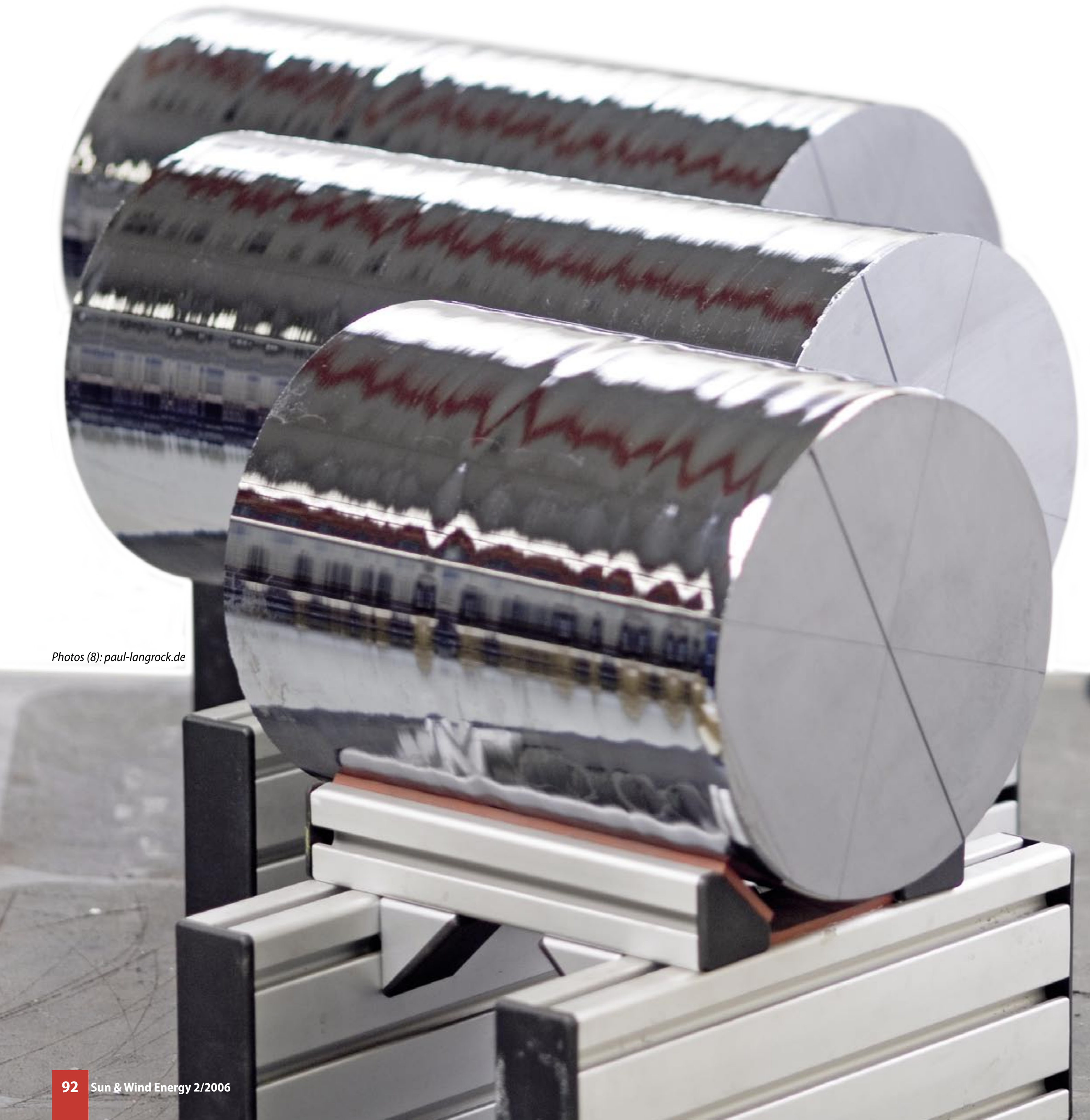
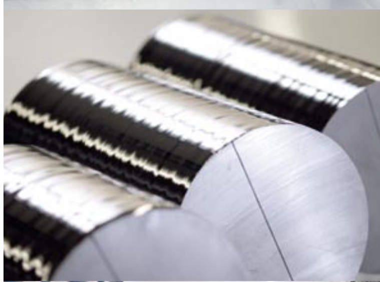
Full steam ahead

The polysilicon market is expected to be tight again next year. Certainly from 2008 production capacities will grow significantly, not least due to a whole series of new entrants. By 2010, supply could already be sufficient for a solar cell production of 12 GW_p.



