

## **REPORT II POLYSILICON 2008 SUMMARY**

### **1.0 INTRODUCTION**

This assessment of the polysilicon market provides a review and analysis of the manufacturers of polysilicon and their two main industry customers, the traditional semiconductor industry and the growing photovoltaic industry. It provides strategic planning information with a comprehensive picture of the current market situation, and substantial background on all three industrial groups. With an understanding of the development, capacity and future of these three industries, and an analysis of the current business environment, likely market scenarios are used to provide a five-year forecast of both supply and demand in the final chapter.

### **1.1 CHAPTER SUMMARIES**

Chapter 1 - Introduction – Provides a brief description of each of the various chapters of the report. The report methodology is then discussed followed by an executive summary with a summary of the market environment and key findings.

Chapter 2 - Polysilicon Manufacturers – Provides a detailed description of many of the current and future polysilicon producers. A two page description of many of the existing and planned polysilicon facilities is provided. Each description provides information on ownership, investment level, location, technology, and hired contractors, where available. The chapter concludes with a table summarizing much of the data contained in the individual discussions.

Chapter 3 - Semiconductor Industry Polysilicon Users – Discusses drivers for demand in the semiconductor industry. A brief discussion of the electronic industry is followed by the generation of semiconductor demand drivers. The producers of silicon wafers, the consumers of polysilicon, and the providers of polysilicon are analyzed on a company by company basis. The chapter concludes with a semiconductor buyer / seller matrix.

Chapter 4 - Photovoltaic Industry Polysilicon Users – This chapter begins with a discussion of the current market factors affecting demand for photovoltaic cells and modules. It then discusses the growth in demand in world primary energy and electricity generation, providing an understanding of global and regional growth in each. Photovoltaic growth scenarios are then compared to show the length of time required to achieve percentile shares of these conventional forms of energy growth. After a discussion of photovoltaic market segments, the chapter describes the progress of photovoltaic growth over the last 25 years and the driving factors increasing that growth. Developing market shares of PV technology are then reviewed, with the factors affecting the dominance of crystalline technology over the last quarter century. Major industry producers are summarized for crystalline silicon photovoltaic cells, with discussion of the large thin film producers.

Chapter 5 - The chapter then describes the silicon wafer and silicon raw material suppliers for photovoltaic industry. After discussing all of the consumers and producers of photovoltaic ingots, wafers, and polysilicon, the chapter presents a silicon material flow chart for each of the major photovoltaic cell and silicon material suppliers. The chapter closes with a photovoltaic wafer buyer / seller matrix and a photovoltaic polysilicon buyer / seller matrix.

Chapter 6 - Semiconductor Polysilicon Forecast – Describes a vertical integration chain starting at the top with GDP and following it through to the electronics and semiconductor industries to the silicon wafer and polysilicon level. Forecasts out to 2012 are presented for GDP, Electronic Systems, Integrated Circuits, and silicon materials needed by the semiconductor industry.

Chapter 7 - Photovoltaic Polysilicon Forecast – A discussion of the changing energy environment as it affects ongoing market development. Historic forecast scenarios and actual growth in the photovoltaic market provide a perspective on future market expansion and polysilicon demand. The history of photovoltaic consumption of polysilicon is used to forecast potential polysilicon demand, in combination with photovoltaic market projections.

Chapter 8 - Polysilicon Supply And Demand Forecast – Market forecasts of semiconductor and photovoltaic industries' product demand are combined to estimate a most likely scenario of polysilicon consumption volume, taking the near term polysilicon

availability into consideration. The end of the silicon raw material shortfall is anticipated for the year 2012.

## **1.2 REPORT METHODOLOGY**

This report is directed toward the planning needs of general management and senior planning and business development managers, as well as providing technical managers with an additional perspective on the industry's progress in technology.

The forecasts included represent a combination of quantitative and qualitative analyses. The author's individual experience of more than 20 years is used in the analyses of market size, development of technology, capacity increases and economic effects. Quantitative information has been gathered over more than 20 years, using primary surveys and personal discussions with experienced personnel in the three involved industries. These are discussed in this report, and used to assess market direction and industry response to changes in the market

Additional quantitative inputs include world demographics which are used in estimating addressable markets, costs associated with various PV and semiconductor technologies, and their corresponding competitors, and the budgets of various national and world agencies.

## **1.3 EXECUTIVE SUMMARY**

The polysilicon industry has supplied the semiconductor industry with ever-increasing purity material for over 40 years. While material quality and timely delivery have seldom been an issue, the profitability of the polysilicon industry has been questionable at best. Patterns have developed where the polysilicon price drops soon after the production plants are constructed and remain low until the semiconductor industry's long term cyclical growth drives polysilicon demand to the point where it outstrips polysilicon supply.

