

Policy Paper
on
Solar PV Manufacturing in India:
Silicon Ingot & Wafer - PV Cell - PV
Module



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Preface

Government of India's commitment to provide access to energy and electricity to all by 2030 necessitates a multi-pronged approach to look into the generation options on the supply side, along with demand-side management. As of April 2018, 100 % electrification of villages has been achieved, as per Ministry of Power. However, around 22 million households (equivalent to about 130 million people) still need to see the glow in their homes. India has also declared to achieve 40% of its cumulative electric power installed capacity from non-fossil fuel sources by 2030 as a part of nationally determined contributions under Paris agreement in 2017 to contribute to global efforts of limiting rise in atmospheric temperature to 2 degrees. Solar capacity additions have emerged as one of the most important component of this strategy, and therefore, a focus on establishing manufacturing base in the country assumes huge significance.



Looking at current manufacturing base through the lens of requirements to meet targets for solar capacity addition, there appears to be urgent need to put manufacturing infrastructure in place so as to be able to pursue implementation of national solar programme without having threat from international fall outs. This is also befitting to the vision of India to be a global solar leader. This report analyzes issues and brings out a perspective to establish ingot-to-wafer-to-cells-to-modules in the country in a phased manner with a clear vision of achieving 15,000 MW full value chain solar modules manufacturing capacity in the country. This vision is coherent with Government of India's goal to accelerate domestic industrial production through 'Make in India' program. I am sure that the concerned government departments will find it useful to make realize the national solar dreams.

A handwritten signature in black ink, appearing to read 'Ajay Mathur'.

Ajay Mathur

Director-General, The Energy and Resources Institute (TERI)





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Manufacturing of solar PV in India

With a national goal of 100,000 MW of solar power by 2022 and continuing the growth trend beyond to be able to achieve 40% of non-fossil fuel power, creation of domestic manufacturing base assumes critical significance. Leveraging the size of domestic market is one of the key strategies adopted world over and China has used it to emerge as the global manufacturing hub for various articles including solar. Power being the state subject, procurement by the Government agencies have always played significant role in developing the market and establishing procurement strategies, and it is very much proven in case of solar.

With the launch of National Solar Mission in 2010, a beginning was made by the Government to require bidders to use domestically manufactured solar PV modules in first ever solar bid of 150 MW, except for thin film and Concentrator PV technology for which there was no credible manufacturing base was available in the country. The stipulation was further strengthened in the second bid of 350 MW to require bidders to use only the domestically produced solar cells and modules, instead of just modules which can be produced using imported solar cells. Indian manufacturing industry met these requirements in terms of quantity and quality, and the projects set up through these bids are reported to be working as per requirements. Later, schemes were launched to reserve 50% of the bid capacity for domestically manufactured solar cells and modules while allowing balance 50% capacity to be set up using imported modules. Differentiated provision to provide viability gap funding (VGF) with lower amount for open category was stipulated to provide generated power at the same pre-fixed tariff from both the categories.

However, this was challenged by the US successfully in the World Trade Organization (WTO) who viewed it not as a government procurement (which is outside the purview of any of international commitments of the Government of India) but a commercial transaction. In view of this the process of bringing tenders with reserved capacities for domestic capacities was stopped, but some avenues were created under the category of Government procurement in the form of special schemes for CPSUs, defence sector and roof top solar projects.

In this background, the moot question is to explore options to support domestic manufacturing of solar modules in a manner which is viable commercially.

Migration of global solar PV manufacturing

Overview of global solar PV industry and its evolution

80% of the world's primary energy supply comes from fossil fuels, primarily oil and coal. Alternative energy source are needed as fossil fuel resources are limited and their use is associated with a number of negative environmental effects – such as global climate change and air pollution. The Inter-governmental Panel on Climate Change (IPCC) estimates that about 70% of all greenhouse gas (GHG) emissions world-wide, particularly carbon dioxide (CO₂) emissions, come from energy-related activities. Avoiding dangerous climate change and staying below a 2 °C warming requires cutting global emissions rapidly.

Among the various renewable energies, solar photovoltaic (PV) has garnered the most excitement in the recent years due to its rapid technological maturation leading to the sharp decline in its generation cost. Governments, communities, emerging markets, and corporations increasingly understand that renewables are sustainable and affordable (even without subsidies), and they want them included in current and future procurement plans.

For about five decades since 1954, solar PV systems have predominantly been installed off-grid for decentralised use, and employed extensively in spacecraft and satellites. While the technology is not new, the large-scale installation of solar PV is a relatively recent development globally, which dates to the late 1990s. Germany was the first country to provide support for investments in renewable energy through the introduction of feed-in tariffs (FIT) in 1990. Since the early 2000s, the world market for PV has grown exponentially, mainly driven by industrialised countries, notably Germany, Japan, Spain and the United States, as well as China. By 2017, 173 countries had introduced policies to support investment in renewable energy through FIT and other support schemes.

During 2009-2018, ten-year period, cumulative installed PV capacity has grown at an average rate of 40% per year. The year 2014 saw the confirmation of a trend which has started in 2013: the formerly European centric solar power market became truly global with rapid deployments in Asia and America, Africa and Latin America. By the end of 2018, cumulative PV capacity has crossed the level 500 GW, which is sufficient to supply



2.6% of world total electricity consumption. As can be seen in Figure-1 below, the growth projections for solar, it can be seen that the present PV market has just begun its growth.

The leading trio – China, the United States and India – will comprise 70% of the projected solar capacity, which will be added between 2019 and 2027. A continued strong decline in PV module Average Sale Prices (ASPs) has spurred greater demand in India, the Middle East, and North Africa. In addition, International Solar Alliance (ISA) has been launched with an aim to help developing solar programmes in the sun-belt countries through

demand aggregation and implementation. In view of this, the solar market is likely to continue growing at a rate exceeding 150 GW/yr in the near future. The Table 1 below presents the cumulative PV in various regions during the past 10-years.

Cost of solar equipment declined significantly due to improvements in technology and economies of scale, even more so when production of solar cells and modules started to ramp up in China. In terms of prices, utility-scale solar has reached price parity in all leading markets. When it comes to self-generation, commercial solar has reached unsubsidized socket parity in parts of all the top

Solar Energy will grow from 2% of global electricity generation today to >10% d 2030

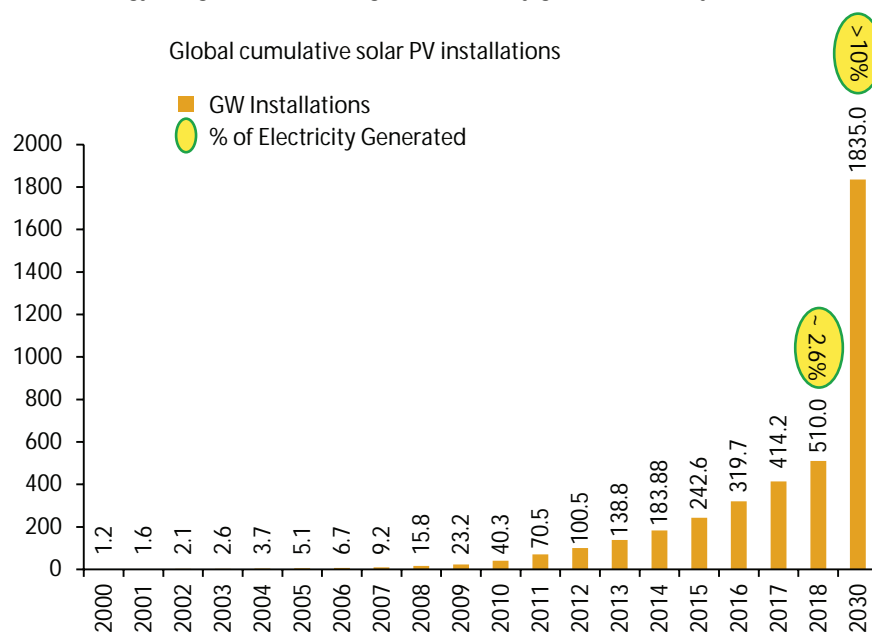


Figure 1: Global cumulative solar PV installations (GW)

Table 1: Growth in world installed solar PV capacity (in GW)

| Region | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|----------------------|------|------|------|------|------|------|------|------|------|------|------|
| North America | 1 | 1 | 2 | 5 | 8 | 13 | 20 | 30 | 45 | 58 | 74 |
| Europe | 11 | 17 | 31 | 53 | 71 | 81 | 88 | 95 | 98 | 105 | 116 |
| Japan | 2 | 3 | 4 | 5 | 7 | 14 | 23 | 34 | 43 | 50 | 54 |
| China | | | 1 | 3 | 8 | 18 | 29 | 44 | 78 | 131 | 176 |
| India (FY) | | 0 | 1 | 2 | 3 | 3 | 4 | 7 | 13 | 22 | 29 |
| Rest of World | 2 | 2 | 3 | 3 | 4 | 9 | 19 | 32 | 43 | 48 | 65 |
| Cumulative TOTAL, GW | 16 | 23 | 40 | 71 | 101 | 139 | 184 | 243 | 320 | 415 | 512 |

Source: IEA PVPS Annual Report 2017, AVCL In-house Data

solar markets that are at grid parity; while incentives such as tax credits and net metering have made residential solar PV competitive in many markets.

