Photo: Wacker Chemie

Wacker Chemie's sprawling polysilicon site in Tennessee. The German company first began exploring FBR polysilicon in 1993.

The slow grind of FBR polysilicon

FBR Poly: Fluidized bed reactor (FBR) technology has been hailed as a means to produce polysilicon for solar at lower costs and with a small fraction of the electricity used by the dominant Siemens process. However, long delays at two new projects and technical challenges are slowing the progress of this promising technology. Will FBR eventually deliver?

The International Technology Roadmap for Photovoltaics (ITRPV) by SEMI is one of the core technical resources for the solar PV industry. Published annually, the document includes research from a range of manufacturers and covers expected developments in technology from polysilicon to modules.

The 2013 ITRPV predicted that the market share of FBR polysilicon would rise to 20% in 2015, and 30% in 2017. However, two years later, two of the three large projects that have been announced have not come online, and the current market share is a fraction of what SEMI expected. As a result, by the 2015 ITRPV, SEMI had brought down its forecast to 13% of the 2015 market, and 18% by 2017.

Experts say that even these numbers are too high, predicting that the 2015 share will be less than half of this. Such dismal results raise the question of what is happening with FBR, and whether these are just delays, or if the technology is dead in the water.

FBR demystified

Since the 1950s, the Siemens process has been the dominant way to produce high-purity polysilicon, at first for the semiconductor industry and increasingly for solar PV. The Siemens process is reliable and can produce very high purities of polysilicon, but it also uses a massive amount of electricity. Some of the inefficiencies in the process arise from start-up and shutdown in the batch process, and the loss of energy when hot gas and silicon contact cold surfaces.

By contrast, FBR works with a continuous batch process, whereby trichlorosilane or monosilane gas is injected into a chamber to grow polysilicon granules on seed crystals. These are then withdrawn from the chamber as new gran-

Photo: Silicor

The process for FBR polysilicon still needs further technical refinement, analysts say.

ules form. The process uses only 10 – 20% of the energy than the Siemens method, and in the case of monosilane, FBR additionally avoids the need for recovery and separation of gases. The three companies with FBR projects under development all promise cash costs of under $10 per kilogram, for silicon sufficiently pure to provide wafers for high efficiency PV cells.

Early FBR

FBR was first used as an industrial process in the petrochemical industry in the 1940s. The first large FBR plant for polysilicon was built by the Ethyl Corporation in the 1980s, and MEMC Electronic Materials (now SunEdison) acquired this project in the 1990s. The technology slowly drew interest, with Wacker Chemie beginning development of a small FBR polysilicon project in 1993, and REC following with a larger project in 1995. Neither was completed until 2009.

Johannes Bernreuter, head of Bernreuter Research, has been publishing analyses of the polysilicon industry for 14 years as a veteran journalist and analyst with experience that spans solar and polysilicon. He says that REC Silicon's plant coming online was an important moment for the technology.

"The only FBR manufacturer that has been around for decades is MEMC Pasadena, and its production costs are pretty high, which did not lure others into the technology," observes Bernreuter. "Only when REC Silicon proved large-scale production and low cash production costs did FBR technology spur more interest."

The new generation of FBR

In 2010, MEMC/SunEdison and Samsung entered into an MOU to form a polysilicon joint venture in South Korea. The 10,000 metric ton SMP project would utilize a high-pressure FBR process, unlike MEMC's plant in Texas. Two years later, GCL-Poly announced that it had successfully completed trial runs of high purity silane gas production, as the first step towards producing polysilicon using the FBR method.

In 2014, REC Silicon announced a new joint venture to build its second FBR project, this time in China through a joint venture with a medium-sized Chinese polysilicon maker, Shaanxi Tian Hong.

While all three of these projects use monosilane as the feed gas, other details of the processes are scarce. Bernreuter says that he believes that the three projects are substantially different, but that such differences are in the realm of company secrets.

All has not gone as planned. SunEdison/SMP expected to begin production of polysilicon at its HP-FBR plant in South Korea in May 2013, but did not report trial production until October 2014. SunEdison declined to comment for this

AT A GLANCE

- Fluidized bed reactor technology has failed to capture the market share recently predicted, with SEMI revising its 2015 forecast down to 13%.
- Less energy intensive than typical polysilicon production techniques, FBR has the potential to lower manufacturing costs to below $10 per kg.
- Leading producers of FBR – including MEMC/SunEdison and REC Silicon – have encountered a set of technical challenges in their attempts to scale the process.
- Johannes Bernreuter believes that the delays caused by tackling these challenges mean FBR will capture less than 6% of the poly market this year.
- Cost reduction has not been as easy to achieve as first thought, but three notable FBR projects promise to propel the industry further over the next two years.

Photo: Mei Llc

Right now, the FBR process is not so far ahead in terms of cost.

Photo: Silicor

The FBR process tends to cause a lot of dust, much of which is difficult to re-use.

article, but at the time of writing has still not reported ramping the full 13,500 metric ton facility.

Likewise, GCL-Poly had planned to bring 10,000 metric tons of polysilicon online in the first quarter of 2014. Instead, it announced that it had begun trial production of FBR polysilicon in November 2014, with only 3,000 metric tons of capacity. The company has not responded to requests for an interview, and produces few press statements.

Technical challenges

Bernreuter cites three main technical challenges with FBR polysilicon. First, it is difficult to move from pilot production to commercial-scale production, as fluid dynamics inside the reactor change at different scales. Second, the walls of the reactor have a tendency to contaminate the polysilicon granules with a high metal content. Finally, the process produces a lot of dust, not all of which can be used in the solar industry.