As the gap between the supply and demand curves narrows, the polysilicon price increases to the point where re-investment in the industry is viable. After each expansion the price drops to the point where there is no profitability left in the industry. This has happened three times in the polysilicon industry's history and the current scene is primed for a recurrence.

While the semiconductor industry has created a rather financially unhealthy supply chain, the photovoltaic industry by contrast has almost no supply chain. For 30 years the photovoltaic industry relied primarily on scrap silicon from the semiconductor silicon production chain. Fortunately for the photovoltaic industry, its new millennium growth spurt occurred at a time when the semiconductor polysilicon industry was in a period of vast overcapacity. Thus a plentiful low-price supply of polysilicon was available for the period ranging from the late 1990s to the year 2003.

The year 2004 brought an end to this era of cheap plentiful polysilicon. In that year semiconductor polysilicon demand increased 15% and photovoltaic polysilicon demand increased by 45%. These demand surges created a dynamic where demand outstripped supply. With the continuing polysilicon shortage of 2006, the two polysilicon demanding industries are left to compete for the available material. The winner of this struggle was the semiconductor industry which owns the production technology and owns (either outright or partially) many of the plants.

This scarcity has evidenced a basic flaw in the development strategy for photovoltaic development. For years (1975-2003) the photovoltaic industry had no viable supply chain of the silicon raw material. It basically has been lucky to be able to develop to its present stage without its own supply chain.

While the polysilicon scarcity continues, the solutions being currently planned are for far more supply than necessary.

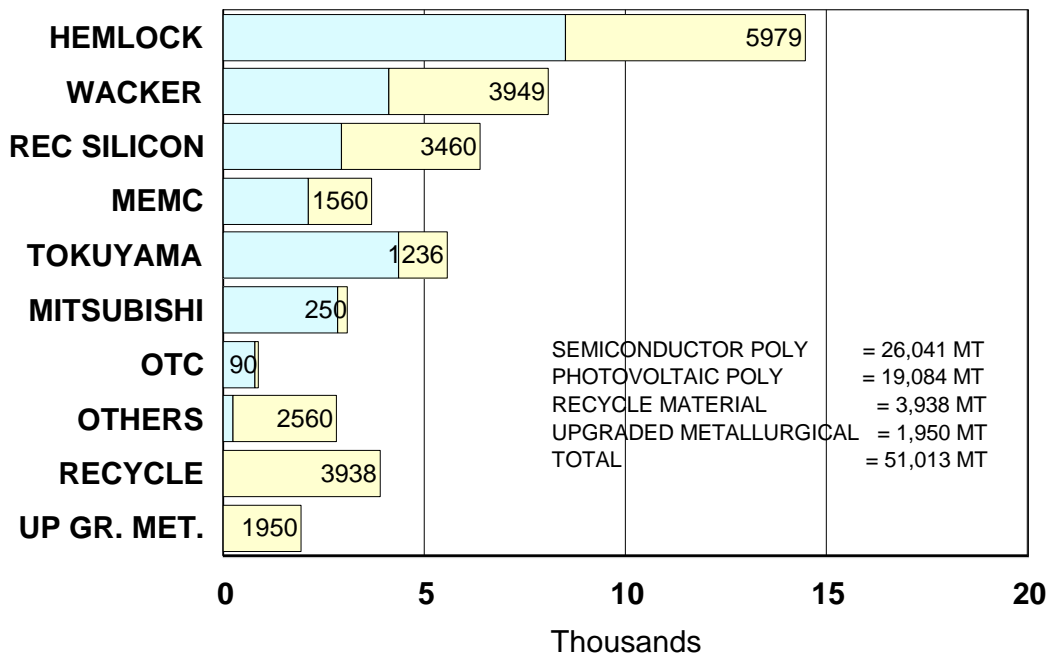
- Existing polysilicon producers and new comers have plans to have an accumulative investment of \$43 billion by the year 2012.
- These investments are to provide 418,000 metric tons of silicon raw material by the year 2012.

- While Sage Concepts does not believe all of the silicon raw material projects will be completed on time, it does expect there to be 353,000 metric tons to be available by the year 2012, unless many companies drastically alter their plans.

### 1.3.1 CURRENT SILICON RAW MATERIAL SUPPLY

The current supply of polysilicon is illustrated in Figure 1-1. The semiconductor polysilicon supply in 2007 was 26,041 metric tons and the photovoltaic supply was 14,208 metric tons. Total photovoltaic polysilicon supply was 19,084 metric tons. In addition to the 19,084 metric tons of polysilicon, the photovoltaic industry also was supplied with 3938 metric tons of scrap silicon material, and 1950 metric tons of upgraded metallurgical silicon, for a total photovoltaic silicon raw material supply of 24,972 metric tons. For the two industries together had a total silicon raw material supply of ( 26,041 + 24,972) = 51,013 metric tons.

