

WACKER

CREATING TOMORROW'S SOLUTIONS

WACKER | POLYSILICON | GLOBAL

**POLYSILICON –
BEFORE THERE IS SOLAR ENERGY
THERE IS WACKER**

“I’D PUT MY MONEY ON THE
SUN AND SOLAR ENERGY.
WHAT A SOURCE OF POWER!
I HOPE WE DON’T HAVE TO WAIT
UNTIL OIL AND COAL RUN OUT
BEFORE WE TACKLE THAT.”

Thomas Edison, 1931





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There Is No Way Around Solar Energy

Of all the ways to produce energy, photovoltaics has seen the steepest cost reduction curve. The costs of generating electricity using photovoltaic technology is driven by continuous improvement in solar cell efficiency and ever-lowering manufacturing costs. WACKER plays an important part in this process, offering top-quality polysilicon and a product portfolio that has been tailored to the needs of our customers.

PIONEERING PROGRESS

Hyperpure polysilicon from WACKER has driven both the digital revolution and the breakthrough of solar energy.

1954

WACKER starts systematic research and development on hyperpure polysilicon. Just one year later, WACKER's polysilicon purity is at the level of one impurity atom in every 10 million silicon atoms.



1959

WACKER begins industrial-scale production of polysilicon for semiconductors (output of 325 kg/a) and continuous upscaling of the site in Burghausen (Germany) over the following years.



1976/77

Every second silicon atom in the semiconductor industry comes from WACKER.



1980/90s

WACKER develops a new cost-efficient process for multicrystalline solar wafers. The technology is introduced on the market and WACKER focuses on expanding its capacity for hyperpure polysilicon.



2000

WACKER starts production of dedicated solar-grade polysilicon in Burghausen (Germany).



1954

The first silicon-based transistors are introduced. Hyperpure polysilicon is needed to ensure functionality.



1960s

Tube receivers are completely replaced by transistor radios. One of the drivers is the increasing availability of hyperpure polysilicon.



1980s

Silicon-based computers are introduced for broader use in industry and society.



1990s

Mobile phones gradually start to appear in the hands of consumers for the first time. By the late 1990s, mobile devices were fast becoming the norm thanks to developments in design and performance.



2000

The German Renewable Energy Act (EEG) is introduced, leading to the rapid growth of photovoltaics and polysilicon demand. The "Energie-wende" becomes a role model for other countries.

2011

Since 2005, WACKER has invested over €2 bn to expand its German sites in Nünchritz and Burghausen; polysilicon production for photo-voltaics increases.



2016

WACKER invests \$2.5 bn and opens a new production site for solar-grade polysilicon in Charleston (USA), increasing WACKER's polysilicon capacity to 80,000 metric tons per year.



Since 2007

Silicon-based smart-phones and then tablets are making everyone's life more convenient.



2012

Worldwide photo-voltaic capacity rises to over 100 GW.

2015

The global capacity of photovoltaics crosses the 200 GW line and continues to grow.



The Road Ahead

The combination of highly efficient solar systems and the latest storage technology represents a game changer for the global energy supply and for mobility.

WACKER POLYSILICON: LEADING IN QUALITY AND QUANTITY

WACKER is a global producer of polysilicon and world market leader in volume, purity and the quality of its services.



At its three polysilicon production sites in Burghausen, Nünchritz and Charleston, WACKER's annual production capacity adds up to 80,000 metric tons, creating over 3,500 jobs.

WACKER was an early pioneer and is today the world market leader in the production of polysilicon. Polysilicon is the key raw material for applications in the photovoltaic and semiconductor industries.

Outstanding Purity

WACKER's polysilicon is renowned for its outstanding purity – a result of our long experience in developing and optimizing production processes. WACKER focuses on quality, cost, security, health and environmental protection. Today we are certified according to ISO 9001, ISO 14001, OHRIS and OHSAS, increasing quality while reducing resource consumption. The high purity leads to benchmark efficiencies in solar modules.



