UACEE International Journal of Advancements in Electronics and Electrical Engineering Volume 1: Issue 2
[ISSN: 2319 – 7498]

Parametric Analysis of Solar Polysilicon Refining Industry in India

Rohit Verma [(1)]
Deputy Director,
National Power Training Institute,
Faridabad , Haryana,India
rohit12_verma@yahoo.com [(1)]

Mahendra Singh[(2)]
Assistant Director,
National Power Training Institute, Faridabad,
Haryana , India
mahendra.npti@gmail.com [(2)]

Abstract-*The polysilicon industry has the potential to make India a major manufacturing hub for solar photo voltaic cells industry. The Indian polysilicon industry, critical to the manufacturing of solar PV cells, is taking shape, fueled by the booming solar PV market. The domestic demand of polysilicon is expected to be 250,000 metric tonnes upto the year 2050, taking into account the JNNSM and the state-level programmes. A coordinated development of solar polysilicon refining industry in India is required. A parametric analysis of polysilicon refining industry has been done in this paper. The opportunities, issues and possible solution* analysis for the development of polysilicon industry and its refining process for the India has been done. *This paper may be helpful to policy makers, investors and solar photo voltaic industry as a whole.*

Keyword-photo voltaic, polysilicon, life cycle assessment,GHG emission.

I. Introduction

Solar energy is potentially capable of supplying most of the global energy need for primary energy and it is expected to change the world energy scenario [1].
Solar power may meet 35 to 40 % of the future energy demand and for the development of solar power, it is required to develop large scale industrial capacity of silicon solar cells made of 100% solar grade silicon [2]. The rapid increasing demand for semiconductor devices resulted in concern for the availability of refined silicon product for photovoltaic (PV) solar cells development and three surveys were conducted to update the information based on the capacities of polycrystalline silicon refiners and plans for expansion [3]. Growth of the photovoltaic industry will be limited by the availability of silicon feedstock and metallurgical grade (MG) silicon using pyro-metallurgical techniques will be an option [4]. European community commissioned a research for SWOT analysis of various energy option focuses on development of solar power [5]. There are alternatives for refining silicon for solar cells and lower Si purity and lower cell conversion efficiencies generally require less expensive Processes [6]. The dissipation of heat transfer practices from the cells requires optimum cooling practices and more refined product [7]. Impurities in silicon are defined in two broad structure i.e. do pant and contaminant which can be refined in various way of manufacturing [8]. Till now all the research reports regarding solar cell development were concentrating on European or American markets. India being geographically in a high solar irradiation zone, it becomes highly important to do analysis of solar PV silicon cell development for the Indian market. Silicon refining capacity is a major hurdle for the development of solar PV cells.

The JNNSM scheme, announced by the Ministry of New and Renewable Energy in the year 2009, envisages a massive capacity addition in solar electric generation in the coming years. It proposes to add a cumulative 22,000 MW (20,000 grid-connected and 2,000 off grids), by the year 2020, of which 13000MW will come from solar photovoltaic (PV) technology. The solar capacity addition would be in phases, with accelerating pace. The Government has also decided to approve the implementation in first phase of the Jawaharlal Nehru National Solar Mission during 2009-2013 and the target to set up 1,000 MW grid connected in voltage of 33 KV and above & solar plants, 100 MW of roof top and small solar plants connected to LT of voltage level 11 KV grid and 200 MW capacity equivalent off-grid solar applications in the first phase of the Mission, till March, 2013. For encouraging project developers, various incentives have been provided, notably Capital Subsidies, Soft Loan, Viability Gap Funding and Green Bonds. Certain policy enablers, such as

Bundling of Power, GBIs and fiscal incentives such as a tax holiday, Custom & excise duties exemption, Capital & Interest Subsidies and Solar specific RPO, are being implemented to attain this aim. With the all the above report it is clear that opportunities, issues and possible solution analysis for the development of polysilicon industry and its refining process has not been done for the Indian polysilicon industry.

The polysilicon industry, critical to the manufacturing of solar PV cells, is taking shape, fueled by the booming solar PV market. In order to achieve energy security, it is imperative for India to take care of the domestic manufacturing of this raw material for solar PV value chain.

