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The Who's Who of Solar Silicon Production

Companies, Technologies, Cost, Capacities
Global Perspectives through 2012

Johannes Bernreuter · Frank Haugwitz

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Your Silicon Expert Guide

What customers say about the report

"The Who's Who of Solar Silicon Production" is the most detailed report covering this subject I have seen so far. It provides not only detailed production capacity ramp-up plans of about 100 companies, but also some interesting insights into technological alternatives for solar silicon production.

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Dr. Hubert Aulich
Executive Director, German Operations at PV Crystalox Solar plc

The report provides an excellent overview with many substantial insights into the polysilicon industry. Therefore, we highly recommend it.

Alexander Berg
CEO at Schmid Silicon Technology GmbH

The Who's Who of Solar Silicon Production provides you with a unique source of comprehensive information on 150 companies in the sector – incumbent manufacturers, new entrants and technology developers in the Americas, Europe, Japan, South Korea, China, Taiwan, Russia and the Commonwealth of Independent States, India and the Middle East.

Numerous details from primary research and secondary sources have been condensed in 96 in-depth company profiles and 54 additional project reviews. Two chapters give you valuable insight by analyzing the latest market and technology trends for electronic and solar-grade polysilicon as well as upgraded metallurgical-grade (UMG) silicon.

- Each company profile contains information on the foundation and background of the company, its web site, shareholders, factory location, start of construction and production, reactor suppliers and engineering companies, the amount of investment, production technology, manufactured volumes from 2006 through 2008 (for companies already in production), and capacity forecasts by the end of 2012.
- Companies at an earlier stage – usually during project development – are covered in project reviews that provide the most important data like factory location, planned capacities and start of production.
- Companies that develop new process technologies are a special focus of the report. They are portrayed in a full profile, including a detailed description of the novel production process, based on extensive patent research.
- The market chapter surveys capacity additions across the world regions, analyzes the impact of the international financial crisis, identifies potential winners among the manufacturers, and provides a global supply/demand scenario for the polysilicon / UMG silicon market through 2012.
- The technology chapter examines nine alternatives to the standard Siemens process in terms of technical viability and potential cost. In particular, the prospects of UMG silicon have been thoroughly analyzed.
- The report is supplemented by eight regional maps with company locations and a list of 56 equipment suppliers and engineering companies.

The Who's Who of Solar Silicon Production comprises 174 pages. It is offered for a price of 950 euros at *www.bernreuter.com*, where you will find the table of contents, three profile samples and an order form.

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Executive Summary

The global financial crisis has not only weakened the demand for polysilicon, but also exacerbated the capital-intensive construction of new polysilicon plants. A whole series of projects has been postponed or totally abandoned – in particular in Europe, Russia and India.

In contrast, Chinese aspirants have greatly profited from the stimulus program the country's central government has introduced, encouraging domestic banks to apply a loose lending policy. From the pool of 51 Chinese companies this report covers, we have classified 35 as serious players. They could produce as much as 80,000 metric tons (MT) in 2012, about one third of the global volume of approximately 250,000 MT in our scenario.

Three of the top ten manufacturers in 2012 will come from China. While they are all pursuing a business model of vertical integration across or at both ends of the photovoltaic value chain, the world's top three producers will remain polysilicon specialists embedded in a chemical company: Hemlock Semiconductor Corp. (with Dow Corning Corp. as the majority shareholder) in the USA, Wacker Chemie AG in Germany and OCI Company Ltd. in South Korea.

After manufacturers reacted to the polysilicon shortage in recent years with massive investment in new production capacities, the market tipped to oversupply in 2009, sending the spot price down from its height of $500 / kg to approximately $55/ kg. With upside potential for demand in major PV markets, we expect that further pressure on the spot price might be limited in 2010.

In 2011, however, a major correction on the polysilicon market appears inevitable. The first candidates for consolidation are about 20 manufacturers in China, which had a nominal capacity of only 1,500 MT or even less at the end of 2009. However, as long as the Chinese polysilicon industry does not yet fully cover domestic demand, we do not rule out protectionist measures by the government.

The silicon shortage has also spurred new production technologies. We have screened nine alternative approaches, but none of them will challenge the conventional Siemens process in the short term. In particular, fluidized bed reactor technology has not delivered on its promise of lower manufacturing costs.

While upgraded metallurgical-grade (UMG) silicon has demonstrated such lower costs, its lower purity demands specific processing know-how in ingot, wafer and cell production. So far, only one company has been able to manufacture UMG cells that show the same quality as multicrystalline cells made of conventional polysilicon. Therefore, we see only a marginal role for UMG silicon: a market share of less than 1% through 2012.


