Capital Market Day 2016
WACKER POLYSILICON: High Quality Polysilicon – Basis for PV Efficiencies beyond 20%

Burghausen, October 11, 2016
Ewald Schindlbbeck, President WACKER POLYSILICON
Contents

- Capacity, Technology and Costs
  - Polysilicon Impact on Ingot and Cell Production
  - Solar Market Overview
WACKER POLYSILICON is Represented Globally With 3 Production Sites And 5 Sales Offices

Office Locations, Sites and Nameplate Capacities*

* in metric tons per year
The Ramp of Poly 11 plant in Tennessee is technically finalized, Focus now on Productivity.
WACKER is The Quality Leader For Polysilicon Due to Its Cutting Edge Production Technology

\[ \text{mg-Si} \rightarrow \text{Trichlorsilane Production (Fluidized Bed Reactor)} \]

\[ \text{Si} + 3\text{HCl} \rightarrow \text{HSiCl}_3 + \text{H}_2 \]

\[ \text{Trichlorsilane Purification (Distillation)} \]

\[ 4 \text{HSiCl}_3 \rightarrow \text{Si} + 3\text{SiCl}_4 + 2\text{H}_2 \]

\[ \text{Polysilicon Rod Deposition (Siemens Process)} \]

\[ \text{Final Treatment (Crushing, Classifying, Etching for Semi only)} \]

\[ \text{mg-Si} \rightarrow \text{HCl} \rightarrow \text{HSiCl}_3, \text{H}_2 \]

\[ \text{SiCl}_4, \text{H}_2 \rightarrow \text{Chunks} \sim 99,999999999\% \]

\[ \text{Rods} \]
Granular Polysilicon PCG® Is a Useful Addition to Our Product Portfolio

Granular Polysilicon (PCG®)
- Hyper pure
- Size ~ 0.8 – 4 mm
- Smooth surfaces, no sharp edges
- Very low dust content
- Spherical shape, perfect (re)charging properties

Solar Multi
- Standard & HPM processes
- Increase crucible charge
- Seeding
Reference: ALD

Czochralski (CZ)
- Solar grade
- Electronic grade
- Increase crucible charge
- Recharging
Reference: Siltronic AG
A Granular Process Based on Trichlorosilane Fits Perfectly to Our Existing Integrated Production Loops

**Trichlorosilane deposition (WACKER)**

Si (mg.) → HSiCl₃ synthesis → HSiCl₃ → Distillation → HSiCl₃ → HT conversion → SiCl₄ → Distillation → HSiCl₃ → Granular deposition → Si

**Monosilane deposition (Competition)**

Si (mg.) → Hydrochlorination → HₓSiClₓ → Distillation → Imp. → HSiCl₃ → Disproportionation → SiH₄ → FBR-deposition → Si

PCG®
WACKER With All Three Production Sites at The Lower Bound of The Polysilicon Industry Cash Cost Curve

Industry Cash Cost Segmentation for Solar Grade Polysilicon 2016e (EUR/kg)

Source: Industry announcements, WACKER estimates
Continuous Strong Focus on Cost And Productivity

**Specific Energy Consumption***
Index = 100

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<thead>
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<th>Year</th>
<th>Specific Energy Consumption</th>
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<td>2010</td>
<td>70</td>
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<td>2015</td>
<td>60</td>
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<tr>
<td>2020e</td>
<td>(estimated)</td>
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- New deposition reactors
- New conversion reactors
- New process design

* Solar polysilicon process only

**Labor Productivity**
Index = 100

<table>
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<tr>
<th>Year</th>
<th>Labor Productivity</th>
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<td>2010</td>
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<tr>
<td>2015</td>
<td>370</td>
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<tr>
<td>2020e</td>
<td>(estimated)</td>
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</tbody>
</table>

- Economies of scale
- Yield improvements
- Automation

** Total average for all sites, direct labor including analytics
Contents

Capacity, Technology and Costs

- Polysilicon Impact on Ingot and Cell Production

Solar Market Overview
High Quality Polysilicon Required For High Cell Efficiency Trend

HP = High Performance
Cell Efficiencies Beyond 20% Are Reality

Average Stabilized Efficiency Values for Si Solar Cells (156 x 156 mm$^2$)

WACKER‘s Top Quality Polysilicon Position Continuously Verified by Benchmarks

Recent Results of Technical Benchmarks for Most Important Impurities

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<tr>
<th></th>
<th>Dopants</th>
<th>Carbon</th>
<th>Iron</th>
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<tr>
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<td>FBR/Granular*</td>
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<td>✔️</td>
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</tbody>
</table>

*D not WACKER

Source: WACKER internal benchmark reports
N-type wafer asks for high quality polysilicon, only imported polysilicon is able to meet our requirement, for example, WACKER’s products are highly desirable. According to our test, WACKER’s poly reached the China National Standard for semi grade poly, while most domestic polysilicon cannot reach this standard yet.”

