HIGH QUALITY POLYSILICON – THE BASIS FOR HIGH WAFER YIELDS AND HIGH EFFICIENCY SOLAR CELLS


CREATING TOMORROW'S SOLUTIONS
DISCLAIMER

The information contained in this presentation is for background purposes only and is subject to amendment, revision and updating. Certain statements contained in this presentation may be statements of future expectations and other forward-looking statements that are based on management's current views and assumptions and involve known and unknown risks and uncertainties. In addition to statements which are forward-looking by reason of context, including without limitation, statements referring to risk limitations, operational profitability, financial strength, performance targets, profitable growth opportunities, and risk adequate pricing, as well as the words "may, will, should, expects, plans, intends, anticipates, believes, estimates, predicts, or continue", "potential, future, or further", and similar expressions identify forward-looking statements. By their nature, forward-looking statements involve a number of risks, uncertainties and assumptions which could cause actual results or events to differ materially from those expressed or implied by the forward-looking statements. These include, among other factors, changing business or other market conditions and the prospects for growth anticipated by the Company's management. These and other factors could adversely affect the outcome and financial effects of the plans and events described herein. Statements contained in this presentation regarding past trends or activities should not be taken as a representation that such trends or activities will continue in the future. The Company does not undertake any obligation to update or revise any statements contained in this presentation, whether as a result of new information, future events or otherwise. In particular, you should not place undue reliance on forward-looking statements, which speak only as of the date of this presentation.
WHAT IS THE LARGEST POWER PLANT?

- **Coal power plant**
  - 0.5-4 GW

- **Nuclear power plant**
  - 2-10 GW

- **Hydro power plant**
  - 2-20 GW
OUR LARGEST POWER PLANT IS JUST 8 MINUTES AWAY

1 trillion GWh reach the earth's surface per year*

8 min.

150 mio. km

* roughly 10,000 times the world's primary energy demand
HOW HIGH QUALITY POLYSILICON HELPS TO HARNESS THE SUN’S ENERGY
EXPERTISE IN POLYSILICON PRODUCTION FOR MORE THAN 50 YEARS

A worldwide market, technology and quality leader in polysilicon, dedicated to the electronic and solar industries.

Facts and figures

- Location of production: Burghausen, Germany
- Polysilicon technology: Trichlorosilane CVD (rod and granular)
- Polysilicon capacity: 6,500 t (as of Dec. 31, 2006)
- Sales: 325.6 Million EUR (2006)
- Employees: 875 (as of Dec. 31, 2006)
SERVING THE ELECTRONIC VALUE CHAIN

- Quartzite, \( \text{SiO}_2 \)
- mg-Si impure + low crystallinity
- Poly-Si hyperpure + increased crystallinity
- Crystal growth hyperpure + perfect + crystallinity
- Wafering
- Device
- Electronics

* mono-crystalline
SERVING THE PHOTOVOLTAIC VALUE CHAIN

Quartzite, SiO₂

Solar cell
Wafering

Poly-Si hyperpure + increased crystallinity

mg-Si impure + low crystallinity

Crystal growth hyperpure + high*/perfect + crystallinity

Module

*multi-crystalline, + mono-crystalline
BROADEST PRODUCT PORTFOLIO – POLYSILICON SOLUTIONS FOR ALL SILICON GROWTH TECHNOLOGIES

- Chunks: Czochralski pulling, Casting
- Rods: Float zone pulling, Czochralski pulling
- Granules: Crucible load enhancement, Edge defined Film fed Growth, String ribbon, Electro Magnetic Casting
RENEWABLE ENERGIES ARE SET TO SURGE

- Dwindling fossil resources
- Carbon emissions
- Global warming
- Increasing oil and gas prices

⇒ Necessity for renewable energies

<table>
<thead>
<tr>
<th>Solar</th>
<th>Wind</th>
<th>Biofuel</th>
<th>Hydro/Tidal</th>
<th>Geothermal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photovoltaics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar Thermal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The success of silicon: availability combined with outstanding semiconducting properties