FIGURE 1-1  
2007 SILICON RAW MATERIAL SUPPLY  
(in Metric Tons)



The largest polysilicon supplier is Hemlock Semiconductor. In 2007 Hemlock supplied 8521 metric tons to the semiconductor industry and 5979 metric tons to the photovoltaic industry for a total of 14,500 metric tons. The position of 2<sup>nd</sup> largest polysilicon supplier was held by Wacker Chemie. In 2007 Wacker supplied 4151 metric tons to the semiconductor industry. Eighty four percent of this material was shipped to its sister company, Siltronic AG. In addition it supplied 3949 metric tons of polysilicon to the photovoltaic industry for a total of 8100 metric tons. The 3<sup>rd</sup> largest polysilicon supplier was REC Silicon. Its Butte, Montana, plant supplied 2940 metric tons to the semiconductor industry and 960 metric tons to the photovoltaic industry. Its Moses Lake, Washington, plant supplied 2500 metric tons to the photovoltaic industry. The sales of these two plants together supplied 6400 metric tons in total and 3460 metric tons to the photovoltaic industry.

In 4<sup>th</sup> position is Tokuyama. Tokuyama supplied 4364 metric tons to the semiconductor industry and 1236 metric tons to the photovoltaic industry for a total of 5600 metric tons. Mitsubishi Materials also operates two polysilicon plants: one in Yokkaichi, Japan, and one in Theodore, Alabama. Both of these plants are primarily dedicated to the semiconductor industry. Similarly the Amagasaki plant of Sumitomo Titanium is dedicated to the production of polysilicon to the semiconductor industry.

The other plant produces polysilicon in a different form than the others. All of the above discussed plants produce rods of polysilicon, which are the broken into chunks. The MEMC Pasadena plant produces granules of polysilicon. The only semiconductor user of these granules is MEMC. In addition to their captive use, a portion of these granules are sold to the photovoltaic industry. In total MEMC produced 3700 metric tons in 2007. Some 2140 metric tons were used internally to produce semiconductor wafers and 1530 metric tons were sold to the photovoltaic industry either as silicon ingot or as granules.

These existing producers announced have expansion plans:

- Hemlock                      37,000 MT
- Wacker                        22,000 MT
- REC Silicon                32,500 MT
- MEMC                         9,100 MT
- Tokuyama                    8,400 MT
- Mitsubishi                  3,650 MT

### 1.3.2 KEY FINDINGS

- The polysilicon industry is headed into a period of drastic (100%) oversupply. Under these conditions prices will most likely fall to below cost, making business difficult for many polysilicon suppliers and their investors.
- Current polysilicon expansion plans would result in a capacity of 418,000 metric tons by the year 2012, if all projects are completed on schedule and produce material of anticipated quality. This amount of polysilicon is more than double that needed to supply even the most aggressive (49% CAGR) photovoltaic growth scenario.
- Because it is believed that many of the new polysilicon suppliers will not be able to achieve their objectives (either schedule, material quality, or both) the anticipated amount of material from the current supply plans is anticipated to be 253,000 metric tons by 2012. While this amount of silicon raw material is far below the planned 418,000 metric tons, it is still enough to create a severe oversupply situation. Serious investors would be well served to study the global polysilicon supply and demand situation for the next five years, before providing additional funding to this industry.
- Crystalline based photovoltaic sales grew from 1697 MWp in 2006 to 2790 MWp in 2007, an increase of 64.4%.
- Photovoltaic silicon raw material demand increased from 16,572 metric tons in 2006 to 24,972 metric tons in 2007, an increase of 50.7 %.
- Semiconductor polysilicon demand increased from 23,967 metric tons in 2005 to 26,041 in 2007, an increase of 8.6%.
- In 2008 the amount of silicon raw material consumed by the photovoltaic industry is anticipated to exceed that consumed by the semiconductor industry for the first time.

### 1.3.3 POLYSILICON SUPPLY AND DEMAND SUMMARY

Polysilicon supply and polysilicon demand are plotted in Figure 1-2. In this figure the three different demand scenarios are presented for the years 2007 through 2012. These scenarios are:

- 1) Moderate PV Growth Scenario of 33%
- 2) Anticipated PV Growth Scenario of 42%
- 3) Accelerated PV Growth Scenario of 49%