*Statement on China New Energy Conference on May 05, 2016 by a leading Chinese wafer producer*

“WACKER’s rectifying technology is the most advanced worldwide. According to our study their product has lowest impurities. Compared with this, China domestic poly has higher content of boron and phosphorus.”

*Statement on China New Energy Conference on May 06, 2016 by a Chinese University representative*
“Imported polysilicon, like WACKER is more competitive. They have lower cost and energy consumption. The production management level is also much higher. Although our poly is narrowing the gap with WACKER we still cannot compete with them on high quality poly.”

Statement on China International Silicon Conference on Sep. 16, 2015 by a leading Chinese polysilicon producer

“Polysilicon quality is critical in achieving high performance wafer and high efficiency cell. We like to use the best poly, such as WACKER products, on our high quality wafer and cells.”

Statement on PV CellTech Conference on March 16, 2016 by a leading Chinese wafer / cell producer
Hyper Pure Feedstock Leads to Higher PV Efficiency And Improves Specific Costs Per Watt

Four Key Benefits of Hyper Pure Silicon Feedstock:

1. Polysilicon purity is relevant for high efficiency approaches:
   - n-type in CZ
   - HPM in block casting
2. Highest charge carrier lifetimes accessible under any later process conditions
3. Highest yields accessible for crystallization processes
4. Most efficient recycling strategies applicable

Hyper pure Silicon feedstock compares to a blank, white piece of paper and enables full flexibility to choose conditions for further processing
1. PURITY FOR HIGH EFFICIENCY: Metals Are Efficiency Killers For Solar Cells

Modelling Results

- Most detrimental in $p$-Si: Cr, Co, Fe
- Most detrimental in $n$-Si: Co, Cr, Ni

“Impurity-Related Limitations of Next-Generation Industrial Silicon Solar Cells”

Thanks for friendly permission to use this diagram.
High purity translates to high efficiencies

- HPM (High Performance Multi) eliminates efficiently critical crystal defects (dislocations)
- High purity feedstock, crucibles and coating maximize bulk carrier lifetime and solar cell efficiency potential
- The combination of high purity and HPM allows to fully tap the efficiency potential
2. HIGHEST CHARGE CARRIER LIFETIME:
Superior Values in Multi Ingots With 100% WACKER Polysilicon

Ingot from 100% Wacker Poly

Ingot from lower grade Poly

156 mm

270 mm
3. HIGHEST YIELDS:
High Purity Poly Improves Basic Yield of CZ Ingots

High Purity (Fe 50 pptw) vs. Low Quality Feedstock (Fe 10 000 pptw)

Customers’ Application Experience
- High grade poly ensures maximum in spec yield
- ~6% yield loss caused by low grade poly
- Fluctuating poly qualities prohibit stable yields
- Solar cells quality varies when low grade poly is used

Yield not limited by feedstock

*) typical high efficiency wafer specification for τ > 1 msec
3. HIGHEST YIELDS:
High Purity Polysilicon Enables Efficient Multiple Pulling

High Purity (Fe 50 pptw) vs. Low Quality Feedstock (Fe 10 000 pptw)

- Up to 86 % cumulated losses after 4 crystals due to low grade poly

*) typical high efficiency wafer specification for $\tau > 1 \text{ msec}$

(= yield NOT limited by feedstock)
3. HIGHEST YIELDS:
Multiple CZ Pulling Requires Extremely Pure Small Size Chips

Advantages of WACKER Small Sized Chips

- Small chips with high purity are needed especially for feeding in multiple pulling
- Small size chip production is in particular critical with respect to surface impurity content
- WACKER’s small sized materials define benchmark purity
- CZ recharge chips: Fe, Cr, Ni, … < 0.5 ppbw
- WACKER’s chips allow CZ multiple pulling with high lifetime
4. **MOST EFFICIENT RECYCLING:**
Recycling is a Must For Wafer Producers

- Depending on the technology, 20 to 30% of the silicon is recycled
- High purity polysilicon results in low impurity levels in out of spec ingot material, which guarantees efficient recycling and reduced waste
- Low purity polysilicon causes material loss and more waste material

- **Highest recycling rates achieved with purest feedstock**
Hyper Pure Feedstock Leads to Higher PV Efficiency And Improves Specific Costs Per Watt

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Hyper pure Silicon feedstock compares to a blank, white piece of paper and enables full flexibility to choose conditions for further processing
High Quality Polysilicon Helps Multi And Mono Technology

