Polysilicon production in India

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Polysilicon is the basic semiconductor material used in the manufacture of the most popular type of solar photovoltaic (PV) cells as well as the ubiquitous integrated circuit (IC) chips. With increased importance of renewable energy, the production of polysilicon globally has increased from hundreds to thousands of tonnes. Comparing the various available technologies, it is seen that single crystal and multicrystalline silicon cells comprise 87% of the market. This note provides comparative data of the production of polysilicon and PV modules in various countries. In spite of the importance of solar PV in the Jawaharlal Nehru National Solar Mission, India does not produce any polysilicon.

The Jawaharlal Nehru National Solar Mission (JNNSM)[1] has as one of its objectives 'domestic production of critical raw materials, components and products, as a result to achieve grid tariff parity by 2022'. The break-up is given in Table 1. Referring to photovoltaic (PV) power generation, the output projected is 20,000 MW by 2022. In the first phase a capacity of only about 4300 MW has been realized, mostly in Rajasthan and Gujarat. There are various PV technologies competing the world over. Figure 1 illustrates the relative market share of the competing technologies.

It is clear that the overwhelming technology (up to 87%) is that of single crystal and multi-crystalline silicon. These require the production of ultra-high purity polysilicon by an energy-intensive chemical process[2]. It is found that with current technology 1 MW of PV output requires 7–10 tonnes of silicon material. Although the second phase of JNNSM states a capacity of 15 MW for 'ingots and wafers', the startling fact is that India, aiming to be a superpower, does not manufacture even 1 kg of semiconductor-grade silicon. Tables 2 and 3 give the annual production capacities of polysilicon and solar cells by various countries as of 2011.

While China leads both the tables, small countries such as Korea and Taiwan have appreciable outputs competing with the likes of Germany and Norway. Does this not reflect the mistaken policies of the Indian government and industries alike? Recounting the history of PV history in India, in the late seventies the Central Electronics Ltd (CEL), Sahibabad was the pioneer in PV cell production based on single-crystal silicon with completely indigenous technology. This needs reiteration since the JNNSM website claims that silicon technology started with JNNSM. The production at CEL reached a few MW by the late eighties. B. K. Das (National Physical Laboratory, New Delhi) and the present author had written a status report[3] on multicrystalline silicon PV technologies at that time, but obviously this was put on a back-burner. The PV task force then made a crucial decision – they plumped for R&D investments in thin film amorphous silicon (a-Si) technology, to the exclusion of well-established crystalline silicon technology (c-Si). a-Si seemed to afford lower cost as it did not require single-crystal silicon wafers, albeit at lower efficiencies of 5–8% and while c-Si could deliver efficiencies of 14–16% at that time. What the so-called experts lost sight of was the degradation of the amorphous films under sunlight from 9% to 5% in a matter of months. Remedies proved worse than the disease, pushing up costs. Soon other thin films with efficiencies as high as 14–18% based on CdTe and CIGS came to the fore. As a result, amorphous silicon cells now account for only ~5% of the global production (Table 2), while crystalline silicon accounts for more than 87%. This disastrous choice in technology included importing a production line in Gurgaon, which had mechanical problems from the start. In electronics, technology changes so rapidly that organic solar cells (both small molecule and polymer) with flexibility and lower cost are now threatening to be the next 'killer' device as these have already reached 10% efficiency in small areas. In PV efficiency matters in more ways than one, because lower efficiencies will require larger areas for a given output and more maintenance, the area required for c-Si being ~3 acres/MW.

Table 1. Proposed manufacturing capacity in JNNSM (MW)

Component	Capacity (MW)
Ingots and wafers	15
Solar cells	848
Solar modules	1932

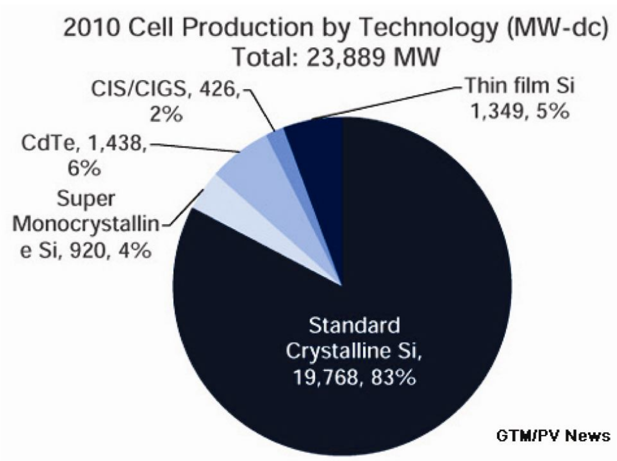

Figure 1. Break-up of global photovoltaic technologies.

