

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

Burghausen, October 11, 2016

Ewald Schindlbeck, President WACKER POLYSILICON

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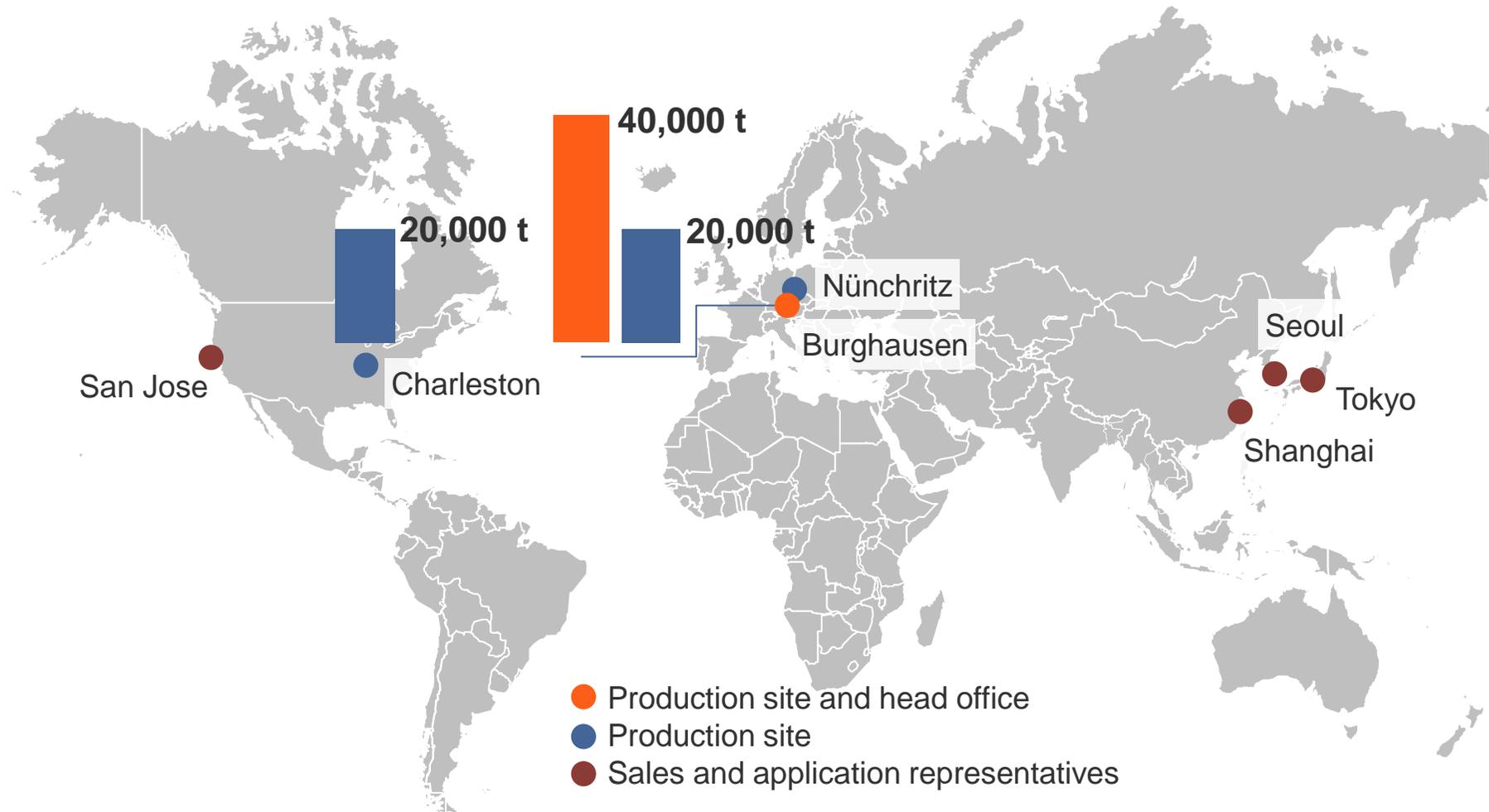
▶ **Capacity, Technology and Costs**

Polysilicon Impact on Ingot and Cell Production

Solar Market Overview

WACKER POLYSILICON is Represented Globally With 3 Production Sites And 5 Sales Offices

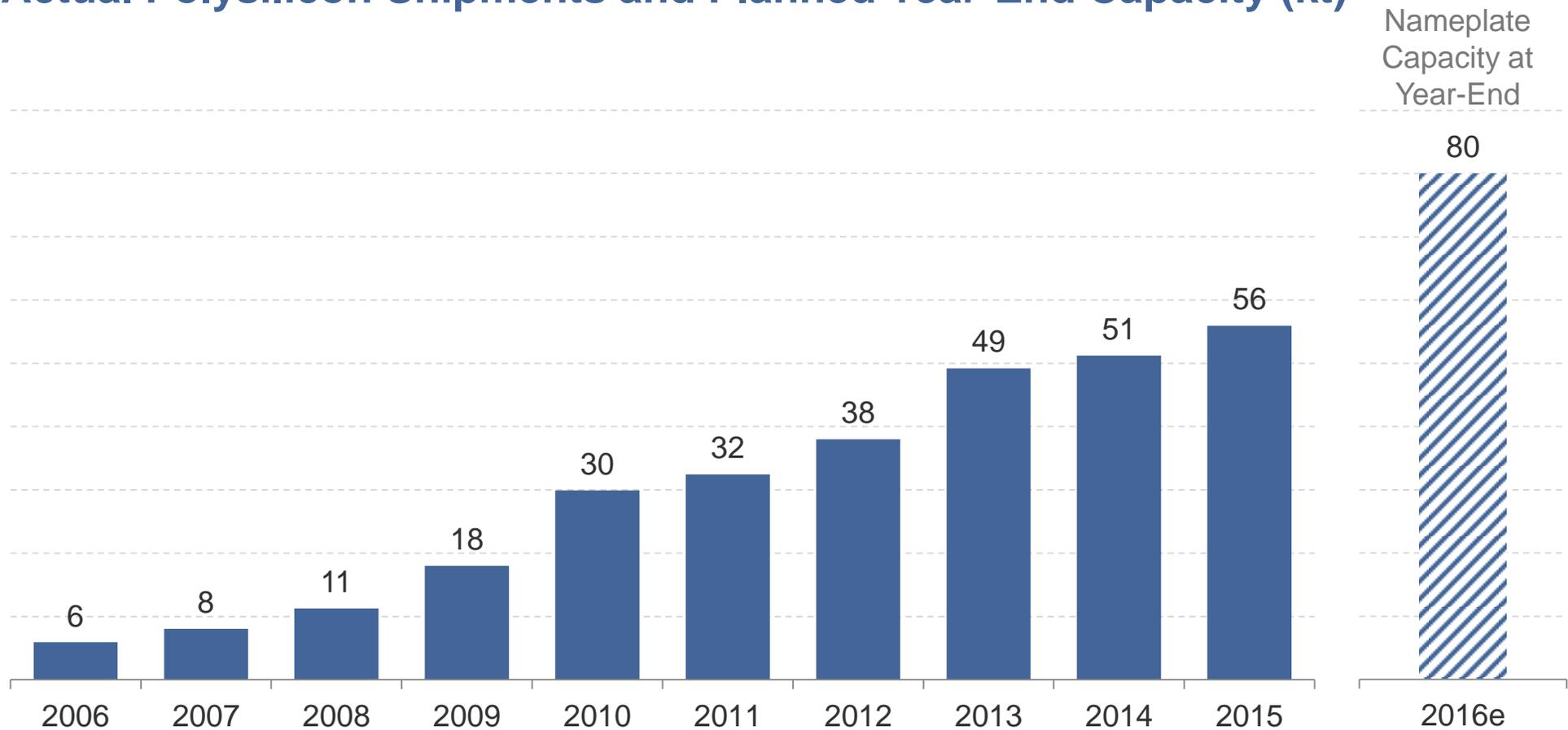
Office Locations, Sites and Nameplate Capacities*



