

GLOBAL TECHNOLOGY WATCH GROUP-RENEWABLE ENERGY TECHNOLOGIES

Interim Report August 2016

Divecha Centre for Climate Change, IISc Centre for Energy Studies IIT-D National Institute of Advanced Studies Gujarat Energy Research and Management Institute



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1 Introduction

The National Mission on Strategic Knowledge for Climate Change (NMSKCC), coordinated by Department of Science Technology, was formulated as one of the eight missions under the National Action Plan on Climate Change. Under NMSKCC, Global Technology Watch Group-Renewable Energy Technologies (GTWG-RETs) (Other being GTWG for Advanced Coal Technologies) is one of the six programmes that have been set up. The primary aim of this programme is to keep track of the state-of –the-art technologies emerging globally. GTWG-RET project is carried out by a network of institutions which is a mix of bodies involved in conducting basic scientific and application related research, policy, market assessment and evaluation. They are: DIVECHA Centre for Climate Change, Indian Institute of Advanced Studies, Bangalore (convener) and Gujarat Energy Research and Management Institute (GERMI). Areas covered by each of these institutions are solar photovoltaics; solar thermal and other renewable energy technologies, storage, integration and business and policy respectively. This report presents work done as part of first phase of the project. Along with this introduction chapter, this report consists following four major chapters.

- 1. Solar Photovoltiac Technologies
- 2. Solar Thermal Technologies
- 3. Storage for Energy Management and
- 4. Business Models and Policy

The report follows the proposed framework of the analysis i.e., to examine the relevance of the technology, assessing the role of the technology in contributing to the mission goals, examine the lifecycle and progression of the technology and finally commercial applicability of the technology. Accordingly, major chapters, covering different RETs under question, comprise of following aspects: introduction to the topic, current status in India, international best practices, applicability in the Indian context and finally recommendations. Major findings of each of these chapters are presented below.

Solar Photovoltaic Technologies (Divecha Centre for Climate Change, IISc, PI: Prof. J. Srinivasan and Co-PI: Dr. Sheela Ramasesha). This chapter begins by presenting the basic working principle of photovoltaic cells and history and development of PV technologies. Along with the progress made by various solar PV technologies, relative penetration of various PV technologies in the total PV installed capacity world-wide is also provided. Two major kinds of PV cells- wafer and thin film cells are discussed in detail. Under silicon wafer PV cells structure, advantages, disadvantages and manufacturing process of mono-crystalline and multi-crystalline cells are discussed. Under Thin Films PV cells Gallium Arsenide, Amorphous Silicon, Cadmium telluride thin films, Copper Indium Gallium-Selinide. For each of these cells, most recent

treatment and manufacturing processes, advantages and disadvantages of these cells are presented. Discussing the emerging technologies in this area, this chapter discusses structure, efficiency, manufacturing of multi-junction PV cells, Dye-Sensitized Solar cell, organic photovoltaic solar cell and Pervoskite solar cell. Finally, SPV technology status in India is presented through technology wise installation capacity. Based on irradiation measurements, the chapter recommends photovoltaic technologies for main cities in different states. Assessing the efficiency of different PV technologies, temperature and geographical conditions, the chapter makes recommendations to enhance manufacturing base, ensure quality control during installation and research and development in the filed of solar materials and the auxiliary electronic systems is critical.

Solar Thermal Technologies (Centre for Energy Studies IIT-D, PI: Prof. G. N. Tiwari

And Co-PI: Prof. T. S. Bhatti). This chapter covers wide-range of solar thermal applicationsconcentrating solar power, passive heating and cooling systems in building, daylight modeling concepts and energy saving assessment, solar heating of biogas plant, solar distillation, greenhouse photovoltaic dryer and solar water heaters. For each of these applications, their present status in India, lessons learnt from international best practices and recommendations are made for technological changes, enhancing the applicability of these technologies and policy recommendations. For example, for larger application and visibility this chapter recommends use of solar thermal energy for steam cooking, space heating in educational institutions, community centers and hospitals. Similarly, a policy recommendation is made to integrate most of available passive heating and cooling concepts for all newly constructed houses by builders. Integrating community cooking centers with solar water heating is another recommendation.

Storage for Energy Management (National Institute of Advanced Studies, PI: Prof. D. R. Ahuja and Co-PI: Prof. T.S. Gopi Rethinaraj). In the wake of increasing percentage of renewable energy in total installed capacity, present chapter examines the role of energy storage and management system. After presenting need for energy storage technologies, the chapter discusses types of existing storage technologies. This is followed by international scenario and technology overview. Following technologies are discussed: Thermal energy storage, Chemical energy storage, Fuel cells/Hydrogen Storage and Mechanical energy storage. Particularly, this chapter deals with Pumped hydro storage in detail. Operation, design criteria for economic viability, overview of the status world-wide are presented. Further, novel pumped hydro storage like variable speed motor-generator system, sea water pumped storage are discussed. Examining status of hydro storage system in India, regulatory framework issues and business models, for PHS system to emerge as sustainable technology, are discussed. Given the need for large upfront investment, this chapter recommends different financial instruments to support pumped hydro storage.

Business Models and Policy (Gujarat Energy Research and Management Institute. PI: Dr. Omkar Jani and CO-PI: Mr. Akhilesh Magal). The objective of this chapter is to document and evaluate policy support designed for solar photovoltaic technology; examine market and business models and suggest modifications for Indian photovoltaic market to evolve into a competitive and sustainable one. After highlighting the need to study State policies, regulations and market conditions for India to achieve its ambitious solar target, the chapter presents a detailed account of National Solar Mission deconstructed into different Batches. Following this, state level policies, regulations and business models for 17 major states are presented. International best practices in utility based policy interventions and utility based business models are also discussed. To this end, few examples across countries are also presented which will provide few insights for India's PV industry. Finally, few key challenges of India's PV sector, both supply and demand factors, are identified and corrective methods are suggested to address the same. In this regard, following recommendations are made. Stringent check on RPO targets, adoption of reverse bidding for project allocation, implementation of virtual and group net metering, disbursement of capital subsidy for rooftop market and utility owned business models.

2 Solar Photovoltiac Technologies

2.1 Introduction

Sun radiates energy uniformly in all directions in the form of electromagnetic waves. Solar energy is clean, non-depleting and abundantly available to mankind. It can be harnessed using photovoltaic and thermal technologies. The word Photovoltaic comes from the combination of two words *Photon* and *Voltaic* which means light and generation of electricity, respectively. In Photovoltaic (PV) system sunlight is converted to electricity using solar cells.

2.1.1 Solar Cells – PV basic Principle

PV cells consist, in essence, of a junction between thin layers of dissimilar semiconducting materials, known as p (positive) type semiconductors, and n (negative) type semiconductors respectively.

In a silicon solar cell, the n-type semiconductors are doped with small quantities of impurities (usually phosphorous) in such a way that the doped material possesses a surplus of free electrons. The p-type semiconductors are doped with boron, as this element has fewer electrons than silicon; thus creating holes in the valence band of silicon. At the p-n junction, due to hole-electron recombination, a small neutral area called the "depletion zone" is formed. On either side of this depletion zone, charge build up takes place and the charge particles cannot pass through the other side of the zone. Additional energy is needed for the charge particles to move across the zone which is provided by the solar radiation. Thus, under solar light, the circuit in a solar cell is closed and power is generated. This shows how important it is to have materials that have band gaps in the solar spectrum region and have large absorption coefficients in this region.Pictorial representation of photovoltaic effect is shown in Figure 2.1.



Figure 2.1: Photovoltaic Effect(NREL, 1982)

2.1.2 History and Development of PV technologies

In 1839, a French physicist Edmund Becquerel first observed physical phenomenon of light electricity conversion. In 1877 W.G. Adams and R.E. Day observed the PV effect in solidified selenium. In 1883, Charles Fritts built thefirst solid-state solar cell from selenium wafers(Fritts, 1883). Russell Ohl an American scientist developed a first solar cell using silicon in 1941(Ohl, 1941). Low conversion efficiency of these cells has limited their applications for terrestrial power generation. In 1958, the US Navy let a few small PV cell-powered radio transmitters go into orbit on a satellite called Vanguard I(EERE, 1958). The oil crisis in 1970's initiated the countries to move towards the alternative energy sources where the main emphasis was given for the development of solar cells. Researchers across the globe have made efforts in understanding and developing the photovoltaic properties from various kinds of materials. Silicon, gallium arsenide (GaAs), cadmium telluride (CdTe), and copper indium gallium selenide(CIGS) are the commonly used materials for solar cell applications. The typical efficiencies of these cells will be in the range of 10-40%. Recently, organic solar cells, perovskite and dye-sensitized solar cells have gained attention, however, their low efficiency has not attracted much commercial use yet (Green, et al., 2013). Silicon and CdTe based solar cells have dominated the terrestrial solar cell market primarily due to their relatively lower cost, while the high-efficiency III-V compound semiconductor solar cells have dominated the space & satellite applications. However, their complicated technology has limited their use to space applications and have not been implemented as much in the terrestrial level. III-V compound semiconductor based triplejunction solar cells currently hold the world record efficiency of 46% under concentrated sunlight of 508 suns (Fraunhofer, 2014). The progress made by various solar technologies in the last three to four decades has been summarized in a graph plotted by the Department of Energy's National Renewable Energy Laboratory as shown in Figure 2.2.



Figure 2.2: Progress in carious solar cell technologies over the last 35-40 years(NREL, 2016)

2.2 International best practices and technology overview

Globally, solar PV technology grew at a faster rate than all the renewable technologies during 2006-2011 – an average annual installation capacity growth rate of 58%. This was followed by concentrated solar power (CSP) technology which grew at a rate of 37% per annum during the same time period (REN21, 2012). The year 2013 saw an addition of 38.4 GW of solar PV capacity bringing the cumulative global capacity to 138.9 GW and 900 MW of CSP bringing the total installed capacity at 3.4 GW(Helioscsp, 2014)(European Photovoltaic Industry Association, 2014).

As of 2015, c-Si module had a major share in the utilityscale PV installation in the global market of about 85 – 90 %(Fraunhofer, 2016). Of the remaining 10 – 15 % thin film PV is installed, Copper Indium Gallium Selenide (CIGS) is emerging with about 1% share,Cadmium Telluride (CdTe) is leading with over 6% share and a-Si:H: having a share of 5%.(Bridge to India, 2013) (Figure 2.3).



Figure 2.3: Perspective on technology contribution to overall shipments from 1980 through 2010(Mints, 2011).

The PV industry has experienced a significant change in the last five years, with considerable increase in manufacturing capacities. Market prices have drastically reduced – by a factor of five for modules, and by a factor of almost three for systems. The global rate of annual new-built capacities, which was 7 GW in 2009, increased by five times in 2013. In the last ten years, cumulative installed capacity has grown at an average rate of 49% per year. In 2013, about 37 GW of new PV capacity was installed in about 30 countries – or 100 MW per day – bringing

total global capacity to over 135 GW. For the first time since 2004, capacity installed in Asia is more than that of Europe. China alone installed more than all of Europe, with over 11 GW. Japan ranked second with almost 7 GW, and the United States third with over 4 GW (IEA, 2014).

Photo-Voltaic Technologies

PV cells can be classified as wafer PV cells and thin film PV cells. In a wafer-based PV system, cells are assembled together to form a PV module, while in thin film technology, cells are laser scribed after the deposition of semi-conducting thin film onto the substrate. Although thin films have low efficiency, advantages of low cost, low processing temperature and high performance (higher kWh output per kWp installed capacity) due to low temperature coefficient and higher spectral sensitivity make them a preferred substitute(Shahan, 2014)(AppleSun, 2013). The crystalline or thin film modules are connected to form a PV array. The output of a PV system ranges from a few watts to several Megawatts (MW)(International Energy Agency, 2010). In addition to a PV module, a PV system comprises of a junction box, mounting system, inverters, charge controllers, protection relays, energy meters, weather monitoring station, DC switches and transformers. Figure 2.4 shows the schematic representation of a PV system. See Figure 2.5 for different kinds of photovoltaic technologies.



Figure 2.4: Photovoltaic cells, modules, panles and arrays (Leonics, 2013)



Figure 2.5: Different types of PV technologies

Silicon Wafer PV Cells

Silicon wafer PV Cells are broadly classified into mono-crystalline silicon cell and multicrystalline silicon cells (poly-crystalline silicon cells).

2.2.1 Mono-crystalline silicon cells

Mono-crystalline silicon cells are made out of a single continuous crystal lattice structure having virtually no defects or impurities. Mono-crystalline silicon cells are developed using Czochralski process. In this process, high purity silicon is heated to its melting point in a crucible made of quartz. A small seed crystal is dipped into the molten silicon solution which is then slowly pulled upward and rotated simultaneously. The size of the crystal depends on temperature gradient, rate of pulling and speed of rotation of the crucible (PVEDUCATION, 2014).Cells made out of Mono-crystalline silicon are highly efficient, having cell efficiency in the laboratory condition of 25.6% and module efficiency of 23%(Fraunhofer, 2016). Figure 2.6 shows picture of mono-crystalline PV cell.



Figure 2.6 Mono-Crystalline Silicon PV Cell

2.2.2 Multi-Crystalline silicon cell

Multi-crystalline silicon cell basically consists of small grains of mono-crystalline silicon. Multicrystalline solar cell wafers can be manufactured in various ways, where edge-defined, film-fed growth (EFG) is one of the popularly used manufacturing processes. In this process thin, hollow polygonal tubes of polycrystalline silicon up to 6m long are slowly pulled from a 'melt' of pure silicon, then cut by laser into individual cells. In other processes, polycrystalline silicon are moulded into cube shaped ingots with controlled casting and then cut into thin square wafers using fine wire saws and finally fabricated into complete cell (Kalejs, 1991).

The major advantage of multi-crystalline PV cell over mono-crystalline PV cell isthat, these cells areeasier and cheaper to manufacture. The multi-crystalline PV have a cell efficiency of 20.8% and module efficiency of 18.5% which is low compared to mono-crystalline PV cells(Fraunhofer, 2014). A multi-crystalline PV cell is shown in Figure 2.7. See Figure 2.8 for manufacturing process of Crystalline Silicon Cell.



Figure2.7 Multi-Crystalline PV Cell



Figure 2.8 Manufacturing Process of Crystalline Silicon Cell

2.2.3 Thin Films PV Cells

Thin film solar cells are second generation solar cells where deposition of one or more layers of thin films is coated on a substrate, such as glass, plastic or metal.Gallium arsenide (GaAs), cadmium telluride (CdTe), copper indium gallium selenide (CIGS) and amorphous silicon (a-Si) are some of the commercially used thin film PV cells. The following section gives the brief description of the various thin film PV cells.

2.2.4 Gallium arsenide

Gallium arsenide (GaAs) is a single crystalline thin film solar cell. These cells are also called as compound semiconductor. GaAs has a crystal structure similar to that of silicon, but consisting of alternating gallium and arsenic atoms with a band gap of 1.43eV. Molecular Beam Epitaxy,

Metal-organic Vapour Phase Epitaxy and Electrochemical Deposition (or Electroplating) are the three effective processes used for GaAs crystal growth.

1. Molecular Beam Epitaxy

Molecular Beam Epitaxy is one of the techniques used for epitaxial growth with the interactions frommolecules or atomic beams on the surface of a heated crystalline substrate. In this process all the deposition takes place in ultra-high power vacuum. High purity gallium or arsenic compound which is to be deposited on the crystalline substrate is heated in a separate effusion cell. These elements are heated to its melting point and then shot onto the substrate for the formation of solar cell (Rinaldi, 2002). Figure 2.9 shows the schematic setup of molecular beam epitaxy.



Figure 2.9 Molecular Beam Epitaxy(Grfitzeli, 1991)

2. Metal-organic Vapour Phase Epitaxy

Metal-organic vapour phase epitaxy is a chemical vapour deposition process which is used to produce single or multi–crystalline thin films. It is a complex process for growing crystalline structures. In this process, pure gases are injected into a reactor which is made up of stainless steel or quartz. In the reactor, the finely dosed gases deposit a very thin layer of atoms onto a semiconductor wafer. Crystalline growth of materials and compound semiconductors occurs due to the surface reaction of organic compounds and hydrides containing the required chemical elements (Usually hydrogen) (Aixtron, 2011). Figure 2.10 shows the schematic representation of metal-organic vapour phase epitaxy.



Figure 2.10 Schematic representation of a MetalorganicVapour Phase Epitaxy(Zilko, 2002)

3. Electrochemical Deposition (Electroplating)

Electroplating is a process of depositingmetals and alloysfrom molten-salt bath, aqueous and organic electrolytes by reducing the metal ions. Electroplating is the most commonly used process for GaAs thin film deposition due to its low operating temperature, economically feasible, non-toxic volatile raw materials and easy-to-control film properties (Yang, et al., 1992). In this process, cations (positive) and anions (negative) are immersed into a molten bath or aqueous solution. The electric current is then passed into the solution where, negative charge on the substrate (electrode) attracts the cation which in turn causes the metal ions to lie on the surface of the substrate creating a thin layer (Paunovic, 2006). See Figure 2.11 for Electro Chemical Deposition principle.



