Preface

Starting with the National Solar Mission in 2010, solar power, especially solar PV, has been growing at a hectic pace in India.

From almost insignificant installations in 2010, the total installed capacity of solar PV has crossed 20100 MW by January 2018. That is a fairly good achievement in just eight years.

The growth in this sector is set to accelerate even further, with the NDA government at the center significantly enhancing the targets to be achieved – the new targets are now a total of 100 GW by 2022. Adding to the efforts from center is the role of many states, each of which has its own ambitious solar policies.

Not surprisingly, the lion’s share of the capacity addition has come from MW-scale, ground mounted utility solar PV power plants. Solar Mango estimates 85-90% of all capacity added in solar PV since 2010 has been in the MW-scale solar sector. In contrast, the growth in rooftop solar has been slow but is highly likely to pick up pace in 2018 with the central and state governments’ policy initiatives.

These developments signify that there is rising demand for solar modules in India. The interest for module manufacturing in India has been relatively subdued until 2015, due to the sector not being competitive as a result of most of the modules being imported. But with the central government’s aggressive push to support domestic manufacturing, the scenario is getting increasingly attractive for setting up solar module manufacturing units.

It is hence no surprise that there is significant interest among new and existing businesses to venture into or expand operations in solar manufacturing.

The India Solar PV Module Manufacturing Report provides a comprehensive overview of the Indian Solar PV module manufacturing industry. This report is mainly intended for companies and businesses looking forward to invest in this sector. The technology under consideration here is crystalline modules as this constitutes the vast majority of the market.

This report was created by Solar Mango, the #1 Solar Guide.

The report was last updated on March 2018.

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Indian Solar PV Industry Status and Current Trends

1. Introduction

Being the first section of the report, the aim of this chapter is to provide a broad overview of the solar market.

In this section of the report, various aspects of the solar PV modules sector in India are considered. This includes the details about the various technologies like crystalline silicon and thin films, demand and supply gap for PV modules in India, industry trends and an overview of the major players in the solar PV segment in India.

Due to rather low market share of thin film technologies in India and around the world, the focus of this report is on largely on crystalline silicon, even though we also give details relevant to thin-film technology.

Before we go into specifics, take a look at the following table which provides a broad overview of the Indian solar sector.

<table>
<thead>
<tr>
<th>Total available potential</th>
<th>India lies in a sunny tropical belt (high insolation) which means high solar potential. National Institute of Energy has estimated India’s solar potential at 749 GW.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exploited potential (production/installed capacity)</td>
<td>Exploited potential (production/installed capacity) is very little; total installed capacity (grid and off grid) is approximately 20 GW (as of Jan 2018)</td>
</tr>
<tr>
<td>Future expected production/installed capacity</td>
<td>Since the inception of the NDA government in 2014, the JNNSM mission has been revised from 20 GW to 100 GW</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Specific government incentives</td>
<td>National Solar Mission and other subsidies and incentives are available through Ministry of New and Renewable Energy as well as state governments</td>
</tr>
<tr>
<td>Amount of investments happening in this now, expected in future</td>
<td>Government is expected to spend $100 billion until 2022.</td>
</tr>
</tbody>
</table>
| Key bottlenecks and barriers                | • Cost of solar PV  
• High population density (land scarcity)  
• Technology obsolescence |
| Cost of power generation - and trends in the same over years | Current cost of production – Rs 5/kWh. This includes O&M, amortized/depreciated capital costs, loan repayment costs, and other expenses such as insurance over a 25-year period |

### 1.2 Solar Photovoltaics

Solar photovoltaics (SPV) is the process of converting solar radiation (sunlight) into electricity using a device called solar cell. A solar cell is a semi-conducting device made of silicon or other materials, which, when exposed to sunlight, generates electricity. The magnitude of the electric current generated depends on the intensity of the solar radiation, exposed area of the solar cell, the type of material used in fabricating the solar cell, and ambient temperature. Solar cells are connected in series and parallel combinations to form modules that provide the required power.

### 1.3 Current Solar Photovoltaic Market Scenario

#### 1.3.1 Market Share of PV Technologies

1.3.1.1 Crystalline PV

The majority of PV modules produced today use crystalline silicon (c-Si) as it is a light absorbing semiconductor. The c-Si technology was originally developed for the semiconductor industry to produce PV cells for integrated circuits and microchips. These PV modules have energy conversion efficiencies in
the range of 14 - 16 percent. The energy conversion efficiency of a solar module is the percentage of incident sunlight converted into electricity.

The two types of crystalline silicon technologies used to produce PV modules are monocrystalline and multi-crystalline (also called poly-crystalline). Mono-crystalline technology uses cells that are made from thin wafers sliced from a single, pure crystal silicon ingot.

A polycrystalline cell is cut from a multifaceted silicon crystal. More surface area is required due to inherent flaws and these panels are less efficient compared to polycrystalline panels in converting the sun's rays into electricity. Under the current market conditions, a monocrystalline module per watt is 5-10% costlier than polycrystalline module. This has been the main reason driving up the market share for crystalline silicon panels. The market share of crystalline silicon is estimated to be about 90%.

1.3.1.2 Thin-film PV

The high demand for crystalline silicon PV modules had outstripped production, which caused an increase in the prices of crystalline cells. As a result, a number of PV cell manufacturers have begun using less expensive semiconductor materials including amorphous silicon (a-Si), cadmium telluride (CdTe), copper indium di-selenide (CIS) or copper indium gallium selenide (CIGS). These materials are good light absorbers and are fairly thin. Among these, CdTe is the most prominent technology being followed currently, followed by a-Si and CIGS. They are known as thin-film because they are deposited in very thin layers on stainless steel, glass or a flexible substrate. The thickness of the film is less than 1 micron. Like c-Si, thin-film PV cells are combined into modules and laminated to protect them from the elements.

The thin film value chain is much shorter, as the modules are manufactured in one single step from raw silicon and other compounds by depositing the photovoltaic material and other chemicals on glass or transparent film. Take a look at the market share of thin-film technology below.