Photos (8): paul-langrock.de



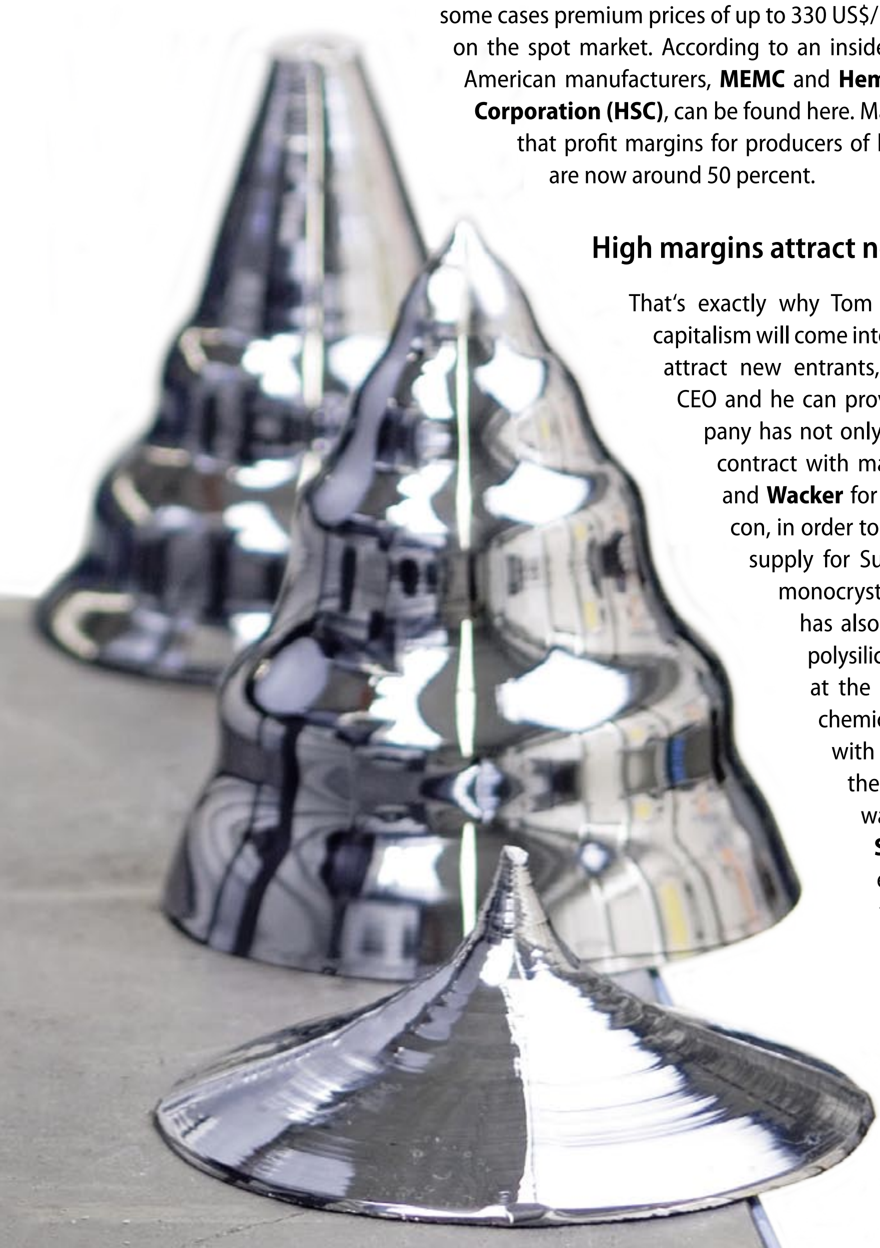





from 2008

Tom Werner is not particularly worried about the shortage of silicon. The CEO of **Sunpower Corporation** can afford to be relaxed as the company only needs less than 8 g of silicon per W_p to manufacture its high-performance solar cells in the Philippines; the second generation cells, whose production will begin at the end of 2006, will only need 7 g/W_p. On average, the competition currently requires 10 to 11 g/W_p. But Werner isn't panicking for another reason: »Capitalism will work,« he says quite relaxed from the company's headquarters in San Jose, California.

Since feed-in tariffs in Germany were amended in 2004 and demand for solar power systems rocketed, making up half the global market, the price of solar grade silicon has shot up with equal rapidity. In 2003 before the big boom, average prices according to the Sun Screen study carried out by the investment consulting company, Credit Lyonnais Securities Asia (CLSA), were still at 24 US$/kg. Industry experts are now reporting a price of between 50 to 80 US$/kg in long-term contracts up to ten years, that is twice or three times as much. In some cases premium prices of up to 330 US$/kg are even being paid on the spot market. According to an insider, materials from two American manufacturers, **MEMC** and **Hemlock Semiconductor Corporation (HSC)**, can be found here. Market observers reckon that profit margins for producers of high-purity polysilicon are now around 50 percent.



High margins attract new entrants

That's exactly why Tom Werner believes that capitalism will come into effect. »High margins attract new entrants,« says the Sunpower CEO and he can prove it as well. His company has not only concluded a ten-year contract with market-leaders Hemlock and **Wacker** for the supply of polysilicon, in order to ensure replenishment supply for Sunpower's suppliers of monocrystalline silicon ingots. It has also supported setting up polysilicon production facilities at the leading South Korean chemical group, DC Chemical, with pre-payments, and at the Japanese ingot and wafer manufacturer, **M. Setek**, by extending an existing supply contract from 2008 to 2010.

According to a reliable industry source, M.Setek intends to enter the market in mid 2007 with an annual

The standard process: In so called Siemens reactors, silicon separates from trichlorosilane or silane, as here at the REC daughter company Advanced Silicon Materials in Butte (Montana) – on thin rods made out of high-purity silicon, which are electrically heated to over 1,000 °C.

Photo: Renewable Energy Corporation

capacity of 500 metric tons (MT) of polysilicon and wants to extend this to 3,000 MT within three years. These quantities will be processed exclusively in-house. No details were available about the manufacturing process, but Dharmappa Barki, managing director of the Indian solar lamp manufacturer, Noble Energy Solar Technologies, does say that he is working with M.Setek on a process using high-purity quartz as a source material. In the south-eastern state of Andhra Pradesh, he has a permit to mine quartz reserves of 40 million MT.