* in metric tons per year

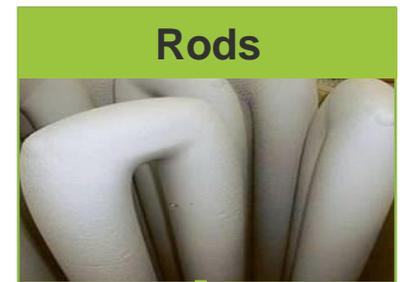
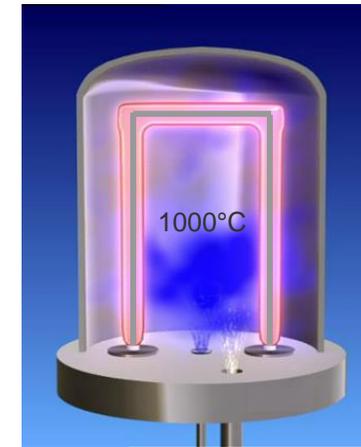
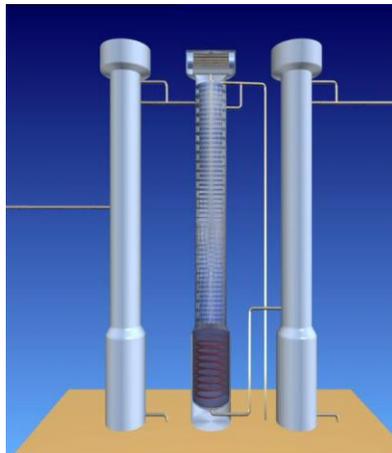
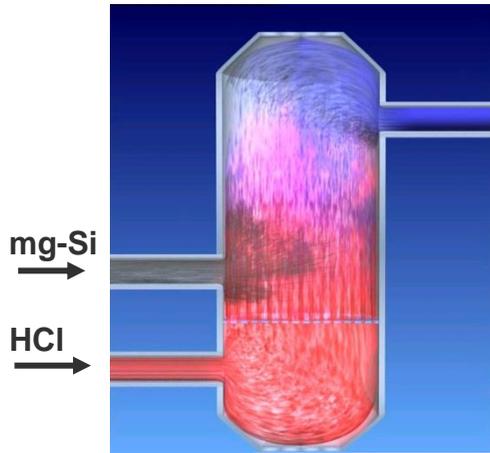
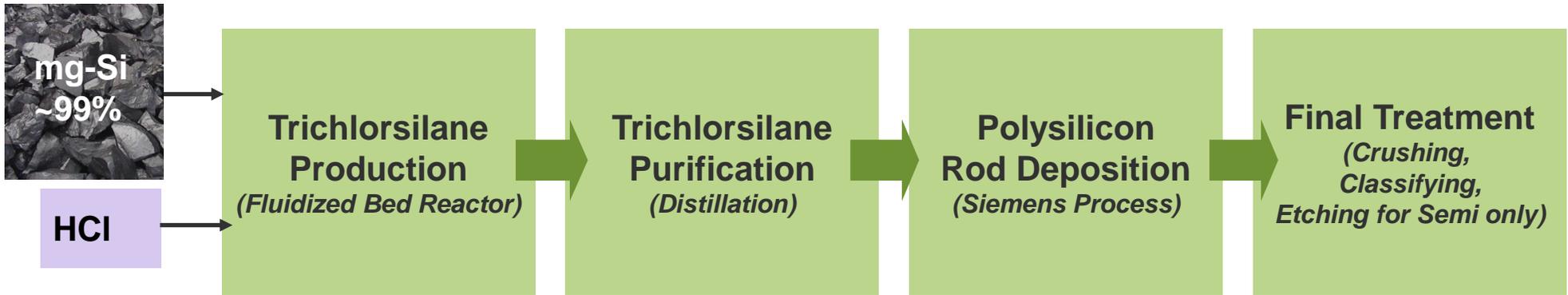
WACKER POLYSILICON: Growing With The Market

Actual Polysilicon Shipments and Planned Year-End Capacity (kt)



▶ 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



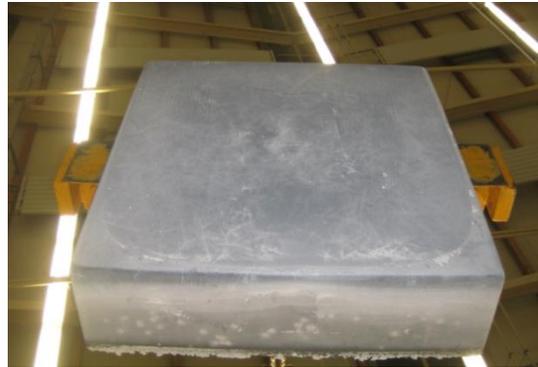
Granular Polysilicon PCG[®] Is a Useful Addition to Our Product Portfolio

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



Reference: ALD

- ▶ Standard & HPM processes
- ▶ Increase crucible charge
- ▶ Seeding

Czochralski (CZ)

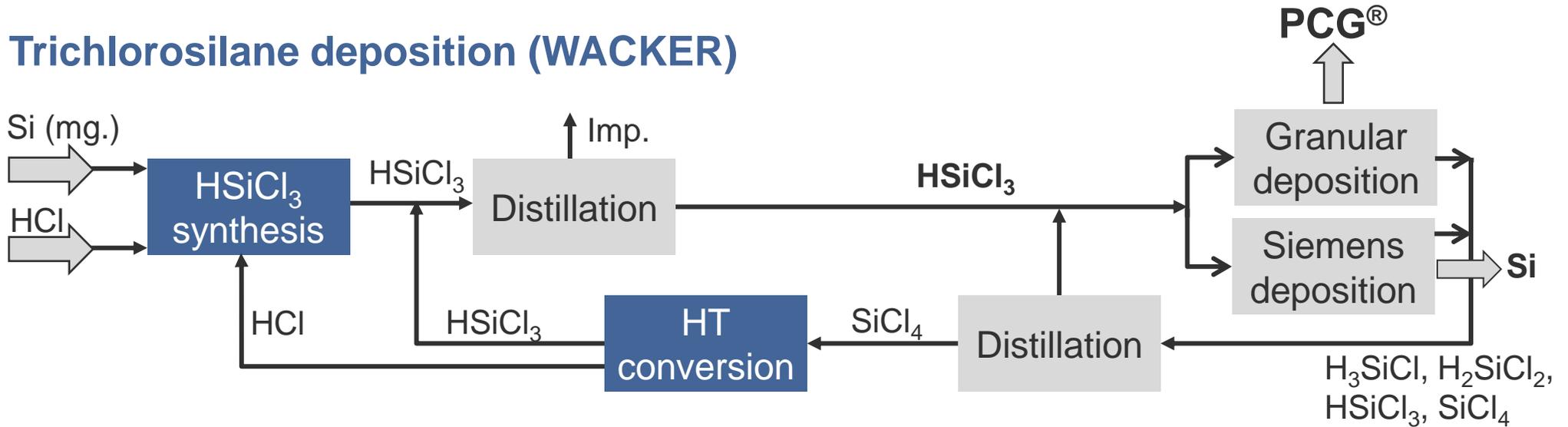


Reference: Siltronic AG

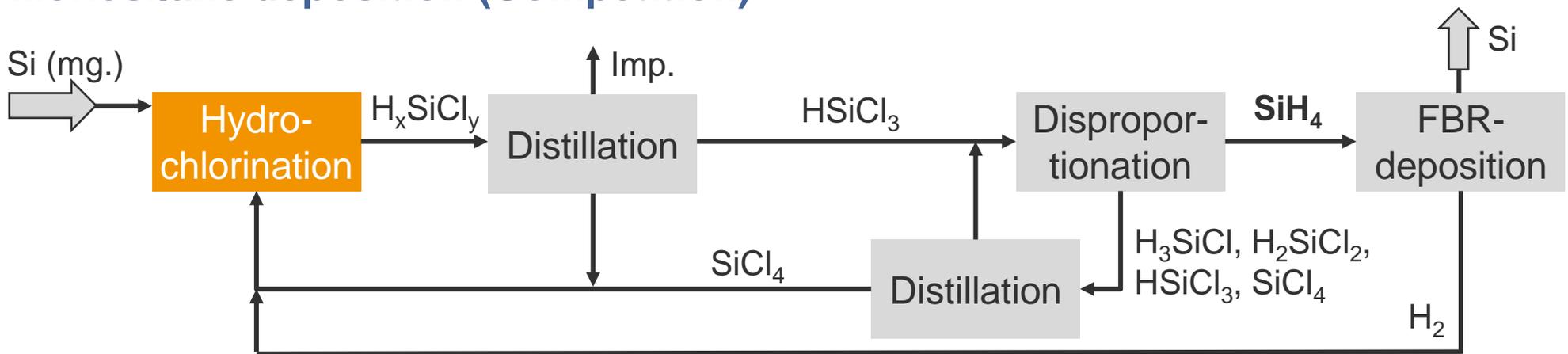
- ▶ Solar grade
- ▶ Electronic grade
- ▶ Increase crucible charge
- ▶ Recharging

A Granular Process Based on Trichlorosilane Fits Perfectly to Our Existing Integrated Production Loops

Trichlorosilane deposition (WACKER)



Monosilane deposition (Competition)



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)