Figure 2.11 Electro Chemical Deposition principle

4. Spin Coating:

Spin coating is a commonly used process to deposit a thin layer, uniform polymer film on a planar substrate. The deposition of GaAs can be performed using spin coating technology. In this process powdered GaAs compound is made into a paste by adding ample amount of water. The paste is then spin coated on the substrate to form layer deposition (Wang, et al., 2013). Figure 2.12 shows the schematic representation of spin coating.



Figure 2.12 Schematic Representation of Spin Coating

The single junction GaAs thin film solar cells have an efficiency of 28.8 % at lab conditions (Green, et al., 2013). 24.1% is the efficiency of the GaAs thin film solar cell in field conditions (Silverman, et al., 2013). Figure 2.13 shows the schematic representation of fabricated cross section of a single junction.



Figure 2.13 Fabricated GaAs solar cell (Phys.Org) and cross section of single junction GaAs Solar Cell (PVlab)

Advantages, disadvantages and applications of GaAs solar cellsare given below:

Advantages

- High light absorption coefficient
- High cell and module efficiency
- Less quantity of materials used
- Light weight(Singh, 2012)(Prakash, et al., 2012).

Disadvantages

- Manufacturing and production processes are not well developed
- Scarcity of Gallium and arsenic elements

- High energy intensive manufacturing process
- These modules are costlier and not economically viable (Singh, 2012)(Prakash, et al., 2012).

Applications

GaAs PV modules are mainly used in satellites and space applications (Singh, 2012).

2.2.5 Amorphous Silicon

Silicon is a semiconductor with four valence electrons in the outer most shell with unique electrical properties. Amorphous silicon (a-Si) is a non-crystalline allotropic form of silicon. Silicon is the primary element used in the development of a-Si solar PV cells and modules; same as that of crystalline silicon. The amount of silicon used in manufacturing a-Si solar cell is one hundredth or less the amount than that of c-Si(Mount, 2010). Amorphous silicon thin film solar cellsare made up of thin film layers of silicon and can be deposited at low temperatures on a variety of substrates, like glass, plastic or steel. In a-Si, some percent of silicon atoms form covalent bond with three neighbouring silicon atoms, the remaining one electron forms 'dangling bonds' that can absorb any additional electrons which is introduced by doping, thus rendering any p-n junction ineffective(Ochs, 2004). The effective formation of p-n junction can be made by the process in which a-Si solar cells are manufactured. The development of an a-Si solar cell is performed in four steps;

1. Film Deposition

Silane (SiH4) gas and a small quantity of dopant (Boron) are decomposed electrically to deposit a thin film of a-Si on a suitable substrate. Silane gas containing a-Si is passivated by hydrogen which combines with the dangling silicon bonds to form hydrogenated amorphous silicon (a-Si:H) alloy. Diborane (B2H6) for P-type and phosphine (PH3) for N-type are the dopants added to the SiH4 vapour in vacuum chamber to form cell. The junction formed in a-Si is little different from the c-Si cells. P-I-N pattern junction formation occurs in a-Si, where extremely thin layers of p-type a-Si is on top, followed by a thicker intrinsic (i) layer made of un-doped a-Si, and then a very thin layer of n-type a-Si(Shah, et al., 1999). Figure 2.14shows the schematic of P-I-N junction formation of a-Si.



Figure 2.14 P-I-N junction of a-Si

2. Substrate Cleaning:

The glass substrates are cleaned with deionised water and coated with textured transparent conducting oxide (TCO) film usually made of tin oxide or zinc oxide which are deposited on the glass by sputtering or using an organo-metallic precursor (diethyl zinc). To enhance the light scattering properties of the glass substrate, the glass etching treatment is carried out on the zinc oxide films (Weisheit, 2013). The TCO layer now acts as an electrode.

3. Cell Fabrication:

The six layers of a-Si are fabricated on the coated TCO glass using plasma enhanced chemical vapour deposition ¹ (PECVD). The silicon thin film layer coated on TCO glass is cut into small cell using laser scribing machine. Finally, back contact layer is coated with silver or aluminium using physical vapour deposition² (PVD) sputtering which eventually acts as a negative electrode.

4. Module Assembly Process:

Photovoltaic cells are connected electrically in series and/or parallel circuits to produce required voltages, currents and power levels. Photovoltaic modules consist of PV cell circuits sealed in an environmentally protective laminate using encapsulant and back-sheet. Ethyl vinyl acetate is most commonly used encapsulant and back-sheets are made up of tedlar, tefzel or Mylar. PV modules are assembled as a pre-wired, field-installable unit. A photovoltaic array is the complete power-generating unit, consisting of number of PV modules (Florida Solar Energy Center, 2013).

Figure 2.15 shows an Amorphous Silicon PV Module and Figure 2.16 shows the manufacturing process of a-Si thin film module.



Figure 2.15 Amorphous Silicon PV Module (Bpress)

¹ Plasma enhanced chemical vapor deposition (PECVD) is process of depositing various thin film materials on a substrate at lower temperature.

² Physical vapor deposition (PVD) is a vacuum deposition method used to deposit thin films by the condensation of a vaporized form of the desired film material onto the desired surface.



Figure 2.16 Supply chain of tandem-type thin-film Silicon photovoltaic module production (Mount, 2010)

Advantages and disadvantages of amorphous silicon thin film solar cell are given below.

Advantages

- Requires less amount of silicon.
- Uniform deposition can be done over a large area.
- The substrates used in coating are economically feasible.
- Cost effective cells
- a-Si thin film solar cell perform well under poor lighting conditions and are not affected as much by shading issues.
- These cells are flexible and lightweight.
- The substrate deposition can be done at low temperatures (below 300°C)(Maehlum, 2013).

Disadvantages

• Low efficient solar cell and modules

- Complex and energy intensive manufacturing process
- a-Si panels degrade rapidly.
- a-Si requires large area for producing same amount electrical power as that of c-Si(Solar Facts and Advice, 2013).

2.2.6 Cadmium telluride thin films

Cadmium telluride (CdTe) thin film is categorized under inorganic solar cell. CdTe is a p-type semiconductor, and acts as the absorber layer. The band gap of CdTe is 1.5eV which falls under visible region of the solar spectrum. P-type CdTe along with n-type semiconductor material forms p-n junction, which avoids recombination of electron and hole pairs in solar cell and helps in generating electricity on absorption of solar spectrum. The efficiency of these cells is18.7 % (Wesoff, 2013).See Figure 2.17 and 2.18 for the working and the structure of CdTe cell respectively.



Figure 2.17 Working of CdTe thin film



Figure 2.18 Schematic representation of CdTe PV cell

2.2.7 CdTe thin film preparation:

CdTe can be depopsited by different processes such as physical vapour deposition(PVD), chemical vapour deposition (CVD), chemical bath deposition (CBD), closed spaced sublimation (CSS), and Radio Frequency (RF)sputtering(Gouda, et al., 2012). Most of the commercial deposition of CdTe cell are prepared from Rf sputtering and CVD.

SputteringDeposition:

Sputtering is a physical vapor deposition process for depositing thin films, sputtering means ejecting material from a target and depositing it on a substrate such as a silicon wafer or glass. The target is the source material. Different targets are used depending upon the material that needs to be deposited. Substrates are placed in a vacuum chamber and are pumped down to a prescribed process pressure(varies with depositing material). Sputtering starts when a negative charge is applied to the target material causing a plasma or glow discharge. Positive charged gas ions generated in the plasma region are attracted to the negatively biased target plate at a very high speed. This collision creates a momentum transfer and ejects atomic size particles form the target. These particles are deposited as a thin film on to the surface of the substrates(Sultana, 2010). Magnetron sputtering can be done in direct current (DC) and Radio frequency (RF) modes. DC mode requires between 2000 to 5000 volts while RF mode uses radio waves and requires 1012 volts to achieve the same rate of deposition.

CdTe thin films can be deposited by sputtering technique onto the glass subsrates $(1 \times 1 \text{ in }2)$. The substrate is cleaned prior to the deposition using acetone and ethanol by ultrasonication. Substrates are finally rinsed with water and dried in inert atmosphere. A commercially available CdTe target of highest purity (99.999%) of diameter 1inch is used. For deposition, the base pressure of vaccum chamber should be $2 \times 10-5$ Torr. The substrate and target distance is 5cm. The deposition is done using RF source at different timings to get films of varied thicknesses.(E, 2014)(Huda, 2013). Figure 2.19 demonstrates the sputtering process .



Figure 2.19 Schematic representation of sputtering process

Chemical vapour deposition(CVD):

CVD is a process in which chemical reaction takes place in the vicinity of the heated target surface where it evaporates and grows epitaxially on the substrate. The target material is obtained as a powder, or as a single crystal. By varying the experimental conditions (target material, target temperature, composition of the reaction gas mixture, total pressure gas flows etc.,) materials with different properties can be deposited. See Figure 2.20 for schematic representation of chemical vapour deposition.



Figure 2.20 Schematic representation of Chemical Vapour deposition process(Suzuki, 2010)

CdS/SnO2/glass substrates are used to deposit CdTe. Dimethylcadmium is used as a source for cadmium, and diallyltellurium (DATe) and diisopropyltellurium are used as tellurium sources. The substrate temperature is varied from 300 to 360 °C for the diallyltellurium source and 360-400°C is maintained for the diisopropyltellurium source. The inlet ratio of partial pressures of cadmium to tellurium is 0.025, resulting in a growth rate of about 1.5 μ mh- 1) (Rohatgi, 1990)(Carlsson, 1994). Following are the advantages of CdTe.

Advantages:

Cadmium is a heavy and hazardous metal, a waste byproduct of zinc refining, CdTe PV module provides safe and benefitial way to use cadmium.

- Cadmium telluride PV is the more cost effective thin film technology compared to other conventional solar cells(Biello, 2008).
- CdTe PV has lesser carbon footprint, uses lesser water and energy payback time is also less(Wild-Scholten, 2013).

The main drawback for CdTe thin films is that tellurium is a rare element that may run out soon.

2.2.8 Copper Indium Gallium-Selinide

Chalcopyrite Cu(In,Ga)(Se,S)2 CIGS band gap is 1.68 eV(Shafarman, et al., 2011). The band gap can be tuned from about 1.9 eV to about 1.1 eV by controlling the In/Ga ratio. CIGS being a p-type semiconductor can be used as an abosorber layer. The window layer used along with CIGS is CdS(n-type) with a bandgap of 2.45 eV. In thin flim solar technology there are three basic catogories of energy losses. They are optical loss, recombination loss and parasitic loss which affect the overall efficiency of PV cell. In the device structure of CIGS solar cell, Molybdenum (Mo) is sputtered on a substrate which acts as a backcontact. On Mo, CIGS is deposited and CdS buffer layer is grown. n-Type Zinc Oxide (ZnO) is sputtered over the buffer layer. The top electrode is used for the collection of charge carriers(Reinhard, et al., 2013)(Ramanathan, et al., 2003). The achieved efficiency in thin film based on CIGS is 20.1% (NREL, 2011). See Figures 2.21 and 2.22 for schematic representation and cross sectional view of CIGS cell.



Figure 2.21: Schematic diagram of CIGS PV cell

Deposition of polycrystalline active layer of CIGS on substrate is easier process compared to growing large silicon crystals and uses less energy. It can be deposited on flexible substrate. Compared to silicon solar panels, CIGS cells are more resistant to heat but not as efficient as silicon solar cells.



Figure 2.22 Cross sectional View of CIGS solar cell (GreenTech)

Emerging PV Cells

In recent times, the global focus from the wafer based PV technologies hasshifted towards newer and upcoming technologies. Significant research and development is taking place across the globe in multi-junction solar cells, dye-sensitized, organic solar and perovskite solar cells(Leo, 2014). The following section gives the brief description of these emerging PV cells.

2.2.9 Multi-Junction PV cells

Multi-junction solar cells consist of multiple layers of p-n junction made of different semiconducting materials. These layers are stacked one on top of the other, where each layer has a unique band gap which absorbs energy from a specific segment of the solar spectrum. Solar cell with more than one layer is called as tandem device. The band gap and efficiency of the multi junction cell with respect to number of junctions is shown in Figure 2.23.



Figure 2.23 Band gap and Efficiency of multi-junction cell (Appropedia, 2012)

Cell Structure

Multi-Junction solar cells are mainly made from III – V semiconductor materials. The band gap of these cells varies between 0.6 eV-1.9 eV with a concentration ratio of 1000 and an efficiency of 44.4% (NREL, 2014) (Jain, 2013). These cells are basically configured in stacked form wherein, the top layer absorbs the lowest wavelength radiations. Figure 2.24 shows the schematic diagram of multi-junction solar cell in stacked configuration. These cells absorb all the visible radiation in the range of 450 nm-750 nm.



Figure 2.24 Stacked configuration of Multi-Junction Solar Cell

As shown in Figure 2.24the top layers of the cell can absorb all the visible radiation falling in the range of 450-495 nm, while the intermediate layer will absorb the radiation from 495-570 nm and the bottom layer will absorb radiation with higher wavelengths(Weisse, 2010). Figure 2.25

shows the schematic representation of a multi junction cell. These cells mainly consist of antireflective coating layer, window layer, back surface field and tunnel junction.



Figure 2.25 Schematic of Multi- Junction Solar Cell (Lin, 2013)

Anti-Reflective Coating:

Anti-Reflective coating is one of the most critical part in the development of multi-junction cells. As these cells have larger spectrum area, bilayer coatings are been induced. Aluminium Oxide (Al2o3), Titanium dioxide (TiO2), Magnesium fluoride (MgF2) and Zinc Sulphide (ZnS) are the commonly used anti-reflective coating materials (Friz and Waibe, 2003). Figure 2.26 shows the bi-layer anti-reflecting coating deposition on the multi-junction solar cell.



Figure 2.26 Anti reflecting coating Bi-Layer

Window Layer:

Window layer as the name itself suggests allows solar radiation to pass through it with less amount of reflection. These layers are deposited on the front side of the cells which are usually made up of semi-conductor material having larger band gap. Aluminium indium phosphide (AlInP) and Indium gallium phosphide (InGaP) are most commonly used window layer compounds. The advantages of window layer is that it provides a very good surface passivation and low surface recombination velocity(Zhang, et al., 2010). In a window layer, the electrons at the conduction band tunnels through the barrier which are collected across the lane, while the holes at the valence band repel back due to the high barrier width. Figure 2.27shows the line diagram of electron and hole flow in window layer.



Figure 2.27 Electron and Hole flow in window Layer

Back Surface Layer:

As shown in Figure 2.26, behind each cell there is a back surface layer. These cells are made up of semiconducting materials of higher band gap, usually aluminium gallium indium phosphide (AlGaInP)/Indium gallium phosphide (InGaP)/Germanium (Ge). The main function of back surface layer is that it acts as an interface between two semiconductor materials/PV cells. The back surface materials are doped heavily with P++ ions in such way that the holes at the bottom can be easily collected across the valence band. The electrons in the conduction band repel back due to higher barrier width. The line diagram of electrons and hole flow in the back surface layer is shown in Figure 2.28.



Figure 2.28 Electron and hole flow in Back Surface Layer

Tunnel Junction:

The main function of a tunnel junction is to provide low electrical resistance and optically lowloss connection between two sub-cells(Yamaguchi, et al., 2006). Figure 2.29 shows the schematic representation of the upper and lower tunnel junctions between the top, middle and bottom sub-cells. Indium Gallium Phosphide (InGaP) is the commonly used compound for tunnel junction. This compound is heavily doped with p++ and n++ ions for the easy flow of electrical current.



Figure 2.29 Layers and electrical circuit diagram of top, middle and bottom junction diode with interconnecting upper and lower tunnel junction (Hector Cotal, 2008)

The advantages and disadvantages of multi-junction solar cells are mentioned below:

Advantages:

- High efficiency
- Absorb wide range of solar spectrum radiations
- Higher resistivity against high-energy rays

Lower rate of panel degradation due to heat (Esfandyarpour, 2012).

Disadvantages:

- These cells are not economically viable
- The development and manufacturing of these cells are still in nascent stage.
- Scarcity of materials
- Energy intensive process of manufacturing(Cherucheril, et al., 2011).