The South Korean new entrant, **DC Chemical**, is also not giving anything away about its manufacturing process. But certainly it will be similar to the classical Siemens process, in which high-purity silicon is extracted from highly volatile liquid trichlorosilane and deposited on slim rods heated to over 1,000 °C. Sunpower has announced that DC Chemical has expertise producing gases used in polysilicon manufacturing. The South Korean chemical giant wants to start off with a capacity of 3,000 MT at its Gunsan location in the first half of 2008.

In addition, Sunpower has invested in a research company which has developed a new process for manufacturing polysilicon. Sunpower spokesperson and vice president of external affairs, Julie Blunden, wouldn't give any details or names, but did say, »There is currently no project with a realisation probability of 80 %; but if it is successful this would bring a real improvement and cost reduction.«

New entrants from Hawaii and Canada

In contrast, a rather exotic new entrant, **Hoku Scientific**, from Kapolei on Hawaii, will use the traditional Siemens process. Up to now the company has produced membranes and membrane electrode assemblies for fuel cells and now wants to establish a second pillar in the photovoltaic market. They plan to produce solar modules with an initial output of 30 MW_p, beginning in the second half of 2007 and to set up polysilicon production with an annual capacity of 1,500 MT in Singapore.

Hoku has obviously found partners there because when asked about reasons for the choice of location, Scott Paul, Vice President of Business Development, said that by answering the question he would be entering ›confidential territory‹. Silicon production should begin in the second half of 2008, initiated by its new subsidiary, Hoku Materials – provided that all the technical and financial issues have been solved in accordance with the proposed schedule. Hoku will cover the US$ 250 million investment with loans and pre-payments from customers.

In Canada, a small technology company is also making the giant leap to silicon production. To date, **Arise Technologies** in Kitchener near Toronto has earned its revenue primarily as a wholesaler and installer of PV systems but has developed, together with researchers at the University of Toronto, a solar cell with a so-called heterojunction between monocrystalline and amor-

phous silicon which promises an efficiency of over 18 %. In order to tackle the raw material problem, the company has been testing a new silicon production process in two laboratories since the beginning of 2006. The basis for this new process is the pre-treatment of quartz before it is reduced to metallurgical grade silicon and a more cost-effective process for producing trichlorosilane, which is traditionally created by combining metallurgical grade silicon with hydrogen chloride. Whether the trichlorosilane is deposited to silicon as rods or as granules is not yet known.

A consortium, of which the Danish monocrystal ingot and wafer manufacturer, **Topsil**, is also a part, has paid 13.3 million Canadian $ (US$ 11.7 million) to set up a pilot production plant; Sustainable Development Technology Canada, a Canadian government foundation for the promotion of clean technologies, has also put up 6.5 million Canadian $ (US$ 5.7 million). The location of the plant, which should start operating in 2008, is the research and technology park of the University of Waterloo. By the end of 2009, Arise CEO, Ian MacLellan, intends to establish commercial production with an annual capacity of 2,000 MT. To this end, the Canadian Provinces of Quebec, Manitoba and British Columbia can provide cheap electricity from hydroelectric power. MacLellan sees no problems financing the factory: Arise Technologies is a listed company and there are enough interested investors, he says.

Table 1: Polysilicon capacities and project announcements in China. A whole series of silicon plants is to be constructed in China. Just how realistic the ambitious plans are is still hard to say at the moment.

Sources: Piper Jaffray, Asia Pulse, People's Daily Online, ITI Energy, China Security Newspaper, Chen Liang, Shanghai Daily, China Business News Online, Global Executive Forum

Company	Location	Province	First phase	Second phase
Emei Semiconductor Materials	Emeishan	Sichuan	100 MT in 2005	220 MT/year
China Silicon High-Tech Co. Ltd.	Luoyang	Henan	300 MT in 2005	3,000 MT/year
Sichuan Xingguang Silicon Technology Co. Ltd.	Leshan	Sichuan	1,000 MT in 2007	3,000 MT/year
Ningxia Sunshine Silicon	Shizuishan	Ningxia Hui *)	1,000 MT/year	4,000 MT/year
CSG Holding Co. Ltd.	Yichang	Hubei	1,500 MT/year	4,500 - 5,000 MT/y.
Yunnan Qujing Aixingui Ltd.	Qujing	Yunnan	3,000 MT in 2008	10,000 MT in 2010
Suntech Power Co. Ltd.	Wanzhou	Chongqing **)	3,000 MT/year	6,000 MT/year

*) Autonomous region **) Centrally administered municipality

Chemical cleaning: The highly volatile liquid trichlorosilane, produced by combining ground metallurgical grade silicon and hydrogen chloride, is being filtered from contaminants in house-high distillation columns like those here at the Wacker facilities in Burghausen. The purified trichlorosilane then serves as a source material for polysilicon.

Photo: Wacker Chemie

Game of large numbers in China

The Spanish cell and module manufacturer **Isofotón** also wants to break away from the large polysilicon producers. At the beginning of July, a consultant from the Andalusian Office for Innovation, Science and Business announced that Isofotón, the utility Endesa and the Andalusian authorities agreed to set up a € 250 million polysilicon factory with an annual capacity of 2,500 MT. According to Isofotón spokesperson, Lucia Sainz, the factory will be built in Los Barrios in the Andalusian Province of Cadiz and should be in operation by 2009. The German cell manufacturer, Sunways, is also planning to start silicon production.