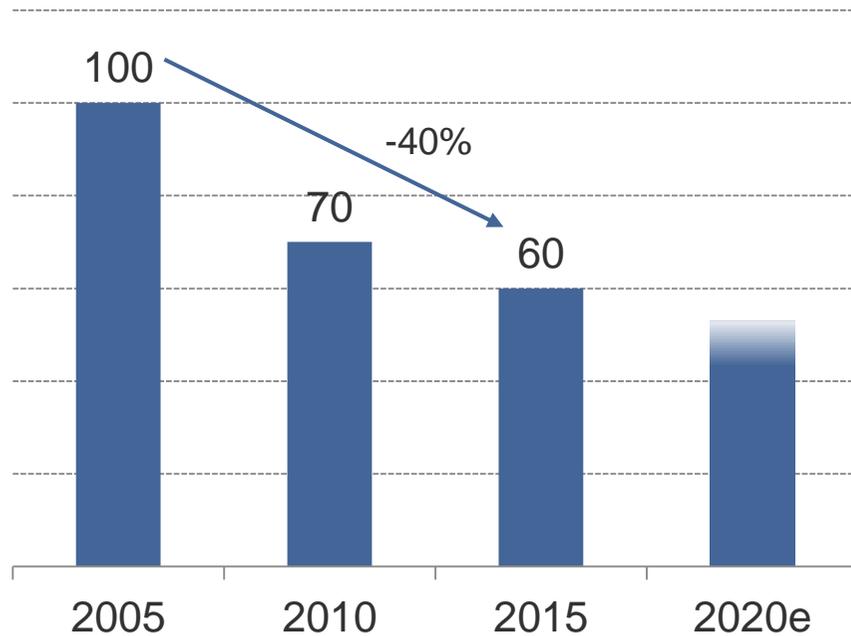


Source: Industry announcements, WACKER estimates

Continuous Strong Focus on Cost And Productivity

Specific Energy Consumption*

Index = 100

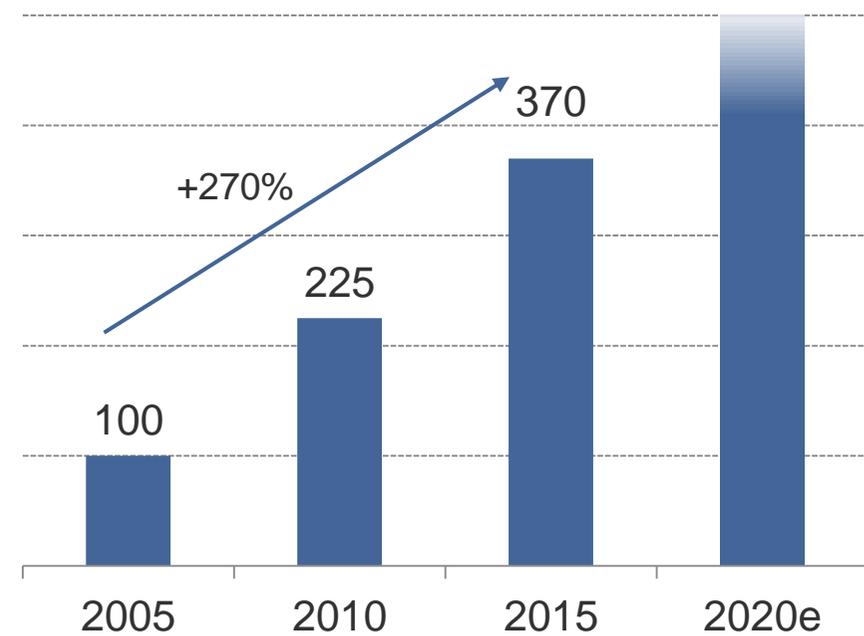


- ▶ New deposition reactors
- ▶ New conversion reactors
- ▶ New process design

* Solar polysilicon process only

Labor Productivity**

Index = 100



- ▶ Economies of scale
- ▶ Yield improvements
- ▶ Automation

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

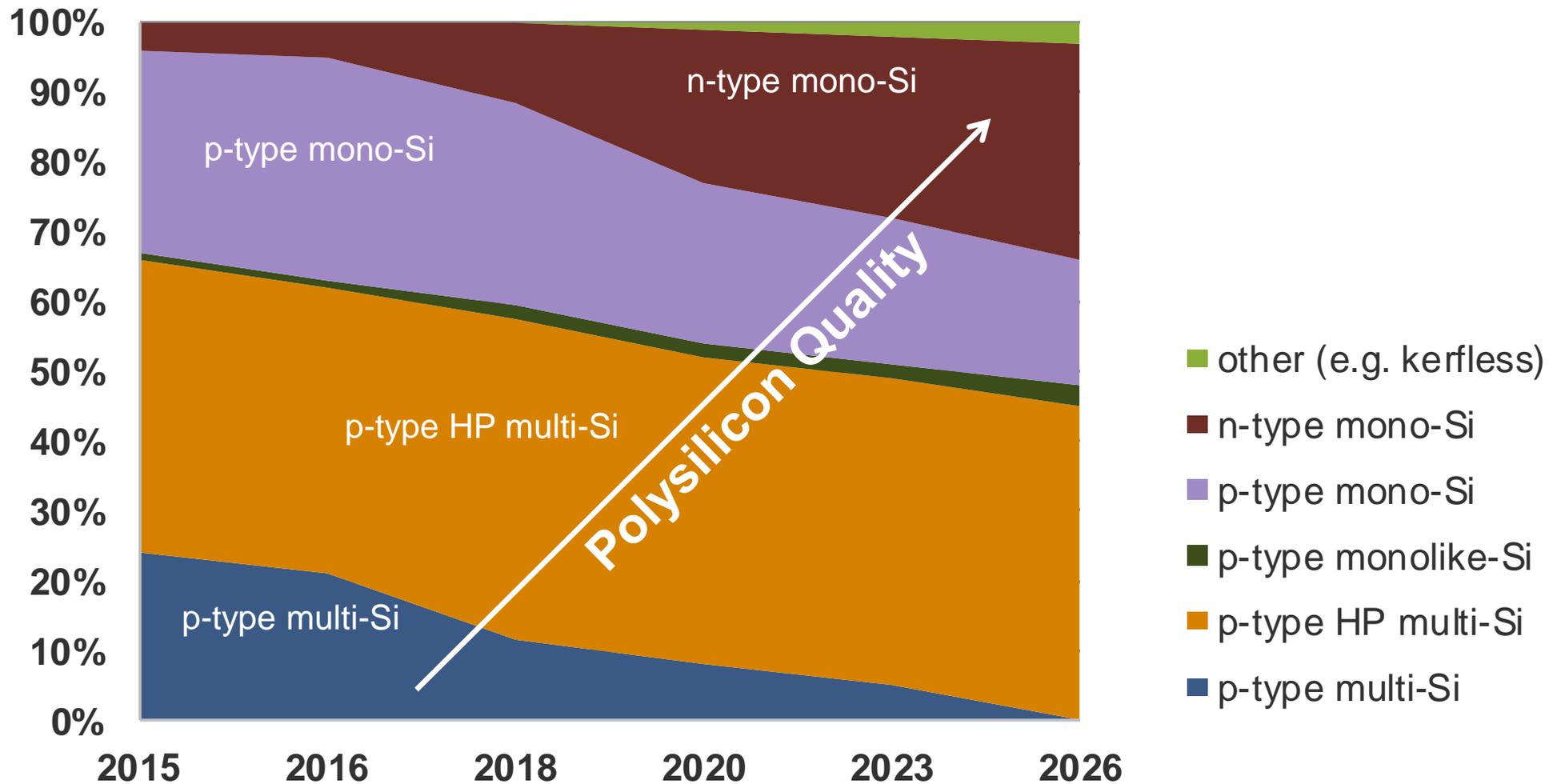
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Capacity, Technology and Costs