**Figure 1: Market Share of Solar PV Technologies (Source: Photovoltaic Report, Fraunhofer ISE)**

The market share chart tells us that Crystalline Silicon technologies (both mono- and poly-silicon) dominate the market with over 90% market share at the global level. In 2017, the market-share of all thin-film technologies...

**Figure 2: Thin-film annual global PV module production (Source: Photovoltaic Report, Fraunhofer ISE)**

On an interesting note, thin film had a much higher market share in India, owing to the penetration of...
1.3.1.3 Summary

The table below gives the breakup of the various technologies.

**Table 2: Market share of solar PV technologies (Source: Compiled from various sources)**

<table>
<thead>
<tr>
<th>Type</th>
<th>Share of total solar PV market by installed capacity – 2017 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystalline</td>
<td></td>
</tr>
<tr>
<td>Monocrystalline</td>
<td></td>
</tr>
<tr>
<td>Polycrystalline</td>
<td></td>
</tr>
<tr>
<td>Thin-film</td>
<td></td>
</tr>
<tr>
<td>a-Si</td>
<td></td>
</tr>
<tr>
<td>CdTe</td>
<td></td>
</tr>
<tr>
<td>CIGS</td>
<td></td>
</tr>
</tbody>
</table>

Market share for polycrystalline modules is expected...

Now, let us take a look at the average cost of PV modules and cells.

**Table 3: Cost Trends for PV Cells & Modules - Feb 2018 (Source: PVinsights, Energy Trends)**

<table>
<thead>
<tr>
<th>Type</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Polycrystalline module ($/W)</td>
<td></td>
</tr>
<tr>
<td>Monocrystalline module ($/W)</td>
<td></td>
</tr>
<tr>
<td>Thin-film module ($/W)</td>
<td></td>
</tr>
<tr>
<td>156 mm multi solar cell ($)</td>
<td></td>
</tr>
<tr>
<td>156 mm mono solar cell ($)</td>
<td></td>
</tr>
</tbody>
</table>

1.3.2 Global Market Overview

1.3.2.1 PV installed Capacity by region

The increased competitiveness of solar PV coupled with attractive government policies and incentives has encouraged the growth of solar PV all around the world. Earlier, although Europe was by far the largest
contributor to solar PV installations around the world, the scenario has changed significantly since 2008 when the Chinese solar PV manufacturing boom drove down the prices of solar panels.

The total Solar PV installed capacity reached 227 GW in 2018, growing at CAGR of 41.5% since 2010.

*Figure 3: Solar PV Growth by Region (Source: IEA PVPS)*

1.3.2.2 PV Manufacturing Value Chain

In this section, we discuss the market trends witnessed along the PV manufacturing value chain. The solar PV manufacturing chain consists of polysilicon, ingots and wafers, cells followed by modules, as shown below.

![Solar Upstream Value Chain Diagram](image)

*Figure 4: Solar Upstream Value Chain*

I. Global Polysilicon Trends

*Figure 5: Polysilicon capacity forecasts (Source: REC Silicon, PV-tech)*

II. Global Wafer and Cell Trends

III. Global Module Production Trends

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The module production capacity during 2018 is about 77 GW and China accounted for two-thirds of this capacity. Monocrystalline cells and modules continued to gain market share from multi-crystalline in 2017.

1.3.2.3 Price Trends along the PV Manufacturing Value Chain

The following table represents data on global prices of module, cell, wafer and polysilicon.

*Figure 6: Price Trends along the PV Manufacturing Value Chain (Source: Mercom, EnergyTrends, PVInsights)*

Take a look at key price trends observed in the solar market as of January 2018.

- Polysilicon spot prices have seen a significant uptrend over the last month after experiencing inventory sell-off in September. The reason for this can be attributed to significant demand increase downstream.
- Wafer prices...

1.3.3 Domestic Market Overview
1.3.3.1 Manufacturing Trends in Upstream Solar PV Value Chain

The business opportunities in the solar energy sector is among the fastest growing in the world. Solar manufacturing, as a business opportunity, has been witnessing sharp growth in the recent past in India.

To get a glimpse of solar manufacturing in India, let's take a look at the comparison table below.

*Table 4: Global Solar Manufacturing Capacities*

<table>
<thead>
<tr>
<th></th>
<th>Polysilicon (Metric Tons, MT)</th>
<th>Ingots &amp; Wafers (GW)</th>
<th>Cell (GW)</th>
<th>Modules (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Despite increasingly attractive policies for solar manufacturing, India significantly lags behind other Asian countries such as China and Taiwan in expanding its solar manufacturing capabilities. The following table clearly depicts the magnitude of solar module manufacturing in China, which highly contrasts with the Indian scenario.

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Table 5: Top 3 Module Manufacturers in China & India

<table>
<thead>
<tr>
<th>China’s Top 3 Module Manufacturers</th>
<th>India’s Top 3 Module Manufacturers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

There is a wide differentiation with regard to the business opportunities and their drivers in different manufacturing sectors in the solar value chain. A summary of the opportunities for businesses in the solar PV upstream value chain in India (and globally) is as follows:


<table>
<thead>
<tr>
<th>Value chain component</th>
<th>Competitio n</th>
<th>Investment required</th>
<th>Paybac k period</th>
<th>Margin Potential</th>
<th>Key Drivers</th>
<th>Suitable for</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polysilicon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingots &amp; Wafers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar Cells</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar Module(Crystalli ne)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar Module(Thin Film)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
1.3.3.2 Domestic market growth
Solar PV installations in India have grown from a mere 460 MW in 2011 to almost 20000 MW by Jan 2018–a stunning 83% annual growth. Solar Modules in India- Industry Trends

1.3.4 Competition from Chinese Imports
Despite the growing capacity of solar module manufacturing capacities in India, a large proportion of solar module requirements is met by imports.

As expected, bulk of the imports have been from China, accounting for nearly 80% of imports.

The graph below provides a clear estimate of the trends in solar module imports.