Independently of the project in Andalusia, the Spanish research consortium Centesil, in which Isofotón is also participating, wants to develop a new production process which is a modification of the classic Siemens process. Initiated by Antonio Luque, head of the Institute for Solar Energy at the Polytechnic University of Madrid, a pilot system with an annual capacity of 50 MT should be set up by the end of 2009 on the University campus.

No less than half a dozen new projects have been announced in China in the past few months, most with a capacity of 3,000 MT and more (see table 1). However, more detailed information and schedules could not be obtained from the companies involved. Chen Liang, a journalist working for the China Security Newspaper, also says it is very difficult to confirm the figures announced. Liang is sceptical as to whether the companies will be able to get hold of western production technology.

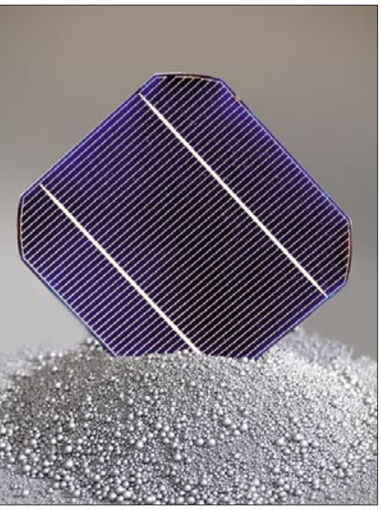
Two Chinese companies, **Emei Semiconductor Materials** in Emeishan (Sichuan Province) and **China Silicon High-Tech** in Luoyang (Henan Province), currently manufacture small amounts of polysilicon. Liang believes that the technology available in China is not exactly the best. Alexander Lebedev, head of Swiss Wafers AG, confirms this: »We cannot use this material.« Estimates of the total capacity that will actually be achieved by 2010 differ. Deren Yang, a professor at the laboratory for silicon materials at the University of Zhejiang in Hangzhou, reckons it could be 5,000 MT; Cui Rong Qiang, head of the Institute for Solar Energy at the University of Shanghai Jiao Tong expects 10,000 MT.

There is more precise news from Russia: Already in December, the state **mining-chemical combine** intends starting production of polysilicon at the former Soviet Union's plutonium production site in Siberian Zheleznogorsk near Krasnoyarsk and should achieve a capacity of 1,000 MT/year by 2009. This was reported by Andrey Tretyakov, project manager at the Moscow office of US consulting firm, Solarius Technologies. About 900 km further south-east in Usolye-Sibirskoye near Irkutsk on Lake Baikal, the Russian Nitol Group, which specialises in chlorine chemistry, will go into production in December 2007 and should also reach a capacity of 1,000 MT by 2010. And in Abakan, 300 km south of Krasnoyarsk, the firm **Russian Silicium** intends manufacturing 2,000 MT annually from 2009, according to managing director Alexander Suponenko. Russian Silicium is a branch of the Basic Element Group which is one of the largest producers of aluminium in Russia. All three production plants will work with the Siemens process.

Market leaders on major expansion course

The large, established silicon producers have now realised that the photovoltaic industry is growing into their most important customer. By 2007 at the latest, silicon consumption in the solar sector will exceed that of the semiconductor industry for the first time. Accordingly, the silicon producers are now beginning to bolster their

Company	Country	Location	Feed material	Process	Current project phase	Annual capacity
REC Silicon	USA	Moses Lake	silane	fluidised bed reactor	pilot plant	200 MT
Joint Solar Silicon	Germany	Rheinfelden	silane	pyrolysis in tube reactor	pilot plant	100 MT
Wacker Polysilicon	Germany	Burghausen	trichlorosilane	fluidised bed reactor	2 pilot reactors	2 x 50 MT
Hemlock Semicon.	USA	Hemlock	trichlorosilane	fluidised bed reactor	pilot plant	30 MT
Tokuyama	Japan	Tokuyama	trichlorosilane	vapor to liquid deposition	semi-commercial plant	200 MT
Chisso	Japan	Minamata	silicon tetrachloride	reduction with zinc vapor	lab and pilot stage	n/a
City Solar Technol.	Germany	Wolfen	silicon tetrachloride	plasma reactor and pyrolysis	pilot plant	n/a
Arise Technologies	Canada	Ontario	trichlorosilane	proprietary	lab scale	n/a
Centesil	Spain	Madrid	metallurg. grade silicon	Siemens related	planning	–
JFE Steel	Japan	Kurashiki	metallurg. grade silicon	metallurgical purification	commercial plant	100 MT
Elkem Solar	Norway	n/a	metallurg. grade silicon	slagging/etching/refining	pilot plant	100 - 250 MT
Apollon Solar, PEM/ Ferroatlantica	France	Bourget du Lac	metallurg. grade silicon	plasma purification	pilot equipment	200 MT
Scheuten Solar	Netherlands	Venlo	metallurg. grade silicon	direct refinement	pilot plant	100 MT
GT Equipment	USA	Merrimack	metallurg. grade silicon	refining in molten stage	lab scale	n/a
Solsilc Development Company	Norway	Trondheim	quartz and carbon	arc furnace and proprietary	lab for downstream steps, towards pilot for upstream	50 MT
Girasolar	Netherlands	Deventer	n/a	electrolysis	lab scale going to pilot	n/a



Highly sought after raw material: In order to produce silicon ribbons using the EFG or string ribbon method, silicon granules made in fluidised bed reactors from trichlorosilane or silane are required.