▶ **Polysilicon Impact on Ingot and Cell Production**

Solar Market Overview

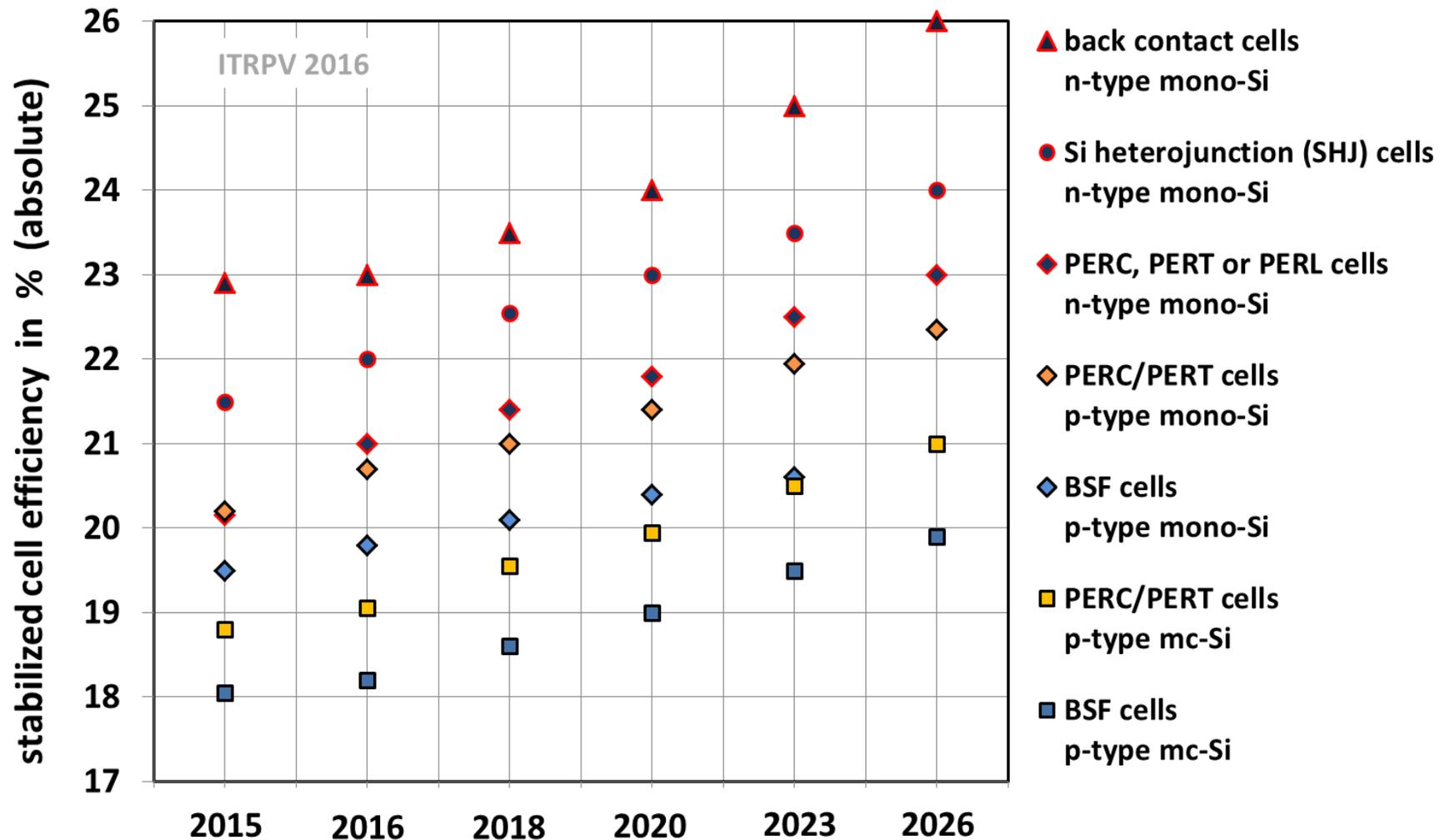
High Quality Polysilicon Required For High Cell Efficiency Trend



Source: ITRPV = International Technology Roadmap for PV Initiative of Semi, www.itrpv.net
HP = High Performance

Cell Efficiencies Beyond 20% Are Reality

Average Stabilized Efficiency Values for Si Solar Cells (156 x 156 mm²)



Source: ITRPV = International Technology Roadmap for PV Initiative of Semi, www.itrpv.net

WACKER's Top Quality Polysilicon Position Continuously Verified by Benchmarks

Recent Results of Technical Benchmarks for Most Important Impurities

	Dopants	Carbon	Iron
WACKER	Green	Green	Green
Tier 1	Green	Green	Green
Tier 1	Yellow	Orange	Green
Tier 1	Orange	Orange	Yellow
Tier 2	Yellow	Green	Yellow
Tier 2	Yellow	Green	Green
Tier 2	Orange	Green	Yellow
Tier 2	Orange	Yellow	Orange
Tier 2	Orange	Orange	Orange
Tier 2	Orange	Green	Green
FBR/Granular*	Orange	Orange	Orange

	Dopants	Carbon	Iron
Green	< 20 ppta	< 20 ppba	< 500 ppta
Yellow	< 300 ppta	< 50 ppba	< 5,000 ppta
Orange	> 300 ppta	> 50 ppba	> 5,000 ppta

* not WACKER

Source: WACKER internal benchmark reports

WACKER's Polysilicon Quality is Widely Acknowledged And Gives Customers a Leading Edge

(1/2)

- ▶ 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

WACKER's Polysilicon Quality is Widely Acknowledged And Gives Customers a Leading Edge

(2/2)

- ▶ “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

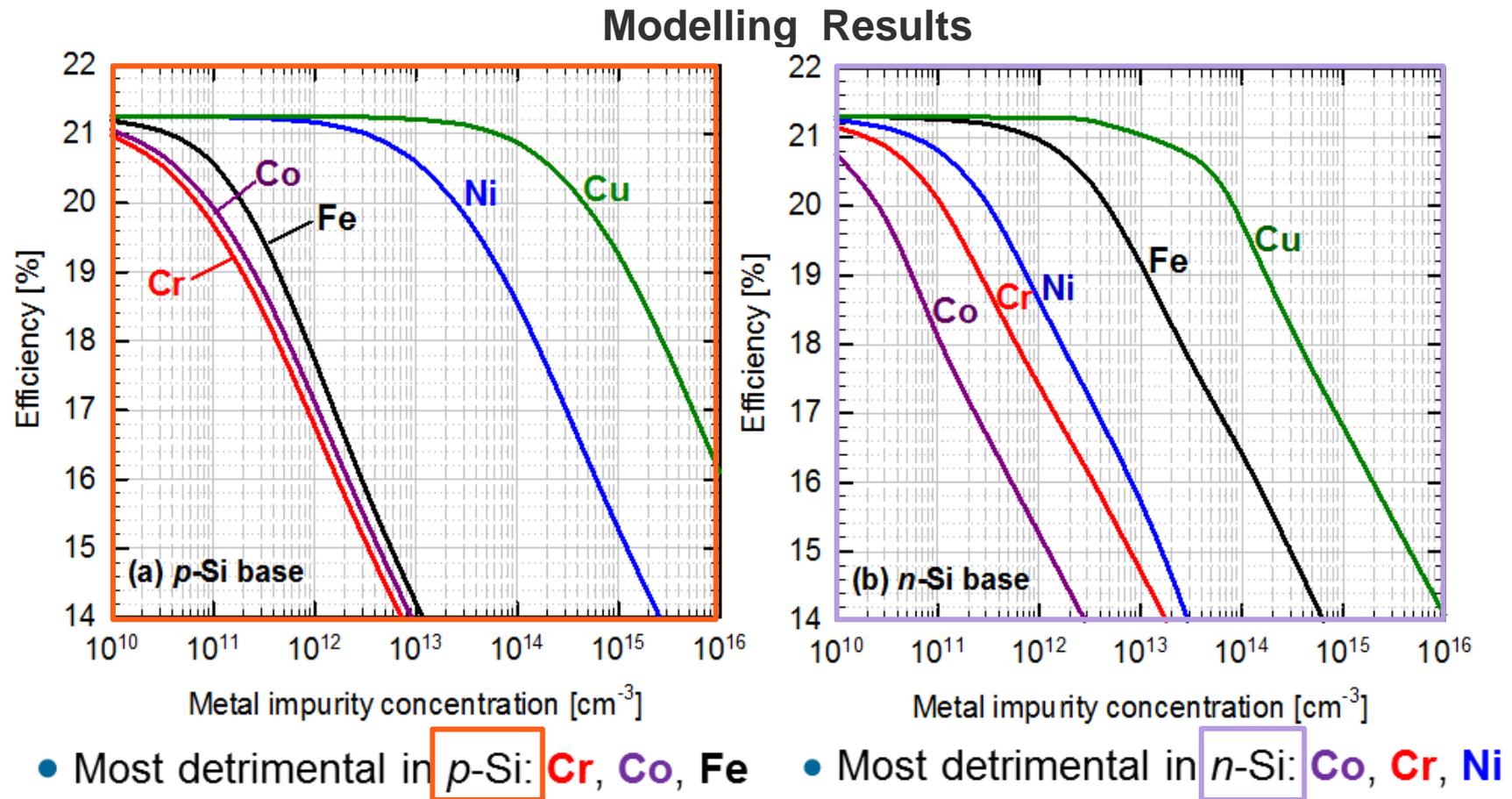
Hyper Pure Feedstock Leads to Higher PV Efficiency And Improves Specific Costs Per Watt