*Figure 7: Solar panel imports by Value (Source: Solar Mango Research)*

*Figure 8: India Solar Imports by Value - Country-wise breakdown (Source: Mercom Capital Group)*

While the reasons behind the massive Chinese advantages in the solar PV sector can be debated, there can be no doubt that there are about large Chinese solar module makers whose quality will qualify under most evaluations, and at the same time, whose prices are the lowest in the world for the premium quality.

1.3.5 Exports
India today has a domestic module manufacturing capacity of about 9600 MW. Of this, India's top tier module manufacturing companies...

*Figure 9: Imports and Exports of Solar Cells & Modules by Value (Source: Mercom Capital Group, Data from Dept. of Commerce)*

In the period November-February 2018, ...

*Figure 10: India Solar Exports by Value - Country-wise Breakdown (Source: Mercom Capital Group)*

1.3.6 Impact of GST
The Good and Services Tax (GST) is based on the foundation of reduction of exemptions. Considering the fact that solar energy sector currently benefits from various exemptions and concessional duty and the
central level as well as in many states, the implementation of the GST bill is likely to remove these exemptions/concessions. Due to the removal of most of these exemptions, the cost of procurement of solar components like panels, inverters, cables, mounting structures etc. is likely to go up by 12-20% depending on the project (Source: MNRE). This could stall many solar projects and affect solar developers and installers in a big way.

1.4 Demand and Supply of Modules

1.4.1 Estimates for DCR Market Potential

The Domestic Content Requirement (DCR) policy which made it mandatory to locally sourced modules created a market for Indian solar module makers. Prior to this, until about 2011 when the Indian solar market started gathering pace, most of the Indian solar module capacity catered to the export market.

Table 7: Yearly DCR Installations (Source: Solar Mango & MNRE)

<table>
<thead>
<tr>
<th>Year</th>
<th>Yearly Installations (MW)</th>
<th>DCR Installations (MW)</th>
<th>DCR %</th>
<th>Cumulative Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td></td>
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<td>2011</td>
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<td>2017E</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2018E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TAKEAWAY for DCR Estimates

Our preliminary inference is as follows:

- **Overall**, we expect...
- **For the year 2016**, ...
- **For the year 2017**, ...
- **For the year 2018**, ...

1.4.2 Demand - Total Market Potential for Indian Module Makers

This section quantifies the market for Indian module makers for the following:
• **Ground-Mounted Projects**
  - Under DCR
  - Non-DCR

• **Rooftop Projects**
  - Under DCR
  - Non-DCR

• **Exports**

1.4.2.1 **Ground-Mounted**

**a) DCR Market for Ground-Mounted Solar**

<table>
<thead>
<tr>
<th>Year</th>
<th>MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td></td>
</tr>
</tbody>
</table>

**b) Non DCR Market for Ground-Mounted Solar**

<table>
<thead>
<tr>
<th>Year</th>
<th>MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td></td>
</tr>
</tbody>
</table>

1.4.2.2 **Rooftop Market**

**a) DCR Market for Rooftop Solar**

<table>
<thead>
<tr>
<th>Year</th>
<th>MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td></td>
</tr>
</tbody>
</table>
b) Non DCR Markets for Rooftop Solar

With all the above inputs, and based on historical data available with Solar Mango for this sector, we estimate the following to be the market for domestic solar modules for the non-DCR rooftop solar market.

Table 11: Non-DCR for Rooftop Sector (Source: Solar Mango Estimate)

<table>
<thead>
<tr>
<th>Year</th>
<th>MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td></td>
</tr>
</tbody>
</table>

1.4.2.3 Export Market

Table 12: Solar Capacities in US & Europe

<table>
<thead>
<tr>
<th>Region</th>
<th>2015 Installation (total in GW)</th>
<th>2018 expected (in GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 13: Export Potential for Indian Module Makers (Source: Solar Mango)

<table>
<thead>
<tr>
<th>Year</th>
<th>Export potential (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>150</td>
</tr>
<tr>
<td>2017</td>
<td>200</td>
</tr>
<tr>
<td>2018</td>
<td>250</td>
</tr>
</tbody>
</table>

TAKEAWAY - Total Available Market for Indian Module Manufacturing Companies

With all the above sectors taken into account, Solar Mango estimates the following market size available for Indian module makers next 3 years.

Table 14: Market Size for Indian Module Manufacturers (Source: Solar Mango Estimate)

<table>
<thead>
<tr>
<th>Year</th>
<th>DCR Ground Mounted (MW)</th>
<th>Non-DCR Ground Mounted (MW)</th>
<th>DCR Rooftop (MW)</th>
<th>Non-DCR Rooftop (MW)</th>
<th>Exports (MW)</th>
<th>Total Range (MW)</th>
</tr>
</thead>
</table>
1.4.3 Supply

<table>
<thead>
<tr>
<th>Year</th>
<th>Installed Capacity (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016F</td>
<td></td>
</tr>
<tr>
<td>2017F</td>
<td></td>
</tr>
<tr>
<td>2018F</td>
<td></td>
</tr>
</tbody>
</table>

1.5 Major Module Manufacturers

This section discusses the major players in module manufacturing from around the world and in India.

1.5.1 Domestic Players

According to the latest published MNRE data (Jan 2018), Indian module manufacturing capacity stands at 9600 MW. But Solar Mango research suggests that many of these are not operational or obsolete facilities. The operational module manufacturing capacity is estimated to be around 7700 MW.

The table below gives a list of module manufacturers in India by capacity, as announced by them.

<table>
<thead>
<tr>
<th>Companies</th>
<th>Installed Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waaree Energy</td>
<td>500 MW</td>
</tr>
<tr>
<td>Vikram Solar</td>
<td>500 MW</td>
</tr>
</tbody>
</table>

www.solarmango.com
The complete list of module manufacturers is provided in the Annexure A1.

**Highlights**

- Although still a fairly slow market, several prominent Module Manufacturers such as Vikram Solar, Waaree and smaller manufacturers such as CEL, PV Power, ...

- **Future Trends for Capacity Addition**

  - **Vikram Solar's** annual PV Module production capacity...

1.5.2 **International Module Makers**

PV Tech, one of the credible solar industry sources, ranks the top solar panel manufacturers according to the shipments they have made for a fiscal year.