Photo: Wacker Chemie

plans for expansion. In January, **Wacker Chemie** confirmed in a press release that they would implement plans made in the previous year to expand their capacity at Burghausen from 5,500 to 9,000 MT by the end of 2007. Then, at the end of June, they announced plans to expand production by the end of 2009 to 14,500 MT/year. By the beginning of 2008, capacity should reach 10,000 MT instead of the originally targeted 9,000 MT by optimising processes.

CEO Peter-Alexander Wacker said of the plans, »we are currently the world's second largest producer of polysilicon and are aiming to become market leaders in this sector«. But Wacker won't be able to achieve this so easily as market leader Hemlock also has ambitious expansion plans – from 7,700 MT at the end of 2005 to 19,500 MT by the end of 2009. In addition, Hemlock has started the search for a potential second manufacturing site and would like to have the new facility operational within the next five years.

The world's number three, **REC Silicon**, is also planning a large step forward. In 2005 the silicon branch of the Renewable Energy Corporation (REC) from Norway produced 5,300 MT through subsidiaries, Solar Grade Silicon in Moses Lake (US State of Washington) and Advanced Silicon Materials in Butte (Montana). After gradual increases, a US$ 600 million plant with a capacity of 6,500 MT will be built in Moses Lake in 2008. It will be based on fluidised bed technology which Solar Grade Silicon has been successfully testing at a pilot plant since December 2004 (see table 2). Here the silicon precipitates from silane, flowing in from the bottom of the reactor, onto tiny seed particles of silicon, which grow into larger grains before falling on the ground of the reactor; they are then extracted as granules. The new plant will allow REC to more than double its capacity to an estimated 12,800 MT.

MEMC is also looking to double production by 2008, albeit at a somewhat lower level – from 4,000 to 8,000 MT. Capacity at both the Siemens reactors in Merano, Italy and at the fluidised bed reactors in Pasadena (Texas) will be increased – to what degree has not yet been figured out, said Bill Michalek, Director of Investor Relations.

New deposition processes have their risks

Expansion figures from Hemlock and Wacker, however, are based exclusively on classic Siemens technology, although both manufacturers operate pilot reactors with fluidised bed technology – Wacker has been doing so since October 2004 and Hemlock only since last June. In contrast to REC and MEMC, the source material is not silane but trichlorosilane and it seems to have its risks. »It is a very demanding process,« says Wacker spokesman Florian Degenhart. In the previous year, the company planned to set up a production reactor at the beginning of 2007 with an annual capacity of 500 MT, but they are no longer as willing to commit themselves to a concrete target. »The current situation is that large scale is still being tested«, explains Degenhart. But he emphasises that there »can be no question« of dropping the technology.

When Hitoshi Takashi, product and market specialist at Hemlock, talks about fluidised bed technology, he sounds less assured than he did eighteen months ago. »We don't see many cost advantages,« says Takahashi. The technology requires a very high initial capital, he argues. This will »definitely offset a part of the cost savings« that would be achieved through continuous operation and lower energy consumption. In order to produce granules profitably it is necessary to minimise the

Start	Production target	Planned start	Homepage
December 2004	6,500 MT/year	3rd quarter 2008	*www.recgroup.com*
2nd quarter 2005	850 MT/year	2008	*www.js-silicon.de*
October 2004	n/a	n/a	*www.wacker.com*
June 2006	n/a	n/a	*www.hscpoly.com*
1st quarter 2007	n/a	n/a	*www.tokuyama.co.jp/eng*
early 2004	n/a	n/a	*www.chisso.co.jp/english*
July 2006	2,500 MT/year	2008	*www.city-solar-ag.com*
early 2006	2,000 MT/year	late 2009	*www.arisetech.com*
May 2006	50 MT/year (pilot)	4th quarter 2009	*www.ies.upm.es*
October 2006	500 - 1,000 MT/year	fiscal year 2007	*www.jfe-steel.co.jp/en*
late summer 2005	5,000 MT/year	2008	*www.elkem.com*
September 2006	n/a	n/a	*www.apollonsolar.com, www.foundrysolution.com*
late 2006	1,000 MT/year	1st quarter 2008	*www.scheutensolar.com*
2004	n/a	n/a	*www.gtequipment.com*
2000 (lab scale)	> 100 MT/year (pilot)	2007	*www.ecn.nl/en/zon/rd-programme/ silicon-photovoltaics/ siliconmaterials*
early 2006	n/a	n/a	*www.girasolar.com*

Table 2: Development status of alternative manufacturing processes

Source: manufacturers' information

formation of silicon powder. »If there is any cost advantage, it's not so big as Wacker originally stated.« At the first solar silicon conference in 2004 in Munich, Karl Hesse, head of process development at Wacker Polysilicon in Burghausen, announced that with the fluidised bed reactor, costs can be reduced by 10 % compared to the leaner version of the Siemens process for producing solar grade silicon.