- Proven technology
- 1-2 years energy payback
- Eco-☺: 1 kg Poly-Si avoids 2 tons CO₂
- Contain no toxics (Cd, Se, Te)
- Maintenance-free, noiseless
- High conversion efficiencies
- 50+% cost reduction potential* → grid parity

source: Q-Cells, 3rd PV Industry - Forum, Dresden, Sept. 6, 2006
PRINCIPLE OF A CRYSTALLINE SILICON SOLAR CELL

- n-type Si-layer (Phosphorous-doped)
- p-type Si-substrate (Boron doped)
- front contact
- backside contact
- anti-reflection coating
- resistivity: 1-3 Ohmcm
METALLIC IMPURITIES DETERIORATE THE CELL EFFICIENCY

- n-type Si-layer (Phosphorous-doped)
- p-type Si-substrate (Boron doped)
- backside contact
- anti reflection coating
- front contact

Metal atoms, B-O-complexes trap charge carriers

Resistivity: 1-3 Ohmcm
ELECTRONIC PROPERTIES OF SILICON RESPOND VERY SENSITIVE TO DOPANT CONCENTRATIONS

Example: p-type silicon substrate

- Target resistivity: 1-3 Ohmcm
- Small boron window: ~ one piece of sugar in a 20 ft container!
HOW TO MANUFACTURE A MONOCRYSTALLINE P-TYPE SILICON SUBSTRATE

Crucible charging

Melt down

Crystal growth

Growth finish

Quartz (SiO₂)-crucible

Poly-Si

Addition of boron

Si-melt

Boron-atoms (from Poly-Si+doping)

Phosphorous-atoms (from Poly-Si)

Si-monocrystal

top

tail

Dopants are incorporated differently

Boron – weak effect → homogeneous distribution

Phos. – strong effect → Phos. enriches in the crystal during growth
POLYSILICON ENSURES HIGH WAFER QUALITY

- **Purity gap!**

- **Impurities / ppt**

- Mg-Si
- upgraded Mg-Si
- Blended silicon
- Polysilicon
- Si solar wafer

- **Addition of boron on purpose during crystal growth (easy to control!)**

- **2000x**

- One 1 €-cent coin on 2000 football fields

- One 1 €-cent coin on a large pizza

- **Purity**

- **10% 90%**

- **1-3 Ωcm, p-type**
POLYSILICON ENSURES HIGH CRYSTAL YIELDS

100% Wacker Polysilicon*

90% Wacker Polysilicon*
10% mg-refined Silicon**

100% in-spec.!
60% off-spec.!

* Poly-Si: P = 30 ppta, \( \rho = 4250 \ \Omega \text{cm} \) n-type, Wacker Baseline data
** Upgraded mg-Si: P = 16 ppma, \( \rho = 0.16 \ \Omega \text{cm} \) n-type, Analysis by Wacker
HIGH INITIAL PHOSPHOROUS KILLS CRYSTAL YIELD AND QUALITY

Ingot resistivity profiles for high phos. feedstock (target res. 1-3 Ohmcm p-type)*

* Calculations based on normal freezing

- High phosphorous feedstock requires addition of high but variable dose of boron
- High boron deteriorates cell efficiency (→ LID)

[Graph showing resistivity profiles and percentages out of spec. for different phosphorous concentrations]
USE OF POLYSILICON GUARANTEES HIGH CRYSTAL YIELD AND CONSISTENT WAFER QUALITY

Ingot resistivity profiles for polysilicon feedstock (target res. 1-3 Ohmcm p-type)*

polysilicon feedstock allows addition of a medium and constant dose of boron

100% in spec.
CLOSED LOOPS FOR HYDROGEN AND CHLORINE YIELD SIGNIFICANT ADVANTAGES

Metallurgical Silicon → HCl → Membrane Electrolysis + HCl Synthesis → Salt from WACKER’s mine → H₂