TABLE 1: Future Demand Potential of Solar Polysilicon

Duration	Installation target (MW)	Annual Installation (MW)	Polysilicon Demand (tons/yr)
2011-13	600+900*=1500	500	3500
2014-17	2400+1100*=3500	875	5500
2018-22	8000	1600	8500
2023-30	15000	1875	9500
2031-35	6250	1250	6250
2036-38	3750+1500**=5250	1750	8750
2039-42	5000+3500**=8500	2125	10625
2043-47	6250+8000**=14250	2850	14250
2048-50	3750+5625**=9375	3125	15625

* = State level solar PV installation parallel To JNNSM
**= replacement of old PV module after 25 yr life

Present Scenario: According to data obtained from MNRE, during 2009, 15 companies were actively engaged in the manufacture of solar cells and 20 companies in the manufacture of PV modules. In addition, about 50 companies were actively engaged in manufacturing a variety of PV systems but no major footprints of polysilicon manufacturers. There were just 2 polysilicon manufacturing units in India of capacities 40 TPA and 100 TPA. LANCO Solar Private Limited, Hyderabad, is coming up with a 1250 TPA manufacturing unit in Cuttack (Orissa). While these efforts are commendable but they are, in no way, anywhere near sufficing the country's needs. At present India is importing silica ingots and wafers for PV module manufacturing.

II. Opportunities

A. Demand Potential: In addition to JNNSM, several states are also concentrating on solar PV installation. Gujarat, Rajasthan and Karnataka are the states with aggressive plans. By 2030, solar capacity will reach 50000 MW and by 2050 the target is to reach 100000 MW [11]. Considering 30-40% of that capacity will come from solar PV and the technology will improve with time, following demand projections are worked out in decades. If this demand is also included, the annual demand will be double of the above stated numbers. There is therefore, a strong case for the setting-up of not on, but several polysilicon manufacturing units in india of capacities ranging from 2500 TPA to 3000.

B. Employment Generation: The industry will also generate ample employment opportunities. Each MW installed capacity of solar energy generates 40-50 direct and indirect employments, out of which 20% attributes to the polysilicon manufacturing industry. Film is more costly generation than the cells [10]

C. Low Threat of Substitution: The only alternative to polysilicon comes in the form of thin-film technologies. However, due to lower module efficiencies, thin-film might not always be a suitable alternative. Switching costs, however, are very high, as manufacturing processes for crystalline and thin-film modules are very different. In the electronics market, there is no substitute for high purity silicon.

D. Decreasing Cost of Raw Material: The input material is metallurgical grade silicon with around 98.5% purity. This is a commodity that is traded on international exchanges. Costs in 2009 were around $1,700 per ton, down from $2,500 per ton in 2008. Suppliers of metallurgical grade silicon tend not to forward integrate into polysilicon production, and the life cycle analysis (LCA) of the cell materials are ranged from 2 to 3 years.[13]

E. High Margins: The average gross margins have been exceptionally high at 83%, although they have come down to 49% by the end of 2009. As the technology ramp up the profit margin increases [5]

F. Cheap Skilled Labor: Figure 1 shows the breakup of manufacturing cost of polysilicon. Almost 10% of the manufacturing cost accounts for labor. In India there is a vast pool of skilled, semi skilled and unskilled labor which is cheaper then the labor in other countries. It may bring down the labor cost by 50% and the overall cost may come down by 5%.[11]

G. Government Policies: Special Incentive Package Scheme (SIPS-1) was announced by the Union government in 2007 as part of the Semiconductor Policy to boost the semiconductor manufacturing sector. SIPS-1, which ended on March 31, 2010, attracted 26 proposals, worth $51.7 billion (Rs 2.3 lakh crore). SIPS-2 has come into effect and its benefits could be extended to the solar polysilicon manufacturing industry.

III. Issues

A. Capital Equipment & Raw Material: The raw material for polysilicon manufacturing, metallurgical grade silicon, is not available in the country at present, and has to be imported from abroad. This makes us dependent on the economic

and political relationships with other countries for sustaining the downstream activities. Most customers have long-term contracts with existing suppliers, making it difficult for new entrants. Even the import duties for these materials and equipments are quite high and do not encourage indigenous production. On in cost of power may result in change in cost of 1 tonne polysilicon by Rs 2,00,000.