The Japanese producer, **Tokuyama**, is also making slow progress with its alternative process called Vapor to Liquid Deposition (VLD). Here, trichlorosilane is fed from above into a graphite tube heated to 1,500 °C. The silicon precipitates from the trichlorosilane and is deposited on the tube wall as a liquid, which then drops to the floor of the reactor and solidifies into granules. Originally, a semi-commercial plant producing 200 MT/year was supposed to go into operation at the end of 2005, but now the go-ahead is planned for the first quarter of 2007. Project manager Hiroyuki Oda explains the delay by saying, »we still have so many problems that need to be solved in detail«.

Tokuyama has been holding back with its expansion plans and obviously been focussing fully on its VLD process. In view of the technological difficulties, the chemical group is now employing a dual strategy: According to Oda, plans to expand the Siemens reactors are being made in parallel to the VLD project, in order to save time. By the end of 2006, the board members will finally decide which option to take. If they go for the Siemens process, »we have to make an effort for optimising the VLD process using this semi-commercial plant,« Oda says. »It may take about one more year.«

A similar scenario is developing at the Japanese chemical group, **Chisso Corporation**. The research project for obtaining solar grade silicon by reducing silicon tetrachloride with zinc vapour, which began in 2002

Table 3: End-of-year capacities for polysilicon (in metric tons). Alongside freshly produced polysilicon, the photovoltaic industry can fall back on off-spec silicon from the semiconductor sector. In addition to this off-spec silicon, the figures from 2004 and 2005 contain further quantities of polysilicon, which the semiconductor companies sell on from their stocks to the solar industry because of the high market price.

Sources: manufacturers' instructions, Cui Rong Qiang, own assumptions (numbers in brackets), Deutsche Solar AG (demand electronics, off-spec silicon)

Year	2004	2005	2006	2007	2008	2009	2010
Incumbent manufacturers							
Hemlock Semiconductor	7,000	7,700	10,000	10,500	14,500	19,500	19,500
Wacker Polysilicon	5,000	5,500	6,500	10,000	(11,000)	14,500	(15,000)
REC Silicon	4,900	5,300	5,800	(6,300)	12,800	(12,800)	(12,800)
Tokuyama	4,800	5,200	5,200	5,200	5,200	5,200	5,200
MEMC Electronic Materials	3,800	4,000	4,400	(5,000)	8,000	(8,000)	(8,000)
Mitsubishi Materials (J)	1,600	1,600	1,600	1,600	1,600	1,600	1,600
Mitsubishi Polysilicon (US)	1,150	1,300	1,300	1,450	1,600	1,600	2,600*)
Sumitomo Titanium	800	900	900	1,300	1,300	1,300	1,300
Subtotal	**29,050**	**31,500**	**35,700**	**41,350**	**56,000**	**64,500**	**66,000**
New entrants							
Elkem Solar	–	–	–	–	5,000	5,000	10,000
Dow Corning			1,000	(2,000)	(5,000)	(5,000)	(5,000)
Solarvalue Production				2,600	5,000	(5,000)	(5,000)
DC Chemical	–	–	–	–	3,000	3,000	3,000
M.Setek	–	–	–	500	(1,000)	(1,500)	3,000
Econcern/PPT/Norsun					2,500	(2,500)	(2,500)
City Solar Technologie					2,500	(2,500)	(2,500)
Isofotón/Endesa	–	–	–	–	–	2,500	(2,500)
Arise Technologies	–	–	–	–	–	2,000	2,000
Russian Silicium	–	–	–	–	–	2,000	2,000
Hoku Materials	–	–	–	–	1,500	(1,500)	(1,500)
Scheuten Solar	–	–	–	–	1,000	> 1,000	> 1,000
JFE Steel	-	–	100	(500)	(700)	(1,000)	(1,000)
Mining-Chemical Combine	–	–	–	200	500	1,000	1,000
Nitol Group	–	–	–	–	200	500	1,000
Joint Solar Silicon	–	–	–	–	850	(> 850)	(> 850)
Total China	**70**	**400**	**400**	**1,400**	**3,000**	**(6,000)**	**10,000**
Subtotal	**70**	**400**	**1,500**	**7,200**	**31,750**	**43,000**	**54,000**
Total	**29,100**	**31,900**	**37,200**	**48,550**	**87,750**	**107,500**	**120,000**
Demand electronics	18,500	19,500	20,400	21,400	22,500	23,600	24,700
Polysilicon for PV	10,600	12,400	16,800	27,150	65,250	83,900	95,300
Plus off-spec silicon	3,700	3,900	2,050	2,150	2,250	2,350	2,500
Total silicon for PV	**14,300**	**16,300**	**18,850**	**29,300**	**67,500**	**86,250**	**97,800**

*) Possible but not announced yet

Demanding process: Wacker Polysilicon is operating two fluidised bed pilot reactors for granulated silicon in Burghausen, Germany. The date of construction for a large production reactor is not yet fixed.

Photo: Wacker Chemie

and was financially supported by the New Energy and Industrial Technology Development Organisation (NEDO), officially ended at the beginning of 2006, and Katsumi Kumahara, Manager at the group's Research and Development Division in Tokyo, says that the company has achieved its production-cost targets. But development remains at the laboratory and pilot stages. »As soon as we complete the production technologies, we will move to the commercial production,« says Kumahara, »but the schedule for market entry is still unknown.«

In contrast, **Joint Solar Silicon (JSSI)**, a joint venture founded in 2003 between the German chemical group, Degussa, and Solarworld AG, has decided to construct a production plant with an annual capacity of 850 MT. The plant will be located at Degussa in Rheinfelden and should be finished in 2008 and not, as originally planned, in 2007. To date, JSSI has been obtaining silicon powder from the decomposition of silane in a pilot-scale tube reactor heated to 800 °C. The powder is then mechanically compressed into little rods or pillows.