2.2.10 Dye-Sensitized Solar cell (DSC)

Dye-sensitized PV cell consists of a sintered mesoporous oxide layer for electronic conduction. The mesoporous oxide materials are Titanium di-oxide (TiO2), Zinc Oxide (ZnO) or Niobium pentoxide (Nb2O5). This layer of TiO2 is deposited on the surface of crystalline monolayer dye for the conduction of charge carriers. The electrons which are excited by the photons from solar spectrum are injected to the mesoporous oxide's conduction band. Immediately the imbalance in the dye is compensated by donation of electron from the organic solvents such as iodide / triiodide (redox system). The iodide sensitizer obstructs the recombination of the excited electron from the conduction band. Finally in the external load the electron is migrated by the reduction of tri-iodide to iodide. The generated electric power is due to the difference in the Fermi levels. The potential of the redox should be high; so that the imbalance of electron be acquired by absorbing the donated electron. The direct injection of electrons into the TiO2 layer obstructs the recombination of electrons with the holes. DSC's can operate in cloudy skies and indirect sunlight(Grätzel, 2003). DSC works at low internal temperatures and does not fade away with higher temperatures. The liquid electrolyte used in DSC could freeze at low temperatures and even evaporate at very high temperatures. So the disadvantage in DSC is the potential instability of liquid electrolyte and expensive electrical series connection(Shah, et al., 1999). Dye-Sensitized solar cell has a peak efficiency of 11.9% (NREL, 2015).

Figure 2.30 shows the working Principle of Dye-Sensitized Cell.



Figure 2.30 Working Principle of Dye-Sensitized Cell

2.2.11 Organic photovoltaic (OPV) Solar cell

Organic solar cells are transparent, conformal and flexible. The electricity generated from OPV is due to the transfer of excited electrons through the potential electric field (p-n junction) between two different semiconductor materials. Material with excess of holes is called an acceptor and the other with electrons is called a donor. The excitons are separated at the interface of two materials by keeping the energy difference between the lower unoccupied molecular orbital (LUMO) larger than the electron binding energy (Hiramoto, et al., 1990)(Ameri, et al., 2009)(Flores, 2011). In an organic solar cell the output voltage is given by the difference between the energies of highest occupied molecular orbital (HOMO) and the LUMO. Organic solar cell can generate electricity in diffused light (Thurm, 2011). Organic Photovoltaic cell efficiency is 11.5% (NREL, 2015). The operating principal of organic photovoltaic cell is shown in Figure 2.31.



Figure 2.31 Operation of Organic Photovoltaic cell (Flores, 2011.)

2.2.12 Perovskites Solar cells

Perovskite solar cell is a type of thin film technology that has taken the centre stage of R&D focus in the past few years. The distinct properties of perovskites such as high absorption coefficient, tunable band gap and longer carrier diffusion length have facilitated the increase in efficiency of perovskite solar cells from 3.8% in 2009(Kojima et al. 2009)to 9.7% in 2012(Kim, 2009)to above 16.2% in 2014(Jeon, 2014)to 22.1% in 2016(NREL, 2016).

Commonly used Perovskite is methyl-ammonium lead trihalide. The general chemical formula for Perovskite compounds is ABX3 where A is organic, B is a divalent metal ion and X is the halide material as shown in Figure 2.32. The disadvantage in Perovskite solar cell is the use of lead which is a toxic material. Recently lead is replaced by tin and the efficiency has increased from 17.9% to 20.1%(NREL, 2015).



Figure 2.32 Perovskite (green is organic or inorganic material, grey is metal and purple are halides) (Jeon, 2014)

Emergence of perovskite solar cell: Evolution to revolution

The ability of halide perovskite to convert electricity to light was initially discovered by Mitzi and group in 1990 and it was applied to Light Emitting Diodes (LED) (Mitzi, 1995). The reverse i.e., light to electricity conversion was reported almost after two decades (Kojima). Basically perovskite solar cell evolved from DSSC. Typical DSSC consisting of mesoporous n-type titania sensitized with a light absorbing dye in a redox active electrolyte. Porous titania provides greater internal surface area to the sensitized dye for efficient absorption of incident photons. The film thickness of the order of 10 μ m is required for complete absorption over the absorbing range(O'regan, 1991). The requirement of 10 μ m was not practical for Solid State Dye Sensitized Cell (SSDSC) as it used solid hole conductor instead of liquid electrolyte and film thickness was reduced to 2 µm(Hardin, 2012). As an alternate, thin film semiconductor active layers and quantum dots enable complete light absorption in much thinner layers while at the same time pushing the photosensitivity further into near infrared (NIR)(Kamat, 2008)(Kamat, 2013). This was the motivation to find more efficient light sensitizers for DSSCs. Miyasaka et al reported first perovskite solar cell, using organometallic perovskite and liquid electrolyte in 2006 and efficiency of 2% was achieved(Case, 2014). Power conversion efficiency (PCE) of 0.4% was reported with solid state electrolyte(Kojima, 2008). The first peer-reviewed report for perovskite-sensitized solar cell was published in 2009; CH3NH3PbI3 absorber in aniodide/triiodide redox couple achieved an efficiency of 3.5%. The evolution process of perovskite solar cells is schematically represented in Figure 2.33. Retaining the liquid electrolyte reported by Kim and coworkers achieved an improved efficiency of 6.5% by optimizing the titania surface morphology and perovskite processing(Im, 2011). The tumbling block in the liquid electrolyte based perovskite-sensitized solar cell was the dissolution and decomposition of perovskite in the liquid electrolyte. Resultantly the solar cells exhibited poor stability and would degrade within minutes. The solution to this problem lied in adoption of solid state hole transport medium in place of electrolyte as was originally tried by Kojima and coworkers in 2006(Kojima, 2006). Methyl ammonium trihalogenplumbates, being relatively insoluble in nonpolar organic solvents, paved the way for realizing first perovskite sensitization and made subsequent infilling with the organic hole conductor possible. Thismade T. N. Murakami and T. Miyasaka and N. G. Parkin collaboration with M. Gr"atzel and co-workers developed solid-state
perovskite solar cells employing(2,2(7,7)-tetrakis-(N,N-dipmethoxyphenylamine)9,9(spirobifluorene))(spiro-MeOTAD) as the hole transporter with maximum full sun power conversion efficiencies of between 8 and 10% employing CH3NH3PbI3–xClx mixed halide perovskite and CH3NH3PbI3, respectively with maximum full sun power conversion efficiencies of between 8 and 10% employing CH3NH3PbI3–xClx mixed halide perovskite and CH3NH3PbI3, respectively. The primary advantage of the perovskite absorbers over the dyes is that, they are much more strongly absorbing over a broader range, enabling complete and broader light absorption in films as thin as 500 nm. This is specifically advantageous for the solid-state cells, where thickness limitations of around 2 μ m have historically limited the light absorption and photocurrent generation(Schmidt-Mende, 2007).



Figure 2.33 Evolution of Perovskite Solar Cell (Case, 2014)

Henry Snaith further investigated Meso-Super Structured cell (MSSC) to understand the chargetransport properties of the perovskite-sensitized solar cells, noticed that the charge extraction rates were significantly faster for the perovskite-sensitized in comparison to conventional DSSCs. He constructed solar cells where the mesoporous TiO2 was replaced with insulating mesoporous Al2O3, with a very similar meso-morphology, with the primary intention to study and elucidate whether electron transport occurs through the perovskite phase and whether we require the mesoporous TiO2 at all. Surprisingly; not only was the charge transport faster and the photocurrent unaffected when the TiO2 was replaced by the insulating Al2O3,but for a liketo-like comparison, the open-circuit voltage increased by 200 to 300 mV, leading very quickly to a high efficiency of 10.9% (Lee, 2012). This indicated perovskite can also act as absorber rather than being just sensitizer. The ambipolar nature of perovskite was demonstrated by many researchers found the potential of perovskite to transport both holes and electrons and achieved efficiencies more than 8% (Etgar, 2012) (Etgar, 2013). A planar device made using perovskite via vapour deposition and efficiency of 15% was achieved (Liu, 2013). This categorically confirmed the ambipolar nature of perovskite.

Preparation of the Perovskite solar cell:

For the synthesis of active perovskite layers different thin film deposition techniques such as one-step precursor solution deposition(Xing, 2013) [100]; two-step sequential deposition (Burschka, 2013); dual-source vapor deposition; vapor assisted solution process(Zhou, 2014); and sequential vapor deposition (Hu, 2014)approaches are reported. One-step solution processing is the simplest of all the solution processing technique for the growth of perovskite layer. The process is depicted in Figure 2.34.



Figure 2.34 Schematic representation of preparation of Perovskite solar cell by solution process(Jung, et al., 2015)

Stability

Research effort has been focused at enhancing the efficiency of perovskite devices by adoption of various device architectures, compositions, and manufacturing techniques. This has resulted in substantial increase in efficiencies to a proven efficiency of 19.6% (Li, 2016). The limiting factor to this success story is the lack of stability. High efficiency devices reported are synthesized under controlled environments and lose their efficiencies rapidly. For their commercial viability it is imperative that studies be undertaken on issues of stability and reproducibility to enhance the lifetime of these devices. Degradation in perovskite solar cells is a synergetic effect of exposure to humidity, oxygen, ultraviolet radiations, and temperatures.

CH3NH3PbI3 is highly sensitive to the water, it tends to hydrolyze in the presence of moisture and degrade as follows(Niu, 2015):

CH3NH3PbI3 (s)
$$\leftarrow \rightarrow$$
 PbI2 (s) +CH3NH3I(aq) (1)
CH3NH3I (aq) $\leftarrow \rightarrow$ CH3NH2 (aq) + HI(aq) (2)
4HI (aq) +O2 (g) $\leftarrow \rightarrow$ 2I2 (s) + 2H2O(l) (3)
2HI (aq) $\leftarrow \rightarrow$ H2 (g) + I2(s) (4)

The equilibrium species, in the presence of water, oxygen, and UV radiation, are thus CH3NH3I, CH3NH2, and HI. HI can either decompose by a one-step redox reaction (3) or by photochemical reaction under UV radiation to H2 and I2. This sensitivity requires synthesis in a controlled environment like a glove box(Liu, 2013)(Burschka, 2013). A humidity of 55% reported to deteriorate performance and is evident by a colour change from dark brown to yellow(Im, 2013). Devices incorporating Al2O3 scaffold showed better stability in line with the reports on stability of DSSC with such scaffold(Ma, 2009)(Li, 2013). CH3NH3PbBr3with is reported to be more stable to moisture exposure and CH3NH3Pb(I1–xBrx)3 based absorbers retained good efficiency on exposure to humidity of 55% for 20 days(Im, 2013). A moisture induced reconstruction mechanism has also been proposed for controlled humidity synthesis in planar geometry. An efficiency of 15.76% has been achieved for devices synthesized in ambient conditions with humidity of 50% by incorporating a substrate preheating step before spin-coating lead iodide(Ko, 2015).

2.3 Current status in India

In order to address the global challenges of clean energy, climate change and sustainable development there is a pressing need to accelerate the development of advanced energy technologies. Solar energy is abundant in India and can contribute towards reducing dependence on oil and coal imports. Solar power enhances energy diversity and stabilises costs of electricity generation in the long term. Solar PV involves no greenhouse gas (GHG) emissions during operation and does not emit other pollutants (such as oxides of sulphur and nitrogen); additionally, it consumes little water.

The PV installations in India are driven by Jawaharlal Nehru National Solar Mission (NSM) at central and state level targets. The (NSM) aims to install 20 GW of grid-connected solar by 2022 and an addition 2 GW of off-grid systems, including 20 million solar lights. The mandatory compliance of Solar Renewable Purchase Obligation (RPO) by obligated entities is also leading to increased installations under Renewable Energy Certificate (REC) mechanism. In 2013, the total solar power installed capacity in India is around4.5 GW(Bridge to India, 2013).Figure 2.35 shows the cumulative and annual addition of solar PV in India from 2008 to 2013.



Figure 2.35 Solar Power Development in India (Kapoor, 2013)(Nimje, 2014).

National Solar Mission coupled with state solar policies (Rajasthan, Gujarat, Karnataka and Maharashtra) have been instrumental in the incremental installations of solar power plants. Gujarat Electricity Regulatory Commission (GERC) have been the prime motivator for the development of solar energy in Gujarat by fixing benchmark tariff of Rs. 15/kWh and applicable for first 12 years and Rs. 5/kWh for the life of the system for the subsequent 13 years(Government of Gujarat, 2010). In the case of National Solar Mission, firm 25 year power purchase agreement with National VidyutVyapar Nigam, arm of National Thermal Power Corporation (NTPC) was a major driver for developers. Figure 2.36 highlights the policy support for the development of solar energy in India. In 2013, the cumulative installed capacity of solar was 1.96GW(Bridge to India, 2013). The solar installations have been growing at compound annual growth rate (CAGR) of 276% over the past five years. The state of Gujarat (851 MW) has added the maximum amount of solar capacity followed by Rajasthan (575 MW).

The Solar energy sector in India is witnessing unprecedented activities. With the Ministry of New and Renewable Energy (MNRE) of Government of India announcing the Jawaharlal Nehru National Solar Mission (JNNSM)(MNRE), the interest in the sector has gone up and new opportunities are presenting themselves for anyone wishing to enter this industry. The PV installations in India are driven by JNNSM at central and state level targets. The JNNSM aims to install 20 GW of grid-connected solar by 2022 and an addition 2 GW of off-grid systems. As on December 2015, the cumulative solar power installed capacity in India is around 4.6 GW.



Figure 2.36 Policy Interventions in the Development of Solar Power in India

A PV system consists of PV cells that are grouped together to form a PV module, and the auxiliary components (i.e. balance of system - BOS), including the inverter, controls, etc. There are a wide range of PV cell technologies in the market today, using different typesof materials. A detailed study was conducted to identify various technologies that are deployed in India. This study covers around 4 GW of solar power plants installed in different states in the country. Here the solar power plants were classified based on the solar PV module technology used in various project locations. Based on our study a map is prepared, which shows capacity of technology wise solar power plants installed in several states. But these locations have different range of Global Horizontal Irradiance (GHI), which is the very important parameter to affect the module output and to decide its performance. Figure 2.37 shows the map of Technology wise solar PV power plants installed in India.

The states which have the highest annual average solar irradiance of 5.5 - 6.0 kWhr/m2/Day (NREL India Resource Map) are Tamil Nadu, Karnataka, Andhra Pradesh, Telangana, Maharashtra, Gujarat and Rajasthan. Punjab, Haryana, Madhya Pradesh, Chhattisgarh, Jharkhand, Kerala, Odisha, West Bengal and Uttar Pradesh gets the irradiance of 5.0 - 5.5 kWhr/m2/Day. Uttarakhand and some part of the Uttar Pradesh receives irradiance of 4 - 4.5 kWhr/m2/Day.

Despite the high potential for tapping solar energy to generate electricity, the cost of the solar PV systems is posing a hindrance to the large deployment of SPV plants. The cost of generating

1 unit of electricity should be at least at par with the grid supplied power, if not less. The main strategies that can apply to reduce the cost of SPV plants are:

- Start manufacturing the panels from scratch in India. This will be in sync with Prime Minister's "Make in India" initiative. Currently, solar cells are imported and assembled into a panel by some companies. Others just import the panels itself. The imported panels will be more expensive because of the added shipping and handling costs. Once large scale manufacturing of panels, inverters and other supporting equipment starts in the country, the SPV plants can be priced at much lower level.
- Quality control during installation of SPV plants. Strict regulations must be followed to ensure that the plants that are set up work for at least 15 years. Currently, many of the plants are not well maintained because of which, in spite of large investments, do not give rated returns.
- **R&D** in the field of solar materials and the auxiliary electronic and electric systems is critical. Making the panels and inverters more efficient and cutting down the losses in transmission can improve the performance of SPV plants.



Figure 2.37 The map of Technology wise solar PV power plants installed in India.

Table 2.1shows the list of states with capacity of technology wise solar PV power plants.

	Installed Capacity in MW	Types of Solar module technology installed in MW					Solar Irradiance
States	As on 30-11-2015	c-Si	a-Si	CdTe	CIGS	CIS	(GHI) kWhr/m²/ Day
Andhra Pradesh	233.74(34-54, 159)	145.94	-	23	-	30	5.5 - 6.0
Chattisgarh	43.18(122)	9.5	-	30	-	-	5.0 - 5.5
Delhi	6.712(124-125)	3.41	-	-	-	-	5.0 - 5.5
Gujarat	1024.15(55-61, 148)	567.95	297.85	144	3	5	5.5 - 6.0
Haryana	12.8(149)	8	2.8	-	-	-	5.0 - 5.5
Jharkhand	16(144, 150)	8	8	-	-	-	5.0 - 5.5
Karnataka	104.22(62-66, 151)	101	10	10	-	-	5.5 - 6.0
Kerala	12.025(123)	13	-	-	-	-	5.0 - 5.5
Madhya Pradesh	673.58(67-71, 152)	551.42	20	75		-	5.0 - 5.5
Maharashtra	378.7(72-75, 153)	262.7	77.5	1.25	5	-	5.5 - 6.0
Odisha	56.92(76-77, 154)	40	7	5		-	5.0 - 5.5
Punjab	200.32(78-82, 155)	127.52	1.5	40	1	-	5.0 - 5.5
Rajasthan	1104.2(83-90, 160)	504.1	114.5	243.5	25	21	5.5 - 6.0
Tamil Nadu	385.87(91-114, 156)	299.46	8	-	1	5	5.5 - 6.0
Telangana	91.45(34-54, 159)	114.34	-	20	-	-	5.5 - 6.0
Uttar Pradesh	71.26(115-121, 157)	54.11	1	12	-	2	5.5 - 6.0
Uttarkhand	5(3)	2	3	-	-	-	4.5 - 5.0
West Bengal	7.21(158)	7	-	-	-	-	5.0 - 5.5
Total(MW)	4427.337	2819.45	551.15	603.75	35	63	

Table 2.1 State wise Installed Capacity: Types of solar module technology.