B. Absence of Technology: India does not have the requisite technology for setting up indigenous production without foreign collaboration. Siemens and Silane FBR(Fluidized Bed Reactor) are the only viable technologies exist. Further, the risk of technological obsolescence is high, with breakthroughs in efficiency improvements in the area, which calls for continuous R & D and process up gradation. The level of R & D is not at par with the global standards at present. Very few manufacturers used the space content heating. As an alternative, direct solar radiation can be concentrated by optical means [15].and used in concentrator solar cell technologies pipe arrangement [8].

C. Capital-Intensive Nature: This act as a high entry barrier, moreover long lead times required to add capacity. According to the report on polysilicon industry the capital required for setting up a plant of 2500TPA capacity is Rs 1200 crores. For a manufacturing hub of 15000 TPA, investment of Rs 7200 crores is required. Such high investment in a highly volatile market is **considered too risky by most of** the project developers and financial institutions.

D. Difficulty in Arranging Finances: Due to the risk involved in new technology and absence of industrial expertise in the sector, getting finance at competitive rates is a big hurdle. Even if the developer gets the financial closure, the interest rates in India are way too high from global standards.

E. Environmental Concerns: GHG emission coefficient for silicon is 181. The by- products of polysilicon manufacturing are highly toxic and their adequate disposal is an issue for the developers. The process generates a lot of waste heat which is difficult to be reused efficiently. As pollution control norms become stricter, the industries would come under pressure to cut-down emissions.

F. Global Competition: The industry is dominated by 7 companies that supply around 90% of the total polysilicon market: Hemlock, Wacker Chemie, REC, MEMC, Tokuyama, Mitsubishi and Sumitomo Titanium (now Osaka Titanium). They dominate the market by virtue of their superior technology and economies of scale. Newer firms will find it hard to match them. China also has some aggressive manufacturing capacity addition plans in near future. They want to produce as high as 100000 TPA. The domestic market gets partial security due to the government's preference for indigenous manufacturing, but finding newer markets worldwide will be a pressing concern. Moreover the government's policy for domestic content may raise some eyebrows at WTO and other trading partners.

G. Projected PV oversupply situation in coming years: If there is an oversupply situation of solar PV modules in the coming years, on account of the withdrawal of key subsidies by GoI, it might impact the polysilicon industry adversely. If the same policy environment changes negatively at worldwide level, the export scenario will be grim.

H. Lack of Industry Standards: There is an absence of Industry standard in the sector, due to which producers face the challenge of deciding optimum parameters.

I. Lack of Reliable Power: The industry is energy- intensive in nature, requiring large amount of reliable power for operations. For US/European technologies the required power is as high as 200kWh/kg. The specific energy requirement is higher (300kWh/kg) for low capacity plants. Getting economical power is a challenge in the already energy- deficient country. A plant of 3000 TPA capacity will require 600 million units of electricity every year. Power contributes for almost 30%-35% of the total cost of production and even 33% reduction in power cost may reduce the price of polysilicon by 10 %.

J. New Export Market: Once India will be self sufficient in polysilicon manufacturing, the project developers may think of going global and exporting their polysilicon to the emerging Asian, African and Middle East markets. encouragement

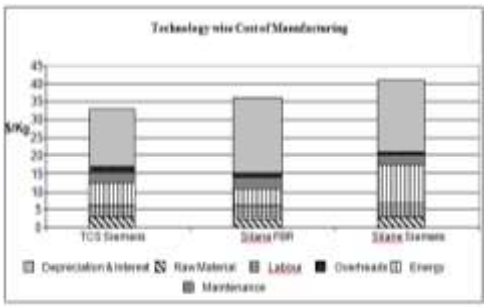


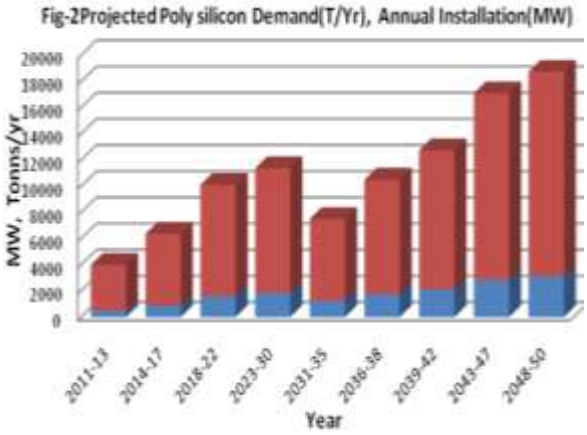
Figure 1: Technology Wise Manufacturing Cost of polysilicon