Please find the international module manufacturer ranking for 2017 below:

<table>
<thead>
<tr>
<th>Rank</th>
<th>Manufacturer</th>
<th>Country</th>
<th>Shipments,2017 (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td></td>
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<td>3</td>
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<td>4</td>
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<tr>
<td>5</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
1.6 Drivers and Barriers for Solar PV Module Investments

1.6.1 Drivers

*Solar Mango* has complied and analyzed all the major levers and the type of impact they will likely have on the industry.

<table>
<thead>
<tr>
<th>Lever</th>
<th>Chances that this will drive/affect module sales by</th>
<th>Current Situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic Content Requirement (DCR)</td>
<td>High</td>
<td>NTPC announced a total DCR of 1900 MW on 7190 MW of solar projects under JNNSM Phase 2 as of Mar 2016. This is 26% of the total planned capacity. Solar projects taken up by the Indian Army, Railways and other public sector enterprises (including NTPC) will be subsidised by INR 1 crore for each MW of capacity.</td>
</tr>
<tr>
<td>WTO Ruling</td>
<td>Medium</td>
<td>The recent Ruling by the World Trade Organisation (WTO) against India with regard to using domestic cells and modules for DCR projects could be of significant relevance in the context of overall demand for locally made cells. There is a possibility that the Indian government could arrive at some compromise, failing which the government has assured solar cell and module makers that it will resort to purchasing local cells and panels through solar power plants fully owned and developed by PSUs (railways, defence, NTPC etc., for which the WTO ruling does not apply.</td>
</tr>
</tbody>
</table>
Solar Mango’s India PV Module Manufacturing Report

<table>
<thead>
<tr>
<th>Anti-Dumping Duty</th>
<th>Low</th>
<th>Medium</th>
</tr>
</thead>
</table>

- Imposition of Anti-Dumping duties by countries such as USA and Europe is causing global solar module manufacturers to consider setting up plants in India. There are however no signs of the Indian Government imposing any anti-dumping duties on solar products imported from outside the country. We do not expect any support from ADD for the next 2-3 years.

<table>
<thead>
<tr>
<th>Module Manufacturing Support</th>
<th>Low</th>
<th>Medium-High</th>
</tr>
</thead>
</table>

- Modified Special Incentive Package Scheme (M-SIPS): 20% and 25% subsidy on capital expenditure has been announced for entities establishing cell and module lines in Special Economic Zones (SEZ) and Non-SEZs, respectively. Some state governments are providing further incentives. For example, Andhra Pradesh, which has one of the better policies, provides additional financial assistance of up to INR 2.5 million (USD 40,000) along with subsidy in power tariffs, exemption of stamp duty, VAT/CST tax exemption for first five years of operation.

Y – Yes; N – No

1.6.2 Barriers

1. Because of the ease of entry, it is important for a new comer to invest heavily in “Marketing” capabilities.

2. High working capital requirement - the major cost factor is the material cost. Typically, the working capital requirement is about 3-4 times that of capital expenditure.

3. Policy Stability - As mentioned earlier, the demand for Solar PV modules is driven by the government policies and the subsidies offered for the Solar PV power projects. In India, especially at state level, there is significant uncertainty about successive governments continuing with the policies of their predecessors. This creates a barrier to investments for projects such as solar PV that depend on long term power purchase agreements for their viability. This can lead to reduced capacity utilization.
2 Basics of Modules - Technology Involved

The Big Picture

- Crystalline Silicon modules, which is the dominant market technology with over 90% of global market share, can be categorised into monocrystalline and polycrystalline. Current polycrystalline modules have achieved efficiencies of 14-16.5% while monocrystalline modules have achieved higher efficiencies of 17-21%.
- In a semi-automated facility, ...

2.1 Introduction

Solar PV modules can be produced using different technologies. Today, crystalline silicon technology leads the Solar PV module production, followed by thin films. There are also other technologies being developed, but crystalline silicon technology and thin film technology will continue to dominate the solar PV module space for the foreseeable future, unless some technology breakthrough happens. As mentioned in earlier sections, since thin-films are very nascent in India, only crystalline silicon technology is discussed in detail in this section, even though details about thin-films is also provided for the sake of completion.

In this section, the technology details of the crystalline silicon and thin film modules are provided. The production processes for both these technologies is also explained in detail. The important equipments used for the production are discussed subsequently. Once a module is produced, it is important to test and certify them before they can be sold to customers.

The details about the various testing and certification standards for modules are discussed in this chapter followed by some of the latest developments in the Solar PV technology.

2.2 Modules

A solar panel (photovoltaic module or photovoltaic panel) is a packaged interconnected assembly of solar cells, also known as photovoltaic cells. The solar panel can be used as a component of a larger photovoltaic system to generate and supply electricity in commercial and residential applications.

History

Solar energy was developed about a century ago. Solar power was initially used for the production of steam to drive machinery. Later on Henri Becquerel discovered the "photovoltaic effect" explaining the process of converting sunlight into electric energy. The first solar cell was invented in 1893 by Charles...
Fritts by coating sheets of selenium with a thin layer of gold. Subsequently, the solar panel came into existence by Russel Ohl. These solar panels were used in space satellites.

Today, solar panels and complete solar panel systems are used to power a wide variety of applications. Solar panels in the form of solar cells are still being used in calculators, keyboards and other mobile devices. Recently, they are being used to provide power to entire homes and commercial buildings. The world is presently witnessing the evolution of next generation solar power plants powering the needs of an entire nation.

Family

Where does solar module come in the product chain?

The picture below shows the Solar PV Value Chain. The solar PV module production is the final stage in a series of steps that starts with the raw material Quartz. The Quartz is first converted to Poly-silicon which is then converted to Ingots (mono-crystalline or multi-crystalline). These Ingots are then sliced to form thin wafers. In the next stage, these silicon wafers are subjected to chemical processing and are converted to semi-conductors by doping the wafers with elements like Phosphorous, Boron, etc. The final product is the PV module which is produced by assembling several cells and interconnecting them.

