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Feasibility Analysis for c-Si PV Manufacturing in India

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Executive Summary

- India has set a target of deploying 100 GW solar power by 2022. Solar installations in the country primarily use Photovoltaic (PV) technology. It is estimated that 339-395 GW of solar PV will be deployed by 2040. At present, the domestic cell and module manufacturing capacities stand at approximately 3.2 GW and 8.4 GW, respectively.
- The existing manufacturing capacities are underutilised. The key reasons for this could be higher cost of manufacturing domestic modules (as compared to importing them) and missing upstream components (polysilicon, ingot/wafer) of the c-Si PV supply chain.
- This analysis suggests optimal requirements (of plant size, manufacturing processes, raw material procurement, financial incentives, etc.) to attain economies of scale and become price competitive for various supply chain components (polysilicon, wafer, cell, and module). The analysis is based on the conditions of a stand-alone and vertically integrated module manufacturing plants.
- The manufacturing cost of a module in a stand-alone and vertically integrated plant are INR 20.94/Wp and INR 18.94/Wp, respectively. An overall reduction of INR 2/Wp is seen in a module manufactured in a vertically integrated plant, as compared to one manufactured in a stand-alone plant.
- With economies of scale, assured market demand and quality assurance, Indian manufacturers can be more competent, globally. A vertically integrated plant will be of strategic importance to the country and help in job creation as well.

1. Introduction

Globally, efforts toward decarbonisation of the energy sector, via large-scale adoption of renewables, have witnessed the emergence of solar PVs as one of the key technology options, accounting for 47% of the total added capacity of renewables in 2016. According to a report by IRENA (The International Renewable Energy Agency), the cumulative global solar PV installations increased from 39 GW in 2010 to 312 GW in 2016, at a CAGR[1] of 41.4% (IRENA, 2017). As a consequence, the PV module production capacity increased from 46 MW in 1990 to 80 GW in 2016, which corresponds to a CAGR of 33%. Due to high growth in demand and economies of scale, production optimisation and improved efficiencies, the PV industry has experienced a significant decrease in the cost of PV systems (decrease by 85% since 2008), resulting in a decrease in investment required, despite a huge growth in installations, worldwide (Jager-Waldau, 2017).

Crystalline silicon (c-Si) is the most widely installed solar PV technology across the globe and is likely to have the largest share in the targeted installation of 100 GW of solar in India. Based on NITI Aayog's projections for PV installations, the capacity is estimated to reach 339-395 GW by 2040. Moreover, since the inception of the National Solar Mission, the module manufacturing industry has seen significant growth. The manufacturing capacities for cell and module had

[1] CAGR is Compound Annual Growth Rate

increased to approximately 3.2 GW and 8.4 GW in 2017 (from 45 MW and 80 MW in 2007), respectively. The PV supply chain is illustrated in Figure 1. Domestic manufacturing facilities of upstream supply chain components for c-Si PV, like polysilicon and ingot/wafer, are non-existent in India.

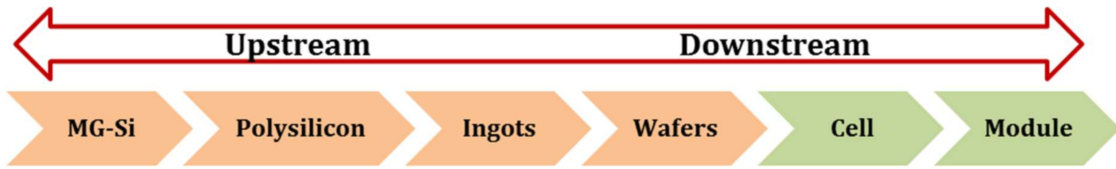

Figure 1: c-Si PV module supply chain

2. Solar PV Manufacturing in India: Current Scenario, Challenges and Future Outlook

The current module manufacturing capacity in India is sufficient to cater to the domestic demand, but the capacity utilisation is very low. A major reason for underutilisation is the low demand for domestic products due to higher cost (around 10-12% higher), as compared to that of imported modules. The high cost of domestic production may be attributed to the fact that raw materials used in making solar cells (wafers, metallisation pastes, etc.) are imported. Secondly, most Indian cell/module manufacturers operate at very small scales. Therefore, they cannot procure the raw material in bulk, which, in turn, increases the transportation cost and ultimately impacts the final cost of manufacturing (CSTEP, 2017). Another reason could be the higher capital expenditure made for the plants built before 2010. These plants were built with a very high capital cost (three times higher than current capital norms) and are burdened with high debts. Further, the old manufacturing lines have become inefficient and technology up-gradation costs are high. Given these challenges in the solar manufacturing industry, this paper tries to present the best business scenario to attain economies of scale and facilitate competitive PV module manufacturing in the country.