As the deployment of renewable energy continues to expand globally, driven by various inputs, such as capital allocation and investment, falling capital costs, competitive LCOE and various policy mechanisms, we are now moving towards a new era for renewable energy. 'Renewables 2.0' will have significant, wide-ranging consequences for all market players, as regulators reduce their support and power producers seek new revenue models. The tipping point, where the world shifts from oil and gas to renewables, could be the year 2035. This is when renewables and electric-based technologies converge, with around 20% of global power needs being met by solar or wind, and roughly 20% of miles travelled by cars, trucks, buses and bikes using electricity.

The increased investment in renewables has also enabled equipment manufacturers to achieve increased economies of scale. This has brought down the capital cost to build solar PV projects by 68%, between 2010 and 2017. Together with economies of scale, improved production processes have cut the number of defective cells produced and thus improved yields contributing to further cost reductions.

PV manufacturing: Strategies of various leading countries

The breakthrough production of the world's first silicon photovoltaic (PV) cell occurred in 1954 at Bell Laboratories. Since then, the Solar PV technology has been developed and advanced over many decades, through state-regulated monopolies and government initiatives.

Since the early 2000s, the solar PV market has grown exponentially, notably in Germany & EU countries (through Feed-In-Tariffs) and in the United States (through Tax Credits & other incentives). That kicked off a competition for silicon between the emerging solar panel makers and chip companies. The result: a silicon shortage that lasted several years. At one point, the price of silicon skyrocketed from \$200 per kg in 2007 to \$500 per kg by the following year 2008. However, many of the European and US PV manufacturing companies, couldn't make investments for scaling up of silicon & PV Manufacturing plants due to the tech bubble of 2000 (scaled-up capacities in semi-con sectors were suddenly found redundant without any takers); the Lehman crisis of 2008 only added to the reluctance for any scale-up in Solar PV manufacturing.

Hence, during this period (2000-2008) of High Demand vs Extreme financial caution, the early pioneers of PV industry, i.e. Germany, USA, Japan & India, chartered different paths to capture the solar pinnacle over the next 10-years, with unexpectedly disastrous results (in hind-sight). On the other hand, the challenger China and neighbouring SE Asian countries (Taiwan, Singapore, Malaysia, Vietnam) followed a more aggressive and co-ordinated approach to succeed.

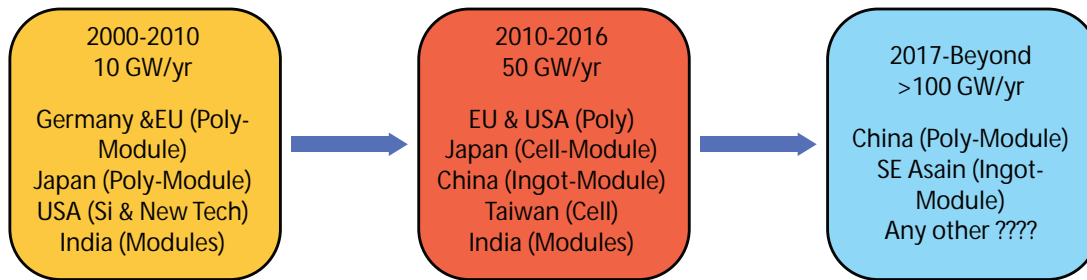
Germany PV manufacturing: boom to bust

The strategy of high level of automation in manufacturing, with little focus on cost reduction and scale-up led to the fall of the mighty German solar PV manufacturing.

- Germany was one of the first European countries to promote renewable energy in 1991 through Grid Feed-In Law, revised later in years 2000, 2004 and 2014. Under these laws & act, Germany's renewable energy industry boomed, and in short term by 2004, the industry growth had reached 100%; and long term growth as high as 40% CAGR, as solar had become profitable due to the above market feed-in tariff investors received for producing excess clean energy.
- Q-Cells, a German manufacturer of solar panels, saw its revenues growing from 17.3 million euros to 299.4 million euros in three years 2002-2005. Conergy, a German PV manufacturer and EPC firm, saw its sales increase by 132% in 2004 alone. Similarly scores of other companies have grown during the early 2000 period. The subsidy-fuelled rapid growth of the German solar industry continued for several years and was further encouraged by a significant transition in Germany's energy policy that was passed in 2011.
- As Germany's (and also EU's) solar industry continued to grow, China's solar market dropped world solar panel prices by 80% between 2008 and 2013. This generated a cascading effect of lower panel prices leading to phasing out subsidies. Germany's solar industry experienced a surge of insolvencies. For example, Gehrlicher Solar, a distributor of PV components for solar projects, reported \$415 million in revenues in 2011, but by 2013, they filed for bankruptcy. Both previously mentioned companies, Q-cells and Conergy also filed for insolvency in 2012 and 2013, respectively. By 2014 all other companies like Bosch, Schott solar and many others in EU zone have also went out of business. Solar World and the few were left, which went bust recently.



MIGRATION OF SOLAR PV MANUFACTURING



MIGRATION OF PV MANUFACTURING EQUIPMENT SOURCES

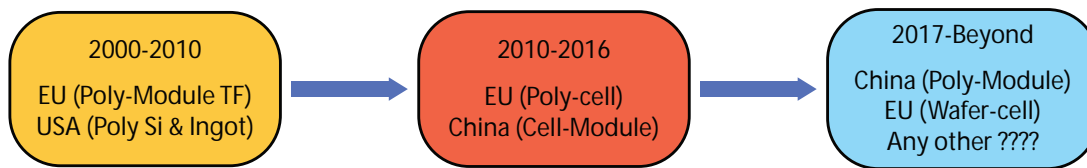


Figure 2: Migration of solar PV manufacturing over the decades

- To support the PV manufacturing industry, the EU has introduced import restrictions on Chinese PV Cells & Modules through Minimum Support Price controls. But despite these import restrictions, European PV Module manufacturing capacity had fallen from 6.9 GW to 3 GW. So, this “learning” can not to be ignored by other countries.
- There are still handful smaller module manufacturers left. But successful manufacturers need large peers for sustainability, quality and technological advancement. In recent years, almost all technological advances came from Europe, but they still lost the leadership as they do not put the results on the market in a timely manner.
- European Photovoltaic Industry Association (EPIA) believes that PV production including wafers, cells and modules is competitively possible in Germany; and in 2018 called on Europe to set up 5 GW of solar PV module manufacturing capacity to cater to the likely 15 GW of annual demand. Problem in financing major new production in Europe is that manufacturers need direct and indirect support; a level playing field; a policy framework by relaxing state aid laws, more accessible financing and land acquisition, low energy costs and less red tape and the removal of minimum import price. Over 35 leading EU solar industrial players are said to backing the call, including Wacker, SMA, Total, Weidmuller, Voestalpine, SolarWatt, ABB and Enel.

USA PV manufacturing: debacle due to focus away from Si

- Around 2000, a turning point came as California suffered a series of blackouts, after energy traders manipulated the energy market to create a power shortage and inflate electricity pricing, the federal government created tax credits and other incentives to promote renewable energy.
- The resultant skyrocketing price for silicon represented a big opportunity for venture capital investors, who pumped billions of dollars into new tech companies to develop cheaper alternatives for making solar cells. Silicon Valley became a hub for start-up companies flush with cash. Some of the high-flying Silicon Valley start-ups at that time included SoloPower, AVA Solar and Nanosolar, each of whom raised more than \$100 million. The U.S. government also threw a lot of support behind solar companies as part of its broader effort to boost job growth and promote low-carbon technology. It created programs to give grants for research and loan guarantees to help solar companies secure loans for building solar panel factories and solar power plants.
- Focus was shifted from crystalline Silicon to many new technologies for reducing the cost rather than on scaling up of existing Si based manufacturing facilities. Many of these newcomers commonly resorted to the use of new materials to create “thin-film” solar cells.