WACKER employs about 17,000 dedicated specialists. Shown here are the Burghausen (top) and Nünchritz (center) production sites. The Charleston production site (bottom), which was inaugurated in 2016, has a capacity of over 20,000 metric tons per year and will employ some 650 people.



Charleston



Burghausen

Nünchritz



Seoul

Tokyo

Shanghai

- Head office, production site, sales and application representatives
- Production site, sales and application representatives
- Sales and application representatives
- Production site



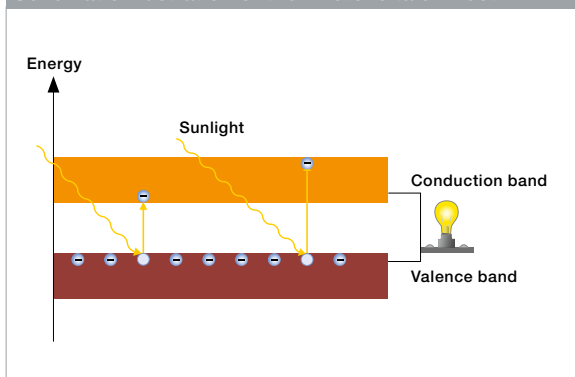
HARVESTING THE SUN WITH SAND: THE FASCINATION OF POLYSILICON

Silicon: an Extraordinary Material

Silicon is the second most abundant element on earth. In nature it is predominantly found in the form of silicon dioxide (quartz), which is the raw material for silicon production. Silicon has a highly extraordinary characteristic: as a semiconductor, it is the ideal material for exploiting the photovoltaic effect. When sunlight hits the surface of the semiconductor silicon, electrons absorb the light energy and are promoted from an immobile bound state (the valence band) to a higher energy level (the conduction band) where they can move freely. By controlled insertion of minute amounts of boron and phosphorus atoms into the hyperpure silicon, an internal p-n junction is created, which causes an electrical current to flow as soon as an external electricity consumer is connected. The only "fuel" required for this process is sunlight.

Silicon's electrical characteristics can be adjusted with great precision, even when it is produced on an industrial scale. That is how it established itself as the primary material for memory chips, processors and photovoltaics.

Schematic Illustration of the Photovoltaic Effect



Production of Polysilicon

1

The starting material for polysilicon is quartz (SiO_2).



2

The oxygen atoms are removed from the silicon dioxide (SiO_2) by heating the SiO_2 with carbon. The product is metallurgical silicon (Si_{mg}), which contains one to two percent impurities.



3

In a fluidized-bed reactor, hydrogen chloride (HCl) is used to transform the metallurgical silicon (Si_{mg}) into liquid trichlorosilane (HSiCl_3).



4

Extremely pure trichlorosilane is obtained through distillation.



5

The hyperpure trichlorosilane distillate is heated to about $1,000\text{ }^\circ\text{C}$ and passed over thin heated silicon rods.



6

The trichlorosilane decomposes and the purified silicon is deposited on the rod's surface.



7

Finally, the hyperpure silicon is crushed into chunks – the raw material for solar cells and semiconductor wafers.



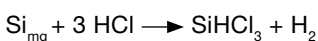
One kilogram of our hyper-pure polysilicon saves more than 7,000 kilograms of CO₂ emissions during the lifetime of a solar cell. *

The production of hyperpure polysilicon is a highly complex process. Two steps are essential:

Distillation

Metallurgical silicon already has a purity of 98 –99 percent. But this isn't nearly sufficient for building a highly efficient solar cell.

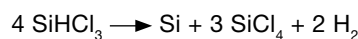
This is where WACKER's expertise comes into play. Distillation is a chemist's method of choice when it comes to purification. It represents an efficient process, with relatively low energy consumption and high throughput. For distillation, the raw silicon has to be transformed into a liquid called trichlorosilane (SiHCl₃), which is produced by reaction with hydrogen chloride gas (HCl):



The liquid is then distilled to remove the contaminants.