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

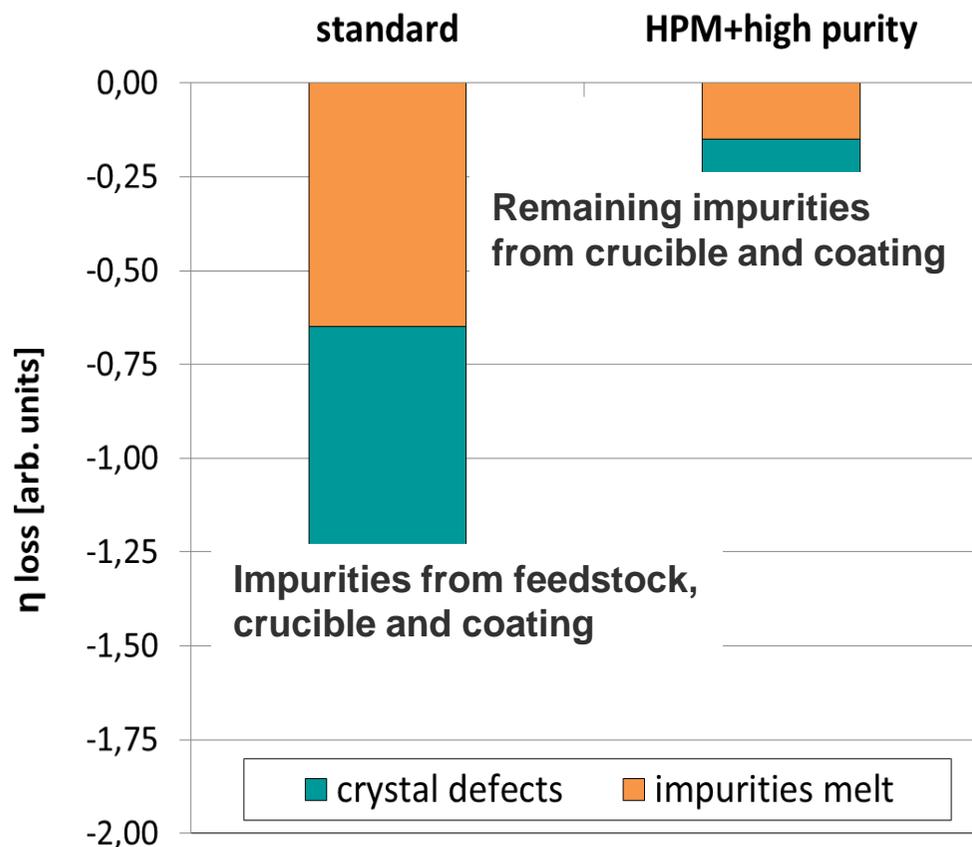
1. PURITY FOR HIGH EFFICIENCY: Metals Are Efficiency Killers For Solar Cells



Source: J. Schmidt et al,
IEEE Journal of Photovoltaics, vol 3 No 1, Jan. 2013, p. 114 ff.
“Impurity-Related Limitations of Next-Generation Industrial Silicon Solar Cells”

Thanks for friendly permission to use this diagram.

1. PURITY FOR HIGH EFFICIENCY: Solar Cell Improvement Strategies Require High Quality Poly

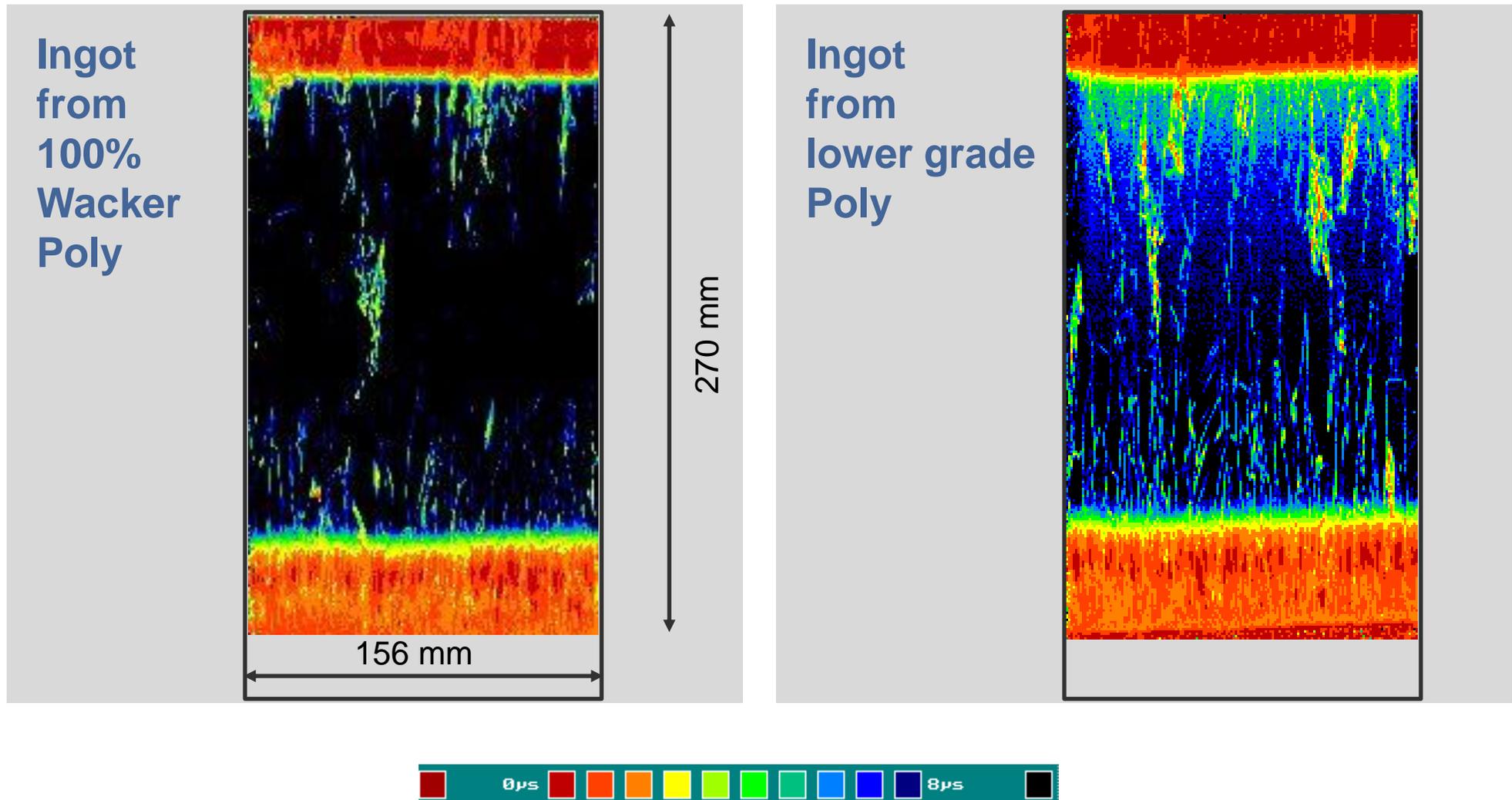


Route of improvement for multi-crystalline silicon solar cells

- ▶ 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

▶ **High purity translates to high efficiencies**

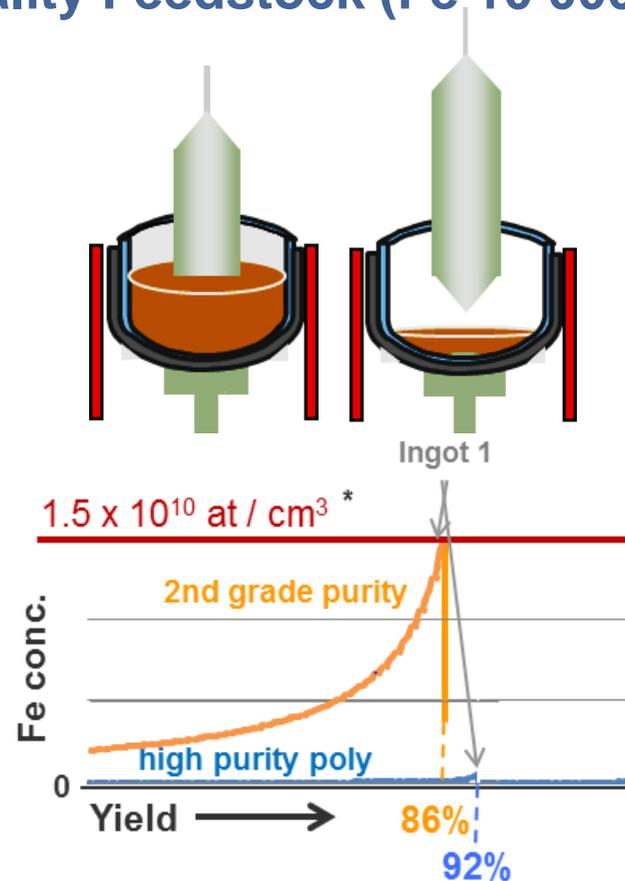
2. HIGHEST CHARGE CARRIER LIFETIME: Superior Values in Multi Ingots With 100% WACKER Polysilicon



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)