Johannes Bernreuter


Frank Haugwitz

About the authors

Johannes Bernreuter, 44, head of Bernreuter Research and lead author of the report. Bernreuter is one of the most reputable photovoltaic journalists in Germany because of his diligent research, clear style and unbiased approach. He has earned several awards, among others the prestigious RWTH Prize for Scientific Journalism from the RWTH Aachen University, one of the nine elite universities in Germany. Originally an associate editor at the monthly photovoltaic magazine *Photon*, Bernreuter authored his first analysis of the upcoming polysilicon bottleneck and alternative production processes as early as 2001. In 2008 he founded Bernreuter Research to publish technology-focused special reports.

Frank Haugwitz, 44, photovoltaics consultant in Beijing and co-author. An industrial mechanic by profession, with a degree in Applied Business Languages (Sinology) and International Business Management, the native German has been working as a long-term expert on photovoltaic and renewable energy projects in China – supported by Germany and the European Union – since the summer of 2002. Due to his extensive and sound knowledge of Asia's photovoltaic development, international news media and photovoltaic associations often refer to Haugwitz as an expert resource. Furthermore, he regularly publishes articles in related magazines like *New Energy* and is frequently invited to speak at conferences. In late 2006 he launched the China Renewable Energy Information web site *(www.frankhaugwitz.info)* as part of his efforts to provide advisory services on market intelligence, government institutions and policies, as well as business development regarding photovoltaics in China.

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Bécancour Silicon, Inc.

Founded in 1976

www.timminco.com

Shareholder: Timminco Limited (100%)

Factory location: Bécancour, Quebec, Canada

Start of construction: August 2007

Start of production: December 2007

Production technology: physical purification of metallurgical-grade silicon

Vol. 2006	Cap. 2006E	Vol. 2007	Cap. 2007E	Vol. 2008	Cap. 2008E	Cap. 2009E	Cap. 2010E	Cap. 2011E	Cap. 2012E
0	300	90	1,200	1,045	6,000	(8,400)	(8,400)	(8,400)	(8,400)

Bécancour Silicon, Inc. manufactures metallurgical-grade silicon with an annual capacity of 50,000 MT as well as upgraded metallurgical-grade (UMG) silicon. The company was established as SKW Electro-Metallurgy Canada Ltd. (later renamed as SKW Canada, Inc.) in 1976 by SKW Trostberg AG (now Evonik Degussa GmbH), then a subsidiary of Viag AG (now Eon AG). In 1999 Viag sold SKW Canada to the US-based private equity firm Safeguard International Fund, L.P., who renamed the company as Bécancour Silicon, Inc. (BSI).

In September 2004 Safeguard sold BSI to Timminco Limited, a producer of specialty metals that is listed on the Toronto Stock Exchange. Safeguard controlled the majority of Timminco's shares via an affiliate at that time. In November 2006 Safeguard created the AMG Advanced Metallurgical Group N.V., who now has an equity interest of 38.7% in Timminco. The mastermind behind all these transactions is Heinz Schimmelbusch, CEO both of Timminco (since 2003) and AMG, as well as a founder of Safeguard. The native Austrian was fired as the CEO of the German conglomerate Metallgesellschaft AG (MG) in 1993 after hazardous bets on oil futures had almost bankrupted MG.

BSI began to develop a process for upgrading silicon metal in 2004. According to patent applications, the company uses a rotary drum furnace with an oxy-fuel burner that applies a 2:1 ratio of oxygen to natural gas to melt the silicon at up to 1,500 °C. The burner creates a slightly oxidizing atmosphere that removes boron from the melt. A slag made of pulverized quartz and soda ash is added to draw out metal impurities. The liquid silicon is poured in a mold and directionally solidified from the open top while an electromagnetic force from a coil below the mold stirs the liquid silicon to prevent impurities from inclusion at the solidification front. When over 50% of the ingot has solidified, it is tapped and the remaining, impurity-enriched liquid poured off. Feeding the furnace with the solid silicon again, BSI makes three passes of the entire process.

In April 2007 Timminco announced it would build three UMG production lines with a capacity of 1,200 MT each, following a 300 MT pilot plant that started in late 2006. In February 2008 the company decided to add nine lines for a total capacity of 14,400 MT by mid-2009. It announced customer contracts with Q-Cells SE, Canadian Solar Inc., Calisolar Inc., Solar Power Industries, Inc. and four anonymous firms. However, the expansion was halted in early 2009 at a capacity of 8,400 MT; sales plunged to 2 MT in the fourth quarter. Consequently, the company suspended the production of UMG silicon. Timminco says in 2008 the average level of boron was 0.8 ppm and of phosphorus 3 ppm (lowest: 0.5 and 1.5 ppm, respectively); in December 2008 the production cost was C$26 (US$21) per kg. In March 2008 the company still projected C$12/kg for 2008, thus provoking a C$520 million class-action by investors in May 2009.