Note: Reference no. 4 - 33 in appendix –I are the names of the major project developers who are having solar PV power plants in most of the states and Reference no. 126 -147 in appendix – I are the list of major EPC contractors.

According to the study, the major solar PV technology deployed is the c-Si type, which has 69% of the total installation and the Thin Film technology covers remaining 31%. Amorphous silicon and Cadmium Telluride type of solar modules are the major Thin Film technologies which has 44% and 48% of the total Thin Film Installation, respectively, and around 8% uses Copper Indium Selenide technology. See Figure 2.38 for technology wise solar PV Installed in India.



Figure 2.38 Technology Wise Solar PV Installed in India

Crystalline and Thin Film technology both have their own advantages and disadvantages. There are no Thin Film module manufacturers in India, which makes the cost of the thin film modules higher than the crystalline modules available in the market. c-Si modules have higher efficiency compared to thin film modules that leads to higher power output. Because of this thin film power plants require more land area to generate same amount of electricity as the c-Si modules. In situations where space is not an issue, thin-film solar panels can make sense because high temperatures have less impact on solar panel performance.

The regions where annual average daily GHI is more, installing Thin Film based SPV power plants would be beneficial. High irradiance will increase the module temperature and CIGS/CIS/CdTe based thin films work well.For states like Uttar Pradesh and Uttarakhand that receive low GHI, c- and poly-Si technologies can be suggested.

Under 'The Smart Cities' mission launched by the central government, uninterrupted power supply is one of the focal point. A mix of electricity generation resources will have to be used to meet this requirement and photovoltaics will play a major role in this respect. Table 2.2, gives the list of the 20 cities across the country that are chosen for the phase 1 of the mission. Annual irradiance of these cities are also presented in the table. Accordingly, photovoltaic technologies are recommended. Table 2.3 shows details of SPV panel sourcing companies in India.

Sl. No.	State	City	GHI (kWh/m ²)	DNI (kWh/m²)	Suggested technologies	
1	Odisha	Bhubaneswar	5.0-5.5	4.5-5.0	Thinfilms, SC/poly-silicon	
2	Maharashtra	Pune	5.5-6.0	5.0-5.5	Thinfilms, SC/poly-silicon	
3	Rajasthan	Jaipur	5.5-6.0	5.5-6.0	CPV, thinfilms, SC/poly- silicon	
4	Gujarat	Surat	5.5-6.0	5.0-5.5	Thinfilms, SC/poly-silicon	
5	Kerala	Kochi	5.5-6.0	5.5-6.0	CPV, thinfilms, SC/poly- silicon	
6	Gujarat	Ahmedabad	5.5-6.0	5.5-6.0	CPV, thinfilms, SC/poly- silicon	
7	Madhya Pradesh	Jabalpur	5.5-6.0	5.5-6.0	CPV, thinfilms, SC/poly- silicon	
8	Andhra Pradesh	Visakhapatnam	5.5-6.0	4.5-5.0	Thinfilms, SC/poly-silicon	
9	Maharashtra	Solapur	5.5-6.0	5.0-5.5	Thinfilms, SC/poly-silicon	
10	Karnataka	Davangere	5.5-6.0	5.0-5.5	Thinfilms, SC/poly-silicon	
11	Madhya Pradesh	Indore	5.5-6.0	4.5-5.0	Thinfilms, SC/poly-silicon	
12	New Delhi	New Delhi	5.0-5.5	4.0-4.5	Thinfilms, SC/poly-silicon	
13	Tamil Nadu	Coimbatore	5.5-6.0	5.0-5.5	Thinfilms, SC/poly-silicon	
14	Andhra Pradesh	Kakinada	5.5-6.0	4.5-5.0	Thinfilms, SC/poly-silicon	
15	Karnataka	Belagavi	5.5-6.0	5.0-5.5	Thinfilms, SC/poly-silicon	
16	Rajasthan	Udaipur	5.5-6.0	5.5-6.0	CPV, thinfilms, SC/poly- silicon	
17	Assam	Guwahati	4.5-5.0	3.5-4.0	SC/poly-silicon	
18	Tamil Nadu	Chennai	5.5-6.0	5.0-5.5	Thinfilms, SC/poly-silicon	
19	Punjab	Ludhiana	5.0-5.5	4.5-5.0	Thinfilms, SC/poly-silicon	
20	Madhya Pradesh	Bhopal	5.5-6.0	5.5-6.0	CPV, thinfilms, SC/poly- silicon	

Table 2.2: List of 20 'Smart Cities' identified by Government of India and the suggested SPV technologies suggested

Note: CPV - Concentrated photovoltaics, Thinfilms - CdTe/CdS, CIGS/CdS, SC/poly-silicon, GHI - Global Horizontal Irradiation, DNI - Direct Normal Irradiation. See Appendix- 2A for the companies consulted for the study.

1. No.	Name of the sources of solar modules					
1	Solar Frontier					
2	Tata BP Solar REC Solar					
3	REC Solar					
4	Bharat Heavy Electricals ltd.					
5	First Solar					
6	CNPV Solar power					
7	Yingli Solar					
8	Canadian Solar					
9	LDK Solar Co. Ltd					
10	Astronergy Solar					
11	Suntech					
12	Nex Power Technology Corporation					
13	Trina Solar					
14	Sharp Solar					
15	Titan Energy Systems Ltd.					
16	Del Solar (Neo Solar Power Corporation)					
17	Csun					
18	Dupont					
19	Moser Baer India Ltd (MBIL)					
20	Solar Fun					
21	SolarWorld					
22	Jinko Solar					
23	Hanwa solar					
24	Sun Well					
25	Sungen Solar					
26	Tainwei Solar					
27	AUO Solar					
28	MiaSole					
29	China Sunergy					
30	QS Solar					
31	EMMVEE					
32	SHAN Solar					
33	ReneSola					
34	WAAREE					
35	Vikram Solar					
36	Dhoop Solar (Agrawal Group)					
37	Websol Energy System Ltd					
38	BP Solar					
39	Sunpower					
40	Abound Solar					
41	Lanco Solar					

Table 2.3 SPV panel sourcing companies in India

2.4 Applicability in the Indian context

In the 21st century, solar energy is one of the most discussed topics in the realm of energy literature across the globe. As we gather more evidence on the effects of climate change and its impact towards on livelihood, solar energy is proving to be one of the more feasible options in the addressing these issues.

Wafer based silicon solar cells were the first solar cells developed in 1939 and till now have been the most successful of all solar PV cells. The main advantages of these cells are its reliability and low cost. In the past 3-4 decades many thin film and emerging solar cells have been developed across the globe. Currently, in terrestrial applications there are many plants installed using amorphous silicon and cadmium telluride thin film solar cells. Gallium Arsenide thin film solar cells have dominated the space andsatellite applications due to their high efficiency. In emerging technology considerable research and development istaking place on Perovskite and multijunction solar cell. Multi-junction solar cells are the next generation solar cells as these cells have very high efficiency (> 35%). The major disadvantage of this technology is its high manufacturing cost. In the case of Perovskite solar cells, unless stability issues under ambient atmospheric conditions are addressed, these cells will not be viable for application on a large scale.

To conclude, PV technologies play a vital role in solar energy development of the country. With advanced lab facilities and new material research across the globe; efficiencies of wafer based, thin films and multi-junction solar PV cells can be enhanced.

References

- Aixtron, DEPOSITION TECHNOLOGY FOR BEGINNERS "How MOCVD Works," Germany, 2011.
- Ameri T, Dennler G, Lungenschmied C and Brabec C.J, "Organic tandem solar cells: A review," Energy and Environmental Sciences, vol. 2, pp. 347-363, 2009.
- AppleSun, 2013, http://energi-tek.se/data/files/solenergi/AmpleSun_solenergi.pdf
- Appropedia, "Multi-junction solar cells," 14 March 2012. [Online]. Available: http://www.appropedia.org/Multi-junction_solar_cells. [Accessed December 10 2014].
- Biello .D, "Solar Power Lightens Up with Thin-Film Technology," Scientific American, 25 April 2008.
- Bridge to India, "India Solar Compass," New Delhi, 2013.
- Burschka J, Pellet N, Moon S.J, Humphry-Baker R, Gao P, Nazeeruddin M.K and Grätzel M, "Sequential deposition as a route to high-performance perovskite-sensitized solar cells", Nature, Vol. 499, no. 7458, pp. 316-319, 2013.
- Bpress, Available Online : http://www.bpress.cn/im/tag/Sharp-Solar/
- C.-E. E, "Effects of temperature and deposition time on the RF- sputtered CdTe films preparation," Sociedad Mexicana de Ciencia y Tecnología de Superficies y Materiales vol. 27(1) 15-19, 2014.
- Carlsson J.O, "Chemical Vapor Deposition," in Deposition Technologies for Films and Coatings, 1994.
- Case Christopher, "From 0 to 20 % in two years _ Perovskite based photovoltaics separating hype from hope", September 2014.
- Cherucheril G, March S and Verma A, "Multijunction Solar Cells," Iowa State University, United States, 2011.
- Cotal Hector, Fetzer Chris, Boisvert Joseph, Kinsey Geoffrey, King Richard, Hebert Peter, Yoon Hojun and Karam Nasser, "III–V multijunction solar cells for concentrating photovoltaics", vol. 2, 2008
- Esfandyarpour R, "Multi-Junction Solar Cells," United States, 2012.
- Etgar L, Gao P, Xue Z, Peng Q, Chandiran A.K, Liu B, Nazeeruddin M.K and Grätzel M, "Mesoscopic CH3NH3PbI3/TiO2heterojunction solar cells", Journal of the American Chemical Society, Vol. 134, no. 42, pp. 17396-17399, 2012.
- European Photovoltaic Industry Association, "Global Market Outlook," European Photovoltaic Industry Association, Belgium, 2014.
- Flores E, "Bulovic Lab: Eletha Flores," Department of Electrical Engineering and Computer Science, MIT, United States, 2011.
- Flores E, "Bulovic Lab: Eletha Flores," Department of Electrical Engineering and Computer Science, MIT, United States, 2011.
- Florida Solar Energy Centre, 2013. [Online]. Available: http://www.fsec.ucf.edu/en/consumer/solar_electricity/basics/cells_modules_arrays.ht m. [Accessed July 2013].
- Fraunhofer Institute for Solar Energy Systems, ISE, "Photovoltaics Report", 06 June 2016. [online]. Available: https://www.ise.fraunhofer.de/de/downloads/pdf-

files/aktuelles/photovoltaics-report-in-englischer-sprache.pdf [Accessed on 26 July 2016]

- Fraunhofer, "Photovoltaics Report," Fraunhofer ISE, Freiburg, 2014.
- Fraunhofer-InstitutfürSolareEnergiesysteme ISE, "New world record for solar cell efficiency at 46%," Fraunhofer ISE, 01 December 2014. [Online]. Available: http://www.ise.fraunhofer.de/en/press-and-media/press-releases/press-releases-2014/new-world-record-for-solar-cell-efficiency-at-46-percent. [Accessed 24 March 2015].
- Fritts. C, "On a New Form of Selenium Photocell," American journal of science, vol. 26, P.465, 1883.
- Friz M and Waibe F, "Coating Materials," Germany, 2003.
- Gouda L, Aniruddha Y.R and S.K, "Correlation between the Solution Chemistry to Observed Properties of CdTe Thin Films Prepared by CBD Method," Journal of Modern Physics, Scientific Research, vol. 3, pp. 1870-1877, 2012.
- Government of Gujarat, "Solar Power Policy 2009," 22 June 2010b. [Online]. Available: http://geda.gujarat.gov.in/policy_files/GERC%20order%20Solar%20Energy.pdf. [Accessed 02 January 2014].
- Grätzel M, "Dye-sensitized solar cells," Journal of Photochemistry and Photobiology, p. 145–153, 2003.
- Green M.A, Emery K, Hishikawa Y, Warta W and Dunlop E.D, "Solar cell efficiency tables," Progress in Photovoltaics: Research and Applications, Vol 21 No. 5, pp. 827-837, 2013.
- Green M.A, Emery. K, Hishikawa .Y, Warta.W and Dunlop E. D, "Solar cell efficiency tables (version 41)," vol. 21, 2013.
- GreenTech, Available online: https://www.greentechmedia.com/green-light/post/lets-talk-about-cigs
- Hardin B.E, Snaith H.J and McGehee M.D, "The renaissance of dye-sensitized solar cells", Nature Photonics, Vol. 6, no. 3, pp. 162-169, 2012.
- Helioscsp, "Concentrated Solar Power (CSP) in 2013 increased by nearly 0.9 GW, up 36%, to more than 3.4 GW," 05 June 2014. [Online]. Available: http://www.helioscsp.com/noticia.php?id_not=2528. [Accessed 25 March 2015].
- Hiramoto M, Fujiwara H and Yokoyama Masaaki, "Three- layered organic solar cell with a photoactive interlayer of codeposited pigments," in Technical Digest of 5th International Photovoltaic Science and Engineering Conference, Kyoto, 1990.
- Hu H, Wang D, Zhou Y, Zhang J, Lv S, Pang S, Chen X, Liu Z, Padture N.P and Cui G, "Vapour-Based Processing of Hole-Conductor-Free CH3NH3PbI3 Perovskite", RSC Advances, Vol. 60, no. 4, pp. 28964-28967, 2014.
- Huda Q, "CdZnTe Thin Films Growth by RF Sputtering for CdTe Solar Cells," 2013.
- Im J.H, C-R. Lee, J.W Lee, Park S.W, Park N.G, "6.5% efficient perovskite quantumdot-sensitized solar cell", Nanoscale, Vol. 3, no. 10, pp. 4088-4093, 2011.
- Im S.H, Heo J.H, Mandal T.N and Seok S, "Chemical management for colorful, efficient, and stable inorganic-organic hybrid nanostructured solar cells", Nano letters, Vol. 13, no. 4, pp. 1764-1769, 2013.
- International Energy Agency, "Technology Roadmap Solar Photovoltaic Energy," IEA, Paris, 2010

- International Energy Agency, "Technology Roadmap Solar Photovoltaic Energy", 2014 Edition
- Jain N, "Design of III V Multi junction Solar Cells on Silicon Substrate," Virginia Polytechnic Institute and State University, United States, 2013.
- Jeon N.J, Noh J.H, Kim Y.C, Yang W.S, Ryu S and Seok S, "Solvent engineering for high-performance inorganic-organic hybrid perovskite solar cells", Nature materials, Vol. 13, no. 9, pp. 897-903, 2014.
- Jung H.S and Park N-G, "Perovskite solar cells: from materials to devices", Small, vol.11, pp.11-25, 2015
- Kalejs J. P, Mobil Solar Energj Corporation, Billerica, Massachusetts, "Thin edgedefined, film-fed growth (EFG) Octagons, NREL, 1991.
- Kamat P.V, "Quantum dot solar cells. Semiconductor nanocrystals as light harvesters", The Journal of Physical Chemistry C, Vol. 112, no. 48, pp. 18737-18753, 2008.
- Kamat P.V, "Quantum dot solar cells. The next big thing in photovoltaics", The journal of physical chemistry letters, Vol. 4, no. 6, pp. 908-918, 2013.
- Kapoor T, "Presentation before Forum of Regulators," New Delhi, 2013.
- Kim H.S, Lee C.R, Im J.H, Lee K.B, Moehl T, Marchioro A, Moon S.J, Humphry-Baker R, Yum J.H, Moser J.E, Gra⁻tzel M and Park N.G, "Lead iodide perovskite sensitized all-solid-state submicron thin film mesoscopic solar cell with efficiency exceeding 9%", Scientific reports, Vol. 2, no. 591, pp. 1-7, 2009.
- Ko H.S, Lee J.W, and Park N.G, "15.76% efficiency perovskite solar cells prepared under high relative humidity: importance of PbI2 morphology in two-step deposition of CH3NH3PbI3", Journal of Materials Chemistry A, Vol. 3, no. 16, pp. 8808-8815, 2015.
- Kojima A, Teshima K, Miyasaka T, and Shirai Y, "Novel photo electrochemical cell with mesoscopic electrodes sensitized by lead-halide compounds (2)", 210thECS Meeting Abstracts, abstract MA2006-02, p. 397, 2006.
- Kojima A, Teshima K, Shirai Y, Miyasaka T, "Organometal halide perovskites as visible-light sensitizers for photovoltaic cells", Journal of the American Chemical Society, Vol. 131, no. 17, pp. 6050-6051, 2009.
- Kojima A, Teshima K, Shirai Y, and Miyasaka T, "Novel photo electrochemical cell with mesoscopic electrodes sensitized by lead-halide compounds (11)", 214th ECS Meeting, Vol. 27 abstract,MA2008-02, 2008.
- Laban W.A and Etgar L, "Depleted hole conductor-free lead halide iodide heterojunction solar cells", Energy & Environmental Science, Vol. 6, no. 11, pp.3249-3253, 2013.
- Lee M.M, Tsutomu J, Miyasaka T, Murakami T.N and Snaith H.J, "Efficient hybrid solar cells based on meso-superstructuredorganometal halide perovskites", Science, Vol. 338, no. 6107, pp. 643-647, 2012.
- Leo K, "Breakthroughs in emerging PV technology," KAUST, 2014.
- Leonics, "Basics of Solar Cell," 2013. [Online]. Available: http://www.leonics.com/support/article2_13j/articles2_13j_en.php. [Accessed December 2013].
- Li W, Li J, Wang L, Niu G, Gao R and Li J, Wang L, Niu G, Gao R and Qiu Y, "Post modification of perovskite sensitized solar cells by aluminum oxide for enhanced performance", Journal of Materials Chemistry A, Vol. 1, no. 38, pp. 11735-11740, 2013.