A techno-economic analysis was performed to see the impact of efficient manufacturing processes, lower raw material procurement costs and favourable policy incentives on the cost of module manufacturing. This analysis is divided into two cases: the first case analyses a hypothetical case of stand-alone manufacturing facilities for major components like polysilicon, ingot/wafer, cell and module of a c-Si PV supply chain. The second case studies the manufacturing of modules in a vertically integrated facility.

Case 1: Stand-alone Facilities for c-Si PV Manufacturing in India

The cell and module manufacturing plant capacities in India vary from 5 MW to 400 MW; however, based on global scenarios and discussions with experts from the PV industry, the minimum capacity for achieving economies of scale is 200 MW for module, cell and ingot/wafer, and 10,000 Tonnes Per Annum (TPA) for polysilicon manufacturing. These plants exhibit certain advantages like low raw material procurement cost, higher productivity and low inventory levels, as compared to smaller plants. Table 1 provides the assumptions[2] used in the financial model to calculate the costs of indigenous manufacturing.

Table 1: Assumptions for indigenous manufacturing and cost calculations in stand-alone facilities

Assumptions	Polysilicon	Ingot/Wafer	PV cells	PV modules
Capacity	10,000 TPA	200 MW/yr	200 MW/yr	200 MW/yr
Raw materials	Imported	Imported	Imported	Imported/local
O&M costs	1% of Capex	1% of Capex	1% of Capex	1% of Capex
Electricity price	3.6 INR/kWh	5.5 INR/kWh	5.5 INR/kWh	5.5 INR/kWh
Interest rate	9.0%	9.0%	9.0%	9.0%
Return on equity	13%	13%	13%	13%
Debt to equity	70:30	70:30	70:30	70:30
Life of plant	25 yrs	25 yrs	15 yrs	15 yrs
Capacity utilisation	90%	90%	90%	90%

Based on the assumptions listed in Table 1, the manufacturing costs (per Wp/Kg) for modules, cells, ingot/wafers and polysilicon plants have been calculated. The cost of various components for stand-alone facilities are listed in Table 2.

Table 2: Total project cost calculation for various components

Components (INR/crore)	Polysilicon	Ingot/Wafer	PV Cell	PV Module
Land & Development	20	13	9	7
EPC costs	2470	260	286	16
Other costs (Pre-op, WC Margin, IDC)	477	23	29	16
Total project cost	2967	296	324	39

The financial model provides the manufacturing costs as an output. These calculations represent a typical business case with optimal requirements of a module and cell manufacturing plant. Figure 2 shows the break-up of various cost components in a module. The module cost is calculated to be INR 20.94/Wp. In the overall module cost, raw materials such as cell and Balance of Module (BOM) components have the biggest share (92%), out of which the cell contributes 60%. Module manufacturing is a working-capital intensive industry and raising working-capital is a challenge sometimes.

Similarly, calculations reveal that the costs per Wp for cell manufacturing is around INR 14.96/Wp. 80% of the total cost is attributed to raw material costs. Within this, the share of the cost of wafer is around 56%, and wafers are imported. Figure 3 shows the cost share of various components included in the total cost of cell manufacturing.

[2] These assumptions are based on literature review and stakeholder interviews.