Deposition on Rods

The resultant highly pure trichlorosilane is used to make rods of hyperpure polycrystalline silicon (polysilicon). These rods are produced via chemical vapor deposition (CVD) at some 1,000 °C:



Finally, the rods are crushed and packaged without contaminating the surface.

Hyperpure polysilicon produced by WACKER enables the production of more efficient cells – the main driver for shorter energy payback times, reduction of CO₂ emissions and continuous cost decline.

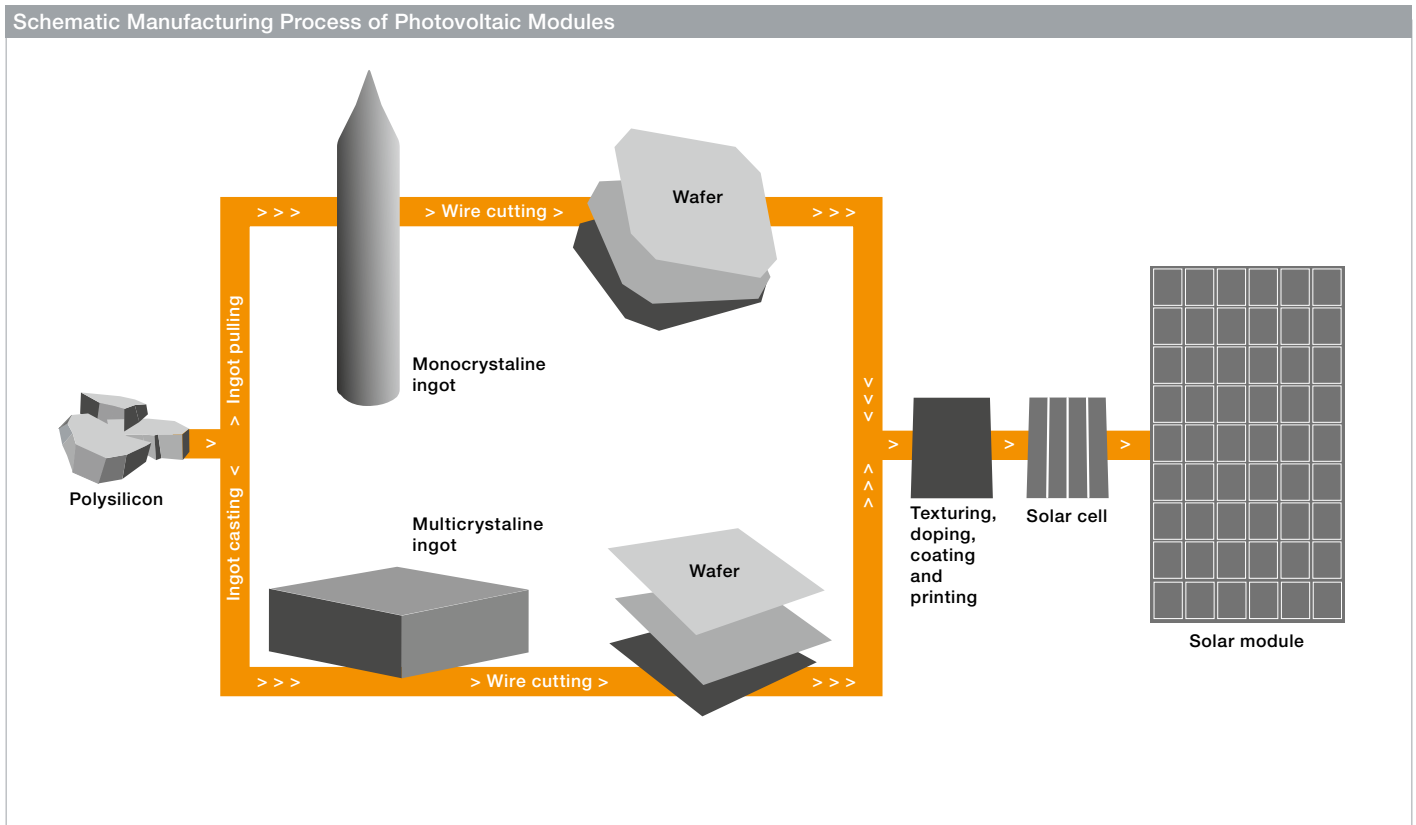
* SolarPower Europe/EPIA and WACKER analysis