**Usable Ingot Length (%)**
- Production Costs (%)
  - 100%
  - 86%
  - 76%
  - 66%
- Ingot Yield
  - 60%
  - 70%
  - 80%
  - 90%

**Solar Cell Efficiencies (%)**
- Multi (PERC)
- Mono (PERC)
- Super Mono

**Cell Efficiency Distribution**
- high-purity Polysilicon
- low-quality Polysilicon

- cells with price discount
- cells with price premium

**Higher quality**
- Longer usable length
- Lower cost per wafer

**Higher quality supports greater efficiencies**
- Lower cost per wafer

**Narrow distribution and higher mean**
- Lower cost per wafer

Source: WACKER estimates
Contents

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» Solar Market Overview
High Quality And Efficiency Allow Levelized Cost of Electricity to Decline Further – System Price of 0.5 €/W Within Reach

**Benchmark PV System Prices*** (€/Wp) and **LCOE**** (€/kWh, 30 Year Lifetime)

*ground-mounted PV systems (utility scale)

**Levelized cost of electricity**

- 1.5 €/Wp
- 1.0 €/Wp
- 0.5 €/Wp
- Wind Offshore
- Wind Onshore
- Gas
- Coal

Sources: market surveys, industry announcements, WACKER estimates

Irradiation in kWh/kWp

Germany, China, USA, India, Japan
Power Rates Already Down to 0.02 €/kWh in Sunny Regions

Benchmark PV Power Rates (2016) in €/KWh

- USA: 3ct
- Mexico: 4ct
- Brazil: 6ct
- Chile: 7ct
- Peru: 2ct
- Germany: 7ct
- Spain: 5ct
- Morocco: 2ct
- UAE: 6ct
- India: 5ct
- Australia: 5ct
- Zambia: 4ct
- Mexico: 3ct

Source: SeeNews Renewables, Industry Announcements
## Global Installations Further Broaden And Grow

<table>
<thead>
<tr>
<th>Country</th>
<th>2013</th>
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<th>2015</th>
<th>2016e</th>
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<td>France</td>
<td>0.6</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9 – 1.1</td>
<td>1.3 – 1.5</td>
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<td>Germany</td>
<td>3.3</td>
<td>1.9</td>
<td>1.5</td>
<td>1.0 – 1.2</td>
<td>1.2 – 1.4</td>
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<tr>
<td>Italy</td>
<td>1.1</td>
<td>0.6</td>
<td>0.3</td>
<td>0.4 – 0.5</td>
<td>0.4 – 0.5</td>
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<td>Europe other</td>
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<td>4.0</td>
<td>5.9</td>
<td>4.5 – 5.0</td>
<td>4.6 – 5.6</td>
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<tr>
<td><strong>Europe total</strong></td>
<td><strong>10.8</strong></td>
<td><strong>7.4</strong></td>
<td><strong>8.6</strong></td>
<td><strong>6.8 – 7.8</strong></td>
<td><strong>7.5 – 9.0</strong></td>
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<td>Australia</td>
<td>0.9</td>
<td>1.0</td>
<td>0.9</td>
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<td>1.0 – 1.2</td>
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<td>China</td>
<td>12.9</td>
<td>13.2*</td>
<td>16.5*</td>
<td>18.0 – 22.0</td>
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<td>4.5 – 5.0</td>
<td>8.0 – 9.0</td>
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<td>9.3</td>
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<td>8.0 – 8.5</td>
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<td>USA</td>
<td>4.8</td>
<td>6.2</td>
<td>7.3</td>
<td>11.0 – 13.5</td>
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<td>Rest of World</td>
<td>2.8</td>
<td>6.0</td>
<td>10.0</td>
<td>11.0 – 12.5</td>
<td>14.0 – 16.0</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>40 GW</strong></td>
<td><strong>44 GW</strong></td>
<td><strong>~56 GW</strong></td>
<td><strong>~60 – 70 GW</strong></td>
<td><strong>~65 – 80 GW</strong></td>
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Sources: SPE, IHS, Industry announcements, WACKER estimates; *2.6 GW allocated from 2015 to 2014, ~4 GW from 2016 to 2015 (installed and not connected capacity)
WACKER POLYSILICON: Maintain Leadership in Cost And Quality

Our Roadmap 2017

1. Cost
   - Competitive pressure drives module cost and conversion efficiency
   - Multi-year cost reduction roadmap implemented to maintain WACKER’s leading cost position

2. Quality
   - C-Si-PV moving towards efficiencies above 22% (module)
   - Pricing differentiates between polysilicon qualities

3. Customer
   - Develop products for all crystallization technologies in close cooperation with our customers
   - Keep broad customer portfolio to react flexibly on market changes
   - Expand capacities according to market demand
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