- Two things happened which destroyed the dreams of these entrepreneurs and investors : (i) Makers of silicon in China expanded their production, ended the shortage, and significantly lowered the price of silicon well before many of the thin film solar tech start-ups figured out how to manufacture their technologies cheaply. (ii) The 2008 global financial crisis shook up the young solar thin-film market. By 2012, dozens of companies had filed for bankruptcy or sold for pennies. The financial market turmoil made it difficult for power project developers to borrow money, leading to a crunch in demand for domestic solar panels, a price war among solar panel makers, and layoffs and factory shutdowns by companies such as BP Solar—all before the end of 2009.
- Post Lehman-crisis, when the United States and other countries began implementing legislation to stimulate economic growth, including an extension of a key federal tax for renewable energy, Chinese manufacturers built up giant fleets of factories and stood ready to offer solar panels at lower prices than many of their competitors. All this expansion in China led to an oversupply of solar panels by 2011 and prices tumbled 50% in 2011 alone. This led to growing resentment towards Chinese companies.
- SolarWorld filed a trade complaint, against Chinese solar companies, and won a decision in 2012 to impose tariffs on silicon solar cells from China. Despite the trade barriers like Section 201, many of the high-profile US PV Manufacturing companies like SunEdison, Solyndra, Evergreen, Suniva (unique cell design), Megacell filed for bankruptcy. Sunpower (Ultra High Efficiency IBC panels) struggling to stay afloat with losses accumulating in the past 3-quarters of 2018.
- First Solar (CdTe) is the only company in the global Top-10 Module supplier, competing with improving Chinese technology as well as dropping prices, more because of its locational advantages in Malaysia & Mexico.

Japan

The Japanese government was already ahead with success in electronics and semi-conductors, and therefore they concentrated their efforts on Ultra High Efficiency Cells & Modules catering mainly to the domestic & global niche roof-top markets. Further, to protect the domestic industry, during 2010-2015, formal (quality approvals) & informal (nationalistic) trade barriers were imposed. However, by 2018, the niche high efficiency products also could not compete with the Chinese products and the manufacturing declined.

India

During the period 2007-2015, India introduced slew of measures to grow the solar PV Manufacturing: (i) SIPS capex incentive : Companies under this scheme were not benefitted as incentives under these schemes could not be disbursed (ii) Introduced Domestic Content Requirement in JNNSM Phase-1 : Little benefit to industry due to skewed pattern of allowing Thin Film imports. Subsequently, WTO objections led to the withdrawal of the scheme; (iii) Reserving capacities with higher VGF.

India introduced revised measures in 2018 : (a) Safeguard Duty on imports of PV Cells and Modules - the resultant increase in project costs led to slowdown of Indian PV Market coupled with the crash of cell & panel prices - little benefit to the Indian industry; (b) Mandatory BIS certification (c) Registration of Cell & Module companies with MNRE. India has been heavily dependent on Chinese imports for implementation of its solar program.

Taiwan PV sector growth strategy

Initial learning from European turn-key lines provided the basis for gradual capacity expansions. Cell production has been the raison d'être of the Taiwan manufacturing community since 2006 (synergies to Semiconductor expertise). Taiwan cell manufacturing was widely considered to be professionally operated, processing-savvy, and quality-output guaranteed. Cells flowed in abundance to overseas markets, both to pure-play module producers globally, but also as essential third-party cell supply to leading integrated Chinese module suppliers. For a few years, Taiwan led the way with process-related improvements to multi casting and the quality of the bricks produced was the envy of every multi c-Si producer in China.

Taiwanese manufacturers enjoyed a period of relative success in 2012 and 2013 on the back of the US & EU trade disputes with cell shipments hitting record highs, this changed (i) in 2014, when the US closed a loophole allowing Chinese manufacturers to avoid tariffs by using cells manufactured in third countries; with the primary effect was to stem the tide of dumped solar products in the United States; secondary impact saw Chinese solar companies revert in their droves to their domestic market, resuming the production of cheaper, home-made solar cells for sale to the U.S. market; (ii) in 2018, China's 531 impacted Taiwan PV industry by increasing cost pressures. These led to a serious consolidation phase, which will be difficult to reverse. While many Chinese solar companies could afford to navigate the U.S. Anti-

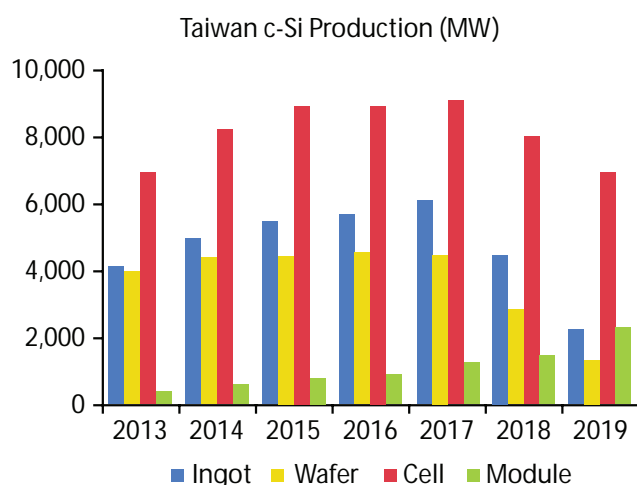


Dumping tariffs, higher costs in Taiwan meant the U.S. market was prohibitively expensive for all the Taiwan companies. The Challenges faced by the Taiwan PV Manufacturing include:

- Ingot & Wafer production: Today ingot & wafer production in Taiwan has no technical advantage compared to lower-cost channels available within China, despite spending and efforts moving multi wafering to diamond-wire saws and to 'black-silicon'. It is argued that there is a strong possibility that this part of the value-chain will disappear entirely by 2020.
- Similarly, the cell and module segments have seen falling utilization rates, beginning with the multi c-Si segment.
- Taiwan industry blames China's new PV subsidy policy, and the US-China trade war; EU and US anti-dumping, the rise of the Chinese pure-play entrants, and the LONGi-mono effect, for the difficult situation of its solar business
- While companies have four options open to them to respond to the new market dynamics – upgrades to enable poly black silicon cells; produce quasi-mono-Si ingots; turn to mono-Si wafers; or exit the business – none are attractive for Taiwan makers, due to either tighter environmental protection standards, or for financial reasons. Taiwanese producers are having financial troubles embracing n-type Heterojunction Intrinsic Thin Film (HIT) technology and, consequently, are not able to remain competitive.

Strategy to stay relevant:

1. Long-term stable government policy for solar deployment in Taiwan: It aims to install 20 GW of solar PV by 2025. This measure will help the domestic PV Manufacturing companies.



2. Certification: Taiwan put in place a remarkably simple process "local factory auditing pre-requisite", which should enable Taiwan companies to benefit. For projects to qualify for the top-up FIT incentive rate, modules used must receive local certification which requires a factory audit that appears to be confined to Taiwan only. Preference for Taiwan-companies making Taiwan-modules for Taiwan-projects is possibly the overarching safety net.
3. Government is extending financial support by direct investment in manufacturing companies.
4. Manufacturers rationalising the Technology/ Operations / Business:

Technology Changes: A significant portion of multi capacity will be permanently retired until the cell landscape is stabilized with competitive technology (performance and cost), like Mono-PERC. Sino-American Silicon, (SAS) is considering exiting the wafer business.

Business Revamping: The modus operandi is to move quickly from merchant cell producer to flexible power plant enabler. Neo Solar, Gintech and Solartech completed a merger to form UREC with capacity of 4.5 GW Cells & Modules. They made the full transition from p-multi to 100% p-mono PERC; vertical integration Ingot-to-downstream solar PV. GET is entering the downstream module manufacturing.

Downstream Expansions: Taiwan Solar 2.0 will see changes whereby modules will become a major focus in the country, resetting the focus from Wafer & Cell to module revenues. Taiwanese manufacturing costs are much higher than Chinese cell makers. So, the strategy of companies going to downstream is seen as a good strategy.

CHINA PV sector growth

China leads the renewable energy field globally in terms of investments, installed capacity and manufacturing. The Chinese government has supported R&D on solar PV since the 1950s. By the mid-1990s, China's PV module manufacturing capacity was 5 MW, much of this capacity did not meet modern international standards and actual production was only 1.4 MW. The timeline of China's rise began in the late 1990s when Germany, overwhelmed by the domestic response to a government incentive program to promote rooftop solar panels, provided the capital, technology and experts to lure China into making solar panels to meet the German demand. When Spain and Italy began their own rapidly expanding solar

incentives, adding to the demand, the Chinese took it and basically ran with it.