- Li X, Bi D, Yi C, Décoppet J.D, Luo J, Zakeeruddin S.M, Hagfeldt A and Grätzel, "A vacuum flash--assisted solution process for high-efficiency large-area perovskite solar cells", Science, PP. aaf8060 (1-9), 2016.
- Lin, G.J, Song, J.Bi.M., Liu, J., Xiong, W., and Huang, M., "III-V Multi-Junction Solar Cells", 2013.
- Liu M, Johnston M.B and Snaith H.J, "Efficient planar heterojunction perovskite solar cells by vapour deposition", Nature, Vol. 501, no. 7467, pp. 395-398, 2013.
- Ma B, Gao R, Wang L, Luo F, Zhan C, Li J and Qiu Y, "Alternating assembly structure of the same dye and modification material in quasi-solid state dye-sensitized solar cell", Journal of Photochemistry and Photobiology A: Chemistry, Vol. 202, no. 1, pp. 33-38, 2009.
- Maehlum M.A, "Amorphous Silicon Solar Panels," Energy Informative, 26 June 2013. [Online]. Available: http://energyinformative.org/amorphous-silicon-solar-panels/. [Accessed 2014 December 8].
- Mariska de Wild-Scholten M.J, "Energy payback time and carbon footprint of commercial photovoltaic systems," Solar Energy Materials & Solar Cells, vol. 119, pp. 296-305, December 2013.
- Ministry of New and Renewable Energy
- Mints Paula "Price, technology, and the illusion of control", 2011. Available online : http://www.renewableenergyworld.com/articles/2011/04/price-technology.html
- Mitzi D.B, Wang S, Field C.A, Chess C.A, Guloy A.M, "Conducting layered organicinorganic halides containing (110)-oriented perovskite sheets", Science, Vol. 267, no. 5203, pp. 1473- 1476, 1995.
- Mori Shinsuke and Suzuki Masaaki, "Non-Catalytic, Low-Temperature Synthesis of Carbon Nanofibers by Plasma-Enhanced Chemical Vapor Deposition", 2010
- Mount D.J, "Producing high-performance thin-film silicon PV panels," Renewable Energy World, 2010.
- NimjeRajendra, former MD Solar Energy Corporation of India,"Pilot Scheme on Grid Connected Rooftop PV Systems", 14th February 2014.
- Niu G, Guo X and Wang L, "Review of recent progress in chemical stability of perovskite solar cells", Journal of Materials Chemistry A, Vol. 3, no. 17, pp. 8970-8980,2015.
- NREL, "Basic Photovoltaic Principles and Methods", 1982.
- NREL, "Best Research Cell Efficiencies," United States, 2014. NREL, Best Research Cell Efficiencies, Available at http://www.nrel.gov/ncpv/images/efficiency_chart.jpg
- NREL, "CIGS-Based Solar Cells Prepared from Electrodeposited Precursor Films," United States, 2011.
- NREL, Available Online: http://www.nrel.gov/ncpv/images/efficiency_chart.jpg. (date?)
- NREL, Best Research Cell Efficiencies, Available at http://www.nrel.gov/ncpv/images/efficiency_chart.jpg, 2015.
- NREL, Best Research Cell Efficiencies, Available at http://www.nrel.gov/ncpv/images/efficiency_chart.jpg, 2016.
- O'regan B and Grfitzeli M, "A low-cost, high-efficiency solar cell based on dyesensitized", Nature, Vol. 353, no. 6346, pp. 737-740, 1991.

- O'regan. B and Grfitzeli .M, "A low-cost, high-efficiency solar cell based on dyesensitized", Nature, Vol. 353, no. 6346, pp. 737-740, 1991.
- Ochs R, "Amorphous Silicon Solar Cell," Rutgers University, United States, 2004.
- Ohl R.S, "Light-sensitive electric device including silicon". Patent US2443542 A, 27 June 1941.
- Paunovic .M, "Fundamentals of Electrochemical Deposition," A JOHN WILEY & SONS, INC, Canada, 2006.
- Phys.org, Available Online: http://phys.org/news/2009-09-imec-unveils-mechanically-stacked-gaasge-multijunction.html
- Prakash J and Garg H, Solar Energy: Fundamentals and Applications, Tata McGraw-Hill Publishing, 2012.
- PVEDUCATION, "Czochralski Silicon," PV Education, 2014.
- PVlab, Available Online: http://pvlab.ioffe.ru/about/solar_cells.html
- Ramanathan, Kannan, Contreras M.A, Perkins C.L, Asher S, Hasoon F.S, Keane J, Young D, Romero M, Metzger W, Noufi R, Ward J and Duda A, "Properties of 19.2% Efficiency ZnO/CdS/CuInGaSe2 Thin-film Solar Cell," vol. 11, no. 4, pp. 225-230, 2003.
- Reinhard P, Chirila A, Blosch P, Pianezzi F, Nishiwaki S, Buecheler S and Tiwari A.N, "Review of Progress Toward 20% Efficiency Flexible CIGS Solar Cells and Manufacturing Issues of Solar Modules," IEEE Journal of Photovoltaics, vol. 3, no. 1, pp. 572-580, 2013.
- Renewable Energy Policy Network for the 21st Century (REN21), "Renewables 2012, Global Status Report," 2012.
- Rinaldi .F, "Basics of Molecular Beam Epitaxy," Annual Report 2002, Optoelectronics Department, University of Ulm, Germany, 2002.
- Rohatgi A, "Investigation of metalorganic chemical vapor deposition," Solar Cells, vol. 31, pp. 143-150, 1991
- Shafarman W.N, Siebentritt S and Stolt L, "Handbook of Photovoltaic Science and Engineering", New York: John Wiley & Sons, Ltd, 2011, p. 546–599.
- Shah A, Torres P, Tscharner R, Wyrsch N and Keppner H, "Photovoltaic Technology: The Case for Thin-Film Solar Cells," vol. 285, 1999.
- Shah A, Torres P, Tscharner R, Wyrsch N and Keppner H, "Photovoltaic Technology: The Case for Thin-Film Solar Cells," Science, vol. 285, no. 5428, pp. 692-698, 1999.
- Silverman T.J, Deceglie M.G, Marion .B, Cowley S, Kayes B and Kurtz S, "Outdoor Performance of a Thin-Film Gallium-Arsenide Photovoltaic Module," in 39th IEEE Photovoltaic Specialists Conference, Colorado, 2013.
- Singh S.C, Solar Photovoltaics : Fundamentals, Technologies and Applications, New Delhi: PHI Learning Private Limited, 2012.
- Snaith H.J and Schmidt-Mende L, "Advances in liquid-electrolyte and solid-state dyesensitized solar cells", Vol. 19, no. 20, pp. 3187-3200, 2007.
- Snaith H.J, "Perovskites: the emergence of a new era for low-cost, high-efficiency solar cells", The Journal of Physical Chemistry Letters, Vol. 4, no. 21, pp. 3623-3630, 2013.
- Solar Facts and Advice, "What Is Amorphous Silicon? Why is it so Interesting Now?" 2013.

- Sultana S, "RF Magnetron Sputtering system," Centre for Excellence in Nano-Electronics, Indian Institute of Science, Bangalore, 2010.
- The History of Solar U.S. Department of Energy, Energy Efficiency and Renewable Energy.
- Thurm M, "Organic Solar Cells: Advantages, Possibilities and Limits of Bulk heterojunction solar cells," Sustainability Marketing and Innovation, Munich, 2011.
- Wang .X and Wang Z.M, High-Efficiency Solar Cells: Physics, Materials, and Devices, Springer, 2013.
- Weisheit A, "Inside a Thin-Film Silicon Solar Cell Fabrication Plant," 2013. [Online]. Available: http://www.interpv.net/market/market_view.asp?idx=682&part_code=02.
- Weisse J, "Concentrated Solar Photovoltaics," Stanford University, United States, 2010.
- Wesoff E, "First Solar Reclaims CdTe PV Efficiency Record," Greentechmedia, 26 february 2013.
- Xing G, Mathews N, Sun S, Lim S.S, Lam Y.M, Grätzel M, Mhaisalkar S and Sum T.C, "Long-range balanced electron-and hole-transport lengths in organic-inorganic CH3NH3PbI3", Science, Vol. 342, no. 6156, pp. 344-347, 2013.
- Yamaguchi M, Takamoto T and Araki K, "Super high-efficiency multi-junction and concentrator solar cells," vol. 90, no. 18-19, 2006.
- Yang M.C, Landau .U and Angus J.C, "Electrodeposition of GaAs from Aqueous Electrolytes," Journal of The Electrochemical Society, vol. 139, no. 12, pp. 3480-3488, 1992.
- Zachary Shahan, "First Solar's Thin-Film Solar Panel Advantages". [Online]. Available: http://cleantechnica.com/2014/07/30/first-solar-thin-film-solar-panel-advantages, 30 July 2014.
- Zhang Y.G, Li C, Gu Y, Wang K, Li H, Shao X.M and Fang J.X, "GaInP–AlInP– GaAs Blue Photovoltaic Detectors with Narrow Response Wavelength Width," vol. 22, no. 12, 2010.
- Zhou H, Chen Q, Li G, Luo S, Song T.B, Duan H.S, Hong Z, You J, Liu Y and Yang Y, "Interface engineering of highly efficient perovskite solar cells", Science, Vol. 345, no. 6196, pp. 542-546, 2014.
- Zilko J.L, "Metal Organic Chemical VaporDeposition:Technology and Equipment", Elsevier, 2002.

Appendix – 2A

Name of the companies consulted

- [1]. Welspun Renewables
- [2]. Azure Power
- [3]. SunEdison
- [4]. ACME Solar Energy Pvt. Ltd
- [5]. MAHAGENCO
- [6]. Essel Infra Projects Limited
- [7]. NTPC
- [8]. Torrent Power Limited
- [9]. Hindustan Power (Hpppl)
- [10]. Malpani Group
- [11]. Aditya Birla
- [12]. Tata Power Solar
- [13]. Renew Power
- [14]. Waneep Solar Pvt. Ltd.
- [15]. Today Green Energy Private Limited
- [16]. Roha Solar Energy
- [17]. Solairedirect Energy India Pvt. Ltd
- [18]. Reliance Power
- [19]. PunjLlyod
- [20]. Hero Future Energies
- [21]. Adani Group
- [22]. IL&FS Energy Development Company Limited
- [23]. Lanco Solar Energy Pvt Ltd
- [24]. Kiran Energy Solar Power Private Limited
- [25]. Mahindra Susten Private Limited
- [26]. Madhav Infra Projects Ltd
- [27]. Apex Clothing Solar Private Limited
- [28]. Vikram Solar
- [29]. Swelect Energy Systems Ltd.
- [30]. Andhra Pradesh Power Generation Corporation Ltd.
- [31]. Sri Power Generation (India) Private Limited
- [32]. Aditya Green Energy Pvt Ltd hyderabad
- [33]. Value Labs LLP
- [34]. RMR Solar Energy Pvt. Ltd.
- [35]. Sri City (P) Ltd.
- [36]. Arhyama Solar Power Pvt. Ltd.
- [37]. Bhagyanagar India Ltd.
- [38]. Visaka Industries Limited
- [39]. Sri Surya NarayanaSwamy Solar Power Pvt. Ltd.

- [40]. B G Channapa
- [41]. KCP Ltd.
- [42]. Emmvee Energy Pvt. Ltd.
- [43]. Mahabubnagar Solar Parks Private Limited
- [44]. Marikal Solar Parks Private Limited
- [45]. Abhedya Power Pvt. Ltd.
- [46]. Pennar Industries Limited
- [47]. Pennar Engineered Building Systems Limited
- [48]. Surana solar Systems Pvt. Ltd.
- [49]. Arkha Solar Power Pvt.Ltd http://www.armstrongenergyglobal.com/projects/operating/rajahmundry/
- [50]. Cosmic Power Solutions Limited
- [51]. Gujarat Power Corporation Ltd.
- [52]. Gujarat State Electricity Corporation Ltd.-Canal
- [53]. Gujarat State Electricity Corporation Ltd.-TPS
- [54]. M/s. Jaydeep Cotton Fibres Pvt. Ltd.
- [55]. Essar Power Ltd.: http://www.essar.com/article.aspx?cont_id=b9y62i3v5xA
- [56]. Hiraco Renewable Energy Pvt. Ltd.:

http://www.adb.org/sites/default/files/projectdocument/75839/44932-014-ind-scar.pdf

- [57]. Universal Solar System: http://www.universalrenewable.com/current_project.php
- [58]. United Telecoms Limited
- [59]. Bhoruka Power Corporation Limited
- [60]. Sharda Construction and Corporation Private Ltd
- [61]. Waa Solar Private Limited
- [62]. KPCL
- [63]. Alpha Infra Pvt. Ltd.: http://www.cdmindia.gov.in/project_details_view.php?id=2081
- [64]. Bhadresh Trading Corporation Ltd
- [65]. Focal Energy Solar one India Pvt. Ltd

[66]. FinnSurya Energy Pvt Ltd.:http://www.fortum.com/countries/in/fortum-inindia/news/pages/fortum-connects-the-first-solar-project-of-.aspx

[67]. IL & FS Energy Development Company Ltd.: http://www.vikramsolar.com/projectsand-services/pdf/mp-india.pdf

- [68]. Varroc Engineering Pvt Ltd
- [69]. Morries Energy Limited
- [70]. Sunilhitech Solar (Dhule) Pvt Ltd.

[71]. TATA power renewable energy ltd., Mumbai: http://www.tata.com/article/inside/Tata-Power-successfully-commissions-its-second-25-MW-solar-farm-in-Palaswadi-Maharashtra

- [72]. Raajratna Energy Holdings Private Limited: http://www.energetica-india.net/power-plants/1-mw-plant-in-orissa
- [73]. Alex Green Energy Private Limited
- [74]. RSSB Educational & Environmental Society:

http://mnre.gov.in/file-manager/akshay-urja/november-december-2014/EN/10-14.pdf

[75]. PL Surya Urja Ltd

[76]. AdityaMedisales Limited

[77]. NexgenSoluxPvt. Ltd.: http://www.statensolar.com/#/news

[78]. Soma Enterprises: http://www.meeco.net/blog/soma-plant-in-punjab-india-synchronized-with-the-electricity-grid/

[79]. PunjLlyod Solar Pvt. Ltd: http://www.odi.org/sites/odi.org.uk/files/odiassets/publications-opinion-files/7786.pdf

[80]. Indian Oil Corporation Ltd.: http://headwaysolar.com/blog/2012/03/indian-oil-corporation-commissions-5mw-project-in-rajasthan/

[81]. Conflux InfratechPvt. Ltd.:

http://www.barmersolar.blogspot.in/2015/03/performance-report-of-1mw-thin-film.html

[82]. FonrocheSaaras Energy Private Limited: http://www.mahindra.com/news-room/press-release/1357735750

[83]. Solarfield Energy Two Pvt Ltd.: http://shaktifoundation.in/wp-content/uploads/2014/02/India-Kiran-Energy-Profile-IP_05.pdf

[84]. LEPL Projects Ltd.: http://www.lepl.in/solar-power.html

[85]. Trimex Sands Private Limited.: http://www.taniljain.com/anil-jains-refex-energy-ltd-has-successfully-commissioned-a-10-mwp-solar-plant-in-kolayat-region-in-rajasthan.html

[86]. Palimarwar Solar Project Pvt Ltd.: http://www.tatapowersolar.com/news_files/press
[87]. CCCL Infrastructure Limited:

http://www.thehindubusinessline.com/companies/consolidated-construction-ties-up-funds-fortn-project/article2150725.ece

[88]. Swelect Energy Systems Ltd.