Table 2. Polysilicon manufacturers country-wise

Country	Capacity (tonnes)
China	90,000
Korea	70,000
USA	58,000
Germany	33,000
Norway	19,000
Japan	9,200
Taiwan	8,000
India	0

Table 3. Global solar cell manufacturers, 2011

Country	Annual capacity (MW)
China	10,500
Taiwan	4,300
Korea	1,100

Polysilicon production[4,5] involves chemical processes using chlorination followed by fractional distillation to eliminate impurities such as B, P and As and metallic impurities down to less than 1 part per billion. Of the three common processes, the Siemens process involving hydrogen reduction of trichlorosilane ($SiHCl_3$) is the most popular. Others are the Union Carbide process utilizing cracking of silane (SiH_4), the third being the Ethyl Corporation process from silicon tetrafluoride (SiF_4). Energy, cost and purity of the polysilicon are prime considerations. Komatsu developed a process reacting ammonia with metallurgical-grade (MG) Si to produce silane, while Hemlock Semiconductors developed a process via dichlorosilane (SiH_2Cl_2).

In India, polysilicon production leading to Si wafers at a commercial level started at Mettur Chemicals in the mid-seventies and continued till the mid-eighties. The scale was limited to a maximum of 20 tonnes per annum, but production never reached more than a few tonnes/annum. Economies of scale required much higher production. Another drawback pointed out by the Department of Electronics (DOE) Review Committee was that the process involved silicon tetrachloride ($SiCl_4$) as feedstock, which required higher decomposition temperature and hence higher energy than trichlorosilane used in the conventional Siemens process. A plan to import technology from USA in the mid-eighties proved controversial and a non-starter. Considerable R&D was carried out at NCL, Pune and NPL, New Delhi, but these did not lead to technology transfer. Thus all Si device production at SCL, BEL, BHEL and ITI has depended on imported wafers.

Many in business and industry are satisfied with the present situation and say it is not worthwhile making large investments in a mature technology. Some incentives are necessary initially, as is the case in Germany and elsewhere to encourage public–private partnerships. Is a country as large as India with ambitions of becoming a global superpower, content to be a software and service-oriented society? Semiconductor technology in the form of PV energy conversion is also a potent weapon against global warming, since direct conversion of light into electricity is clean and pollution-free. It also requires little or no maintenance with silicon PV cells having a lifetime of at least 25 years. Now with the Chinese products in PV technology flooding the European market, quite a few large German firms have been forced to shut down. With large-scale production, the cost of solar PV energy has plummeted to less than US$ 1/W and is predicted to reach grid-parity in a matter of 3–5 years depending on location. The top five solar module manufacturers in the world are all Chinese, with a total production capability of 10.5 GW/per year. Till the mid-eighties India was ahead of China, but now China has gone way ahead. The total installed grid-connected PV capacity in India is estimated[6] to be 4500 MW, mainly in Rajasthan and Gujarat, compared with the annual production of 10,500 MW in China, which has much less solar insolation.

The recent budget presented approval for two factories producing 'silicon wafers' involving investment of over Rs 6300 crores. Rather than producing wafers, the factories will import them to fabricate ICs commonly known as silicon chips. While this may not be a constraining factor for IC chips because of the limited quantity of wafers required, it is a different story with JNNSM, where for 20,000 MW solar PV output by 2020, about 200,000 tonnes of semiconductor silicon will be required. Thin-film solar cells are expected to play a minor role. The Planning Commission and the government seem to be oblivious to the requirements of solar PV in the national perspective, forgetting the largest source of renewable energy in India. What the country required was not a nuclear deal, but silicon technology transfer.

1. Jawaharlal Nehru National Solar Mission data.
2. Polysilicon in India – Wikipedia.
3. Das, B. K. and Bose, D. N., Status report on multi-crystalline silicon solar cells, DNES, Government of India, 1988.
4. Runyan, W. R., *Silicon Semiconductor Technology*, McGraw Hill, New York, 1965.
5. Bose, D. N., *Semiconductor Materials and Devices*, New Age International, New Delhi, 2012.
6. Solar power in India. Wikipedia.

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