**Figure 11: Solar PV Value Chain**

The assembly of crystalline Si solar modules is most commonly carried out in the cell plant, but can be done in smaller plants closer to the end market. The latter can be preferable as solar cells are relatively inexpensive to transport, whereas modules with a glass front sheet and an aluminum frame are heavy and bulky. In general, thin film modules must be assembled in the cell plant because the cells are too susceptible to mechanical damage during transportation unless they are packaged within a module.
2.2.1 Technology Options – Crystalline Silicon vs. Thin Film

In the world of photovoltaic (PV) solar power, there are several types of semiconductor technologies currently in use for PV solar panels. Two, however, have become the most widely adopted: crystalline silicon and thin film.

2.2.1.1 Crystalline Silicon

Crystalline silicon panels are constructed by first putting a single slice of silicon through a series of processing steps, creating one solar cell. These cells are then assembled together in multiples to make a solar panel. Crystalline silicon, also called wafer silicon, is the oldest and the most widely used material in commercial solar panels. There are two main types of crystalline silicon panels:

- Monocrystalline Silicon
- Polycrystalline Silicon

**Monocrystalline Silicon**

Monocrystalline (also called single crystal) panels use solar cells that are cut from a piece of silicon grown from a single, uniform crystal. Monocrystalline panels are among the most efficient yet most expensive on the market. They require the highest purity silicon and have the most involved manufacturing process.

**Polycrystalline Silicon**

Polycrystalline (also called multi-crystalline) panels use solar cells that are cut from multifaceted silicon crystals. They are less uniform in appearance than monocrystalline cells, resembling pieces of shattered glass. These are the most common solar panels on the market, being less expensive than monocrystalline silicon. They are also less efficient, though the performance gap has begun to close in recent years.

2.2.1.2 Thin Film

Thin film solar panels are made by placing thin layers of semiconductor material onto various surfaces, usually on glass. The term *thin film* refers to the amount of semiconductor material used, which is thinner than the width of a human hair. Contrary to popular belief, most thin film panels are not flexible. Thin film solar panels offer the lowest manufacturing costs, and are becoming more prevalent in the industry. Three main types of thin film are used:

1. **Cadmium Telluride (CdTe)**
CdTe is a semiconductor compound formed from cadmium and tellurium. CdTe solar panels are manufactured on glass. They are the most common type of thin film solar panel on the market and the most cost-effective to manufacture. Today, CdTe is not as efficient as crystalline silicon, but CdTe panels perform significantly better in high temperatures due to a lower temperature coefficient.

ii. Amorphous Silicon

Amorphous silicon is the non-crystalline form of silicon and was the first thin film material to yield a commercial product, first used in consumer items such as calculators. It can be deposited in thin layers onto a variety of surfaces and offers lower costs than traditional crystalline silicon, though it is less efficient at converting sunlight into electricity.

iii. Copper, Indium, Gallium, Selenide (CIGS)

CIGS is a compound semiconductor that can be deposited onto many different materials. CIGS has only recently become available for small commercial applications.

The following table lists the comparison between various types of Solar cells namely thin film, monocrystalline and polycrystalline solar cells used to make respective types of solar modules.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Thin film</th>
<th>Monocrystalline</th>
<th>Polycrystalline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appearance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexibility</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost ($/watt)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area (acres/MW)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stability</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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2.2.2 Crystalline Module Making

2.2.2.1 Module Structure

A module is a group of cells connected electrically and packaged into a frame (more commonly known as a solar panel), which can be grouped into larger solar arrays. Module manufacturing involves putting together the cells onto glass or other substrates and connecting the cells to form an electric circuit. This is the last manufacturing step before it is distributed to wholesalers.

The Module assembly forms the heart of the module manufacturing process. In this process, the components are arranged together and fed into a laminator.

![Solar Module Assembly](image)

**Figure 12: Solar Module Assembly**

A typical solar module includes the following components:

1) A transparent top surface, usually glass

2) An encapsulant – usually thin sheets of ethyl vinyl acetate that hold together the top surface, solar cells, and rear surface

3) A rear layer – a thin polymer sheet, typically Tedlar, that prevents the ingress of water and gases

4) A frame around the outer edge, typically aluminum
2.2.2 Assembly Process

The Module assembly forms the heart of the module manufacturing process. In this process, the components are arranged together and fed into a laminator. The set of activities involved in the assembly process include the following.

![Diagram of Module Assembly Process]

**Figure 14: Module Assembly Process**
2.3 PV Module Manufacturing Line

2.3.1 Module Line Classification

Depending on the level of automation in the PV module equipment, a PV module manufacturing line can be classified into the following three categories:

1. Manual
2. Semi-automated
3. Fully automated

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Semi-Automated</th>
<th>Fully-Automated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree of Automation</td>
<td>Degree of automation is confined predominantly to tabbers &amp; stringers, and laminators</td>
<td>The facility is completely automated</td>
</tr>
</tbody>
</table>

2.3.2 Features of Module Lines

To understand some features of a typical module production line, take a look at the comparison table below.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>20 MW line</th>
<th>60 MW line</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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</tbody>
</table>

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2.3.3 Scope of Work of a Module Equipment Supplier

During the decision time, the equipment supplier who is entrusted the task of turnkey implementation of the plant will analyze and design the project in close contact with the customer, listening to all specific needs in order to optimize production flow of the photovoltaic modules.

The typical service package offered by equipment suppliers include:

2.3.4 Machines and Equipments

A fully functional and state-of-the art PV module production line (200 MW) has been illustrated below.

*Figure 16: Components of a 200 MW Turnkey production line (Source: Jinchen Machinery)*

The list of machines that would be comprised in such a large capacity, fully-automated solar module manufacturing facility include:

1. Automatic Cell tester and sorter
2. Automatic loading Handler
3. EVA Automatic Cutting and Layup Machine
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21. 
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23.  
24.  
25.  
26.  

Here below, we have discussed the main equipment used with some details on their benefits and features.

2.3.4.1 Auto Cell Tester and Sorter

The automatic cell tester and sorter machines perform a function and quality test on the photovoltaic cells before commencing production of the modules, classifying them according to their electrical characteristic (current, voltage and/or power etc.) avoiding defective cells in the production process.