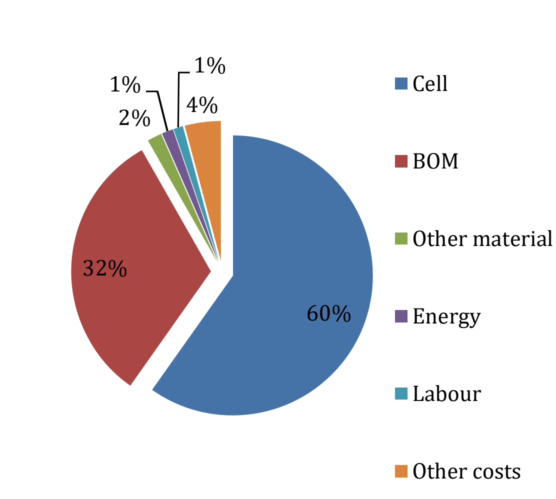

Figure 2: Module manufacturing costs

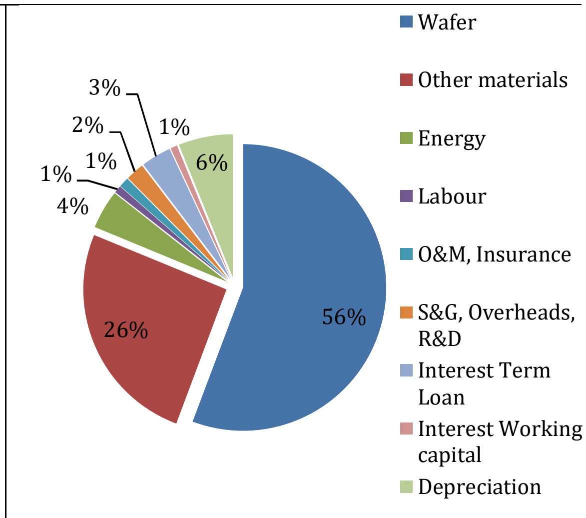

Figure 3: Cell manufacturing costs

For wafer manufacturing, raw materials account for 66% of the cost share, which includes 38% for polysilicon and 28% for other materials. Other significant cost components are energy, depreciation and labour. According to calculations, the Wp cost of a wafer is INR 8.50/Wp. Figure 4 provides the detailed cost share of each component in the overall cost of manufacturing wafers.

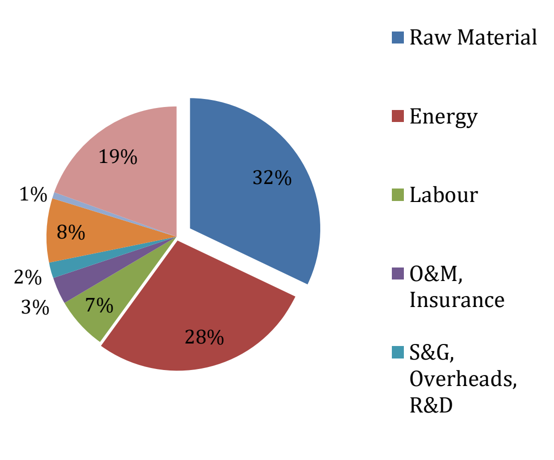

Figure 4: Ingot/Wafer manufacturing costs

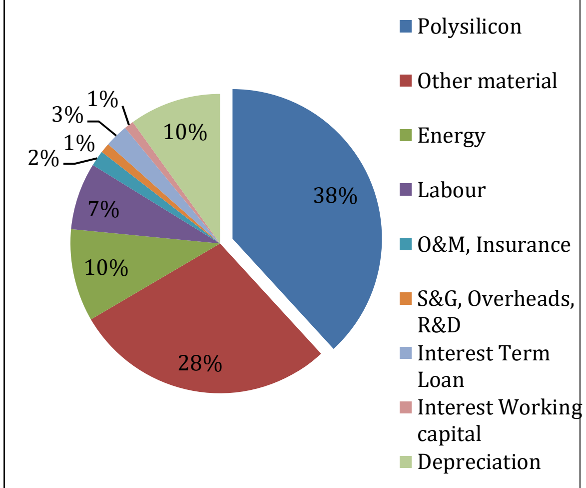

Figure 5: Polysilicon manufacturing costs

A polysilicon plant of 10,000 TPA capacity can produce around 2.4 GW of PV modules per annum. The plant typically uses Trichlorosilane (TCS) Siemens CVD[3] technology to manufacture polysilicon. With these assumptions, the cost of domestically manufactured polysilicon is estimated to be around INR 823/kg. Raw materials contribute 32% of the overall cost, followed by energy costs (28%) and depreciation (19%), which are the other major cost components. The cost break-up is given in Figure 5.

[3] Chemical Vapour Deposition

With the given scale of manufacturing, raw material procurement becomes economical and the workforce can be better optimised, which leads to a lower cost of production.

Case 2: Vertically Integrated Manufacturing Facility

A vertically integrated manufacturing plant includes both upstream and downstream supply chain components, beginning with polysilicon and ending with a finished module (please refer to Figure 1).

The current policy scenario suggests that a vertically integrated facility, where production begins from polysilicon, is likely to be a strategically key option for India. Since metallurgical grade silicon is a global commodity, manufacturing it in India will not be economical. Therefore, in this analysis, a 2000 MW module manufacturing plant has been considered where metallurgical grade silicon is imported. The capital cost for this plant would be about INR 9500 crore. This plant would have certain advantages over a stand-alone manufacturing plant like reduction in overhead costs, lesser sales risk in upstream components, reduction in total capital cost, better control on operations, low inventory costs, competitive advantage, etc.

In this plant, it is assumed that the TCS Siemens technology, with a capacity of 10,000 TPA, will be used to manufacture polysilicon and the DSS[4] process will be used to make the ingots. Further, diamond saw wire technology will be used to cut the ingots into wafers. For cell manufacturing and module assembling, semi-automated facilities have been considered.