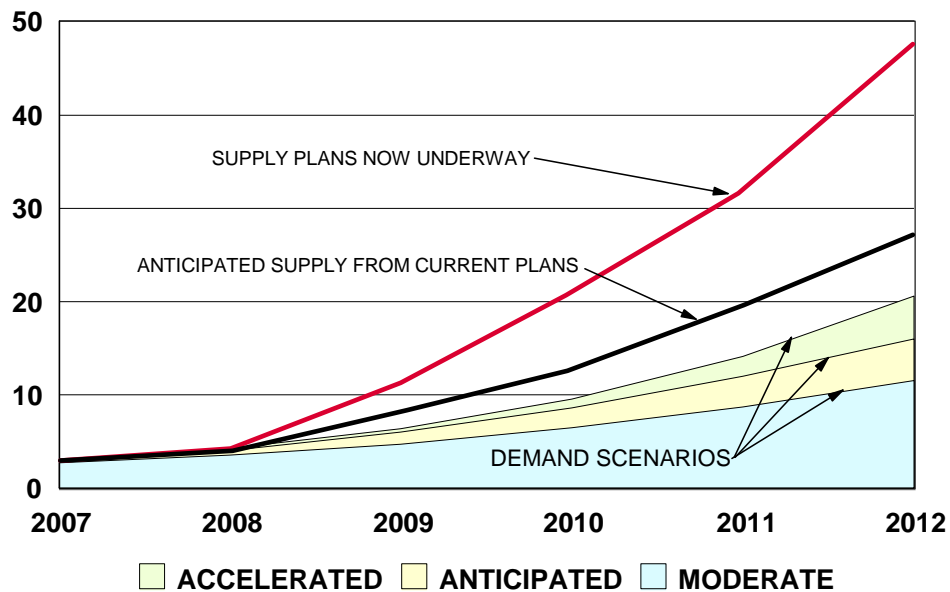
To determine the PV driver for photovoltaic polysilicon consumption the estimated of thin film module production needs to be subtracted from the total demand. This level of crystalline photovoltaic demand is presented in Figure 1-2 for each of the tree scenarios.

Under the moderate scenario, the crystalline demand will reach 11.5 GWp by 2012, under the anticipated scenario the level is 16.0 GWp, and under the accelerated scenario the demand reached 20.6 GWp.

Atop these three demand forecasts are placed two the silicon raw material forecasts. The upper supply forecast assumes that all of the silicon raw material projects will be completed on time and produce material of sufficient quality for photovoltaic needs. Under these assumptions, in the year 2012 there will be 48.3 GWp of silicon raw material available to supply an accelerated scenario demand of 20.6 GWp.

The year 2012 situation as anticipated by Sage Concepts is represented by the lower silicon raw material supply line and the anticipated photovoltaic growth scenario of 42% per year. Under these assumptions the silicon raw material supply will be 27.6 GWp and the demand will be 16.0 GWp. While the oversupply under this set of conditions is less severe than the one discussed above, it still represents a significant (72%) oversupply situation.

FIGURE 1-2  
 POLYSILICON SUPPLY VS DEMAND FORECAST  
 (IN PEAK GIGAWATTS)



The silicon raw material oversupply illustrated in Figure 1-2 will most likely bring about severe change to the photovoltaic silicon supply situation. The most dramatic effect will be on the spot market prices for silicon raw material. Instead of commanding prices reaching as high as \$500 per kilogram, the spot market price could drop to as low as \$25 per kilogram for good quality polysilicon and even less for lower grades of silicon material. Lower quality silicon such as pot scrap, rod ends, compensated ingot, and silicon dust (all of which currently sell for very high prices) will be the first high volume silicon markets to suffer. When high quality material is available at low cost, few will want to pay high prices for off-grade material.

If you are a silicon raw material supplier this is what you will need to survive:

- An iron-clad long term sales agreement. However, even this will not be a panacea in the long run. If your customers' competitors can buy silicon raw material for less than their contract price, they will begin to hurt and when they hurt you will eventually hurt.
- Produce high quality polysilicon. The highest efficiency cells are typically produced from the highest purity silicon. Therefore, the highest quality material will most often sell for the highest price.
- Have the lowest production cost. For Siemens TCS systems this means having a competitive advantage, such as:
  - Access to low cost capital
  - Experience in plant design and operation (uptime is important)
  - Access to low cost and reliable supplies of electricity
  - Access to low cost and reliable supplies of raw material
  - Reliable low cost methods of waste and byproduct recycle and disposal
  - Strong customer relationships
- Fluidized bed processes could have a competitive advantage with lower capital and energy consumption costs, if there product quality is not compromised.

All of this oversupply will be a boon to photovoltaic ingot growers, wafer sellers, and cell and module manufacturers. At \$80 per kilogram the silicon raw material represents approximately 80 cents per peak watt. If this price drops to \$25 per kilogram, it represents 25 cents per peak watt, thus at a minimum reducing the cost of a module from \$3.80/ W<sub>p</sub> to \$3.25/ W<sub>p</sub>, a savings of about 15 percent. This drop could provide an increased profit margin or could be used to lower prices and stimulate demand and encourage governments to continue providing incentives for photovoltaic systems.