TABLE-2 PV Cell technology

Items	Concentrating PV	Emerging Technologies	Novel Technologies
Type of Cell	High Cost , Super High Technologies	Low Cost Moderate Performance	Very High Efficiency , Full spectrum utilization , Low Heat retardant
Status & Potential	23% Alternating Current (AC), System Efficiency demonstrated	Emerging Technology at demonstration level	Wide variety of new conversion principle device concept at device level.
Selected Research & Development Area.	Reach super high efficiency at 45 %, Achieve low cost & high performance solution at high level.	Improvement of efficiency and stability to the level needed for first commercial application	Proof –of – Principle of new conversion concept.

IV. Possible solution

A. Low Interest Rates: Government should give soft loans for the industry as the present cost of debt which is around 12%, is too high and makes the projects unviable. A 70:30 debt equity ratio and decrease in loan rates from 12% to 5% will reduce the interest burden by Rs 2,50,000/tones so that the annual Demand meet up to the year 2050.[11]



B. Priority Sector Lending: Providing sectoral loans by setting up special agency for the same will help eliminate the finance trouble. The agency will not only provide the loans but will also act as a financial consultant for rapid implementation of the projects.

C. Foreign Collaboration: technology superiority is not available in the country. Producers have to procure costly technology from outside. An initiative from the government's level to provide a platform for tech collaboration will be useful.

D. Industrial Clusters: There are synergies of operating a fully integrated chemical plant with cost advantage over pure silicon producers. Developing the entire supply chain, such as metallurgical grade silicon and chemical industry, polysilicon manufacturing, wafers manufacturing, PV cell manufacturing, module manufacturing etc. in a location- specific way so as to improve overall efficiency and economics, and also fulfill the infrastructural requirements, can be thought of. SIPS 2 is expected to provide subsidies in such clusters.

E. Reducing Import Duties on Raw Materials and Equipment: Indigenous production can be boosted by reducing the duties imposed on import of raw material, which is not developed in the

country, and on the capital equipment sourced from abroad for setting up the plant.

F. Encouraging Exports: Duty- free exports will help tap the global markets, enhancing the cost-competitiveness of the indigenous industry. Almost all the nations are recognizing the need to promote renewable sources of energy, especially solar energy and that creates a big polysilicon export market.

G. Prior Supply Chain tie- ups: Long term PPAs with the module manufacturing industry to assure a ready market, and with the material suppliers for uninterrupted production, will boost the sector's robustness. the cell supply chain is rapid change process which can run in the routine [9]

H. Technological Cooperation in Industry: The indigenous industry is in a nascent phase, and therefore, the wealth of experience is not available to the emerging players. Industry- wide cooperation relating to technological challenges can help in faster learning and better knowledge- sharing Table-2

I. Effect of mold velocity on profiles of impurity Concentration: The impurities in the layer diffuse towards the bulk liquid with or without the help of liquid convective movement, which eventually accumulate. The severity of this is a salute difference [6].

J. R & D: In 1998, the polysilicon industry was responding to rapidly increasing demand from the semiconductor industry, [14].The technology in the sector is changing very fast. The Siemens's technology is the most widely used at present, but the other promising ones such as FBR etc, offer more important scope for efficiency improvement.

V. Conclusion

The solar PV industry in India is on the threshold of expansion based on the demand being created in the domestic market due to the GoI's policy initiatives in the form of the JNNSM and the state level solar programmes. The industry cannot progress without the development of the upstream supply chain partners, which would include solar grade polysilicon manufacturing.[3] Dependence on imports is not a satisfactory solution due to the global market risks that would have to be accounted for. For this reason there is a focus on the polysilicon manufacturing industry.