PURELY MORE EFFECTIVE: OUR CHUNKS FOR SOLAR CELLS

WACKER's Polysilicon Is the Base Material for Photovoltaics

Polysilicon is the starting material for mono- and multicrystalline silicon solar cells. The first step is to melt polysilicon in a crucible. Monocrystalline ingots are pulled as single crystals from the melt using the Czochralski process. Multicrystalline ingots are grown by directional solidification in a square quartz crucible. After crystallization and cooling, both types of ingots are sawed into wafers by wire cutting. The wafers are then processed into solar cells. Typical process steps are texturing, doping, etching, coating, printing of electrical contacts, and firing.

Finally, several cells are connected to a solar module, ready for mounting on a surface such as a rooftop. The cell efficiency is highly dependent on the quality of the materials and components used. For polysilicon feedstock, this means that the higher the purity of polysilicon, the more efficient the solar cell.





KEEPING UP WITH TRENDS IN THE INDUSTRY: WHAT WE OFFER



Discover the Broadest and Purest Portfolio

Not only does WACKER polysilicon set the benchmark in purity – we also offer the broadest polysilicon portfolio in the industry. This means we can provide the solar and semiconductor industries with a complete spectrum of polysilicon products specifically customized to each application.

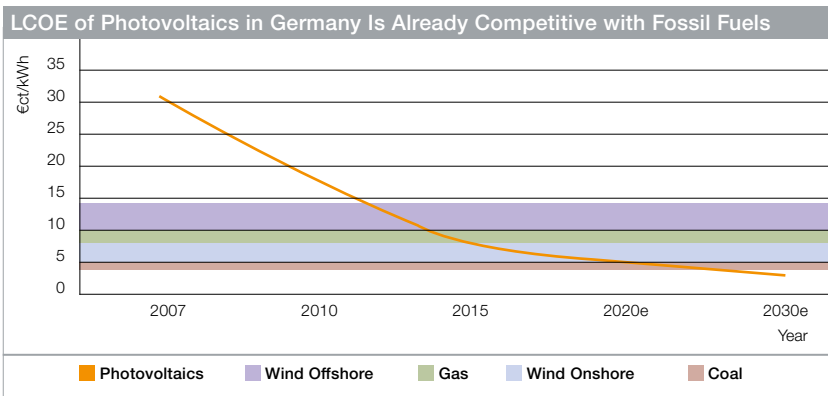
Minimizing Costs Along the Value Chain

Our polysilicon chunks and chips are available in a wide range of weights and sizes. The combination of different sizes allows our customers to optimize crucible filling and maximize output while keeping costs as low as possible. In this way, WACKER contributes to the steadily declining cost of photovoltaics and to its attractiveness as a clean source of energy.

Benefit from Our Support

We also offer a global sales network and continuous technical support. Thanks to our consistently high level of quality, WACKER customers can be sure their production will be steady and trouble-free at all times.