The assumptions used in the financial model to calculate the module manufacturing costs in a vertically integrated plant are detailed in Table 3.

Table 3: Assumptions used in manufacturing-cost calculations

Category	Amount
Manufacturing capacity	2000 MW/yr
Land required	400 acres
O&M costs	1% of capital cost
Energy costs	3.6 INR/kWh
Interest rate	9%
Return on equity	13%
Debt to equity	70:30
Life of plant	15 year
Capacity utilisation	90%
Capital cost	~INR 9500 crore

Figure 6 provides the cost break-up for various components used in a module. Significant reductions in capital costs, raw material procurement costs, labour costs, etc. are seen in a vertically integrated plant. Around 67% of the cost share is attributable to raw materials in the overall cost of modules, followed by financing (15%) and labour costs (12%).

[4] Directional Solidification System

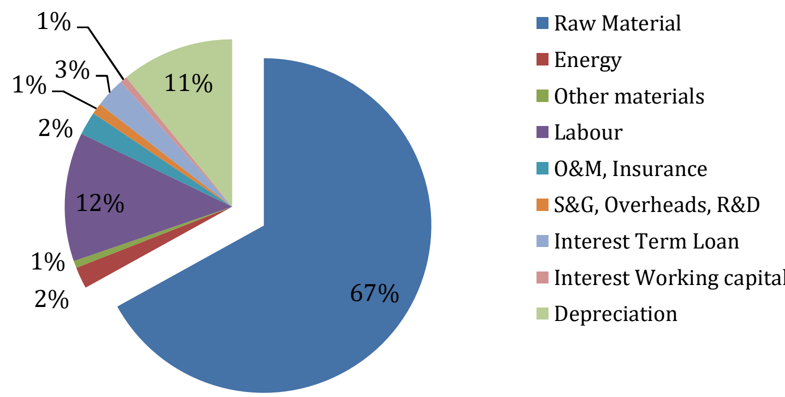

Figure 6: Cost share of various components

Calculations show that the module manufacturing cost is INR 18.94/Wp in a vertically integrated plant. An overall reduction of INR 2/Wp is seen in a module manufactured in a vertically integrated plant, as compared to one manufactured in a stand-alone plant. Other than cost competitiveness, vertical integration ensures self-reliance in terms of procurement of upstream supply chain sector.

The two cases described in the previous sections were further analysed to understand the changes in India's manufacturing costs under various scenarios, like manufacturing modules for domestic content requirement (DCR) category , and stand-alone and vertically integrated plants versus the Chinese modules. In the DCR scenario, wafers are imported and cells are made domestically. In a stand-alone plant, cells are imported and modules are made in India, whereas, in a vertically integrated scenario, metallurgical grade silicon would have to be imported and all the other components would be manufactured domestically. Figure 7 provides the comparison between modules manufactured under DCR category, in a stand-alone (SA) facility and in a vertically integrated (VI) plant. Also, the cost of domestically manufactured modules is compared with the cost of imported (Chinese) modules.

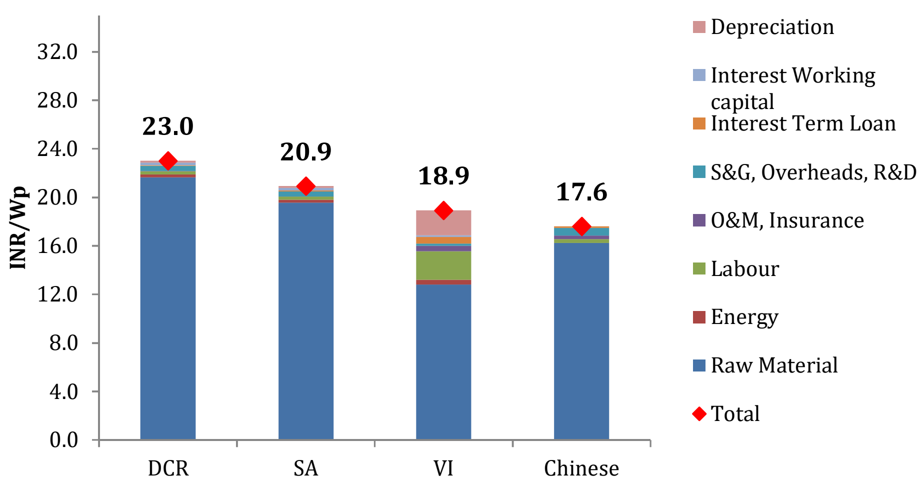

Figure 7: Cost comparison of domestic modules under various scenarios versus Chinese modules[5]

[5] DCR and SA represent a manufacturing capacity of 200 MW each, whereas VI is 2000 MW

China has always dominated the Indian module market. In last year's installations, around 85% of the installed modules were imported from China (Bridge to India, 2017). Considering that they have more than 80% of the global market share for wafers and more than 65% of the market share for cells, there is a possibility of market manipulation because Indian cell manufacturers currently import wafers. Therefore, in order to avoid a situation of market manipulation, the Indian government or industry should actively consider indigenisation of the upstream supply chain components.