Some cell tester and sorter machines are equipped with advanced vision system and solar simulators which allow for precise measurement and checking of various electrical parameters.

The cells are usually sorted into batches following which the cells below quality are rejected. The classification of cells into different quality levels according to their characteristics maximizes the overall production yield, reducing mismatch losses.

A computer with user-friendly software adjusts the lamp intensity, controls the measurement process and cell handling, and acquires cell performance data. The data, as a full I-V curve, allows sorting by a variety of selectable criteria. The computer plots the I-V curve and displays a variety of cell characteristics. Curves and data can be printed and stored on disk.

![Cell Tester and Sorter](Source: Mondragon Assembly)

*Figure 17: Cell Tester and Sorter (Source: Mondragon Assembly)*

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2.3.4.2 Auto Laser Scribing Machine

2.3.4.3 Glass Washer
2.3.4.4 Tabber & Stringer
2.3.4.5 Automatic Layup System

2.3.4.6 Automatic Laminator
2.3.4.7 Edge Trimming Station
2.3.4.8 Module Transfer/Module Conveyor Belts
2.3.4.9 Semi-automatic Framer
2.3.4.10 Automatic Framer
2.3.4.11 Sun Simulator
2.3.4.12 Lighting Table
2.3.4.13 EL tester
2.3.4.14 Hipot Inspection
2.3.4.15 Inspection & Cleaning

2.4 Conditions of Sale

1. Payment Terms
2. Delivery Time
3. Taxes and Duties
4. Warranty and after-sales service
5. Training

2.5 Testing and Certification of Modules

2.5.1 Global Certification Standards

The number of solar PV certifications is increasing and solar system installers are aware that certified solar products are required for market. So it is important to understand and identify the solar certifications that are crucial for solar modules that the company produces. Having the required certifications could mean a competitive advantage in this market. It is also important to know the latest certification developments regarding new solar products. For instance, installing solar panels near a coast line needs resistance to salt mist corrosion (IEC 61701 certification). If a particular region is dealing with large amounts of snow during winter, installing solar panels with an increased load capacity (5400Pa certification) would be a better choice.

For solar products, it is necessary to get CE or NRTL mark.
2.5.2 List of Certifications Made Mandatory by the Indian Government

2.5.3 New Regulations by MNRE

The MNRE has decided to bring out technical regulation for Solar Photovoltaic Systems/ Devices/ Components/ Goods. Concurrently, the MNRE is in the process of bringing out a Lab Policy for Testing,

Under the draft regulation, the specified standards proposed for Indian PV modules has been tabulated below.

<table>
<thead>
<tr>
<th>Table 21: Specified Standards based on Draft Technical Regulations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product</strong></td>
</tr>
<tr>
<td>-------------</td>
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<td></td>
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</tbody>
</table>

2.6 Recent Technology Developments

A matter of concern while setting up a module line could be with regard to emergence of potential new technologies. In a highly dynamic market like solar, constant up gradation of new and emerging technologies is essential and something to look out for.

1. **Shift towards higher bus bar design**

Bus bars connect solar cells to each other to create higher voltages and facilitate the flow of electrons. As you increase the number of bus bars, more electrons are able to pass through, thereby increasing power and efficiency. A one bus bar improvement can generate 5 more watts per panel.

Many panel makers worldwide have shifted from traditional 3 bus bar designs to 4 or 5 bus bar designs. Companies such as Solar World have moved directly from 3- to 5- bus bar design to gain the competitive edge.
Manufacturing lines may need some upgradation to cater to a change in the bus bar design. The automatic soldering machines used to assemble 4 bus bar modules are different, hence it requires extra capital investment by the module manufacturer to upgrade their equipment. In fact, such an improvement will require that the actual cell design, the layout, the spacing, the solder pads are all absolutely specifically optimized for the higher bus bar design implementation.

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3 Investment and Returns

The Big Picture

- The cost per MW for a module manufacturing line depends on the three factors – capacity of module line, degree of automation and equipment supplier (Chinese or European). The per MW cost for 50 MW facility from a European manufacturer ranges from...
- The cost of production for a module line ranges from...

3.1 Capital Costs for a Turnkey Module Assembly Line

The low capital requirement for setting up a module manufacturing line has been a crucial reason why it has been attractive in the Indian context. Moreover, compared to other parts of the PV value chain, the payback period is quite low.

The cost components involved include

- **Machines & equipments**
- **Other Infrastructure** - land, building, storage, water infrastructure, bank processing fees, certification fees, etc.

Now, while considering the costs for a module line, there are three parameters to be considered namely,

- Degree of automation (semi-automated or fully-automated)
- Capacity of the project
- Equipment supplier (European or Chinese)

To get a broad understanding of the costs, *Solar Mango* has compiled some cost estimates based on interactions with various equipment suppliers. Take a look at the table below.

| Table 22: Comparison of CAPEX costs between a European and Chinese Equipment Supplier (Source: Solar Mango Research) |
|---|---|---|---|---|
| | **20 MW** | **50 MW** | **120 MW** |
| European Equipment Cost | | | | | |
| Other Infrastructure | | | | | |

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### 3.2 Cost of Equipment

1. **Sample Costs – European Manufacturer – 23 MW Semi-Automated Line**

   **Table 23: Cost of Equipment for a Semi-automated facility (European Manufacturer)**

<table>
<thead>
<tr>
<th>Name of Equipment</th>
<th>INR (in Lakhs)</th>
<th>% Contribution of Total</th>
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</table>

2. **Sample Quote – Chinese Manufacturer – 20 MW Semi-Automated Line**

   **Table 24: Cost of Equipment for a Semi-automated facility (Chinese Manufacturer)**

<table>
<thead>
<tr>
<th>Name of Equipment</th>
<th>INR</th>
<th>% Contribution of Total</th>
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<tbody>
<tr>
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</tbody>
</table>
3.3 Chinese versus European Equipments

Of late, European module equipment suppliers are facing increased competition from Chinese suppliers of turnkey module lines.