Boosting solar PV manufacturing became part of core government strategy since the early 2000s, with belief that those who moved fastest in the transition to a low carbon economy were likely to gain a significant competitive advantage. China's dominance of nearly all aspects of solar use and manufacturing—came through a unique, complex, interdependent set of circumstances. The central and provincial governments helped local companies through variety of top-down and bottom-up strategies:

A. Central Government (Top-down Policy measures):

- a. China having realized the lack of advanced technologies in producing crystalline silicon, and therefore found transition to a low carbon economy erratic and unpredictable. This led to their efforts in scouring the world, hiring more solar experts and shopping for machinery and polysilicon supplies to meet the expected surge of orders for solar panels.
- b. The heart of solar technology is built on silicon. During the 2006-2008, while China exported up to 95% of its solar PV modules, it imported 95% of its raw materials for PV, especially high cost Polysilicon. A sharp fall in the price of purified silicon was driven by de-licensing of Siemen's CVD & TCS by EU & USA markets; a breakthrough in China in mastering the technology & its strategy for domestic production.
- c. The central and provincial governments helped local companies acquire state-of-the-art technologies and break into the global market. Technology transfer and technology cooperation from industrialized countries occurred particularly through purchasing manufacturing equipment, transfer of complementary know-how, foreign direct investment by multinational firms and the movement of skilled labour across borders, networking, staff exchange schemes, joint ventures, licensing, mergers and acquisitions.
- d. China bought solar companies globally and invited others to move to China, where these companies found cheap skilled labour. Instead of paying taxes, they received tax credits.
- e. China ensured that it will be both buyer and seller, by retaining ownership of customers and suppliers alike. This gave the state a great deal of influence over equipment purchases, sales, and technology development.
- f. Chinese government sought a high degree of local content in equipment / products produced in the country, and force the transfer of proprietary technologies from foreign companies to their joint ventures with China's state-owned enterprises, as a condition of operating in the country. The Chinese government interpreted WTO provisions, by maintaining that decisions of companies trading technology for accessing the markets are purely business decisions.
- g. Further, with its deep government pockets, growing technical sophistication and a comprehensive plan to free itself from dependence on foreign companies, China has set its aim to become dominant in industries of the future like solar PV. Under a plan called "Made in China 2025", China hopes to become largely self-sufficient within seven years including manufacturing machinery. "Made in China 2025" calls for roughly \$300 billion in financial backing: inexpensive loans from state-owned banks, investment funds to acquire foreign technologies, and extensive research subsidies.
- h. On bank funding, the Government recognized & supported the need for large, semi-automated factories making it easier, cheaper, and a lot less risky for solar companies to obtain financing. Low cost long term debt is provided by the Chinese Development Bank (CDB), which raises most of its money via long-term bonds. CDB gives borrowers very low interest rates, and, if the borrower cannot pay back the loan, there is a provision that it may be back-stopped by the Chinese government. In 2010 alone, the bank handed out \$30 billion in low-cost loans to the top five manufacturers in the country.
- i. On fiscal measures, it is noted that the People's Bank of China (i) tightly controls the yuan to dollar value, to manage the prices of exports to the USA; to be a little cheaper than those produced in America; (ii) facilitate raising funds through overseas IPOs –influx of foreign capital enabled the Chinese PV industry to expand its production capacity at an unprecedented rate; armed with tens of billions in loans from the Chinese government & IPOs, Chinese solar companies have scaled up by adding in big chunks of GW scale factories for PV manufacturing. This has enabled China's solar producers to grow to GW scale in a very short period of time, turning the country into a leading exporter of solar and pushing down prices. China's provincial governments designated solar as "strategic industry" which provides more jobs and manufacturing capacities. The result is that in building up the world's largest solar manufacturing industry, China had helped create a worldwide glut, driving higher-cost Western producers into the red.



- j. Market Development: A paradox has emerged in the large-scale growth of the Chinese PV industry, with a strong orientation towards export markets without complementary policy support for the creation of a domestic market. China then decided to follow Germany's lead again, developing its own "feed-in tariff". The result was a huge surge in domestic demand resulting in China's domestic market bypassing Germany's and becoming to be the largest in the world just in two years, by 2015.
- k. Aggressive PV market subsidy structure created a large domestic demand, initially by Central Government. When subsidy payments increased beyond \$17 billion, further support – as part of the new 2020 expansion target, will be provided by local & provincial governments.

B. Role of Local & Provincial Governments:

- a. Free or low-cost loans through local commercial banks are offered. This created a fund-raising and expansion boom in the Chinese PV industry, particularly in provinces such as Jiangsu.
- b. Sometimes the provincial government reimburses interest payments.
- c. Tax rebates - Local tax revenues are calculated in relation to sales, not profits, and officials are promoted according to how much employment they generate. This incentive structure for decision makers reinforces the creation of excess capacity, leading to lower prices.
- d. Received export credits at preferential rates from the Export Import (ExIm) Bank of China.
- e. Cheap land / Land Grants: Many provincial officials provided Chinese entrepreneurs with land at below-market prices or even for free. Land grants thus became larger than what's needed to build a factory and taking benefit of this the Companies build apartment buildings on the surplus land; the cash flow from such investments were used to pay for R&D and also to offset factory losses.
- f. Buildings: Local governments in China typically construct the factory buildings and lease them to the manufacturers. This saves the capital investment & the time to market the product.
- g. Energy & Utility subsidies – Local governments provided low cost hydro power for industries and take the responsibility of treating all wastes at common effluent treatment facilities. This reduces the operational costs and disruptions for the manufacturers.
- h. Labour support: There are flexible labour laws for hiring & firing of staff as per the supply-demand.
- i. In addition, there are provisions to provide technological & research grants.

C. Bottom-up Measures by Industry (Cost reduction):

- a. Scale: The government consolidated several manufacturers into a few national champions, to generate economies of scale (3-5 GW cell and module factories with investments at US\$ 500-1000 million each) with a view to have scales and focus on learning. The cost advantages that larger manufacturers can leverage due to the scale of operation allows them to upgrade factories with higher levels of automation ensuring more consistent manufacturing quality, acquire better materials at lower prices as well as attract and retain higher qualified staff. The larger manufacturers have also attracted more attention from large-scale buyers and investors concerned about quality.
- b. Mergers: China used low-cost government loans to expand solar panel production dramatically. That strategy also led many Chinese solar manufacturers to crash and burn. Some blamed it on the pressure from local government to expand too rapidly. Government now wants survival of the fittest as it expects several small-scale wafer makers companies without competitiveness to be eliminated from the PV industry supply chain.
- c. Improvements in Manufacturing Process: The prevailing PV technology in China is still based on crystalline silicon solar cells. China PV Industry have been conservative on new technologies. The PV manufacturing has undergone incremental changes on regular basis. The important improvements are (i) increase in tool throughput; (ii) development of new process / tools which can be added seamless to the existing lines. The success of these two advancements is due to non-disturbance of existing lines; but integration of few additional tools in the existing lines. The processes involved in the manufacture of various advanced PERC technologies are complimenting in nature requiring few changes in the existing lines.
- d. Indigenous Machinery: The development of indigenous machinery happened initially by localization of Automation equipment for large manufacturing plants. This was followed by Chinese PV manufacturing companies developing their own technologies and designing own in-house equipment and fabricate according to particular specifications. This helped to develop a strong skills' base in engineers

and operators that are needed to run large factories. For example, LONGi applies a series of innovations to its manufacturing chain every three months to a year so as to strike a balance between lowering production cost and improving product efficiency.

- e. Indigenous Supply Chain / Eco-System: Mass production efforts led to the creation of end-to-end supply chain ecosystem which includes a wide variety of material vendors; enabling PV manufacturers to source good quality local materials at competitive prices.
- f. Innovation: China historically depended to a large extent on international technology transfer and cooperation from high income countries for solar energy technology. This has changed over time as the country stepped up its independent innovation and thereby created what the Chinese government calls a “PV industry with Chinese characteristics”. This was supported by the government by increasing investments in R&D, covering almost the entire solar PV manufacturing chain and establishing national key laboratories at several leading firms. Today, leading companies like Yingli Solar, Trina Solar, LonGi have set up national PV key laboratories with annual R&D investment of hundreds of million US\$.
- g. Patents: A common problem is still the “Valley of Death” between product R&D and commercialization. Chinese solar firms tend to file more patents,

particularly to send a signal to public authorities to allocate more subsidies. China's PV industry also recently filed a large number of patents in upstream segments, especially silicon production and ingot manufacturing, suggesting a turning point.

- h. China also issues product standards and specifications that force foreign software suppliers to develop special versions for China, allowing Chinese equipment makers to circumvent Western patents and royalty obligations.
- i. Quality: Today Chinese PV manufacturers advocate that the quality of Chinese PV systems is similar to their Western counterparts.

Through these changes emerged an industry that has turned solar panels into a commodity produced in large-scale factories. The main reason why we have low prices today is because the fragmented industry has consolidated around a single tech. That technology is produced by hundreds of firms around the world, so they are able to tap into the same economies of scale and R&D investments. While in 2006, there were two companies from China in the list of top ten cell producers by 2018, all the top ten are Chinese.

If there was ever a situation where the Chinese have put their whole governmental system behind manufacturing, it's got to be solar modules.