Chongqing Daqo New Energy Co., Ltd.

www.dqsolar.com

Founded in January 2008

Shareholder: Daqo New Energy Corp. (100%)

Factory location: Wanzhou, Chongqing municipality

Start of factory construction: September 2006

Start of production: July 2008

Production technology: modified Siemens process

Reactor supplier: N/A

Engineering companies: Poly Engineering Srl, Evonik Industries AG, Chemical Design, Inc., CDI Corporation

Vol. 2006	Cap. 2006E	Vol. 2007	Cap. 2007E	Vol. 2008	Cap. 2008E	Cap. 2009E	Cap. 2010E	Cap. 2011E	Cap. 2012E
0	0	0	0	291	1,500	3,300	3,300	6,300	9,300

Since rich silicon ore resources are available in Yungang Country estimated at a magnitude of 50 million metric tons, Daqo Group Co., Ltd. *(http://en.daqo.com)* decided in 2006 to set up a polysilicon plant in the Wanzhou Salt Chemical Industry Park near Chongqing. The group was established in 1965 and is based in Zhenjiang, Jiangsu province. The sale of power distribution equipment and electrical supplies generates annual revenues of approx. $90 million.

In September 2006 Daqo celebrated the groundbreaking ceremony for the polysilicon plant which should have an initial capacity of 3,300 MT (phase 1). The company has conducted technical cooperation with Poly Engineering Srl, Evonik Industries AG, Chemical Design, Inc. and CDI Corp. Originally, it intended to reach a capacity of 15,300 MT by the end of 2012; now it is targeting 9,300 MT by March 2012. For the first two phases (6,300 MT), Daqo has earmarked approx. $580 million. The plant is equipped with an automatic, closed-loop facility to ensure environmentally friendly production.

In July 2008 the first 1,500 MT production unit started pilot production. In August 2008 polysilicon samples were sent to potential customers like Suntech Power, Solarfun, Yingli, and Renesola to obtain feedback concerning the quality. Purity is at 9N. The second unit with a capacity of 1,800 MT was commissioned in late June 2009. The electricity input required to produce 1 kg was 150 kWh in 2008, but the target is to reduce it to 110 kWh/kg by 2011. Located close to hydropower from the Three Gorges Dam, Daqo pays only 5.8 $Ct/kWh.

As early as October 2007, Daqo New Material Co., Ltd. – the predecessor of Chongqing Daqo New Energy Co., Ltd. – signed a supply contract with Renesola. The quantity to be delivered amounts to 1,950 to 2,000 MT between 2008 and 2012. In March 2008 Daqo concluded another contract with Suntech Power Co., Ltd., for a volume of 6,850 to 7,350 MT from 2008 through 2013.

In May 2008 Chongqing Daqo (formerly known as Chongqing Sailing New Energy Co., Ltd.) signed an agreement with Yingli Green Energy Holding Co., Ltd. to deliver 1,050 to 1,350 MT from the fourth quarter of 2008 until the end of 2010. Currently, Daqo is negotiating with a leading US solar power company about a polysilicon supply contract.

In late January 2010 Chongqing Daqo's parent company, Daqo New Energy Corp., postponed an IPO on the New York Stock Exchange. After the offering, Daqo Group's shareholders would have owned 59.27% of Daqo New Energy.

New Japan Solar Silicon, Inc.

Founded in June 2008

www.chisso.co.jp/english
www.shinnikko-hd.co.jp/english
www.toho-titanium.co.jp/en

Shareholders: Chisso Corp. (50 %)
Nippon Mining Holdings, Inc. (30 %)
Toho Titanium Co., Ltd. (20 %)

Factory location: Kamisu, Ibaraki prefecture, Japan

Start of construction: March 2009

Start of production: Q4 2010

Production technology: reduction of silicon tetrachloride with zinc vapor

Reactor supplier: N/A

Engineering company: N/A

Vol. 2006	Cap. 2006E	Vol. 2007	Cap. 2007E	Vol. 2008	Cap. 2008E	Cap. 2009E	Cap. 2010E	Cap. 2011E	Cap. 2012E
0	0	0	0	0	0	0	660	1,500	3,000

Chisso Corporation, whose predecessor was founded in 1906, is one of the leading chemical groups in Japan. It manufactures a wide range of products from fertilizers to organic chemicals and silicones to liquid crystals. In 2002 the company started a research project at its Minamata Research Center to obtain solar-grade silicon by reducing silicon tetrachloride ($SiCl_4$) with zinc vapor.