It goes without saying that India is a price-sensitive market which means naturally there is a demand for cheaper Chinese equipments. Nevertheless, the superior quality and safety standards offered by European suppliers are still very attractive in the market.

*Solar Mango* has witnessed the following trends when it comes to equipment selection for module manufacturing facilities.

3.4 Cost of Production

A very critical fact to be noted while implementing a solar module manufacturing facility is that the initial capital cost contributes to only 1-2% of total cost of production. The other components that occupy the total cost of production include:

- Raw Materials – cells, backsheet, EVA, glass, ribbon, J-box etc.
- Manpower – employee salaries, logistics
- Utility and water
- Other costs – tool maintenance, facility maintenance etc.
The running costs per watt-peak associated with the

\[ \text{Table 25: Cost of Operation for Module Manufacturing Facility} \]

<table>
<thead>
<tr>
<th>OPEX</th>
<th>Semi-automated</th>
<th>Fully Automated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>INR/Wp</td>
<td>US cents/Wp</td>
</tr>
<tr>
<td><strong>Raw Materials</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cells</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Raw Materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Other Running Costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power &amp; Water cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Costs – Tool Maintenance, logistics</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\*1 USD ≈ Rs. 66

3.5 Returns – Cash Flow, IRR, Payback Period

The return on investment depends on different factors and hence it is difficult to give a standard number for returns (on any parameter). However, based on some of our calculations, we are providing some ballpark numbers below. For the purpose of calculations, let us consider a 50 MW semi-automated facility (European line).

3.5.1 Inputs

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
</tr>
<tr>
<td>Bank Rate</td>
</tr>
<tr>
<td>Corporate Tax</td>
</tr>
<tr>
<td>Debt</td>
</tr>
<tr>
<td>Equity</td>
</tr>
<tr>
<td>Loan Term</td>
</tr>
<tr>
<td>Moratorium</td>
</tr>
</tbody>
</table>
3.5.2 Expenses

1) CAPEX

<table>
<thead>
<tr>
<th>European</th>
<th>Rs. (Crores)</th>
<th>$ (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment Cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Infrastructure</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2) OPEX

<table>
<thead>
<tr>
<th>Semi-automated</th>
<th>INR/Wp</th>
<th>US cents/Wp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cells</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Raw Materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power &amp; Water cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Costs – Tool Maintenance, logistics</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Other Running Costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3) Financing

<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financing Expenses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 3.5.3 Revenue

<table>
<thead>
<tr>
<th></th>
<th>Year 1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity Utilization</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Module production</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price (US cents/W)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sales (US$ million)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 3.5.4 Returns

The returns for a 50 MW semi-automated facility is provided below.

<table>
<thead>
<tr>
<th></th>
<th>Equity IRR</th>
<th>Project IRR</th>
<th>DSCR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 3.6 Government Incentives to Support Solar PV Manufacturing

The central government has come up a plan to support solar manufacturing in India through the Prayas initiative which intends to expand manufacturing capacity in India to cater to the domestic as well as export demand. This initiative is expected to augment interest in module manufacturing in India through a $3.1 billion fund.

As of now, there are two direct incentives available for module manufacturing in India.
4 Risks and Mitigation

The Big Picture

- The critical risks faced by Indian module manufacturers comes from Chinese competition and the uncertain regulatory environment. With the current Chinese module prices being the lowest-ever, Indian module suppliers are highly dependent on government support mechanisms like DCR, which has been repealed by the WTO and is under threat.
- The only sustainable mitigation strategies are well-thought out business models incorporating differentiation and partnerships.

4.1 Introduction

Before making an investment decision in the solar PV modules segment, one has to thoroughly analyze the risks involved in venturing into solar PV module production. A clear mitigation strategy should also be put in place before committing on investments. Lenders like banks, VCs and PEs will also be extremely keen on understanding the risks and mitigation strategies. In this section, the following risks are analyzed and appropriate mitigation strategies suggested.

- Project completion risk
- Country and financial risks
- Operational risks
- Market risks

4.2 Project Completion Risk

<table>
<thead>
<tr>
<th>Risk</th>
<th>Description</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Overrun</td>
<td>This refers to the various time delays which directly or indirectly affect the course of the entire project</td>
<td></td>
</tr>
<tr>
<td>Shipment Delay</td>
<td>A delay in shipment of the manufacturing equipment may pose a severe time lag in setting up the entire module line and hence in turn may delay the entire project</td>
<td>Set penalty clause with the equipment supplier for delay in shipment</td>
</tr>
</tbody>
</table>
4.3 Country and Financial Risks

Table 27: Country and Financial Risks

<table>
<thead>
<tr>
<th>Risk</th>
<th>Description</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country Risk</td>
<td>This covers a range of economic and political risks including government</td>
<td>This is an external factor over which the promoters have no control.</td>
</tr>
<tr>
<td></td>
<td>stability, status and maturity of the legal system, transparency of business</td>
<td></td>
</tr>
<tr>
<td></td>
<td>dealings and currency risks. It also includes general instability due to wars,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>famine and strikes.</td>
<td></td>
</tr>
</tbody>
</table>

4.4 Operational Risks

Table 28: Operational Risks
4.5 Market Risks

Table 29: Market Risks
5 Next Steps

The Big Picture

Whether you are a business planning on investing in a new module manufacturing facility or expanding an existing facility, the two key areas to focus on include

- Identification of the right technology partner
- Financial Closure of the project

5.1 Introduction

Just like any other venture, setting up of a Solar PV module manufacturing involves a series of steps covering various aspects like Technology vendor selection, Financial closure and project management till the first the modules are produced. Many of the things can be done in parallel, many are done sequentially. In this section, some of the key steps involved in the commissioning of the plant are highlighted.

Once all the details about the solar PV module production are evaluated and a decision taken to invest in the venture, the following steps need to be taken.

Figure 18: Next Steps
5.2 Preparation of Prefeasibility Study

Prefeasibility Report

Prefeasibility studies are well researched yet generic due diligence reports that facilitate a first level understanding of business feasibility for potential entrepreneurs in their investment decision making. While detailed project reports (DPR) are required for external stakeholders (lenders such as banks, for instance), prefeasibility reports are used for to assist internal stakeholders (e.g., board of directors) to take corporate decisions.