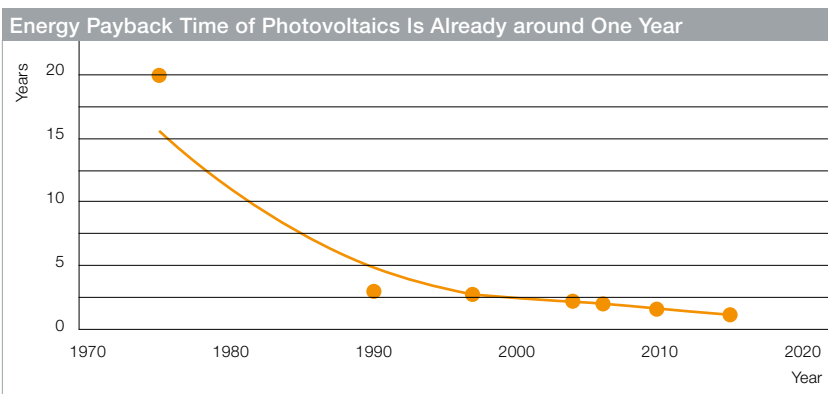
A BUSINESS ON THE RISE: WHY PHOTOVOLTAICS HAVE A BRIGHT FUTURE



Increasing Competitiveness

Solar power is a cost-efficient source of electricity. Photovoltaic system prices of less than 1.0 €/Wp have already been achieved in many regions. Prices less than 0.5 €/Wp will be achievable over the coming years. This causes the levelized cost of electricity (LCOE) to decline, potentially down to 5 ct/kWh in Germany in 2020. Since it depends on solar radiation, the LCOE is also substantially lower in sunnier regions such as California, where photovoltaic systems are already on their way to becoming the cheapest source of electricity today.

The energy payback time of photovoltaic installations in Europe is continually declining and is currently between 0.5 and 1.4 years, depending on the location and type of system used. Moreover, solar modules do not emit any CO₂ during their operation time of 30+ years. Even considering all of the stages in the product life cycle added up (production, installation, recycling, etc.), the carbon footprint of photovoltaics is many times lower than that of fossil fuels (16 to 32 g/kWh for solar, compared to 670 to 1000 g/kWh for coal). So the stage is set for solar electricity to become the world's leading source of electricity within the next few decades.



Most Promising Energy Source

Along with cost competitiveness, stability of supply around the clock is the next big step on the road to solar power becoming the major source of electricity. Energy storage is the key to the broader use of fluctuating renewable energy. Ongoing research and the increasing scale of production will cause the cost of storage systems to decline further, assuring the role of photovoltaics as a decentralized source of energy for millions of households.

Source: SolarPower Europe/EPIA and WACKER analysis



A Bright Future

The combination of efficient solar modules and batteries will boost the spread of electric vehicles, making electromobility an affordable and convenient solution for everyone. Combining photovoltaics and storage solutions will make significant decarbonization possible in the mobility sector.

The overall ecological advantages and the steadily declining cost of photovoltaics will make solar electricity the sustainable energy source of choice for our future.



High-performance lithium-ion batteries with silicon anodes are the best candidate for lowering storage costs. WACKER's R&D facility, the "Consortium für Elektrochemische Industrie," is conducting extensive research in this field. The picture on the left shows a stability test of a lithium-ion battery at WACKER.

YOUR NOTES

Handwriting practice lines consisting of multiple sets of horizontal dotted lines.

EXPERTISE AND SERVICE NETWORK ON FIVE CONTINENTS



WACKER is one of the world's leading and most research-intensive chemical companies, with total sales of €4.6 billion. Products range from silicones, binders and polymer additives for diverse industrial sectors to bioengineered pharmaceutical actives and hyperpure silicon for semiconductor and solar applications. As a technology leader focusing on sustainability, WACKER promotes products and ideas that offer a high value-added potential to ensure that current and future generations enjoy a better quality of life based on energy efficiency and protection of the climate and environment.

Spanning the globe with 4 business divisions, we offer our customers highly-specialized products and comprehensive service via 23 production sites, 18 technical competence centers, 13 WACKER ACADEMY training centers and 48 sales offices in Europe, North and South America, and Asia – including a presence in China. With a workforce of some 13,450, we see ourselves as a reliable innovation partner that develops trailblazing solutions for, and in collaboration with, our customers. We also help them boost their own success. Our technical centers employ local specialists who assist customers world-

wide in the development of products tailored to regional demands, supporting them during every stage of their complex production processes, if required. WACKER e-solutions are online services provided via our customer portal and as integrated process solutions. Our customers and business partners thus benefit from comprehensive information and reliable service to enable projects and orders to be handled fast, reliably and highly efficiently. Visit us anywhere, anytime around the world at: www.wacker.com

The Wacker logo is displayed in a white rectangular box with a black border. The word "WACKER" is written in a bold, black, sans-serif font.

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