The by-product zinc chloride ($ZnCl_2$) is separated by electrolysis into zinc and chlorine. The latter is mixed with hydrogen to create hydrogen chloride (HCl), which reacts with metallurgical-grade silicon – the same method that is applied in the Siemens process to receive trichlorosilane. If the temperature at the reaction is higher, however, one can obtain more $SiCl_4$. New patents filed by Chisso in 2007 describe a potential variation: $ZnCl_2$ is not separated into zinc and chlorine by expensive electrolysis, but reduced by hydrogen to obtain zinc and HCl.

When the $SiCl_4$ is reduced by zinc vapor at approx. 950 °C, silicon grows in a tube-like shape downward from the $SiCl_4$ supply nozzles at the top of the reactor. The small silicon tubes fall down to the bottom and are continuously removed from the reactor. $SiCl_4$ promises a higher silicon yield than trichlorosilane, and unreacted $SiCl_4$ can be easily reused. The silicon purity is 8N to 9N.

The Japanese New Energy and Industrial Technology Development Organisation (NEDO) supported the project until early 2006. In December 2006 Chisso agreed with Nippon Mining Holdings, Inc. and its subsidiary Toho Titanium Co., Ltd. to establish a joint venture, Japan Solar Silicon Co., Ltd. (JSS). The aim was to construct pilot plants for the production of polysilicon at Chisso's Minamata factory and for the electrolysis of $ZnCl_2$ at Toho Titanium's Chigasaki plant. A unit for analytical techniques was set up at the administration center of Nippon Mining's subsidiary Japan Energy in Toda.

In May 2008 the three partners announced another joint venture, New Japan Solar Silicon, Inc. (NJSS), to invest approx. $240 million in a 3,000 MT factory within the Kashima Okunoyahama industrial complex in Kamisu, Ibaraki prefecture. Ground was broken in March 2009. The plant is supposed to start production in late 2010. Originally, an initial capacity of 400 MT was foreseen. In May 2009, however, the partners announced the starting capacity would be raised to 660 MT, due to strong demand from potential customers. NJSS wants to reach the nominal capacity of 3,000 MT in 2012, and 4,500 MT in 2013. In the longer term, the company will strive for an annual capacity of 10,000 MT.

What customers say about the report

The Who's Who of Solar Silicon Production *is the most detailed report covering this subject I have seen so far. It provides not only detailed production capacity ramp-up plans of about 100 companies, but also some interesting insights into technological alternatives for solar silicon production.*

Dr. Christian Reufer
PV Market Analyst at Evonik Industries AG

This is an excellent resource for companies and consultants alike. It provides critical insight and details on both established players and newcomers to the industry as well as profiles and reviews on technology not found elsewhere.

Keith Landry
Vice President, Renewable Energy at CH2M HILL

Altogether, I find the way you have presented the companies and how you have examined the diverse technologies short, succinct as well as precisely summarized and elaborated. What I also like is the presentation of the companies' future development. What would be especially important to us is a more comprehensive consideration of current production and its prospective development, along with a corresponding assessment of volumes. I like the study very much and overall it is a job well done.

Dr. Hubert Aulich
Executive Director, German Operations at PV Crystalox Solar plc

It's surprising how the enormous data and even the widely accepted rumors could be collected and analyzed reliably. More surprising is Bernreuter's expertise in extracting explicit and quantitative essences from them.

Dr. Hee Young Kim
Principal Research Engineer at the Korea Research Institute of Chemical Technology

The report provides an excellent overview with many substantial insights into the polysilicon industry. Therefore, we highly recommend it. There are a few conclusions in benchmarking the different technologies that we view critically because some of the data for energy consumption and the resulting production costs are not comparable. A preferable model would be the Real Cost-of-Ownership calculation. We would be glad to provide our data for the next report as well.

Alexander Berg
Former CEO of Schmid Silicon Technology GmbH

The Who's Who of Solar Silicon Production *is one of the most comprehensive and informative reviews of the current state of the polysilicon market. It provides a detailed snapshot of the sector players and technology advances. A very handy reference source.*

Svetlana Symonenko
Analyst at Nitol Solar Ltd.

The Who's Who of Solar Silicon Production *is the most accurate and comprehensive polysilicon report we've found available in the market. It is a must read if you are looking to establish a fundamental understanding of the current state of the polysilicon industry.*

Chad Fero
Director of Business Development at GT Advanced Technologies Inc.

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