[89]. Great Shine Holdings Pvt. Ltd: http://panchabuta.com/2011/08/14/gemini-communications-to-commission-its-1mw-solar-plant-in-tamil-nadu-by-september/

[90]. Sharadha Terry Products Limited

[91]. G.R.ThangaMaligai& Sons

[92]. Super Auto Forge PvtLtd

[93]. JVS Exports Ltd

[94]. M M Forgings Ltd

[95]. The KTM Jewellery Ltd, Nachas Wind Energy Pvt Ltd, Space Textiles Pvt Ltd, SCMInternationalImpexPvtLtd,SathySilks(P)Ltd.:http://www.tata.com/media/releasesinside/Tata-Power-Solar-successfully-commissions-Phase-II-of-solar-power-project-for-The-Chennai-Silks-group-takes-their-total-capacity-to-7.2MW

[96]. Cheenu Enterprises: http://www.cnpvpower.com/it/HTML/News/Display/Nid_127_Class_9.html

[97]. Freelook Fashions: http://wikimapia.org/33221441/1MW-700-kW-Ground-Mounted-300-kW-Rooftop-solar-PV-plant-at-Dyeing-factory-of-Freelook-Fashions

[98]. Bharat Heavy Electricals Ltd.: http://www.thehindubusinessline.com/companies/bhel-to-set-up-5-mw-solar-plant-at-ranipet/article3935133.ece

[99]. Raagam Exports

[100]. Murugan Textile

[101]. Swelect Energy Systems Ltd: http://www.slideshare.net/nbaluja/solar-power-market-2015

- [102]. Apex Clothing Company India Limited
- [103]. KarurSree Rama Trading Private Ltd
- [104]. Nazareth Green Energy Enterprise (P) Ltd
- [105]. Dev International
- [106]. Best Corporation Private Limited
- [107]. Shiny Knitwear
- [108]. SreeSanthosh Garments

[109]. KarurSree Rama Trading Private Ltd, Asian Fabrics: http://renewables.seenews.com/news/sterling-wilson-installs-10-mw-solar-park-for-indian-

textile-cos-report-430393

- [110]. SRL Green & Clean Power Private Ltd
- [111]. EMC Ltd.
- [112]. DhruvMilkosePvt. Ltd.
- [113]. Technical Associates Ltd
- [114]. Dante Energy Private Limited
- [115]. Priapus Infrastructure Private Limited
- [116]. Rail Coach Factory (RCF), Rae Bareli:
- http://irconnet.blogspot.in/2014/07/commisioning-of-2-mw-solar-power-plant_24.html
- [117]. Jakson Power Private Limited
- [118]. Amvensys Technologies Pvt. Ltd.: http://www.empergy.com/empergy-projects.shtml
- [119]. http://cial.aero/Pressroom/newsdetails.aspx?news_id=360
- [120]. http://timesofindia.indiatimes.com/city/delhi/1-MW-solar-power-plant-to-light-up-

1000-city-homes/articleshow/7142615.cms

- [121]. http://www.canadiansolar.com/solar-projects/igi-airport-new-delhi-india.html
- [122]. Sterling and Wilson Pvt. Ltd.
- [123]. L&T Construction Solar Projects
- [124]. Moser Baer India Limited
- [125]. Juwi India Renewable Energies Pvt Ltd
- [126]. Rays Power Infra Pvt. Ltd
- [127]. Waaree Energies Ltd
- [128]. REFEX Energy Ltd.
- [129]. Rays Power Experts Pvt Ltd
- [130]. Ujaas Energy Limited
- [131]. HarshaAbakus Solar
- [132]. Enrich Energy Pvt. Ltd.
- [133]. Megha Engineering and Infrastructure Ltd.(MEIL Group)
- [134]. Cirus Solar Private Limited

- [135]. EMMVEE Photovoltaic Power Private Limited
- [136]. BHEL
- [137]. Chemtrols Solar Pvt. Ltd.
- [138]. Jakson Power
- [139]. Bosch Solar Energy
- [140]. Premier Solar Systems Private Limited
- [141]. BELECTRIC
- [142]. Photon Energy Systems Limited
- [143]. IBC SOLAR Projects Private Limited
- [144]. Gujarat Energy Development Agency (GEDA)
- [145]. Haryana Renewable Energy Development Agency (HAREDA)
- [146]. Jharkhand Renewable Energy Development Agency (JREDA)
- [147]. Karnataka Renewable Energy Development Ltd. (KREDL)
- [148]. Madhya Pradesh New and Renewable Energy Department (MPNRED)
- [149]. Maharashtra Energy Development Agency (MEDA)
- [150]. Orissa Renewable Energy Development Agency (OREDA)
- [151]. Punjab Energy Development Agency (PEDA)
- [152]. Tamil Nadu Energy Development Agency (TEDA)
- [153]. Uttar Pradesh New and Renewable Energy Development Agency (UPNEDA)
- [154]. West Bengal Renewable Energy Development Agency (WBREDA)
- [155]. Andhra Pradesh Non-Conventional Energy Development Corporation of Andhra Pradesh Ltd. (NEDCAP)
- [156]. Rajasthan Renewable Energy Corporation Limited (RRECL)

3 Solar Thermal Technologies

3.1 Introduction

In India, about 69% thermal energy was produced using coal in 2011, as shown in Figure 3.1 (Banerjee, 2014). There are emissions of CO2 and other greenhouse gases from these coal fuelled power plants. The emitted greenhouse gases including CO2 pollute environment which is not good for health of living organisms. The emitted green house gases are responsible for global warming which causes melting of iceberg thus raising sea level. The CO2concentration at present is around 400ppm which has happened for the first time in 55 years of measurement—and probably more than 3 million years of Earth history (Kunzig and Robert, 2013). Other effects of coal fuelled thermal power plants include soil erosion, river and underground water pollution which damages the crop production and responsible of deteriorating public health. It is high time to tap nonpolluting energy sources (solar energy and Renewable Energy Sources) to minimize the use of fossil fuel. In this chapter we have discussed various solar thermal technologies, their current status in India and abroad and their applicability in the Indian context.



Figure 3.1 Electricity generation in India in 2011 Source : Banerjee, 2014

3.2 Concentrating Solar power

Following solar thermal concentrators namely parabolic disk concentrator, hyperboloid solar concentrator, fresnel lens solar concentrator, compound parabolic concentrator, Cylindrical parabolic solar concentrator, dielectric totally internally reflecting concentrator, flat high

concentration devices, quantum dot solar concentrator, fixed mirror solar concentrator, linear fresnel reflector, central heliostat tower receiver and hemispherical bowl mirror are used for various applications like power generation, heat process, and solar cooking etc.

The optical, thermal and exergy efficiency of some systems have been discussed in terms of concentration ratio in the review. Recent progresses in the advances of solar concentrators integrated with photovoltaic module have also been proposed and analysed with a characteristic equation. It was observed that for low operating temperature say up to 200°C, (non-tracking concentrator with small concentration ratio) can be used for large scale cooking during peak sunshine hours and space heating for cold climatic conditions. It was also reported that for high operating temperature say about more than 200oC which is required for power generation (electricity), tracking concentrator with high concentration ratio should be used.

We have completed a review (Tiwari et al, forthcoming) on concentrating solar power generation titled "Solar thermal power concentrators: a review" and the paper has been sent for publication in an International journal.

3.2.1 Current status in India Concentrating solar power generation:

There are two solar thermal power plant of capacity 50 MW (Parabolic trough type, Godavari green, Nokh,), Figure 3.2 and 125 MW (Compact Linear Fresnel Reflector (CLFR), AREVA India), Dhursar, Rajasthan, Figure 3.3. They are working satisfactorily in India.



Figure 3.2 Cross sectional view of parabolic trough type concentrator used for solar thermal power



Figure 3.3 Pictorial view of compact Linear Fresnel concentrator

There is another solar power plant at National Institute of Solar Energy (NISE), Gurgaon,that has been installed but not working. Some other plants are under construction/planning stage. Recently, 50KW CPC-PVT has been installed in Mohali Chandigarh operating at 70°Cfor process heat, Figure ______ 3.4.



Figure 3.4 Cut sectional front view of partially covered PVT-CPC water collector system

Roof-Top Solar facility:

A 20 kWh test facility based on beam up molten salt based solar power tower technology has been designed, installed at Engineering Hall-7, BARC roof to gain much required experience on solar technology like Heliostat tracking, behavior of molten nitrate salt, natural circulation, Figure 3.5.



Figure 3.5 Different views of solar roof top facility

The actual data generated from these plants are not available. It's economical and CO2 mitigation feasibility will depend on its long-term annual output of electrical/thermal power.

Concentrating solar cooker

The world's largest solar-powered cooking system serving (a) 15,000 pilgrims daily at the Tirumala temple (AP), parabolic trough type concentrating system, Figure 3.6 and (b) 20,000 people per day at saint Sai Baba in Shridi (Maharashtra) have been installed in India. The solar cooking system generates some 3,500 kg of steam daily, which replaces on a yearly basis 100,000 kg of cooking gas. There are many solar cooking installations working satisfactorily like Brahma Kumari's due to regular maintenance and usage. After our visit to Triputi temples, we found the systems for steam cooking is not working.



Figure 3.6 View of parabolic disk concentrator for solar cooking installed at Triputi Temple

3.2.2 International best practices

The preliminary results of the forthcoming International Energy Agency (IEA)- concentrated solar power (CSP) roadmap suggest that CSP would make a contribution of 12% to global electricity supply by 2050. The investment costs would range from USD 4.2 to 8.4 per Watt. It depends on the solar resource and the size of the storage capacity. Levelised electricity cost would range from US cents 17-25 per kWh which mostly depends on the quality of the solar resource. It is also predicted that cumulative CO2 savings for scenario 3 (case c) will be 37,465 million tons (Table 3.1). Further for the Moderate scenario assumptions (case b), the solar thermal power capacity worldwide would be approximately 20 GW by 2020 and 800 GW by 2050 respectively if 61 GW/yr is installed. This would represent around 5% of global demand in 2050.

	2015	2020	2030	2040	2050
CO ₂ Savings in million tons					
(a) Current policy					
Annual CO2 savings	9	17	43	86	143
Cumulative CO2 savings	25	93	390	1,025	2,197
(b) Moderate policy					
Annual CO2 savings	9	35	212	653	1,251
Cumulative CO2 savings	1,390	1,499	2,595	6,983	16,657
(c) Advanced Policy					
Annual CO2 savings	9	67	580	1,564	2,772
Cumulative CO2 savings	1,390	1,566	4,431	15,445	37,465

Table 3.1 Annual and cumulative CO2 savings from STE Scenarios (Teske et al, 2016)

Most of the existing CSP plants are based on trough technology. However the use of tower technology is increasing and linear Fresnel lens is coming up as an emerging technology Table 3.2).

Technology Type	No. of STE plants (No.)	Installed capacity (MW)	Annual expected electricity production (GWh)	Under construction (MW)
Parabolic Trough	73	4,115	10,000	719
Central Receiver	10	497	1,300	410
Fresnel	8	179	350	180

 Table 3.2 Installed Capacities and Produced Electricity by Technology Type

3.2.3 Applicability in the Indian context

There is considerable opportunity for installation of concentrated solar thermal power in India due to availability of high solar radiation particularly in Rajasthan and Northern part of India provided sufficient land is available.

Such technology is not available in India and hence one has to depend on import of technology

3.2.4 Recommendations

Based on our prepared report, we recommend the followings:

- 1. Solar thermal power system can be first encouraged to be used for steam cooking (more than one thousand)/space heating (in a group housing society) for large number of users which can be useful to conserve fossil fuel and further it should be recommended that such large cooking system be encouraged to installed at
 - i) Hostels in educational institutions
 - ii) Mid day meal program
 - iii) Community centers like temples, defense canteen etc. and
 - iv) Hospitals etc.
- 2. Domestic solar cooking system is not successful in India due to ignorance about its limitations in rural and remote regions of the country. Also due to non-availability of local maintenance, domestic solar cooker were not accepted in these area.
- 3. For power generation, first data of installed solar power plant should be analyzed before going for large installations in MW.

Such installation will conserve the fossil fuel and save the environment by reducing CO2 emission.

3.3 Passive heating and cooling systems in building

3.3.1 Current status in India

The heating and cooling of a building depends on climatic condition of a building location. For example, India has been divided in to six climatic conditions/zones and hence we need to design a building for each climatic zone. For example northern part of India belongs to composite climatic condition. In this climatic condition, number of days for cooling of building is more

than 180 days and heating is merely 30 days and hence the building for northern part of India should be designed from cooling point of view (Tiwari et al, 2016a).

Most of old Indian buildings were designed from cooling point of view by using locally available materials with passive cooling concepts like Trombe wall (thick wall) as shown in Figs.3.7 and 3.8a respectively. In such design, the U-value (an overall heat transfer coefficient) is minimum to reduce the transmittance of solar flux inside building. In such building embodied energy is also minimum and we can say that CO2 emission in construction of passive cooled building in minimum. This can be also referred as either heavy structure building or large heat capacity building. However, there is limitation of number of floor in such building. There can be maximum two floors due to heavy structure.

In order to increase the number of floor with minimum U-value and light structure, a modified Trombe wall (a new concept) has been successfully implemented at four storied SODHA BERS COMPLEX (SBC) at Varanasias shown in Figure 3.8b. In this design of wall, an arrangement of cupboard has also been made in the wall to increase its uses. The cost of construction of modified Trombe wall is also reduced.



Figure 3.7 Front view of Fort in Kurukshetra, Haryana



Figure 3.8a Inner view of Fort in Kurukshetra, Haryana



Figure 3.8b Modified Trombe wall at SODHA BERS COMLEX, Varanasi

3.3.2 International best practices

Most developed countries in temperate regions use active heating and cooling systems. Hence research on passive heating is not very common in developed countries.

3.3.3 Applicability in Indian context

Developing countries like India which are located in hot tropical regions need cooling during summer months. However, they are not in a position to afford active cooling arrangements. Hence, these are the main target areas for passive cooling systems.

3.3.5 Recommendation

There should be a mandatory act to integrate most of available passive heating and cooling concepts for all newly constructed houses by builders.

Following recommendations are most appropriate passive concepts for four storied building:

1. Concept of earth shelter and grassing over the roof to mitigate CO2 for clean environment from cooling point of view for northern part of India, Figure 3.9.



Figure 3.9 Grassing over earth shelter building in Netherland

2. All exposed wall of a building to solar radiation should be either opaque with heavy structure materials (Trombe walls) or modified Trombe wall as shown in Figure 3.10 for minimum U –value with clerestory window for day lighting.



Figure 3.10 Cross-sectional view of Modified Trombe wall with cupboard

3. The partitions wall inside building can be light structure with transparent areas in upper portion of partition walls for proper day/artificial lighting purpose to conserve the high grade energy (electrical power) and vice-versa for heating of a building

In addition to above the following concepts should be also incorporated if possible to save conventional fuels:

- Height of a room
- Cross-ventilation
- Rain harvesting
- Roof garden for vegetation
- Roof top PV system to reduce the direct incidence of solar flux
- White tile for maximum reflection of solar flux
- White paint from inside and outside of building
- Double glazed walls for cold climatic conditions to minimize an overall heat loss coefficient and
- Use of exterior wall from materials having low U-value etc.

3.4 Daylight modeling concepts and energy saving assessment

3.4.1 Current status

Figure 3.11 shows that in building sector, 12% of total energy consumption is spent on artificial lighting. If this energy for artificial lighting is saved by natural day lighting to mitigate CO2, it will be a step further to save environment and mitigate climate change.



Figure 3.11 Pattern of energy consumption in a residential building (Source: Department of energy)

Natural day-lighting in the building is not a new concept (Figure 3.12). This has been in practice since long. The daylight provides natural light in a room of a building which can save high grade electrical energy during the day time. Not much additional cost is required for this. The natural day-lighting in a room is available through clerestory window which is fitted at top of unexposed wall to solar radiation if possible. The clerestory window is also used for transfer of thermal energy (hot air) from room to outside for cooling purposes through cross ventilation. This window is made in addition to the conventional window in a building. Unfortunately, builders are not considering the use of natural day-lighting even in four storied building properly.

On the basis of our visit, it is observed that these concepts have been seriously implemented in most of the international airport in our country unlike in residential buildings. Builders should be encouraged and taught through workshop to use this concept in all buildings keeping climatic and environmental condition in mind. It directly saves high grade electrical power to sustain climate and environment (100 lux = 1W).



Figure 3.12 Inner view of residential complex showing day-lighting and Trombe wall concept at Bharati Nager, New Delhi

3.4.2 International best practices

In the developed countries, the use of day-lighting concepts in buildings is most common unlike in emerging economies (IEA, 2010).

3.4.3 Applicability in the Indian context

In India, most of residential houses were designed from day-lighting point of view due to lack of availability of power (fossil fuels) either in rural or urban areas. These concepts should be used in all building depending upon climatic conditions. One can save electricity (mainly generated from fossil fuel) used for lighting by utilizing sun light during the day.

3.4.5 Recommendation

Without much additional cost to the building construction, the daylight arrangement can be made through providing clerestory window in the wall exposed to ambient air. The daylight even works under diffused conditions. The clerestory window can also help in summer to transfer the inside hot air to outside ambient air by natural convection mode for cooling purposes. The size of window depends on floor area. There are standard methods to evaluate the size of window as per user requirement.