TCS Production → HCl

Conversion of SiCl₄

Silicone Chemistry

Membrane Electrolysis + HCl Synthesis → TCS Purification → Polysilicon Deposition

Polysilicon Deposition → H₂

SiCl₄ → Pyrogenic Silica Production

Pyrogenic Silica Production → O₂ (air)

POLYSILICON

PYROGENIC SILICA
## SILICON CHEMISTRY

<table>
<thead>
<tr>
<th>Process</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Synthesis</strong></td>
<td>$\text{Si}_{mg} + 3 \text{HCl} \rightarrow (\text{HSiCl}<em>3)</em>{\text{crude}} + \text{H}_2$</td>
</tr>
<tr>
<td><strong>Distillation</strong></td>
<td>$(\text{HSiCl}<em>3)</em>{\text{crude}} \rightarrow (\text{HSiCl}<em>3)</em>{\text{hyperpure}}$</td>
</tr>
<tr>
<td><strong>Deposition</strong></td>
<td>$4 (\text{HSiCl}<em>3)</em>{\text{hyperpure}} \rightarrow \text{Si}_{\text{hyperpure}} + 3 \text{SiCl}_4 + 2 \text{H}_2$</td>
</tr>
<tr>
<td><strong>Conversion</strong></td>
<td>$\text{SiCl}_4 + 3\text{H}_2 \rightarrow (\text{HSiCl}<em>3)</em>{\text{hyperpure}} + 3 \text{HCl}$</td>
</tr>
<tr>
<td><strong>Pyrolysis</strong></td>
<td>$\text{SiCl}_4 + 2\text{H}_2 + \text{O}_2 \rightarrow \text{SiO}_2 + 4 \text{HCl}$</td>
</tr>
</tbody>
</table>

**Conversion:**

- $n\text{Si}_{mg} + m\text{O}_2 \rightarrow (n-m)\text{Si}_{\text{hyperpure}} + m\text{SiO}_2$

- 99.0 %
- 99.999999 % (8N)
POLYSILICON MANUFACTURING PROCESS

Bell jar type reactor, capable of electronic and solar

- Slim rods*
- Poly-Si
- 1000°C

~ 1 week

- Semiconductor line
- Solar line
- Crushing, etching

*electrically heated

Feed gases (TCS, H₂) → Off-gases

Ø = 200 mm

Semiconductor poly

Crushing, etching

Leading edge reactor design
Flexible reactor technology
Low energy consumption

Solar poly

Crushing
WACKER’S TCS PROCESS COMBINES LOW ENERGY CONSUMPTION WITH MAXIMUM PRODUCT QUALITY

Energy consumption per kg solar silicon (rel. units)

- Monosilane Rod
- mg-Si-Refining
- Monosilane Granular
- WACKER TCS-Rod
- WACKER TCS-Granular

Total process: silane production + deposition

Source: REC Offering Memorandum (May 2006), REC Capital Markets Day (22/11/2006); WACKER estimates
SUPERIOR CRUCIBLE LOAD BY COMBINING CHUNK AND GRANULAR POLYSILICON

100% Chunks
- a few large pieces
- a few large voids

100% Granular
- many small particles
- many small voids

Chunks + Granular
- Voids filled with granules
- higher crucible load*
- larger ingots

* other influencing factors: skills of operators (how to arrange the chunks), boundary conditions for productivity (speed of filling), chunk size / particle distribution, crucible size, melt down process
WACKER POLYSILICON:
BEST IN CLASS TECHNOLOGY AND ECONOMICS

• Independent TCS supply starting with salt and silicon metal
• Advanced reactor technology: high output, yield, quality
• Low energy consumption for the total production chain
• Flexible reactor technology: solar or electronic poly according to demand
• Granular completes product offering

Leading in low cost and high quality