost reduction in smart integrated factories:
1. Investment
   • Reduced investment at interfaces: no packaging, integrated manufacturing equipment, reduced effort in QC (outgoing/incoming inspection)

2. Lower work force number
   • Reduced packaging, storage, QC

3. Decreased overall material loss
   • No material loss by shipment/packaging
   • Optimized process flow over the full value chain

Potential for reduction in manufacturing cost: 6 to 10%
Summary

- Grid parity can be achieved in several locations at system prices below 3 €/W. This requires module manufacturing costs below 1,40 €/W.
- Example of integrated factory in Canada/Germany:
  - 2.500 t of Poly-Si result in 347 MW of solar modules
  - Manufacturing costs of 1,26 €/W using conservative assumptions
  - CAPEX 718 Mio. €
- Customer base for integrated factories include existing PV companies (centrotherm customers and others) as well as new entrants
- Smart integrated factory has potential for cost reductions between 6-10%
Thank you for your attention!