The fluid dynamics problem can be solved the most easily, according to Bernreuter. As for the contamination, REC Silicon says that it is using a liner for the reactor wall to mitigate this problem in its Shaanxi joint venture.

Bernreuter describes the dust problem as the most serious of the three. He says that REC has never published estimates of the amount of dust it creates, but cites a figure of at least 10 – 15% of total output. He says that this is also the main technical concern for SMP's high pressure process. Bernreuter speculates that some of the dust produced in the FBR process can be recycled back into silicon ingot production, but that some must be exported for uses such as steel production.

Mark Dassel has 45 years of experience in the chemical-process industry, and currently serves as Executive VP for polysilicon technology in the Seattle R&D center of SiTec GmbH, a company in the centrotherm group. He says that while high pressure approaches could result in higher productivity in the same sized reactor, that dust formation is a concern.

"Higher pressure means higher molar density," notes Dassel. "Higher molar density means that you could have more dust being formed."

A smaller slice of the market

These technical problems and the delays in completing projects are casting doubt on the future of the technology. Bernreuter says that even the 2015 ITRPV's reduced forecast for an FBR market share of around 13% is "completely unrealistic." He instead estimates that this year FBR production will only be around 5.5% of the total market.

"It will be difficult to reach even a two-digit percentage point market share for FBR in 2017, because I would put big question marks both behind the GCL and the SunEdison projects," says Bernreuter.

Bernreuter is particularly pessimistic about the likelihood of SunEdison's HP-FBR process going into commercial operation very soon. "All the indications that I have got are that the high pressure approach does not work," states Bernreuter. "So they have probably got to re-engineer the design." As for GCL-Poly's project, an inherent challenge is that unlike SunEdison and REC Silicon, this is the company's first foray into FBR. "Any company that is a new entrant into this field, unless it can license technology from a qualified provider, is going to need a lot of test experience to get things to work," says SiTec's Dassel. "That can be quite time consuming and expensive." But both Bernreuter and Dassel give good odds for REC Silicon's FBR-B joint venture.

"I think the Chinese JV of REC is the safest bet at the moment," says Bernreuter. "I cannot rule out that they will have problems during ramp-up initially, but I assume that they will finally succeed with the FBR-B generation in commercial production."

Cost

A central part of the promise of FBR technology is its potential to beat the Siemens process on cost. However, at present this has not yet been achieved. REC Silicon has not been able to bring its cash cost for granules below $10.50 per kg. This is about the bottom of current Siemens production, with China's Daqo New Energy reporting a cash cost of $10.53 per kg in the first quarter of 2015.

"This is a strong indication that on one hand the FBR process is not so far ahead in terms of manufacturing costs as many claim, and on the other hand the Siemens process still has more cost reduction potential than many, including myself, thought a few years ago," notes Bernreuter.

SiTec's Dassel is more optimistic. "The economics for fluid bed are sufficiently good that new plants going in will gravitate towards monosilane FBR," he predicts.

The future of FBR

The future outlook for FBR hinges on successful ramping of the three projects currently underway. However, despite substantial delays at its SMP joint venture, over the past 18 months SunEdison has considered similar joint ventures in India, Saudi Arabia and China. This includes an MOU with Adani Group to build the largest integrated solar PV factory in India, featuring 27,000 metric tons of polysilicon production.

And even with the grim numbers that he is presenting for current and near-future FBR market shares, Bernreuter says that FBR processes will inevitably continue to have a place in production. "It's a good complementary material for the polysilicon chunks from the Siemens process, because you can improve the filling of the crucible," explains Bernreuter. He also notes that FBR granules are an "ideal material" for the continuous Czochralski method to produce monocrystalline ingots.

Dassel expects a slump in activity for the next two years due to low prices, but for FBR to pick up after that. "Fluid bed is still a relatively young technology," he notes. "Smart people like those at SiTec are going to make big improvements in it."

Part of Dassel's optimism comes from SiTec's work. In June the company unveiled a new monosilane production process that it expects to reduce monosilane plant energy costs by 30%. Additionally, Dassel has revealed to **pv magazine** that his company has been working on a new FBR process for polysilicon. The new process fluidizes mechanically by vibrating the reactor bed, as opposed to the hydraulic method which has existed so far.

SiTec's development decouples fluidization from gas feed. According to Dassel, this enables multiple process improvements and cost reductions. He cites tests that show that the new technology produces little or no dust even when fed 100% monosilane (SiTec does not dilute its monosilane feed with hydrogen as is typical for hydraulic FBR). SiTec recently started up a large-scale scale pilot plant for its mechanically fluidized beds. The plant is a scaled-up version of earlier test units and is being used to prove commercial design and product quality, and verify the kinetics and yields demonstrated in earlier test work.

"It is an emergent technology that, when perfected, will be a substantial improvement over hydraulic," states Dassel. He says that due to 37% lower electricity use compared to hydraulic FBR, and 70% lower energy use compared to refined-TCS and Siemens CVD, SiTec's technology has the potential to bring polysilicon production even to places that do not have cheap electricity and energy prices. SiTec also forecasts a 35% reduction in polysilicon plant capital cost using its new technology. Dassel forecasts that SiTec will commercialize this technology in two years. However, he is optimistic about the long-term outlook for FBR, whether provided by SiTec, REC, or SunEdison.

"I see more and more of the new capacity going to fluid bed," says Dassel. "If producers can license fluid bed technology from a qualified provider they will do that. The shift will be driven by superior economics and process improvement. At SiTec we think that the future is monosilane and FBR." ◆

Christian Roselund