Table 2: Top-10 Global Solar PV Manufacturers – The China Dominance

| | 2018 | 2018 | 2018 |
|------|--------------------------------|---------------------------|--------------------------------|
| Rank | Top Cell Mfg | Top Cell Exporters | Top Module Suppliers |
| 1 | JA Solar, China | Tongwei, China (6.5 G W) | Jinko, China |
| 2 | Tongwei, China | Aiko Solar, China | JA Solar, China |
| 3 | Trina Solar, China | Uniex New Energy, China | Trina Solar, China |
| 4 | Hanwha Q-Cells, China/ Kor/ EU | Pingmei New Energy, China | LonGi, China |
| 5 | Jinko, China | United Renewable, Taiwan | Canadian Solar, China |
| 6 | LonGi, China | | Hanwha Q-Cells, China/ Kor/ EU |
| 7 | Shunfeng (Suntech), China | | Risen Energy, China |
| 8 | Canadian Solar, China | | GCL-Si, China |
| 9 | Aiko Solar, China | | Talesun, China |
| 10 | First Solar. Malaysia/US | | First Solar, Malaysia/ US |



Malaysia, Vietnam, Thailand & Singapore PV Sector Growth

SE Asia (Taiwan, Singapore, Malaysia, Vietnam): OEM manufacturing; capital invested by the Chinese companies; local governments providing the infrastructure and tax holidays

Chinese companies are building factories outside China, particularly in Malaysia and Vietnam, to bypass anti-dumping and anti-subsidy measures of USA and EU. Most of the top 10 module suppliers have company-run operations in Southeast Asia (Malaysia, Thailand and Vietnam) or have OEM arrangements with China-financed operations in Vietnam. Chinese companies have set up manufacturing capacity of about 12 GW for solar cells and 14 GW modules in SE Asia.

While the Chinese players search for manufacturing locations outside China; at the same time, few of the USA & EU companies were also searching for manufacturing low cost manufacturing locations outside USA & EU, for their survival against low cost products.

The governments of these SE Asian countries have strategically developed industrial policies to attract the investments from China, US & EU companies. Similarly, the companies have developed their own local strategies like OEM manufacturing (rather than owning the lines) like those of new production capacities in Vietnam are associated with Vina Solar, a Vietnam-based OEM manufacturer, which produces both cells and modules.

Summary: Nations need to look back by analysing Germany's subsidy structure, domestic and international competition, and spurring of domestic demand.

Governments and companies can learn what they need to do to overcome the boom to bust cycle.

Decline in prices of module & profitability of Chinese companies

It is widely believed that module prices will continue to decline due to growing global capacity expansion and economies of scale, as well as technology improvements and decreasing feed-in tariffs and subsidies. PV technology and manufacturing improvements included PERC, diamond wire saws, with "incremental" improvements to solar cell and solar panel technology. The typical manufacturing cost (\$/Wp) of an integrated Ingot & Wafer-Cell-Module facility is shown in Figure-3 below:

Figure below shows the module price trends in global market and India market, during the corresponding period. Since 2015, the average sale price (ASP) for solar panels dove 50 percent to about \$0.31 per watt by end of 2018.

The 50% decrease in module price during the period 2015-2018 is well understood in terms of the following:

- poly-silicon price reductions (led by lower power consumption; recycling of used modules; higher throughputs) from \$20 to \$10 /kg; consumption from about 4.5 to 4 gm/Wp
- wafer processing costs (led by Diamond wire; throughputs) by nearly 40%

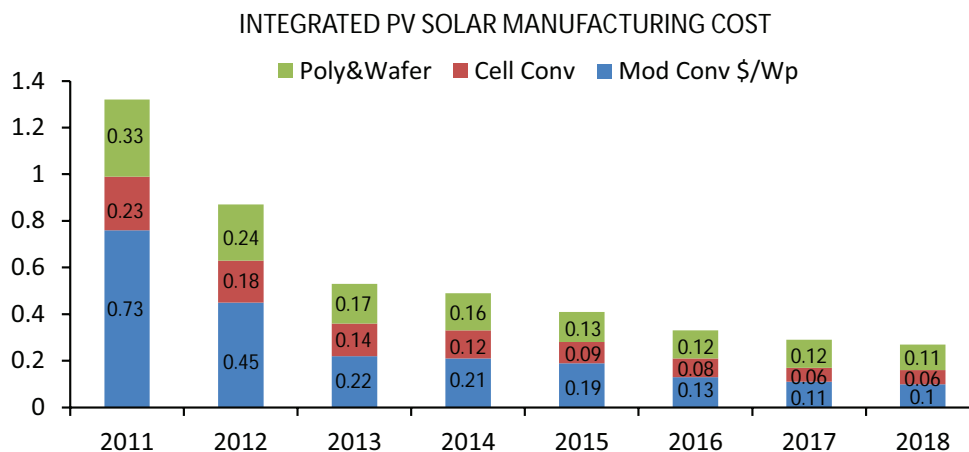


Figure 3: Integrated PV manufacturing cost during the past decade

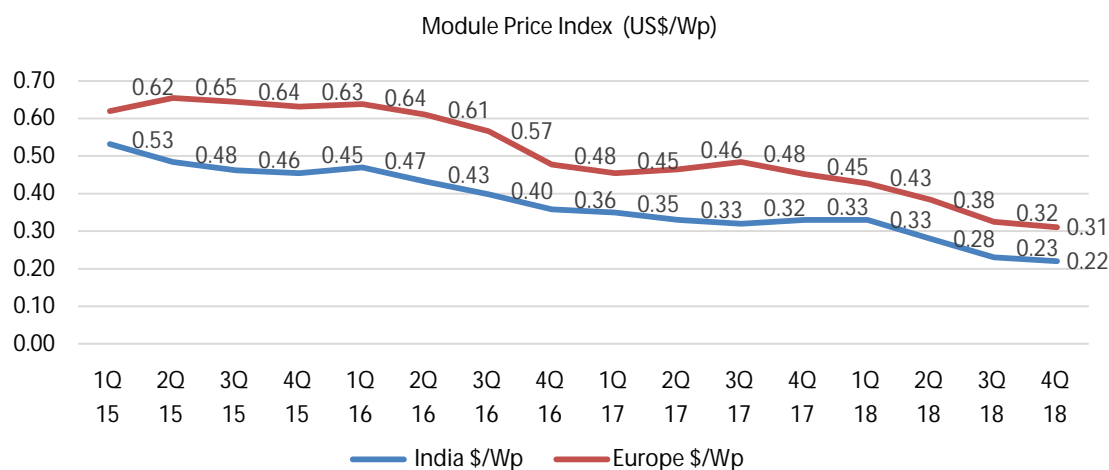


Figure 4: Trend of PV module ASP

- c. Cell processing costs (led by PERC, higher efficiencies; lower silver costs & consumption; higher throughputs) by nearly 50%
- d. Module processing costs (led by lower BOM prices; lower CTM losses) by nearly 30%
- e. Reduction in capex across the PV Value chain by nearly 30-40%

Table below shows the trends of decreasing ASPs and the trends of Gross Profit & Net Profit Margins of the global Top-10 PV manufacturing companies:

It can be seen that while the ASPs declined by 50% during the 4-year period, the Gross Margins remained within the range of 16%+4%. Similarly, the Net Profit remained in the range of 3-5%. This consistency in profit

margins could be maintained by increasing the shipment volumes and the revenues.

R&D Expenditure:

One of the compelling reasons for the consistent profitability of the Chinese companies has been the high level of investment in R&D. These investments are complimented by supported by government as well as networking with other industries & academia within China. LONGi Green Energy Technology set a new solar industry R&D expenditure record in 2017, not only surpassing the two historical leaders, First Solar and SunPower, but spent more in one year than any PV manufacturer to date. The R&D Investments as % of Revenue of LonGi is compared with those First Solar & SunPower are compared in the graph below:

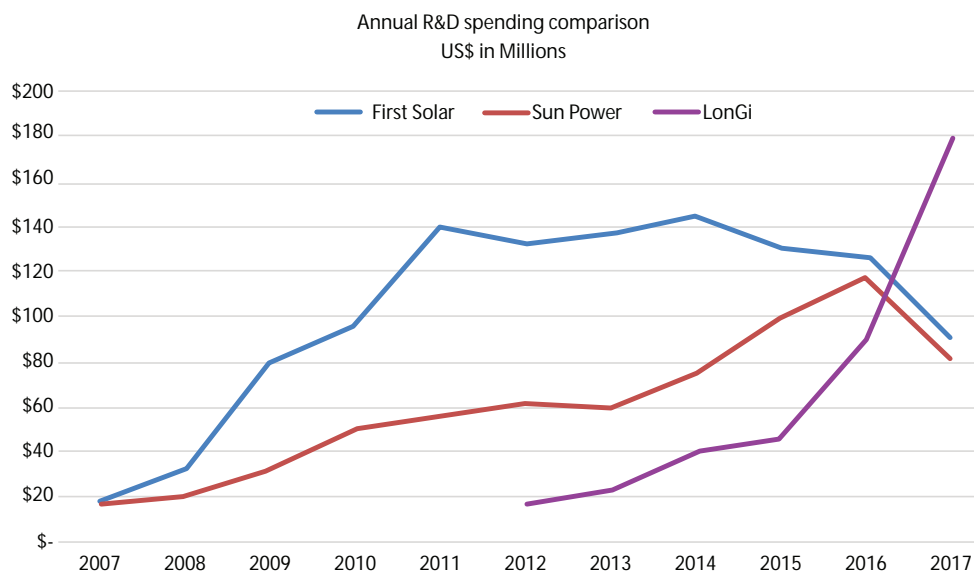
Table 3: Trends of ASPs, Gross Profit & Net Profit of Tier-1 Global PV Module companies

| | | 2015 | 2016 | 2017 | 2018 |
|----------------|--|-------|-------|-------|-------|
| | ASP, \$/Wp | 0.63 | 0.55 | 0.46 | 0.32 |
| | Blended cost, \$/Wp (incl Shipping, Tariffs, Warranty costs) | 0.41 | 0.416 | 0.354 | 0.26 |
| Canadian Solar | Shipment, GW | 4.7 | 5.2 | 6.8 | 6.4 |
| | Revenue, \$Bn | 3.5 | 2.9 | 3.4 | 3.5 |
| | GP % | 16.6% | 16.2% | 18.8% | 14.3% |
| | NP % | 5.0% | 3.3% | 2.9% | 4.9% |
| Jinko Solar | Shipment, GW | 4.5 | 6.7 | 9.8 | 11.7 |
| | Revenue, \$Bn | 2.5 | 3.1 | 4.1 | 3.5 |
| | GP % | 20.3% | 18.1% | 11.3% | 14.3% |