3.5 Solar heating of biogas plant

3.5.1 Current status

It is most successful technology available in India. However it is not properly utilized due to two reasons a) non-awareness of its advantages in rural area and b) non-availability of inputs for slurry. We have suggested solution for the slurry problems locally by collecting the green solid waste through vegetable market, juice shops, seasonal locally available green leaves including algae etc. Biogas is most economical for cooking and lighting purposes. Compressed biogas can also be used for local transport but its economics and viability should be studied before large scale implementation in rural area. It is completely environment friendly.

There are many types of bio gas plants. Broadly they are classified as floating type (Figure 3.13) and fixed dome type biogas plant (Figure 3.14).



Figure 3.13 Floating type biogas plant at IIT Delhi working for last forty years



Figure 3.14 Fixed dome plant Nicarao design:

 Mixing tank with inlet pipe and sand trap. 3. Digester. 3. Compensation and removal tank. 4. Gasholder. 5.
 Gaspipe. 6. Entry hatch, with gastight seal. 7. Accumulation of thick sludge. 8. Outlet pipe. 9. Reference level. 10. Supernatant scum, broken up by varying level.

The production of biogas mainly depends on slurry temperature for best fermentation of slurry which is about 37°C. There is need for heating the slurry during winter months in northern India and for cold climatic condition like Srinagar/Shimla etc. Following methods are generally used for the same:

- 1. Hot Charging: In this case, the slurry is prepared with sufficiently hot water and it is fed in to digester for fermentation. To avoid night heat losses from top of the dome it should be covered with insulating layer to retain the desired slurry temperature.
- 2. Greenhouse integration: Many studies have revealed that the creation of greenhouse over the dome of biogas plant has increased the slurry temperature resulting in enhanced production of biogas during winter months. Some has suggested blackening and glazing of dome surface for the same purpose.

3. Active heating: In this case, flat plate collectors are integrated with digester through heat exchanger for fast heating of slurry. It is most suitable for cold climatic condition. In this case fixed dome type biogas system should be used. Generally heating should be done through cooper pipe spiral heat exchanger.

3.5.2 International best practices

About 1.2% of China's total energy use is provided by biogas. Biogas has replaced fossil fuels and biomass used for cooking in rural areas (Regina Gregory, 2010). More than 30 million households in China are equipped with biogas digesters, which convert wastes into clean-burning fuel. There are 12 significant environmental and social benefits of biogas.

Most villages in China do not have electricity and commercial fuels such as coal and kerosene are expensive. Thus, the rural population still depends majorly on biological sources of energy. 80% of rural household energy use is provided by fuel wood and 54% of total rural energy use is sustained through crop residues (usually straw). Since the thermal efficiency of traditional stoves is only about 10%, a lot of fuel is needed for minor tasks such as cooking (Fig 3.15). This leads to serious environmental problems such as soil erosion, reduced soil fertility, deforestation, and even localized desertification. Also, it causes pollution of indoor air, which in turn leads to severe health effects such as respiratory infections and eye problems.



Figure 3.15 Cooking in rural China Source: Smith (2007)
Biogas can solve many of these problems by just adding one step in the fuel cycle, and provide many additional benefits as well. It is well suited for China, where recycling and pig-rearing have long been common household tasks.

3.5.3 Applicability in the Indian context

The estimate of biogas production in India was about 20,757 lakh cubic meters in 2014-15 which is equivalent to 6.6 crore domestic LPG cylinders (Fig 3.16). Further, this is equivalent to 5% of the total LPG consumption in India today. Within states, Maharashtra tops the production with 3578 lakh cubic meters while Andhra Pradesh comes next with 2165 lakh cubic meters, (Surya, 2015).



Figure 3.16 Production of biogas in different states of India Source: Surya, 2015

Figure 3.16 shows the production of biogas in top 10 biogas producing Indian states. There is a scope for biogas production in other states as well.

3.5.4 Recommendation/Future plan

For current five year plan (2012-2017), the government of India (GOI) had set a target to set up 6.5 lakh biogas plants across the country with a budget of Rs.6500 Million. It is under a program known as the National Biogas and Manure Management Program (NBMMP). It had been estimated that about 1-6 cubic meter of biogas per day and 4745 lakh cubic meter biogas could be produced annually from this program. The program is being implemented by the State Nodal Departments/State Nodal Agencies, Khadi and Village Industries Commission (KVIC) and Biogas Development and Training Centers (BDTCs).

Following recommendations have been made for selecting proper design of biogas systems:

- 1. Floating type biogas plant: This biogas plant is most suitable in the area which requires slurry heating marginally. For example Northern part of India (Composite climate) and moderate climatic condition namely Karnataka etc.
- 2. Fixed dome type biogas plant: In this case, an active heating is needed in addition to hot charging of slurry for cold climatic condition of region where heating is required throughout the year.

3.6 Solar distillation

3.6.1 Current status

Table 3.3 represents the distribution of water on the surface of earth. Out of the available water on earth, less than 3% is fresh water. Out of this fresh water, more than 2% water is locked up in ice caps and glaciers of Polar Regions and only less than 1% is within human reach. The main areas of fresh water requirement are domestic, agriculture and industrial. The use of fresh water resources varies from country to country. Table 3.4 shows the use of fresh water requirement in various sectors of low and high-income countries. The use of water requirement in industries and household sectors of high-income countries are higher in comparison to that of low-income countries. In both low income group countries and high income group countries, agriculture sector needs highest percentage of fresh water. Moreover, the fresh water requirement in agriculture sector is more in low income countries in comparison to high income countries.

Location	Relative proportion (%)
Oceans	97.39
Polar, ice caps, glaciers	3.010
Underground soil moisture	0.580
Lakes and rivers	0.020
Atmospheric water vapor	0.001

Table 3.3 Distribution of water on the earth surface

Sector	Low income countries (%)	High income countries (%)
Agriculture	90	59
Industry	8	30
Household	2	11

Table 3.4 Use of fresh water requirements in low and high-income countries

From Tables 3.3 and 3.4, one can observe that there is only 0.02% fresh water for human consumption. Further out of 0.02%, 90% and 8% are used for agriculture and industry and only

2% is used for household for low income countries. India comes under low income countries. In India, underground water is also polluted due to green revolution which was necessary for meeting the food requirement of growing population. Hence to prevent health issues we need to develop a self-sustaining- system to purify the sea water as well as the polluted underground water for drinking and cooking purposes.

There are many methods to convert/purify brackish/saline/hard water into potable water through desalination processes. Conventional desalination plants would have separate heating unit and condensing surface while solar distillation plants use same surface for heating and condensing. Desalination processes are very energy intensive and can be installed in larger capacity for centralized use. The maintenance is also very high. However, solar distillation device is self-sustained and practically needs no maintenance for family size unit.

There are mainly two types of application of solar distillation (a) for potable water and (b) for commercial/industrial purposes. In India many people are facing acute shortage of potable water due to either hard or arsenic/fluoride presence in underground water. Among them, there is lack of awareness about passive solar distillation cum rain harvesting system developed at IIT Delhi. Such system should be demonstrated in local rural areas to highlight its advantages. Further, an active self-sustained eco-friendly solar distillation system is also not popular for commercialization due to lack of awareness. There is strong need to popularize this system through entrepreneurship (NGO) which may also create jobs in rural area.

Passive double slope solar still:

As shown in Figure 3.17 it is a fibre re-inforced plastic (FRP) double slope solar still to convert brackish/saline/hard water in to distilled water. The life of such solar still is expected to be 40-50 years. It produces 2-3 liter/m2/day in summer weather condition. The rain water can also be treated to become potable water. If rain water is also used as potable water then the daily yield of the system is significantly increased. In that case, the rain water is collected from the top surface of condensing cover as shown in Figure 3.17. After first/two rains the rain water becomes almost free from any acid content because there is less mixing of particulate materials from the atmosphere. The cost of potable water produced by such solar still will be less than 20 paisa per liter. This solar still can be used in decentralized manner in remote areas. This solar still can also filter arsenic/fluoride present in underground water.





PVT active solar still

In order to increase the daily yield/m2 from double slope solar still, the water temperature in the basin is increased by feeding extra hot water from collector panel as shown in photograph 3.18. The increase of yield depends on number of collectors. Such active solar still operates under forced mode and hence pump / motor is required. To make the system self-sustained semitransparent photovoltaic (PV) modules are integrated with collector panel at lower side. However, the cost of distilled water produced from such solar still is much more than passive solar still.



Figure 3.18 PVT active solar still for commercial and industrial applications

3.6.2 International best practices:

Such technologies are more appropriate for low income countries.

3.6.3 Applicability in the Indian context

In India, there are many manufacturers of solar still and no patent is required for manufacturing. However, there is lack of awareness about availability of such solar stills which can purify polluted underground water as potable water. So there is a strong need to have workshops to spread awareness in different part of the country where there is a shortage of potable water. This can also generate employment if PV active system is used for commercial and industrial applications.

3.6.4 Recommendation

Based on work done at IIT Delhi and review of all research work carried out, following recommendation have been made:

- 1. Use of double slope solar still with rain harvesting facility should be encouraged to purify polluted underground water as potable.
- 2. PVT active solar still should be used for commercial applications

Further there is strong need to develop large scale solar distillation plants by integrating steam generating system (parabolic trough, Figure 3.2 and compact Linear Fresnel concentrator, Figure 3.3) with condensing chamber suitable for Indian climatic conditions. Part of work based on above discussion is published in Edalatpour et al, forthcoming.

3.7 Greenhouse PVT Dryer

3.7.1 Current status

Table 3.5 gives the estimates of post-harvest losses in various commodities in India. It can be seen that there are significant losses in Fruits, Vegetables, Floriculture and Fish production sector which can be minimized with drying of each commodities for storage purposes.

e Na	Commodito	Postharvest loss	
5.INO.	Commodity	Quantum (% of produce)	Value (Rupees in Crore)
1.	Grains	10	16,500
3.	Pulses	15	2,000
3.	Fruits	30	13,600
4.	Vegetables	30	14,100
5.	Floriculture	40	400
6.	Fish#	15	2,700
7.	Dairy (Milk)*	1.0	900
8.	Meat§	3.4	800
9.	Poultry§	2	500
		Total	Rs. 51,500 Crore

Table 3.5 Estimates of postharvest losses in various commodities (Ajit Kumar, 2012)

The semitransparent photovoltaic integrated greenhouse dryer developed by IIT Delhi is a selfsustaining dryer (Tiwari et al, 2016), Figure 3.19, which can be used to dry locally available medicinal plant as well as fruits, vegetables, flowers and fish. It can be designed from user's point of view for different capacity with multilayered drying. Field testing is yet to be done in open condition. This is a mixed mode dryer generally recommended for better drying. In this mixed mode dryer direct and indirect drying are combined to ensure better drying quality compared to directly exposed drying of vegetables and fruits. The direct and indirect drying is achieved through non –packing and packing area of PV module. Bitter gourd (Karela) has been dried in PVT dryer. It was cut in to chips before drying. Figure 3.20 shows the fried and powder of bitter gourd (karela) after drying. The dried chips can be used for cooking and powder has a medicinal value. Further, the grapes have been dried in open as well as inside PVT dryer as shown In Figure 3.21. From Photographs one can see the color of dried grapes indie PVT dryer has better color in comparison with open sun drying and has better market value.



Figure 3.19 Photo of PVT dryer



Figure 3.20 Fried and powder of bitter gourd (karela) after drying



Figure 3.21 Packed raisins (kismis) made by drying grapes (in open and in PVT dryer)

3.7.2 Applicability in the Indian context

From Table 3.5, one can observe that there are 30%, 30%, 40%, and 15% post-harvest losses in Fruits, Vegetables, Floriculture and Fish production in India. This indicates the importance of drying in our country. So, solar dryer will play an important role to minimize these post-harvest losses to meet our demand in these sectors. Further, workshops should be arranged to make the farmers aware about the applicability of various dryers. The farmers should be trained to use and maintain the systems. Also after drying their crop, they can store the crop for better return. Wastage of crop due to rain during drying is avoided too.

3.7.3 Recommendation

Following recommendations are suggested:

- 1. There is a strong need to test these PVT dryers in the field condition with help of farmers
- 2. Workshop for farmers should be held at various places to train the farmers

3.8 Solar water heaters

3.8.1 Current status in India

It is a well-established technology all over world as well as in India. However it is not properly harnessed due to lack of awareness about its effect on climate change. For example, solar water heater users feel that they only need hot water in winter and conclude that it is not economical. They have to be informed that hot water requirement is there throughout the year such as cleaning of floor/utensils/cloths/bathing, which can be supported by the solar water heater. This way the bacteria problem inside the house is also minimized from health point of view.

There are two types of small capacity solar water heating system, namely flat plate collector, Figure 3.22 and evacuated tubular (ETC), Figure 3.23 based water heating systems. Further ETC water heater is economical as well as efficient in comparison with flat plate collector. However, the maintenance (replacement if required) of ETC is expensive than flat plate collectors. Figure 3.22 shows the photograph of PVT solar water heater. In this case conventional flat plate collectors (FPC) have been used. It should be noted that the semitransparent PV module of 75Wp has been integrated at bottom of one FPC. The DC electrical power available from PV module is used to run the DC motor to circulate hot water from collector panel to insulated storage tank with minimum heat losses. Without PV module the system becomes conventional solar water heater for domestic use. However, PVT solar water heater is most suitable for large scale solar water heaters for commercial and industrial applications. PVT Solar water heaters give better performance under forced mode of operation for large heat capacity say more than 2000 liters capacity.



Figure 3.22 Photograph of PVT solar water heater

Figure 3.23 Photograph of ETC water heater

Figure 3.23 shows the photograph of evacuated tubular collector (ETC) solar water heating system of capacity 200 liter. ETC solar water heater works under natural circulation of operation and it is mostly used either for domestic applications or small capacity of hot water in dispensaries. It is economical and gives better performance in comparison with conventional solar water heater as shown in Figure 3.23. However, the maintenance of ETC solar water heater is expensive in comparison with conventional solar water heater due to not availability of ETC tube locally.

3.8.2 International best practices

The share of solar water heating system installed by various countries has been shown in Figure 3.24 (Greentech, 2010) till 2008. It can be seen that China's share is maximum (66.6%) European Union with 13.3% is at second position. The share of India is about 1.2% only.



Figure 3.24 Share of Solar Water Heater Capacity till 2008 (Source: Green tech, 2010 p. 1)

Here, we will discuss three scenarios

1. Pessimistic Scenario

State-wise projection of annual number of SWH households is made separately for four categories of households:

- Urban-new
- Urban-existing
- Rural –new
- Rural-existing

2. Realistic scenario

One of the major assumptions is a gradual stronger enforcement of the mandatory provisions for installation of SWH in new housing.

3. Optimistic scenario

One of the major assumptions here is policy and awareness initiative to increase penetration in existing housing. It is assumed that due to these initiatives the ratio of sales to new housing to the sales to existing housing would become 3:2, resulting in increased installation in existing housing. Figure 3.25 shows the prediction of installed SWH till the year 2022 for all three scenarios for residential as well as hotel. It should be noted that residential sector has more potential in comparison with hotel sector.



Figure 3.25a Year-wise cumulative SWH deployment in residential sector for all scenarios Source: Greentech, 2010 p.48



Figure 3.25b: Cumulative SWH installation in million m2 under 3 scenarios for Hotel Source: Greentech, 2010, p.67

3.8.3 Applicability in the Indian context

One can see from Figure 3.25 that there is a strong scope for installation of solar water heaters in India. Realistic and optimistic scenarios mentioned above need a lot of effort.

3.8.4 Recommendation

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Followings are recommendation:

- 1. The users should be encouraged to use domestic solar water heaters (200L) with yearly AMC (annual maintenance cost)
- 2. Community cooking center should be encouraged to use medium capacity solar water heaters (1000L)
- 3. Large scale solar water heaters (more than 5000) should be installed in hotels

Part of work discussed above is published in (Tiwari et al, forthcoming (a)).