Boost for metallurgical processes

While most chemical alternatives for producing solar grade silicon are experiencing difficulties with upscaling, there are signs of an upturn for metallurgical processes. The Norwegian pioneer, **Elkem Solar**, a business division of the world's largest producer of metallurgical grade silicon, has been operating a pilot plant since last autumn and wants to start with an annual capacity of 5,000 MT by 2008. Firstly, scoriae are added to liquid metallurgical grade silicon in order to bind the impurities. Once it has rapidly solidified into chunks, it is treated with acids to remove the scoriae and other contaminants. In the third stage, the silicon is melted down once again so that the remaining impurities are precipitated out. Because the production plant initially needs to be broken in, output might reach 3,000 MT in 2008, said Christian Dethloff, head of Elkem Solar. By 2011, they could have a capacity of 10,000 MT.

New start in Siberia: In Zheleznogorsk, the former Soviet Union's plutonium production plant, the state mining-chemical combine intends to start producing polysilicon using the classic Siemens process.

Photo: Silicon programme

In view of the high silicon prices, the Japanese manufacturer of multicrystalline ingots and wafers, **JFE Steel**, has resuscitated a metallurgical process which the company had developed until 2001 with support from NEDO. Here, metallurgical grade silicon is melted through electron beam guns in order to remove phosphorous. After having solidified, the silicon is broken and further purified before it is remelted with a plasma torch to get the boron out. In October, a »commercial plant« with a capacity of 100 MT/year would start, JFE Steel reported in a press release of late July. The material is only made for in-house consumption. In fiscal year 2007, the production will be upscaled to a volume between 500 and 1,000 MT.

Still longer a history has the process that the German company Solarvalue is going to apply in a metallurgical plant in Slovenian Ruše. The four-step metallurgical refining sequence had been developed by scientists at Solarex (now BP Solar) already back in the eighties. By the end of 2007, Solarvalue wants to reach a capacity of 13,300 MT of metallurgical grade silicon, 20 % of which (2,600 MT) can be used for the refining of solar grade silicon. In 2008, the capacity for solar grade material should increase to 5,000 MT.

Another aspirant will probably find out this year if its entry into solar grade silicon production is worth it. According to the latest information, **Pechiney Electrométallurgie (PEM)**, a producer of metallurgical grade silicon and additives for ferroalloys, such as ferrosilicon, and the French research company, **Apollon Solar**, wanted to start a pilot plant in September with a capacity of 200 MT/year in Bourget du Lac, near Chambery. PEM was sold on to the Spanish ferroalloy producer and electricity provider, Ferroatlántica, in spring 2005 after the Pechiney Group had been taken over by Canadian aluminium manufacturer, Alcan.

In the pilot project, liquid metallurgical grade silicon is purified largely through reactive gases which are positioned on the crucible with a plasma torch. »About the process itself, we are quite confident,« says Robert de Franclieu, general manager of Apollon Solar. »The question is whether or not it is economical.« He will find out by the end of the year.

The metallurgical approach now seems so attractive that even the solar division of the Dutch glass group, **Scheuten**, is looking to start its own silicon production using this method. The concept originated from the management consultancy, Solmic, founded by Albrecht Mozer, former board member of Wacker's wafer subsidiary, Siltronic, and Peter Fath, former provisional head of the Chair for Applied Solid State Physics at the University of Constance, in August 2005.

According to Fath, impurities are outgassed in a way similar to the Apollon Solar process, and scoriae are added to the liquid silicon. This melt is then rapidly cooled from several directions so that the impurities in the silicon, in contrast to the usual directional solidification, are not transferred from the lower to the upper side of the crucible, but to several external sides. Fath assumes that the solidified silicon then needs to be broken up again into chunks, treated with acids and then remelted. If the metallurgical grade silicon is well purified in advance, this step will be unnecessary. A pilot plant with two furnaces each producing 50 MT/year should start operating by the end of this year at Scheuten Solar's research laboratory in Venlo. By the first quarter of 2008, managing director Frans van den Heuvel wants to set up industrial production with an annual capacity of 1,000 MT.

Increased demand for high-purity quartz

The American chemical group, **Dow Corning**, which holds a 63.25 % stake in Hemlock Semiconductor, has also working on a metallurgical process for producing solar grade silicon. The company refuses to issue any details about it; however, we can glean some individual features from their job advertisements. Dow Corning obviously intends to use high-purity carbon from biomass as a reductant for the production of metallurgical grade silicon. This is obtained from quartz using a so-called carbothermic reduction in electric arc furnaces with electrodes made of carbon. Dharmappa Barki, owner of high-purity quartz reserves in India, has reported that Dow Corning has already received material from him. This would indicate that the company is producing high-grade metallurgical silicon from very pure source materials. Production started with a capacity of 1,000 MT at Dow Corning's refurbished old silicon plant in Santos Dumont, Brazil, in early August.