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

Customers' Application Experience

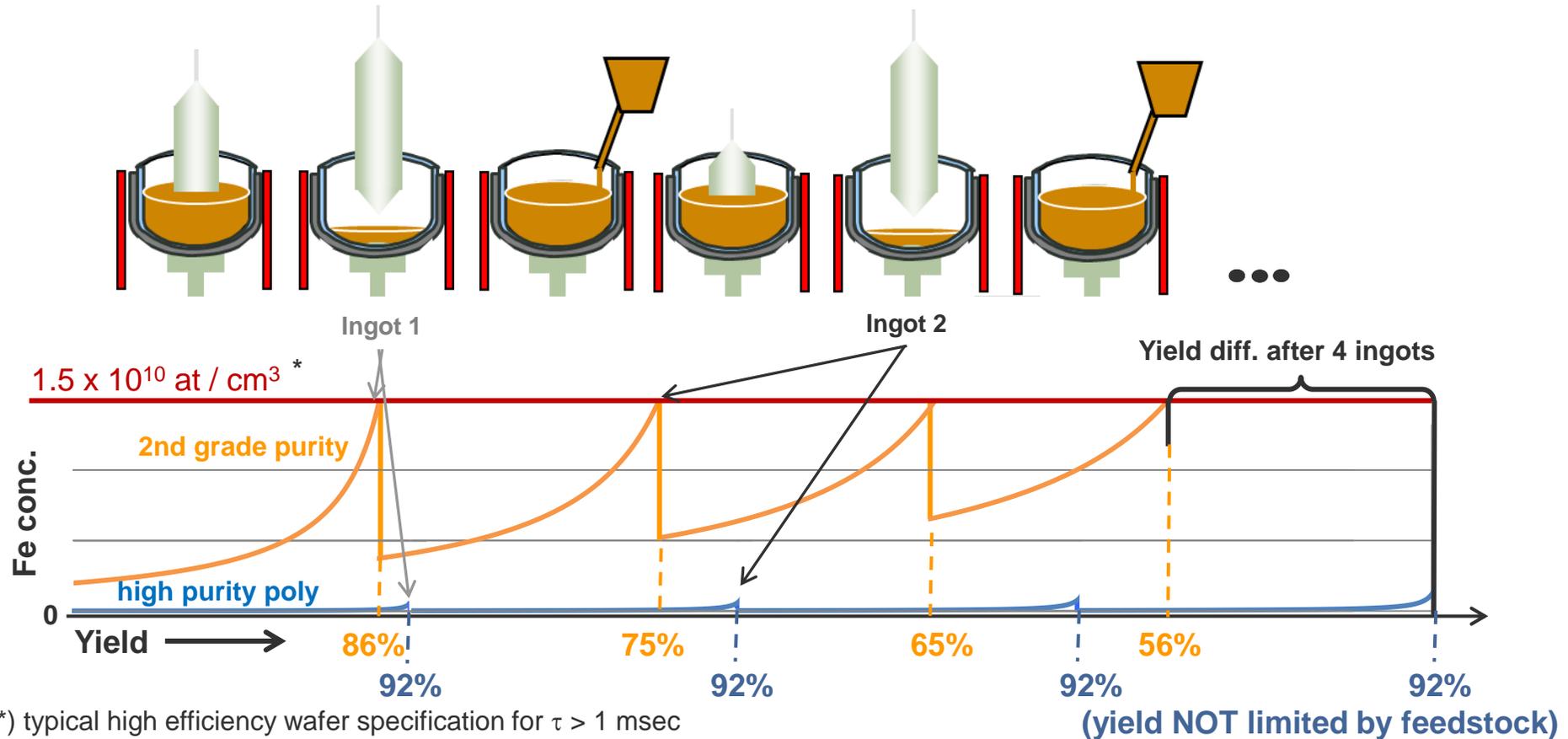
- ▶ High grade poly ensures maximum in spec yield
- ▶ ~6% yield loss caused by low grade poly
- ▶ Fluctuating poly qualities prohibit stable yields
- ▶ Solar cells quality varies when low grade poly is used

▶ **Yield not limited by feedstock**

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

3. HIGHEST YIELDS:

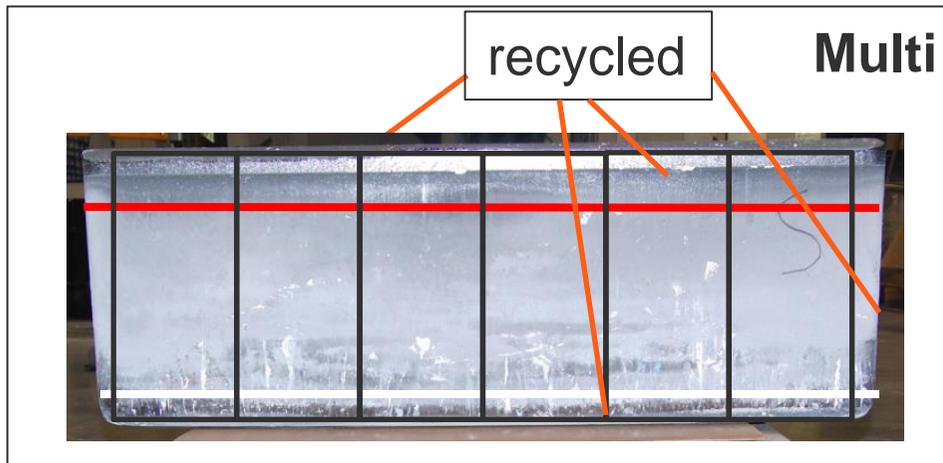
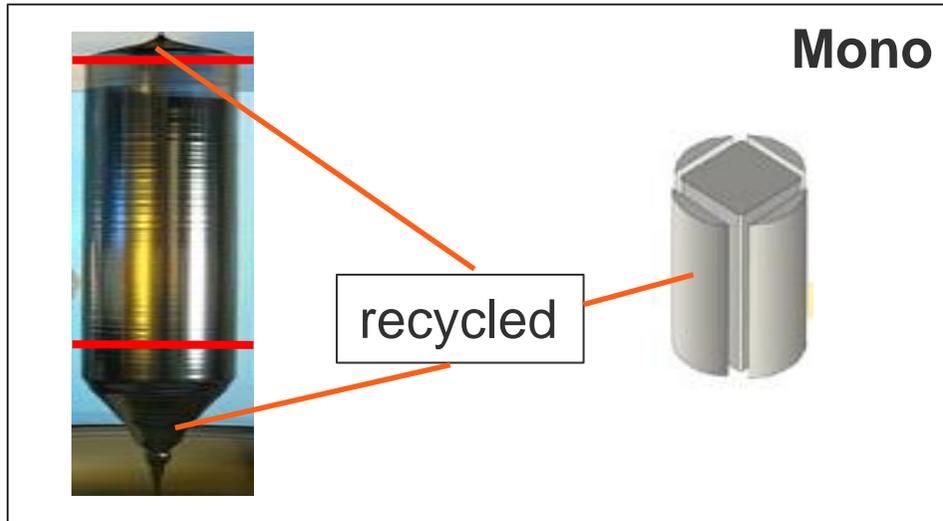
Multiple CZ Pulling Requires Extremely Pure Small Size Chips



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

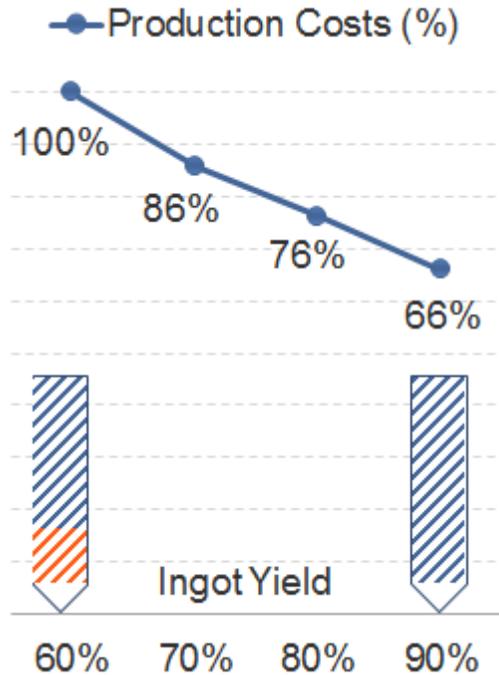
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High Quality Polysilicon Helps Multi And Mono Technology

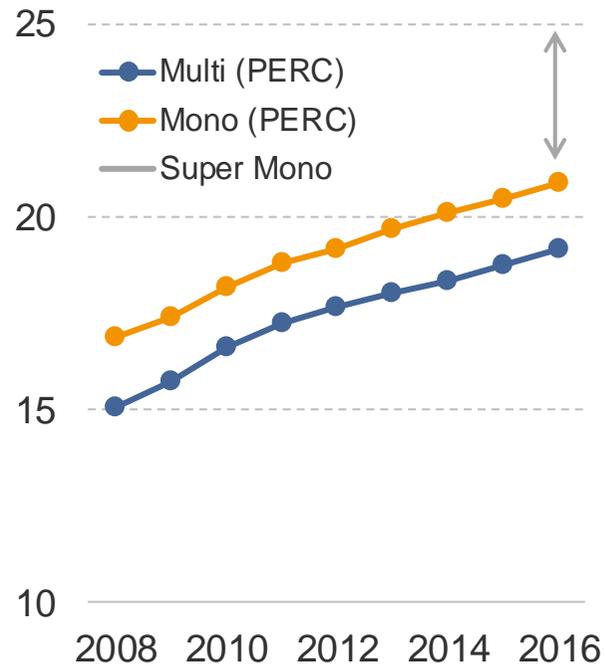
Usable Ingot Length (%)