Table 3: Trends of ASPs, Gross Profit & Net Profit of Tier-1 Global PV Module companies

| | | 2015 | 2016 | 2017 | 2018 |
|----------|---------------------------|-------|-------|-------|------|
| | NP % | 5.4% | 4.6% | 5.0% | 1.7% |
| JA Solar | Shipment, GW | 4.0 | 5.2 | 7.6 | 11.0 |
| | Revenue, \$Bn | 2.1 | 2.3 | 3.0 | |
| | GP % | 17.0% | 14.6% | 12.3% | |
| | NP % | 4.5% | 4.6% | 1.5% | |
| LonGi | Capacity, Ingot-Wafer, GW | 5 | 7.5 | 15 | |
| | Revenue, \$Bn | 1.1 | 1.8 | 2.42 | |
| | NP % | 9.5% | 13% | 21% | |

**Figure 5: Trend of R&D Spending of major PV Manufacturing companies**

Need for Solar PV manufacturing in India

India needs energy security and sustainable energy solutions. Amongst the various energy sources solar energy has emerged as the preferred option since it is available across geographies, relatively unlimited vis-à-vis other green sources, freely available and in fact the country is endowed with possibly the highest band of average annual solar radiation and well suited for decentralized and distributed power requirements.

India's solar market is on a roll with over 25 GW of large-scale solar photovoltaic (PV) capacity installed in the

country as of December 2018. Indian solar boom is set for a 40-50% growth rate over the next five years, as bottlenecks such as integrating solar farms with the grid are overcome. Grid parity was possible due to the quick drop in quoted tariffs by the Indian Solar developers, as per the chart below.

With the record low tariffs, the PV power installations have succeeded beyond expectations; but, the PV manufacturing is yet to attain critical mass. The country's installed manufacturing capacity of Cells is about 3.1GW (consisting of 18 companies) and that of the Modules is about 11GW (consisting of nearly 175 companies). While there are only couple of GW scale companies, majority of the plants are of 50-200MW capacity, having very

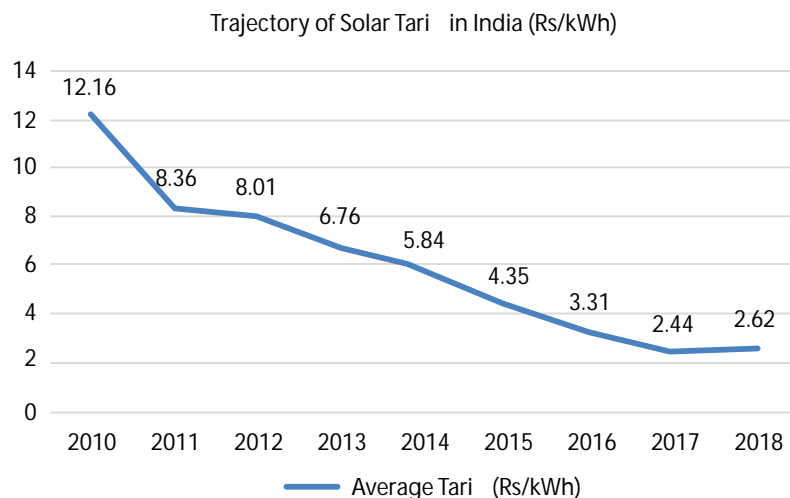


Figure 6: Trajectory of Lowest Solar Tariffs in India, 2018 (Source: Mercom)

high operating costs. Without credible manufacturing capacity, import dependence would move from oil to solar panels.

To facilitate a comprehensive policy, TERI organized a consultative meeting with the industry representatives and the following issues were deliberated upon:

- Government Support: Priorities / Policies / Timelines / Financial / Quality / Market access
- Why do India need PV Manufacturing: Energy Security? Forex saving? Employment?
- Strategy for Market: India? ISA? Global?
- Target Module Market: Grid Parity (lower Tariff) / Socket Parity (prosumers – Higher Tariffs)
- India specific USP for manufacturing: Basic Materials - Eco System - Power - Labour
- What extent of Integration: Poly-Ingot & Wafer- Cell - Module
- Scale of Manufacturing: Country Road Map? Individual plant targets / Roadmap?
- Technology Roadmap: BSF (low tariff)-PERC-HJT-TOPCons (High tariff) – India specific?

Reliable local Supply Chain: One of the compelling reasons for domestic manufacturing was argued to be the quality of modules imported from China. It is generally believed that while China manufacturers export Grade-1 & Grade-2 PV panels to US, EU & Japan; it is the Grade-3 & Grade-4 which find way into India as low-cost PV Panels. A recent study of many of the Indian PV projects is showing annual degradation much higher as compared to the expected degradation of 0.6-0.7%. Many of the

projects are at a greater risk of lower life expectancy.

Securing the supply-chain for solar eliminates the risk of poor quality products getting dumped into India by fly-by-night operators. Further, shortage and glut of products leads to wild fluctuation of prices of PV products, resulting in project disruptions.

Market: Indian market is expected to grow 10-20 GW/yr, which is a huge support base to develop and sustain domestic manufacturing.

Strategic positioning of Domestic Eco-system: At present more than 80% Indian solar value chain is mostly dependent on the imports and lacks economy of scale for the domestic manufacturers. If it continues, the industry will end up perpetuating dependence on imports and this would not be in the country's interest as far as concerned to energy security.

India specific Product development: Mono-crystalline modules with higher wattage are used in premium segment of global market, especially in Europe, USA & Japan and Rooftops. The Multi-crystalline technology has evolved to be the work horse of the industry and is the most preferred in the Indian Solar PV market with more than 90% market share, presently.

Foreign Exchange outgo: To meet the projected 10-20 GW/yr, the recurring annual forex outgo will be US\$ 2.5-5.0 Bn. At this rate, during the next 10 years India may need to forego ~\$50+ Billion foreign exchange only for solar industry.

Employment opportunities in manufacturing sector: Solar photovoltaic (PV) manufacturing in India can leverage certain inherent advantages such as low cost of



HR capital in both white- and blue-collar jobs. Every GW/yr manufacturing capacity (PV Value chain, supply chain eco system & indirect services like transportation etc) will create new skill jobs of the order of 3,000 – 3,500. At 10-20 GW/yr, solar manufacturing has a potential of creating nearly 1,00,000 jobs.

Opportunities for Capital Equipment OEM sector: Every GW/yr integrated PV manufacturing capacity needs capital equipment for their process, utilities & service requirement. The one-time capital equipment expenditure to the tune of \$200-250 million / GW will translate to \$2.5-5.0 Billion opportunity for the Capital equipment fabricators. The employment generation in capital equipment OEM sector is an added benefit over & above those considered above.

India domestic PV manufacturing industry met just 15 percent of the country's annual requirement, according to government estimates. Out of India's annual demand of 10GW PV equipment, nearly 85% is imported, despite having installed manufacturing capacity of nearly 11GW of PV Modules and about 3GW of PV Cell capacity. The major reason for lower capacity utilization is that, most

of this capacity is obsolete, sub-scale and uncompetitive. So, the case is to turn India into a solar capital of the world and earn forex through exports.