The polysilicon industry has a ready market in the homeland, an aggregate demand of 2,50,000 till 2050, with demand rates rising over the years. Cost-competitiveness can also bring the global markets within reach. The sector nevertheless faces a number of issues, such as power shortages, difficulties in procurement of raw material and equipment, and costly technology. The presence of strong global market leaders with advantages of experience and scale brings up some challenges for new entrants. However, ways are there to overcome these hurdles, through adequate regulatory support, industry collaboration, both at the national and the international level, financing options, and R& D.

Industry standardization and pollution control norms ensure that the sector grows in a sustainable manner. A major facilitation could be achieved through industrial clustering wherein all the support industries are closely located, in regions where reliable power and other infrastructural advantages exist. The concerned parties should, therefore, closely examine the various factors which can give this industry a boost. Policymakers and industrialists alike have to judge the opportunity that the sector presents and give due consideration to its strategic importance, to make India emerge as a noted polysilicon hub .

References

1. Hiroshi Kawamoto, Kumi Okuwada" Development Trend for high purity silicon Raw material Technology, Science & Technology Trends" ,Quarter Review No.24/July 2007,
2. A. Halm1, J. Jourdan1, S. Nichol2, B. Ryningen4 and H. Tathgar3, R. Kopecek "Large Area Industrial Solar Cells on Cost 100% MC SOG Si Substrates efficiencies Exceeding 16%" Norwegian Research Council (NRC)and Umoe Solar AS.
3. R. FERBER[a], E. N. COSTOGUE[a] and R. PELLIN[a] " Polycrystalline Silicon Availability for Photovoltaic and Semiconductor Industries", International Journal of Solar Energy, Volume 1, Issue 2, 1982 pages 105-124 .
4. Khattak, C.P.; Schmid, F., Joyce, D.B.; Smelik, E.A. and Wilkinson, M.A. "Production of solar-grade silicon by refining of liquid metallurgical-grade silicon "AIP Conference Proceedings; Journal Volume: 462; Journal Issue: 1; Conference: 15. National Center for Photovoltaics program review conference, Denver, CO (United States), 9-11 Sep 1998; pp. 731-736.
5. Europeon community commission research "Strength,Weakness,Opportunities and Threats in Energy Research, , Directorate-General for Research Sustainable Energy Systems 2005. EUR21612.
6. M.A. Martoranoa, J.B. Ferreira Netob, T.S. Oliveiraa and T.O. Tsubakib "Refining of metallurgical silicon by directional solidification" Materials Science and Engineering B 176 (2011) 217–226.
7. R.A. Hossain a,*, M.A.K Chowdhuri b and C. M. Feroz " Design, Fabrication and Experimental Study of Heat Transfer Characteristics of a Micro Heat Pipe" Volume 4, Number 5, November 2010 Pages 531- 542, Jordan Journal of Mechanical and Industrial Engineering.

8. Gianluca Coletti "Silicon can Power the world " (silicon chunk image courtesy of solar world A.G)" Impurities in silicon and their impact on solar cell performance, 2011.
9. Solar Generation 6 , 2011, Solar Photovoltaic Electricity Empowering The World, 2011, GREEN PEACE, EPIA.
10. Ying Guoi Alan L. Porterii and Lu Huangiii, " Nanotechnology-enhanced thin-film solar cells: analysis of global research activities with future prospects" IAMOT 2005
11. Jawaharlal Nehru National Solar Mission Towards Building SOLAR INDIA, 2009.
12. F.Sheriff, D.Turcotte and M.Ross, "A Comprehensive set of PV system component for the MATLAB/SIMULINK Environment", SESCI 2003 Conference.
13. Nieves Espinosa , Rafael García-Valverde and Frederik C. Krebs "Life-cycle analysis of product integrated polymer solar cells" ***Energy Environ. Sci.***, 2011, **4**, 1547-1557.
14. A. Aulich, F-W Schulze "Silicon Supply for Solar PV" 13thWorkshop on Crystalline Silicon Solar Cell Materials and Processes PV Feedstock Costs—Five Year OutlookH., Renewable Energy World, November, 2002.
15. Technology Road map Solar Photovoltaic Energy "International Energy Agency" OECD/IEA, 2010, IEA Publications,