Higher quality

- ▶ Longer usable length
- ▶ Lower cost per wafer

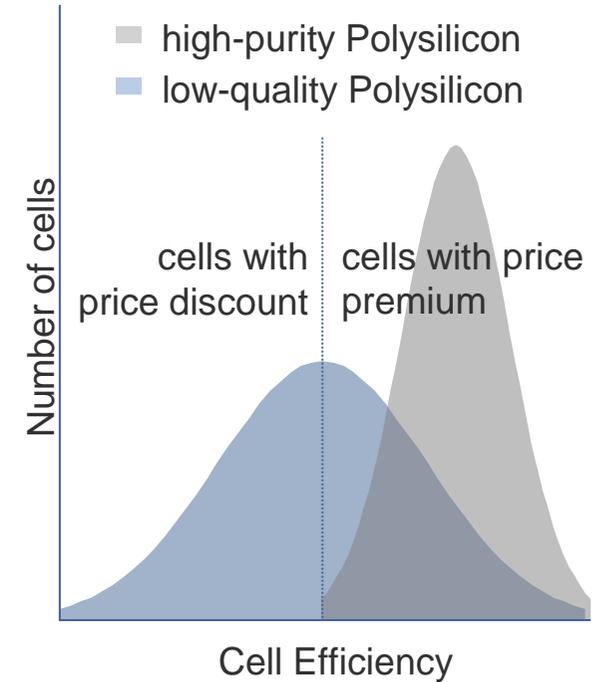
Solar Cell Efficiencies (%)



Higher quality supports greater efficiencies

- ▶ Lower cost per wafer

Cell Efficiency Distribution



Narrow distribution and higher mean

- ▶ Lower cost per wafer

Source: WACKER estimates

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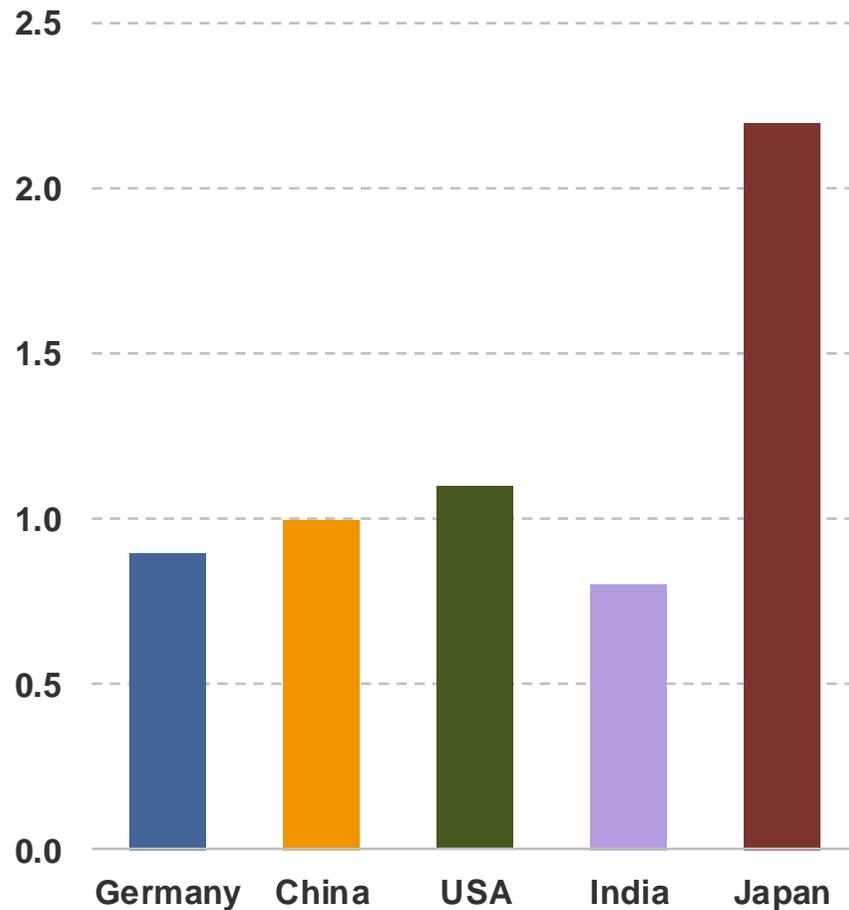
▶ **Solar Market Overview**

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

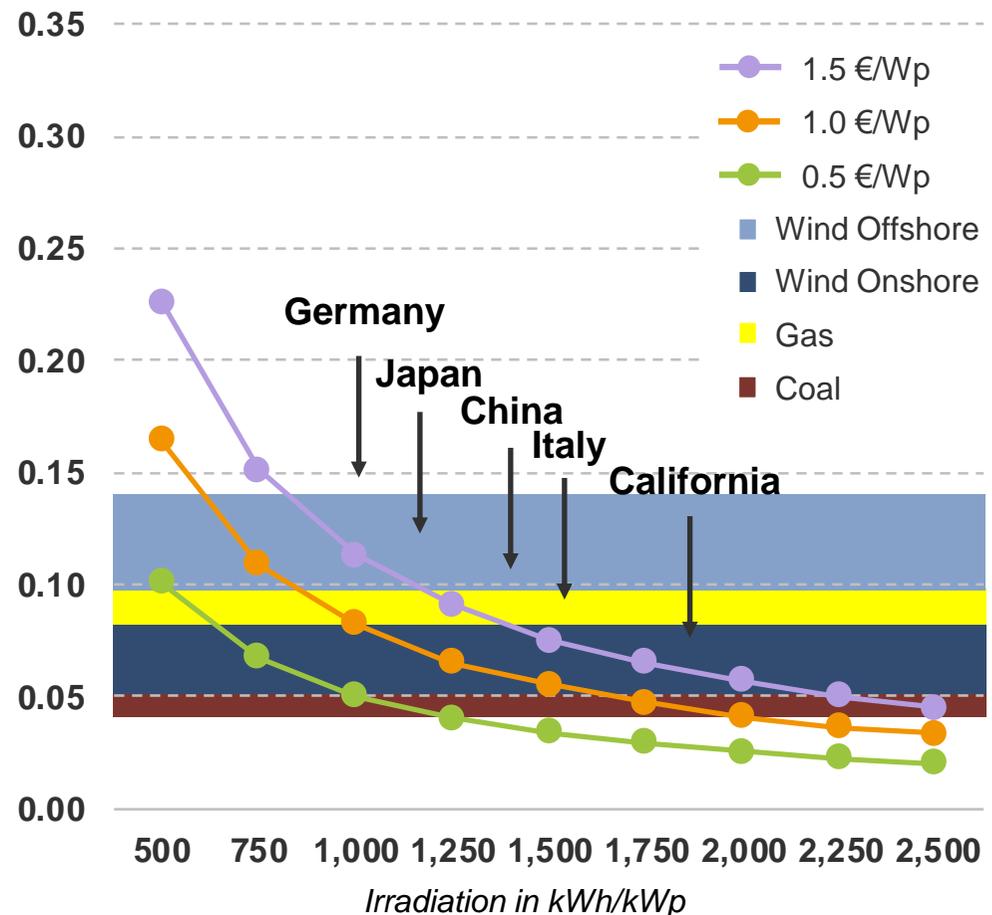
Benchmark PV System Prices* (€/Wp) and LCOE** (€/kWh, 30 Year Lifetime)

*ground-mounted PV systems (utility scale)