High level cost structure of manufacturing & Comparison of India and Chinese costs

The high level manufacturing costs for each segment of PV Value chain mainly consist of Si cost, BOM costs, Utilities, Labour and finance costs. The cost structure of the Integrated PV Manufacturing for an Indian company are estimated based on the capital costs, operating costs information obtained from technology / turnkey solution / BOM suppliers, for a new project in India. Information related to SGA and other expenses are based on the industrial practices followed in India. Table below shows cost estimates of the manufacturing, highlighting polysilicon cost as the main component:

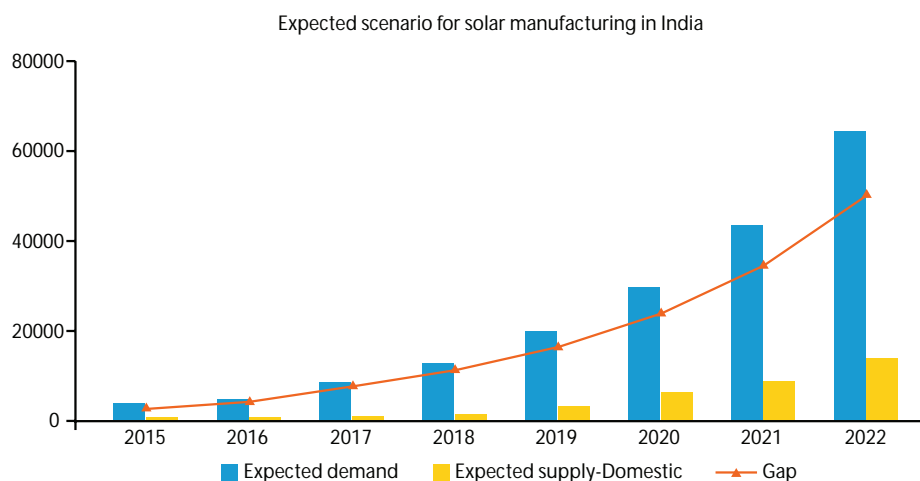


Figure 7: Expected Scenario for Solar Manufacturing in India (Source: Mercom)

Table 4: Manufacturing cost break-up

| Sr No | Cost Item | I & W US\$/Wp | Cell US\$/Wp | Module US\$/Wp | Total US\$/Wp | |
|-------|---------------------------|---------------|--------------|----------------|---------------|------|
| 1 | Raw Materials (BOM) | 6.1 | 4.3 | 9.9 | 20.3 | 72% |
| 2 | Labour & Staff | 0.3 | 0.7 | 0.5 | 1.4 | 5% |
| 3 | Power & Utilities | 0.6 | 1.1 | 0.1 | 1.7 | 6% |
| 4 | Manufacturing Over Heads | 0.8 | 0.6 | 0.3 | 1.7 | 6% |
| 5 | Depreciation Costs | 1.7 | 1.1 | 0.2 | 3.0 | 11% |
| | Total Direct Cost, \$ /Wp | 9.3 | 7.8 | 11.0 | 28.1 | 100% |

A GW scale integrated manufacturing consisting of Ingot-wafer-Cell-Module requires the Electrical Power of 60 MVA (300 million units/year), water supply of 2 MLD and related facilities.

The cost structure of the Integrated PV manufacturing, consisting of Ingot-Wafer-Cell-Module for a Tier-1 Chinese company are obtained from their published balance sheet. From the cost of revenue details, the contribution ratios of RM, Labour, Power & Utilities, Depreciation &

Mfg OH are obtained. These ratios are used to estimate the corresponding costs in \$/Wp. These values are found to be in-line with the actual industrial costs in China. The comparison of both the costs is presented in the Table-5 below:

In summary, it is clear that it would be necessary for Indian companies to maintain comparable & sustainable 10% Net Profit, to have an ASP which will be nearly 40-50% higher than the Chinese ASP.

Table 5: Comparison of Indian Integrated PV Manufacturing costs with Chinese Tier-1 company

| | CHINA, Tier-1 | | | INDIA | | |
|------------------------------|---------------|---------------|------------|-------------|--------------|------------|
| | 2016 | 2017 | | | | |
| Capacity | | | | | | |
| Wafers, GW | 7.5 | 15 | | | | |
| Modules, GW | | 4.5 | | EoS | Medium Scale | |
| | RMB Mn | RMB Mn | | \$ Cent/ Wp | \$ Cent/ Wp | |
| Revenue | 11,531 | 16,362 | | 27 | 38 | |
| Cost of Revenue | (8,361) | (11,082) | | (18) | (28) | |
| Raw Materials | (5,633) | (8,324) | 51% | (13.7) | (20.3) | 53% |
| Direct Labour | (448) | (571) | 3% | (0.9) | (1.4) | 4% |
| Depreciation | (375) | (546) | 3% | (0.9) | (3.0) | 8% |
| Power & Utilities | (554) | (668) | 4% | (1.1) | (1.7) | 4% |
| Mfg OH | (1,351) | (973) | 6% | (1.6) | (1.7) | 4% |
| Gross Profit | 3,169 | 5,280 | | 9 | 10 | |
| GP% | 27% | 32% | | 32% | 26% | |
| Sales Exp (incl freight etc) | (468) | (664) | 4% | (1.1) | (1.1) | 3% |
| Admn Exp (incl R&D, Salary) | (441) | (664) | 4% | (1.1) | (1.5) | 4% |
| Financial Exp | (102) | (198) | 1% | (0.3) | (1.9) | 5% |
| Other Income/ expenses | (390) | 242 | -1% | 0.4 | | |
| Profit from Ops | 1,768 | 3,996 | | 7 | 6 | |
| Other profits | 24 | 22 | | | | |
| Income tax | (242) | (468) | 3% | (0.8) | (1.7) | 4% |
| Net Profit | 1,551 | 3,549 | 22% | 5.8 | 3.9 | 10% |
| | 13% | 22% | 100% | 22% | | 100% |



Indian PV Manufacturing – Comparison with China manufacturing

Table 6: Comparison of Indian Manufacturing competitiveness with Chinese or SE Asian countries

| Parameters | India | Chinese, Other Asian & Countries | |
|------------------|---|--|--|
| Capital Cost | Land & Buildings | Full costs to be absorbed by the project. | Local govt. provides land & ready -to-occupy buildings on lease basis or at subsidized rates |
| | Utilities & Infrastructure | Self-financed by the project for all external works (road, power, pipelines) | Local govt provides power, utilities & waste disposal facilities at plant boundary |
| | Plant & Machinery | Fully imported from China / Europe at higher costs | Designed & Fabricated locally by Manufacturing companies; tax set-offs are available |
| | Technology | Imported with continuous dependence on OEM | In-house and hence cost effective |
| | Economies of scale | Medium scale plants of 0.5-1 GW capacity; | 3-5GW scale; with huge advantage of scale for project savings |
| | Project Finance | 10-13% interest loans, comparatively shorter loan durations | 0-5% per annum interest loans with long tenures by government along with grants. |
| | <i>Hence, the total project cost for Indian companies is higher around 15-25% than other countries.</i> | | |
| Operational Cost | Raw Material (RM) Cost | High as majority are imported; the local RM are costly due to ADD | Low as majority sourced locally; Manufactured with local know-how and eco-system |
| | Supplier Options | Lesser | Higher with regular improvements |
| | Inventory Cost | High due to higher lead times for supply / sales | Low (JIT); many times across the fence |
| | Bargaining Power | Low due to low volumes | High due to high volumes |
| | Yield Losses & recoveries | Higher due to manual / semi-auto / lack of know-how | Lower due to high automation / precision manufacturing; own R&D for improvements |
| | Utilities | Higher prices (due to cross-subsidization requirements) | Subsidized |
| | Manpower | Higher manpower due to semi-automation; Lower productivity | Low manpower due to higher automation; higher productivity |
| | R&D | No co-ordinated Academia-Research Labs- Industry R&D | Govt supported large scale R&D centres in all Tier-1 companies |

Table 6: Comparison of Indian Manufacturing competitiveness with Chinese or SE Asian countries

| Parameters | India | Chinese, Other Asian & Countries | |
|-----------------------------|---|--|--|
| Quality | Standards | Meets international standards – has been exporting to European markets; Semi-automation is a concern | Meets international standards |
| Financing Costs | Interest Cost – Term Loans | Around 11-14% | 0-5 % |
| | Interest rates -Working Capital | Higher interest rates of 12-14% | Lower interest rates of 2-4%; |
| | Working Capital | Not easily available; | Easily available; easier terms |
| | Depreciation | Faster depreciation (5-7 years) due to equipment obsolesce | Normal depreciation (10-years) due to equipment improvements internal to companies |
| | Income Tax | No Tax rebates or holidays | Local governments extend tax rebates & tax holidays |
| SGA / Marketing & Logistics | Mandatory Product Performance Insurance | Not available in India; big disadvantage; higher warranty costs | Available from local / global insurance companies |
| | Logistics | High transportation costs for raw material and finished products | Well established and low transportation costs; available at short distances |
| | Exim Benefits | None | Available with buyer's credit finance mechanism |

It is evident that India is competitive in terms of cost of labour and Quality Standards but is at a disadvantage in terms of high cost of capital, higher power tariff and absence of facilitating ecosystem. The global PV production capacity stood at >100 GW whereas in India it was mere 3 GW cumulative with insufficient demand for domestic products. These capacities deter the Indian companies in terms of economies of scale.