A typical prefeasibility report on Solar PV provides details about the following:

- Potential of solar PV modules production in India
- An introduction to the various solar PV technology options
- Identifying the different players across the solar PV value chain
- Evaluation of the first level technical feasibility of the solar PV module production project
- Evaluation of the first level economic feasibility of the solar PV module production project

This study is only meant to apprise the investor of the business feasibility of the project and is not a bankable study, i.e. this report cannot be submitted to financial institutions for availing loan, though it can be used as a support document to the more detailed project report.

5.3 Preparation of Detailed Project Report

Preparation of detailed project report is further step in firming up the proposal of setting of solar PV power plant. A Solar PV module detailed project report (DPR) will examine the following factors.

5.4 Technology Partner

Selection of equipment is one of the major decisions that a module assembly manufacturer needs to take.

Table 30: List of Turnkey PV Module Line Suppliers

<table>
<thead>
<tr>
<th>Name of Company</th>
<th>Region</th>
<th>Website</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>European</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chinese</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

www.solarmango.com
5.5 Selection of Raw Material Suppliers and Entering into Memorandum of Understanding (MOU) with Them

Once the equipment line has been finalized, it is time to turn start negotiating with suppliers of raw materials. This can be done immediately after finalizing the equipment or it can be more towards the expected completion of the commissioning of the module assembly line. In many cases, the turnkey equipment line providers also assist the project owner in getting into agreements with the raw material suppliers.

The typical raw materials required for a module manufacturing line includes

- Cells
- Backsheet
- Ribbon
- Encapsulant
- Frame
- Glass
- Junction Box
- Connectors

The list of raw material suppliers has been listed in the Annexures I – IX.

5.6 Achieving Financial Closure of the Project

Once the equipment line has been finalized and the complete detailed project report (DPR) ready, it has to be presented to lenders or other investors. If a debt funding is envisaged, the DPR has to be presented to the banks and it has to meet the requirements set by them. In case other private investors come in with equity funding, the DPR should be presented to them as well and the entire business plan explained to them to their satisfaction. As mentioned in earlier sections, if the project meets the expectations of the investors, financial closure can be easily achieved.

5.7 Implementation of the Project

The financial closure of the project sets the stage for the operational implementation of the project. In this case, the advance to the turnkey equipment provider can be given after the closure. Since it takes about 4-6 months for the equipment provider to deliver the turnkey lines and set it up, many other works can be completed in parallel during this period. For example, the following activities can be carried out before the equipments arrive.

a. Securing all relevant approvals
   I. Certificates from Pollution control board
II. Approvals as per the Factory Act
III. Labour certificates as relevant
b. Civil construction of the factory assembly line
c. Electrical connections from the state electricity departments
d. Compliance of other statutory requirements.

5.8 Module Testing and Certification

Module testing is critical since most of the solar PV projects world over are mandated to use only certified modules. The details of the certification are given in section 2.5.

After the equipment arrives and the installation completed, trial runs have to be done. Based on the successful completion of the trial certifications, the first set of PV modules can be produced and sent for testing.

5.9 Contacting Government Officials

While the need for liaising with the central and state governments is relatively low for module manufacturing compared to many other projects, it is always advisable to have good relationships with the government. Given below is a list of the renewable energy agencies in different states.

<table>
<thead>
<tr>
<th>State</th>
<th>Department</th>
<th>Address &amp; Contact Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANDHRA PRADESH</td>
<td>New &amp; Renewable Energy Development Corporation of Andhra Pradesh Ltd.</td>
<td>Vice Chairman &amp; Managing Director, Regd.Office:5-8-207/2, Ptgah Complex, Nampally, Hyderabad - 500 001. Tel. off: +91-40-2320 2391, Fax: 040-23201666 Email: <a href="mailto:info@nredcap.in">info@nredcap.in</a></td>
</tr>
<tr>
<td>ARUNACHAL PRADESH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ANNEXURE-1

6.1 List of PV Module Manufacturers – India

<table>
<thead>
<tr>
<th>Name of Company</th>
<th>Installed Capacity in MW (As on 30-01-2018)</th>
<th>Operational Capacity in MW (As on 30-01-2018)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access Solar Limited</td>
<td>18</td>
<td>NA</td>
</tr>
<tr>
<td>Agrawal Solar</td>
<td>40</td>
<td>NA</td>
</tr>
<tr>
<td>Ajit Solar Pvt Ltd</td>
<td>35</td>
<td>20</td>
</tr>
<tr>
<td>Alpex Exports Pvt Ltd</td>
<td>200</td>
<td>150</td>
</tr>
<tr>
<td>AMV Energy Systems Private Ltd</td>
<td>10</td>
<td>NA</td>
</tr>
</tbody>
</table>

*NA – Information Not Available

6.2 List of PV Cell Manufacturers – India

<table>
<thead>
<tr>
<th>Companies</th>
<th>Installed Capacity (MW)</th>
<th>Capacity Under Installation (MW)</th>
<th>Announcements</th>
</tr>
</thead>
</table>

*Not in Operation
6.3 List of PV Cell Manufacturers – Global

ANNEXURE-II

6.4 List of EVA/Back sheet/ Front sheet/ PET/ TPT/TPE/PVB & TCO Manufacturers – Global

6.5 List of Major Solar PV Back Sheet Brands Imported in India

ANNEXURE-III

6.6 List of Manufacturers of Connectors– Global

ANNEXURE – IV

6.7 List of Ribbon Manufacturers – Global

ANNEXURE – V

6.8 List of Manufacturers of Cables – Global

ANNEXURE – VI

6.9 List of Frame Manufacturers – Global

ANNEXURE – VII

6.10 List of Glass Manufacturers – Global

ANNEXURE – VIII

6.11 List of Encapsulant Manufacturers – Global
ANNEXURE – IX
6.12 List of Junction Box Manufacturers – Global

ANNEXURE – X
6.13 List of Turnkey PV Module Line Suppliers