A consortium made up of the Dutch project developer, Sunergy Investco, the Energy Research Centre of the Netherlands (ECN), the Norwegian research company Sintef and the Swedish firm, Scanarc Plasma Technologies, which has since transformed into the Solsilc Development Company, has also been looking for a direct method of producing solar grade silicon from high-purity quartz and carbon since 2000. The start of pilot production is still planned for 2007, however, the ECN project manager, Bart Geerligs, has become more careful and is no longer talking about 500 but only more than 100 MT per annum. According to Geerligs, negotiations with a partner are still going on.

In Norway, Geir Martin Haarberg from the University of Science and Technology in Trondheim and Jan Reidar Stubergh from the Oslo University College have been researching methods of obtaining solar grade silicon by electrolysing quartz in a saline or fluorine melt for many years. These approaches have not produced anything above laboratory scale, as yet. »The problem is the purity of the source material, particularly of the salts,« explains Armin Räuber, senior consultant at research and marketing service provider PSE in Freiburg. »This usually increases the costs so much that there is no advantage over the conventional process.« Girasolar, the holding company of the module wholesaler Dutchsolar, now believes it can make a breakthrough with another electrolysis process and has already filed for a patent. »It works, but not yet in sufficient quality,« says managing director Wieland Koornstra.

Solmic expert Fath does not give the electrolytic approach much chance of succeeding. In fact, Fath is convinced that metallurgical processes will prove successful for solar cells made of multicrystalline silicon and the classic Siemens process for monocrystalline cells. The tendency is that the metallurgical route is a nose ahead because the advantage of higher efficiencies for monocrystalline cells will »always be eaten up by higher costs«.

Test run: Joint Solar Silicon, a joint venture between the chemical group Degussa and Solarworld AG, is performing tests at the Degussa site in Rheinfelden, Germany, on a tube reactor which decomposes silane into silicon powder. A production plant with an annual capacity of 850 MT should go into operation in 2008.

Photo: Joint Solar Silicon

Table 4: Maximum production of crystalline silicon solar cells. The actual quantity produced annually is lower than the corresponding stated maximum amount, since the newly added silicon capacity is built up over the course of the year, and only reaches its maximum at the end of the year.

Sources: Deutsche Solar AG/EPIA (specific consumption), own calculations

Year	2004	2005	2006	2007	2008	2009	2010
Max. silicon capacity [MT]	14,300	16,300	18,850	29,300	67,500	86,250	97,800
Specific consumption [g/W_p]	13	11	10	9	8.5	8	7.5
Max. cell production [MW_p]	1,100	1,500	1,900	3,250	7,900	10,800	13,000

Table 5: Reduction of wafer thickness

Source: Deutsche Solar AG

Year	1995	2000	2004	2005	2006	2007	2008
Prevalent wafer thickness [µm]	340	330	330	270	210 - 240	150 - 180	150 - 180
Length of wafer edge [mm]	100	125	156	156	156	156/210	156/210

Risky high-price policy

Either way, there will be significantly more polysilicon on the market within the next few years. Expansion plans by the incumbent manufacturers alone add up to a capacity of 66,000 MT by the end of 2010. If you add the pronouncements by new entrants and the more optimistic forecast for China of 10,000 MT, this gives a total of 120,000 MT (see table 3). Of this total, the semiconductor industry would need almost 25,000 MT, given an annual growth rate of 5 %, and if you include off-spec material from the electronics sector, this would leave a capacity of over 95,000 MT for photovoltaics. By the end of 2009, total capacity would already have reached more than 85,000 MT, resulting in actual produced quantities of around 90,000 MT in 2010. If, by then, the photovoltaics industry reaches an average consumption of 7.5 g of silicon per Wp then it would be able to manufacture crystalline solar cells with a total output of 12 GW_p (see table 4). If some forecasts are to be believed, there would also be thin-film modules with up to 2 GW_p.

Silicon capacities will grow most significantly in the course of 2008 – by almost 15,000 MT among incumbent manufacturers and by 24,500 MT among new entrants. However, the introduction of new processes is commonly delayed by one or two years, so that growth should be spread more evenly between 2008 and 2010. In 2007, the extent of production increase is too uncertain yet to give the all-clear – even if wafer thickness and, along with it, specific silicon consumption are strongly reduced (see table 5). Peter Woditsch, CEO of wafer manufacturer Deutsche Solar, does not believe there are still large silicon quantities being stored: »I presume that by the end of 2006, all stocks will be fully exhausted.«

However, if silicon producers continue to keep their prices high, then the scarcity problem could solve itself as demand would crumble, particularly in Germany. »Then the silicon crisis will be over by 2007,« says Wieland Koornstra, managing director of Girasolar. Demand for silicon has been inflated, particularly by excess capacity in China. Wafer, cell and module manufacturers who have established themselves there are prepared to pay excessive prices so that their factories do not stand empty. »The crisis is in the middle of the chain,« says Koornstra. »The end market only has a deficit of 10 %.«

Management consultant Fath is also warning silicon, wafer and cell manufacturers not to destroy their own markets with high-price policies. According to his estimates, solar modules could be sold on the market today for between 2.40 and 2.50 €/Wp (3.05 to 3.20 US$/$W_p$) with reasonable margins of 10 % to 15 %, whereas the actual price is still 3.40 € /W_p (around 4.35 US$ /W_p). Fath believes: »Currently, many firms are too greedy«.

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