Based on the development potential, it is expected that during the next 10-years, the Indian solar energy industry requirement will be growing at a healthy annual rate of 30-40% or more. This growth rate throws up many challenges. Co-ordinated efforts backed up by a strategic policy support can help in the development of the domestic supply chain system. With support, the Indian solar manufacturing industry has the potential to become a global scale industry in a short time.

Recommendations

Government may consider prioritising the PV Manufacturing value chain – as a strategic industry (energy security; Forex savings & Employment reasons).

The PV manufacturing value chain starting from mining of Quartz Silica to PV Module manufacturing has been reviewed for competitiveness in (i) security; (ii) technology & (iii) cost.

Quartz Silica (SiO₂): High grade quartz silica (containing about 99.8% SiO₂) suitable for semi-conductor grade Silicon manufacturing is available in natural hillocks located in AP, Karnataka, Orissa regions. Presently, the quartz is mined in small scale and processed (size & colour separation) manually. The quartz is exported to Japan, Korea and other countries.

Metallurgical Grade Silicon (MG-Si): The quartz (SiO₂) is converted to silicon (Si) by carbothermic Reduction process in submerged (electric) Arc Furnaces with graphite electrodes at 2000 0C, using charcoal as reducing agent. For production of 1kg of MG Silicon, 2.6 kg of Quartz Silica is used along with. The power requirement is about 11-13 kWh/kg of Metal Grade (MG) Silicon. The cost of power is nearly 50-60% of the manufacturing cost of MG Silicon. Hence, countries like China, Norway, Brazil have allocated small hydro power plants of 20-50 MW capacity to each of these SME scale Silicon manufacturing plants. These plants operate seasonally utilizing the low cost hydro power projects. The MG Silicon of >99% (2N) is used as pre-cursor for Solar & Semi-conductor industry.



India produces Ferro grade silicon (75% Si) for Steel & Aluminium industry. However, in the absence of low cost power, it is suggested not to manufacture MG Silicon for Solar applications.

Polysilicon (MG-Si): MG-Si of 2N is purified to 6-11N purity using Hydrochlorination & Siemens CVD process. The economies of scale are ~20,000 tons/year. At a consumption rate of 4gm/Wp, this translates to nearly 8GW/yr of PV manufacturing.

The availability of state-of-the-art technology consisting of low power utilisation (<40 kWh/kg); high quality 6-9N is now available from USA & China only. The cost of power will be 20-35% of the manufacturing cost. Further, the price of Polysilicon is now in the single digits (<\$9/kg). In the absence of low cost & un-interrupted power, it will be difficult to manufacture competitively. The following points are critical in any decision for Polysilicon manufacturing:

- Demand – Supply : The increase in demand due to Solar PV market, nearly 40% CAGR in the past 10-years, has resulted in supply increase by about 20% CAGR (from about 50,000 Tons /year in 2009 to about 300,000 tons in 2017). This lower growth of Polysilicon is due to the increase in efficiency of the solar cell technologies & reduction in silicon wastages throughout the manufacturing value chain (more power out for less polysilicon). Hence, there is no shortage of Polysilicon anticipated in the next few years. Further, China & other countries have more than 200,000 tons of additional idle capacity, due to the high cost of manufacturing. In case of any short supply, if the price-increase, these plants will come on-stream at a very short notice. Hence, any decision based on shortage of supplies will not be viable.
 - Strategy to become Self Reliant: China is a net importer of Polysilicon. Nearly 50% of its requirement of 2017 was imported from OCI (South Korea), Wacker (Germany) & other Japanese & USA markets. India can also source its Polysilicon requirements from a divergent market base. Hence, there is no threat of supply shortages in case of hostilities with neighbouring countries.
 - Quality: Even after 10-years of manufacturing experience in Polysilicon at global scale capacities and access to global R&D, China is still not able to manufacture Polysilicon of higher quality (>7N) which is required for CZ Mono wafer (ultra-High Efficiency PERC & N-type cells) manufacturing. This high quality polysilicon is manufactured only by 4-5 companies located in South Korea, Germany, USA, Japan, who guard the technology very closely.
 - Technology upgradation: The Hydrochlorination-Siemens CVD is the most preferred route with more than 95% market share. Attempts were made by various global majors to introduce Fluidized Bed Reactor (FBR) technology to achieve lower costs. However, the GCL (20,000 tons/yr plant); Samsung (20,000 tons/yr plant); REC (9,000 tons/yr plant) – none of them are able to manufacture the product due to quality & operational issues.
 - High Entry Barriers: Apart from technology barriers, the high capex & high opex will be critical barriers for any new entrant.
- In view of the above, it is suggested that Government may adopt Phased Manufacturing Programme (PMP), under Make in India plan, with the overarching objective of establishing 15GW full value chain Silicon Ingot to solar modules local manufacturing facility at competitive prices in the country by 2024. Phase wise programme is as proposed below:
- (i) **First Stage: Solar Cells & Modules** – About 15 GW capacity could be targeted over a period of 2-3 years for manufacturing of cells and modules with full value addition in India. For this, expression of interests could be invited for approval aiming supply to commence in 2021 with the following provisions:
 - **Scale:** Investors will be keen to install GW scale plants. Minimum capacity could be 1 GW for eligibility for participation.
 - **Technology:** Though investors would be encouraged to go for best in class technologies like PERC+/HJT/TOPCON, yet the investors could pick up usual polysilicon based solar cells and modules and thin film technologies with different efficiency and cost structure. It is suggested that to go for 'Rs per Wp' criterion to decide priority amongst the applicant developers.
 - **Manufacturing Hubs:** In order to provide a scale to manufacturing expeditiously, creation of solar manufacturing hubs could be considered, something on the lines of Solar Parks, with participation of States and pre-approved provisions for land use and availability of infrastructural facilities. Each hub can be designed to accommodate 4-5 GW of Solar PV manufacturing along with all the ancillary industries. Various requirements for each of the manufacturing hubs include the following:
 - ◇ Land: 200 – 500 acres (developed land to be provided on lease basis to the selected manufacturers)

- ◇ Power: 250-400 MVA (220 KV or 440KV to meet stable power requirement)
 - ◇ Water: 5 - 10 MLD
 - ◇ Waste Water Treatment (CETP): 2-7 MLD with adequate recycling facilities
 - ◇ Solid Waste Handling: 1000 Tons/year facility (with 10-20 year design capacity)
 - ◇ **Duties & Taxes:** Allowing duty free imports of all plant, machinery and spares.
 - ◇ **Environmental Clearances:** Waiver on environmental clearance with necessary safeguards for waste disposal is suggested under EIA notification which could be facilitated by the Central Government.
- **Production linked Incentive:** It has been estimated based on inputs from various stakeholders that there could be a price differential of about Rs. 20 lakh per MWp for domestically manufactured solar cells and modules due to higher financial and infrastructural costs. The companies who will be entering into manufacturing under this scheme could be provided production linked incentive to the tune of this amount.
 - **Financing:** Green Manufacturing Fund could be created to support production linked incentives through funds collected i) through realization of safeguard duty, and ii) by levying a cess of Rs. 20 lakhs per MWp on imported solar modules.
- (ii) **Second Stage:** This stage is for integrating cells and modules manufacturing capacity in the country with Silicon Ingot to wafer with an aim to be able to have critical mass of full value chain manufacturing capability so as to allow national solar programme continue even in the circumstances of unforeseen international fall outs. It is suggested to have overlap of second phase starting with second year of first phase.

About 15GW manufacturing being in-place, the domestic PV Value chain can be expanded to integrate INGOT-WAFER & BOM ECO SYSTEM. Bids may be repeated every year for the next 5 years to get competitive industry structure and lower prices.

- Scale: Investors will be keen to install >5 GW scale plants for manufacturing of Ingot-Wafer & BOM Materials, which are of economies of scale for these components. Minimum capacity 5 GW.
- Various financial and fiscal incentives mentioned during First Stage are suggested to continue.
- Assuming duty free imports of all plant, machinery and spare, it is felt that the implications of higher cost of financing in India would be required to be compensated through capital grant to make the product cost competitive. In line with provisions of MSIPS, it is recommended to provide upto 20% of the project cost on reimbursable basis to the manufacturers. Two trenches of equal amount could be considered for disbursement of capital grant; first on the receipt of the machinery at the project site, and the second on commissioning of the facility. In addition, making available power at a tariff of about Rs. 2.00 per kWh would be necessary to keep operational costs competitive and having no necessity to consider providing recurring production linked incentives.

(iii) **Third Stage:** With 10-20 GW manufacturing in-place, the domestic PV Value chain can be expanded to the Plant & Machinery equipment fabrication domestically.

It is, however, needless to emphasize the need to develop comprehensive R&D programme by the Government around manufacturing plants with defined targets and goals for enhancing competitiveness of the industry.