Given the fact that the manufacturing of polysilicon is very capital and energy intensive, and importing polysilicon is not a major problem, as it is available with several countries (Korea, Germany, and the US) other than China, the immediate focus of domestic manufacturers should be on the backward integration of wafer manufacturing. In addition, a wafer manufacturing industry will provide India with the scope for polysilicon manufacturing in the future. Also, Indian manufacturers can adopt advanced and efficient technologies to gain an upper hand in the global market. For example, the recent technology (diamond wire saw) of ingot slicing is more efficient as compared to the conventional slurry-based technology.

3. Policy Suggestions

The following policy suggestions can help the industry, investors and policy makers in taking informed decisions pertaining to investments required for solar manufacturing in India:

- Assured market demand for domestic modules will help to reduce the cost of inventories for new manufacturers and ultimately, lower manufacturing costs
- Special funds in the form of production subsidies should be provided for working capital requirements
- Indian certifications can make a level playing field for Indian companies to compete in the domestic market as Chinese manufacturers will have the added expenditure of getting their modules certified in India
- Attractive financing options from the government may be provided for backward integration of the missing upstream supply chain components (e.g. polysilicon/ingot/wafer), to achieve self-reliance and strengthen the value chain
- Polysilicon manufacturing is a capital and energy intensive process, therefore, assurances to provide low cost financing and electrical power at cheaper tariff can promote polysilicon manufacturing in the country
- Capital subsidy, through the Modified Special Incentive Package (MSIP) Scheme, should be implemented on priority. Early disbursal of capital subsidy will also support the manufacturing sector. The benefits of this Scheme is currently limited to cell and module manufacturers only, but it may be extended to balance of module components (materials like Silver Paste, EVA, Backsheet, Solar and Glass manufacturers)
- Technology up-gradation funds can be facilitated to upgrade the tools for cell and module manufacturing on a continuous basis
- Anti-Dumping Duty or Safe Guard Duty, to an extent of 15-25%, to facilitate a level playing field for the Indian solar PV manufacturers (polysilicon to modules) should be implemented

- Implementation of a uniform GST tariff rate of 5%, not only for solar power generation equipment, but also for the BOM and all other inputs, will enable manufacturing costs to be at par with the imported equipment
- Facilitation of networking amongst government, industrial sector, academic and research organisations, to strategise on areas such as technological innovation, manufacturing process optimisation, manpower training, etc.

4. Concluding Remarks

This analysis presents the findings from two cases, i.e., stand-alone and vertically integrated manufacturing plants for modules. For the stand-alone facility, a techno-economic feasibility assessment of manufacturing modules, cells, ingot/wafers and polysilicon showed the various factors that would help attain economies of scale[6] and enable India to become globally competitive. A module manufactured in stand-alone facility will cost around INR 20.9/Wp, whereas in a vertically integrated plant, the cost will reduce by INR 2/Wp.

For a sustainable and indigenous PV manufacturing industry in India, it is important to support the existing domestic module and cell manufacturers via mandatory Indian certification for imported modules and reasonable financing to reduce the cost of balance-of-systems. Another important step is backward integration of missing upstream components like wafer and polysilicon manufacturing, or establishing vertically integrated facilities. In addition to growth in demand and economies of scale, cost reduction in mature technologies like c-Si PV can be achieved through optimisation and innovation at every stage of the manufacturing process.

5. Acknowledgements

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6. Bibliography

1. Bridge to India. (2017). *India Solar Handbook.* Delhi: Bridge to India.
2. CSTEP. (2017). *State-level Policy Analysis for PV Manufacturing in India.* Bangalore: CSTEP.
3. IRENA. (2017). *REthinking Energy 2017: Acceleratiing the Global Energy Transformation.* Abu Dhabi: International Renewable Energy Agency.
4. Jager-Waldau, A. (2017). Snapshot of Photovoltaics- March 2017. *Sustainability*, Vol-9, Page- 783.

[6] A manufacturing plant with 200 MW capacity can optimise manufacturing processes, raw material procurement, labour costs, etc.