**Levelized cost of electricity

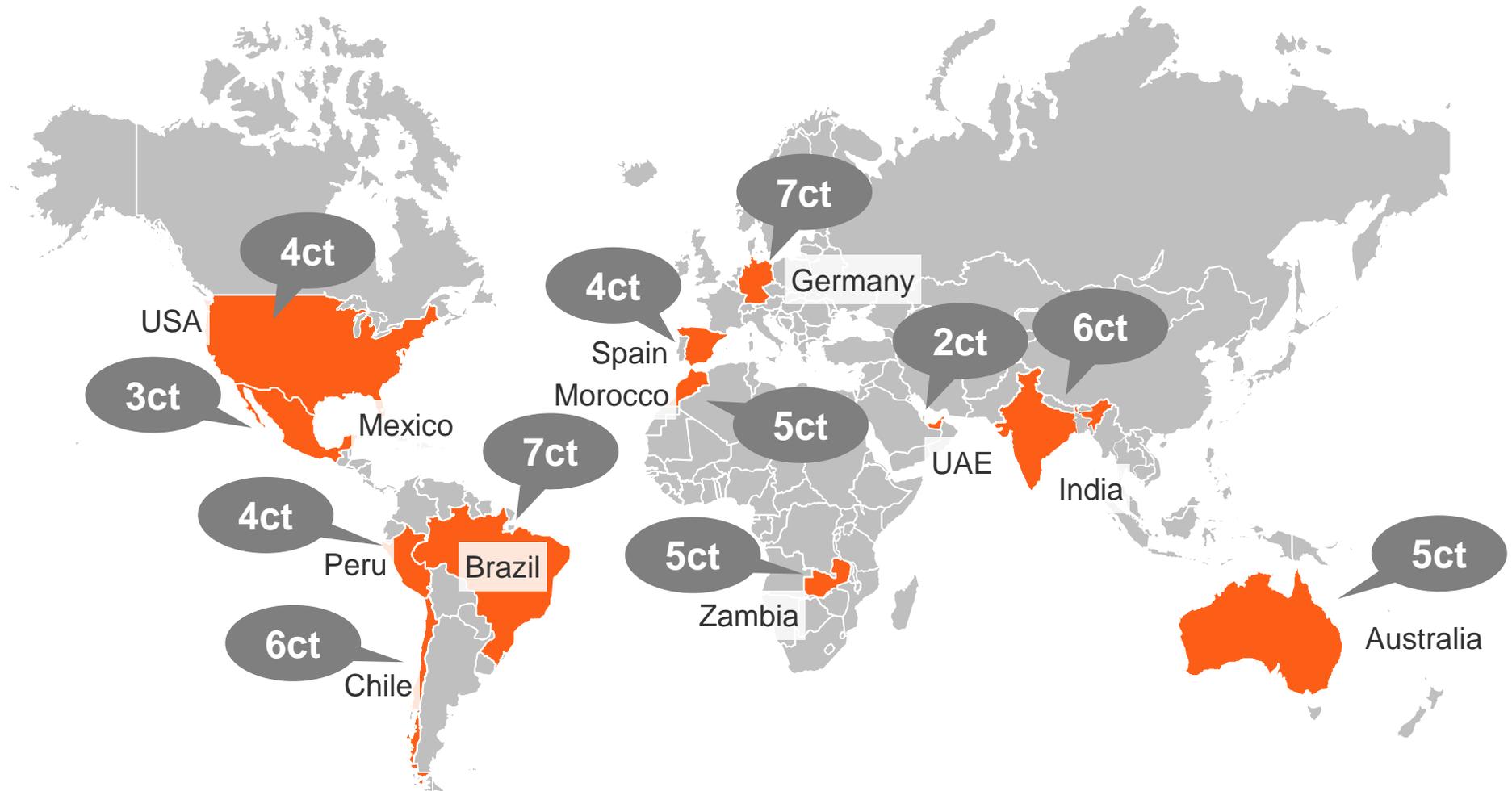


Sources: market surveys, industry announcements, WACKER estimates



Power Rates Already Down to 0.02 €/kWh in Sunny Regions

Benchmark PV Power Rates (2016) in €/KWh



Source: SeeNews Renewables, Industry Announcements

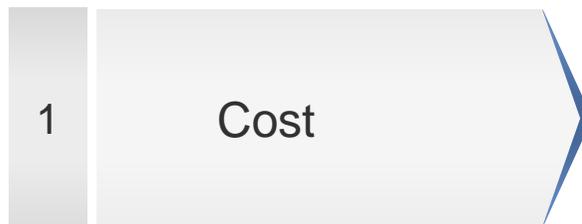
Global Installations Further Broaden And Grow

Country	2013	2014	2015	2016e	2017e
France	0.6	0.9	0.9	0.9 – 1.1	1.3 – 1.5
Germany	3.3	1.9	1.5	1.0 – 1.2	1.2 – 1.4
Italy	1.1	0.6	0.3	0.4 – 0.5	0.4 – 0.5
Europe other	5.8	4.0	5.9	4.5 – 5.0	4.6 – 5.6
Europe total	10.8	7.4	8.6	6.8 – 7.8	7.5 – 9.0
Australia	0.9	1.0	0.9	0.9 – 1.1	1.0 – 1.2
China	12.9	13.2*	16.5*	18.0 – 22.0	16.0 – 23.0
India	1.0	1.0	2.1	4.5 – 5.0	8.0 – 9.0
Japan	6.8	9.3	10.8	8.0 – 8.5	8.0 – 9.0
USA	4.8	6.2	7.3	11.0 – 13.5	10.0 – 13.0
Rest of World	2.8	6.0	10.0	11.0 – 12.5	14.0 – 16.0
Total	40 GW	44 GW	~56 GW	~60 – 70 GW	~65 – 80 GW

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

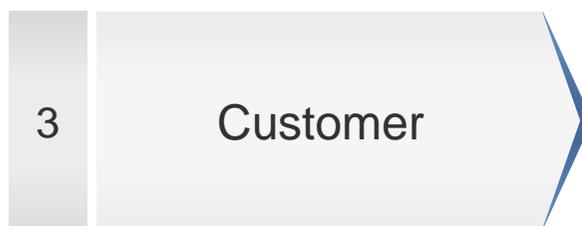
Our Roadmap 2017



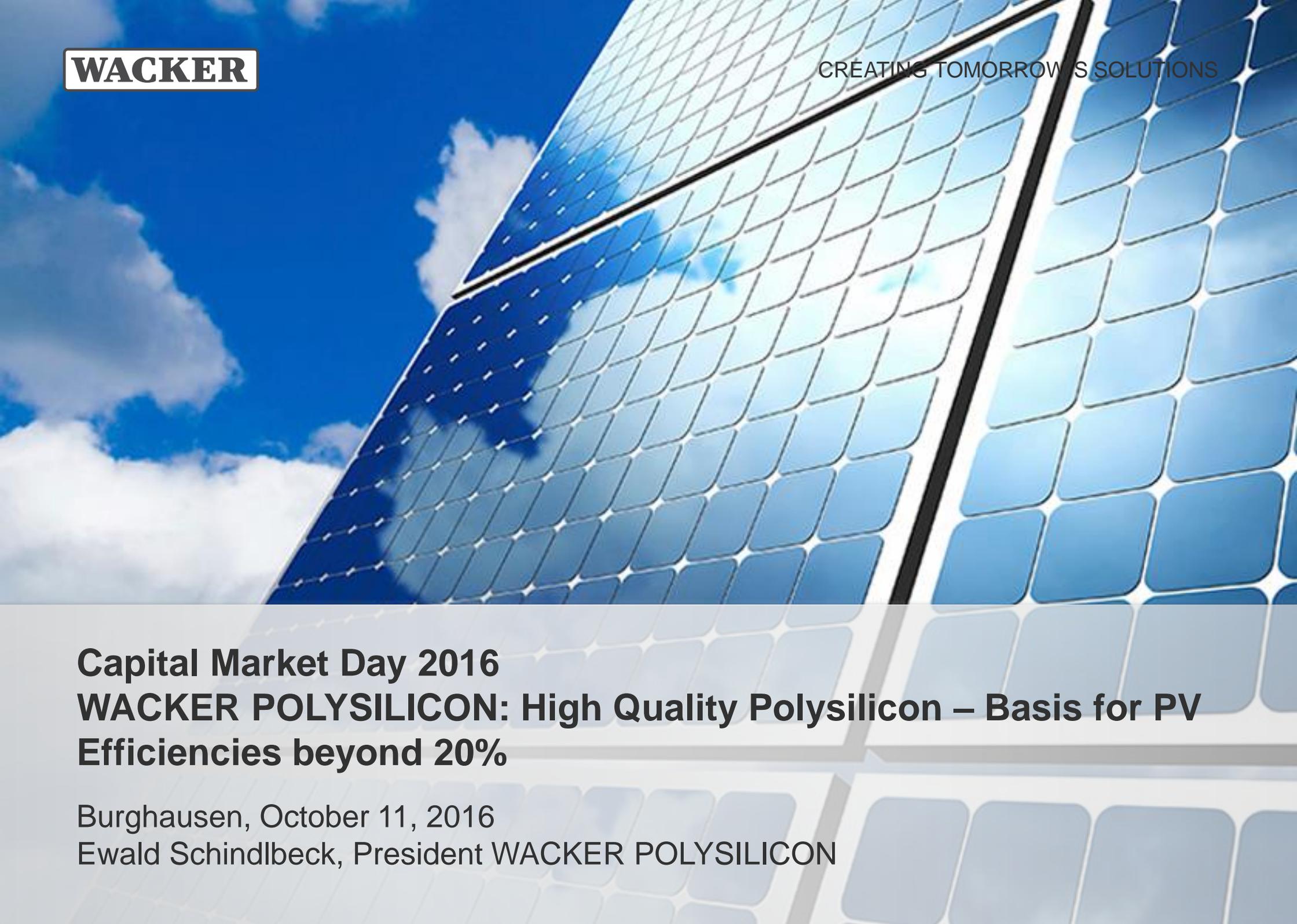
- ▶ Competitive pressure drives module cost and conversion efficiency
- ▶ Multi-year cost reduction roadmap implemented to maintain WACKER's leading cost position



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



- ▶ 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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