References

• Banerjee, 2014: Rangan Banerjee, Coal-Based Electricity Generation in India, Cornerstone: The official Journal of the World Coal Industry, Available at cornerstonemag.net/coal-based-electricity-generation-in-india accessed on July 27, 2016

• Ajit Kumar, 2012: Drying of Medicinal/Vegetable Products by PVT Greeenhouse Dryer (Ph.D. Thesis), Centre for Energy Studies, Indian Institute of Technology, Delhi

• IEA, 2010: International Energy Agency's Energy Conservation in Buildings and Community Systems Programme, Available at

www.iea-ebc.org/fileadmin/user_upload/docs/EBC_Annex_29_PSR.pdf accessed on July 27, 2016

• Edalatpour et al, forthcoming: Edalatpoura M., Aryanaa K., Kianifara A., Tiwari G.N., Mahianc O., Wongwisesd S., Solar stills: A review of the latest developments in numerical simulations Solar energy, Manuscript number_SE-D-15-01602R1, forethcoming

• Regina Gregory, 2010: China - Biogas | The EcoTipping Points Project, Available at <u>www.ecotippingpoints.org/our-stories/indepth/china-biogas.html</u> accessed on July 27, 2016

• Tiwari et al, 2016a: G N Tiwari, Arjun Deo, Vikram Singh and Arvind Tiwari, Foundations and trends (UK) in Renewable Energy 1 (2016) N0. 3

• Tiwari et al, 2016: Sumit Tiwari, G.N. Tiwari, I.M. Al-Helal, Performance analysis of photovoltaic-thermal (PVT) mixed mode greenhouse solar dryer, Solar Energy, Volume 133, August 2016, Pages 421-428

• Tiwari et al, forthcoming: Tiwari G.N., Atheaya D. and Tiwari A., A review on Solar Thermal Power Concentrators, Sustainable Energy Technologies and Assessments, forthcoming

• Tiwari et al, forthcoming (a): Tiwari S., Tiwari G.N. and Al-Helal I.M., Development and Recent Trends in Greenhouse Dryer: A Review, Renewable and Sustainable Reviews, Manuscript number_RSERD1501858, forethcoming

• Teske et al, 2016: Dr. Teske S.(Greenpeace International), Leung J (ESTELA), Dr. Crespo L (Protermosolar/ ESTELA), Bial M, Dufour E (ESTELA), Dr. Richter C (DLR/SolarPACES), Solar-Thermal Electricity Global Outlook - 2016, Available at http://admin.indiaenvironmentportal.org.in/files/file/Solar-Thermal-Electricity-Global-Outlook-2016.pdf accessed on July 20, 2016

• Greentech, 2010: Greentech Knowledge Solutions (P) Ltd, solar water heaters in india: market assessment studies and surveys for different sectors and demand segments, Final Report, New Delhi -110078 (India), Available at http://mnre.gov.in/filemanager/UserFiles/greentech_SWH_MarketAssessment_report.pdf accessed on July 20, 2016

• Surya A., 2015: Surya Abhishek, Biogas Production in India is equivalent to 5% of the total LPG consumption available at

https://factly.in/biogas-production-in-india-is-about-5-percent-of-the-total-lpg-consumption/ accessed on July 19, 2016

• Kunzig and Robert, 2013: Kunzig, Robert (2013-05-09). "Climate Milestone: Earth's CO2 Level Passes 400 ppm". National Geographic. Retrieved 2013-05-13. Available at http://news.nationalgeographic.com/news/energy/2013/05/130510-earth-co2-milestone-400-ppm/ accessed on July 18, 2016.

4 Storage for energy management

4.1 Introduction

Excessive use of fossil fuels all over the world leading to climate change and the possible hazards of nuclear power, post Fukushima, have brought about a sense of urgency worldwide to shift towards renewable and clean energy sources. With increasing penetration of renewables that are inherently intermittent, grid stability is one of the issues that need to be addressed to ensure health of the power system. Unlike conventional generators, renewable energy requires backup and firming to be useful in a utility system. This may be achieved by storing energy which enables using time restricted intermittent renewable energy when demand is high. The technology of energy storage, especially of Pumped Hydro Storage (PHS) has been known for decades. Since 1970 various storage technologies have been used to increase grid reliability, maintain power quality, bridge the gap between generation and peak demand, and maintain flexibility of the system. With injection of renewable energy in to their energy spectrum, economies have exhibited a renewed interest in these technologies.

4.1.1 The Need for Storage Technologies

The benefits of wind and solar power to the utility include reduced fuel use and associated emissions. In spite of having these benefits they have four significant impacts that change how the system must be operated and affect costs. These are as follows,

- 1) The increased need for frequency regulation, because wind can increase the short-term variability of the net load;
- 2) The increase required in the ramping rate, or the speed at which load-following units must increase and decrease output;
- 3) The uncertainty in the wind resource and on the resulting net load;
- 4) The increase in overall ramping range the difference between the daily minimum and maximum demand – and the associated reduction in minimum load, which can force base-load generators to reduce output; and in extreme cases, force the units to cycle off during periods of high wind output.

Variable generation (VG) can be understood as a reduction in load. Hence, we need to subtract the VG from the load to calculate net load which has to be met by the conventional generators (assuming no curtailment of renewable energy).

Figure 4.1 depicts the impact of increased use of renewable energy on net load for 2 weeks' period. This figure uses Electric Reliability Council of Texas (ERCOT) load data from 2005

along with 15 GW of spatially diverse simulated wind data from the same year. The blue line indicates the load while the green line indicates residual load or net load. Due to the use of wind energy the ramp range for the net load is considerably high compared to the earlier load. It is clear from this figure that the increased variability of the net load requires a greater amount of flexibility and operating reserves in the system, with more ramping capability to meet both the predicted and unpredicted variability of demand and supply. Therefore, the use of variable and uncertain resources will require changes in the operation of the existing system, and this will incur additional costs, typically referred to as system integration costs (Denholm et al (2010)).



Figure 4.1 : Impact on net load from increased use of renewable energy Source: Denholm et al (2010)

Large renewable integration needs the grid to be flexible. An inflexible system without any storage facility may require a huge curtailment in renewable generation during minimum load hours. Curtailment increases the cost of the renewable energy, because it reduces the net capacity factor of wind and solar generators making them less attractive for private investment. Storage provides one solution for avoiding curtailment by absorbing otherwise unusable generation and moving it to times of high net system load.

On the other hand, bulk storage technologies can also fetch financial benefits from energy arbitrage, i.e., benefiting from the cost differences in power supplied during peak and non-peak hours. Other benefits include ancillary services like load levelling, balancing and strengthening the grid, improving efficiency and economy of the thermal plants, supplying stable and cost effective power to bring quality to power system as a whole. The services also include 86

contingency reserves to tackle major disturbances, regulating and following reserves to compensate load variability. In Japan and the US, market for these services already exists (Ela et al, 2013). A recommendation for establishing a similar market has been made for India as well. Tongia (2015) calls for an overhaul of the Indian power system to create a market for ancillary services. In fact, purposive efforts in this direction are already in place (GOI, 2015a, 2015b).

4.1.2 Types of Storage Technologies

Electricity storage encompasses a large number of technologies. The choice of a particular type of energy storage mainly depends on its application or the length of discharge of stored energy. Table 4.1 and Figure 4.2 summarize the use of various options depending upon the application, rated power and discharge time requirements. As of 2009, only four energy storage technologies (sodium-sulphur batteries, pumped hydro, Compressed Air Energy Storage (CAES), and thermal storage) had total worldwide installed capacities that each exceeded 100 MW. More comprehensive list of technologies is showed in Figure 4.2.

Common Name	Example Applications	Discharge Time Required
Power Quality	Transient Stability, Frequency Regulation	Seconds to Minutes
Bridging Power	Contingency Reserves Ramping	Minutes to ~1 hour
Energy Management	Load Levelling, Firm Capacity, T&D Deferral	Hours

Table 4.1: Three Classes of Energy StorageSource: Denholm et al (2010)p. 38

The major three types of applications of storage are power quality management (discharge time in seconds), bridging power (discharge time in minutes) and energy management (discharge time in hours)(Figure 4.2). In this Report we are going to discuss the third category, i.e., energy management. This type of storage will help meet the ramps expected in the evenings and early winter mornings. We are also likely to require continuous discharge ratings of several hours. The main options available for these applications are batteries, fuel cells, pumped hydro storage (PHS), compressed air and thermal energy storage (Figure 4.3).



Figure 4.2: Energy Storage Applications and Technologies (excluding thermal energy storage) Source: Denholm et al (2010), p.39



Figure 4.3. Storage System for Energy Management Source: TIFAC (2015) p.48

4.2 International Scenario and technology overview

Energy storages world wide use mainly pumped hydro storage technology (97.5%). The balance 2.5% storages use four other methods for storing energy: Thermal Storage (1.41%), Batteries (0.8%), compressed air storage (0.29%) and hydrogen storage or fuel cells (0.002%) (Figure 4.4) (DOE Global Energy Storage Database, 2016). The efficiency of pumped-storage plants is particularly high and may exceed 80%. Adiabatic compressed air energy storage plants and batteries generally have an efficiency between 65 and 75% (Li-ion > 90%). Compared to pumped-storage plants, the efficiency of stationary storage using Hydrogen as storage medium decreases by a factor of 2 to 4. (TIFAC, 2015 p.52)



Figure 4.4. Global Energy Storages Source: Calculated using data from DOE Global Storage Database

4.2.1 Thermal Energy Storage

Thermal energy storage (TES) includes a number of different technologies. Thermal energy can be stored at temperatures from -40° C to more than 400° C as sensible heat, latent heat and thermo-chemical energy storage (Figure 4.5). At present TES based on sensible heat are commercially available while latent heat and thermo-chemical are mostly under development and demonstration. The costs for latent and thermo-chemical systems are in general higher. In these

systems, major costs are associated with the heat (and mass) transfer technology, which has to be installed to achieve a sufficient charging/discharging power.

Thermal energy storage is ignored sometimes as it is typically not used for storing and discharging electricity. However in some cases it might be functionally equivalent to an electricity storage system. One example is storing thermal energy from sun and later converting it to electricity. This technology is mainly used in concentrating solar power (CSP) plants. The thermal energy from sun is stored in molten salt and other media and can be recovered later to generate electricity. Even though the thermal energy is of low quality energy it can be stored with a very high efficiency. Therefore, the round trip efficiency of CSPs is very high and may be close to 100%. However, CSP can store only thermal part of solar energy and cannot store other energy forms from other sources (Denholm et al (2010)).



Figure 4.5. Global status of Thermal Energy Storage Source: Calculated using data from DOE Global Storage Database Note: Thermo-chemical based thermal energy system at present are still in research and demonstration stage.

Three main type of thermal storage technologies are discussed below. The status barriers and scope for research in these technologies are highlighted in the Table 4.2.

1. Sensible Heat:

Thermal energy storage in the form of sensible heat is based on the specific heat of a storage medium, which is usually kept in storage tanks with high thermal insulation. The most popular and commercial heat storage medium is water which has a number of residential and industrial applications. The use of hot water tanks is a well known technology for sensible thermal energy storage. The ongoing R&D activities in this technology primarily focus on material used to store hot water (super-insulation) to minimize thermal loss and cost-efficiency. Sensible heat storage offers storage capacity ranging from 10-50 kWh/T and storage efficiencies between 50-90%, depending on the specific heat of the storage medium and thermal insulation technologies.

2. Latent Heat:

Compared to sensible heat storage latent heat storage has higher energy density and allows for variable discharging temperature using phase change materials (PCM) based thermal energy storage enables higher storage capacities and target oriented discharging temperatures. PCM can offer higher storage capacity and storage efficiencies from 75-90 %. In most cases, storage is based on a solid/liquid phase change with energy densities of the order of 100kWh/m³. PCM can be used for both short-term (daily) and long-term (seasonal) energy storage. The most relevant PCM are ice, Na- acetate Trihydrate and Paraffin Erythritol.

3. Thermo-chemical:

Thermo-chemical energy storage systems offer higher energy storage capacitates. Thermochemical reactions, such as adsorption (e.g. adhesion of a substance to the surface of another solid or liquid) can be used to accumulate and discharge heat and cold on demand (also regulating humidity) in a variety of applications using different chemical reactants. Typical applications involve adsorption of water vapour to silica-gel. This storage technology can reach capacities of upto 250 kWh/T with operation temperatures of more than 300°C and efficiencies from 75% to 100%.

TES System	Capacity (kWh/T)	Power (MW)	Efficiency (%)	Storage period (h, d ,m)	Cost (€/kWh)	Barriers	R&D topics
Sensible Heat	10-50	0.001-10	50-90	d/m	0.1-10	System integration, high cost, low capacity (solids) low temperature <400 C (liquids)	Material of the tank, stratification, super insulation, compatible materials and system integration
РСМ	50-150	0.001-1	75-90	h/m	10-50	High cost, material stability, performance	Materials (slurries, encapsulation and PCM containers)
Thermo Chemical Storage	120-250	0.01	75-100	h/d	8-100	High cost and complexity	Materials and reactor design.

Table 4.2. Thermal Energy Storage : Status barriers and scope for researchSource: ETSAP-IRENA (2013)

4.2.2 Chemical Energy Storage

Chemical energy storage includes two types of storing techniques, batteries (electro-chemical) and fuel cells or hydrogen storage.

Batteries/ Electrochemical energy storage

High energy batteries are used for energy management. The commercially available batteries for this purpose include various types. A primary application of energy management batteries has been for T&D deferral.

Among the battery storages the Lithium Ion batteries are the majorly used technology (Figure 4.6). Other technologies include sodium based batteries, lead acid batteries, flow batteries and nickel based batteries.



Figure 4.6. Global storages other than PHS focusing on Batteries

Source : DOE Global Energy Storage Database, 2016

1. Lithium (Li) ion based batteries

Lithium (Li) based batteries are largely cobalt or phosphate based. In both embodiments lithium ions move between the anode and cathode to generate electricity. They have a high energy to weight ratio, no memory effect and low self-discharge. Details of some of the Lithium based batteries are listed in Table 4.3.

Types of Li based batteries	Comments	Application
1. Li ion Titanate Battery	Long life, fast charge,	UPS, electric powertrain
	wide temperature range	(Mitsubishi i-MiEV, Honda
	but low specific energy	Fit EV),
	and expensive. Among	solar-powered street
	safest Li-ion batteries.	lighting
2. Li Iron Phosphate Battery	Very flat voltage discharge	Portable and stationary
	curve but low capacity.	needing high load currents
	One of safest	and endurance
	Li-ions. Used for special	
	markets. Elevated self-	
	discharge.	
3. Li Nickel Manganese Cobalt	Provides high capacity and	E-bikes, medical devices,
Battery	high power. Serves as	EVs, industrial
	Hybrid Cell. Favorite	
	chemistry for many uses;	
	market share is increasing.	

Types of Li based batteries	Comments	Application
4. Li Polymer Battery	Being lightweight is an advantage and can easily produce batteries of almost any desired shape	Radio controlled equipment, Personal electronics and Electric vehicles
5. Li Manganese Oxide Battery	High power but less capacity; safer than Li- cobalt which is preferred for mobile phones	Power tools, medical devices, electric power trains
6. Li Nickel Cobalt Aluminum Battery	Shares similarities with Li- cobalt. Serves as Energy Cell.	Medical devices, industrial, electric power train (Tesla)

Table 4.3. Lithium Ion Batteries: Types, comments and applicationsSource : Wikipedia, 2016 and Battery University, 2016

2. Sodium (Na) based batteries

Sodium based batteries use a high-temperature reaction between sodium and sulphur, separated by a beta alumina electrolyte. Sodium based batteries have a high energy density, long cycle life and can operate in harsh environments such as temperatures of -40°C to +60°C. For these reasons they can be found in application in energy grid storage, such as storing energy from intermittent energy sources such as wind- and solar-power (Eurobat, 2010). Details of some of the sodium based batteries are listed in Table 4.4.

Sl No	Types of Na based batteries	Comments	Application
1	Sodium – Sulfur technology	Efficiency of 70% or better and a lifetime of over 1,500 cycles	Used in pilot projects to develop a durable utility power storage device
2	Sodium – Nickel Chloride	No needs of air conditioning,	EV (electric vehicle) cars
	Technology	High energy density, Long cycle	and HEV (hybrid electric
		life, Maintenance-free, Zero	vehicle) buses, trucks,
		emission and high recyclability	vans. Demonstration
		of the raw material, No toxic or	systems for grid support
		dangerous materials are used	in field test phase
		during manufacturing.	_

Table 4.4. Different types of Sodium based batteries (Eurobat, 2010)

3. Lead Acid Battery (Pb-acid)

Pb-acid battery cells consist of spongy lead anode and lead acid cathode, immersed in a dilute sulphuric acid electrolyte, with lead as the current collector. One of the disadvantages of this type of battery is that the sulphate crystals become larger and difficult to break up during recharging, if the battery is over-discharged or kept discharged for a prolonged time period.

Global installation of Pb-acid batteries include advanced lead-acid batteries, valve regulated lead-acid batteries, hybrid lead-acid batteries and lead carbon batteries.

4. Flow batteries

Flow batteries store energy in external electrolytes, which are electro-active materials used to store and convert the chemical energy directly into electricity. They can be divided into redox (vanadium, vanadium–polyhalide, vanadium– polysulphide, hydrogen–bromine, etc.) and hybrid (zinc–bromine and zinc–cerium). Different types of flow batteries are discussed in Table 4.5.

Sl No	Types of flow batteries	Comments	Application
1	Redox Flow Batteries	An economical, low	Suitable for energy storage
		vulnerability means to store	applications with power ratings
		electrical energy at grid scale,	from 10's of kW to 10's of
		offer greater flexibility to	MW and storage durations of
		independently tailor power	2 to 10 hours
		rating and energy rating for a	
		given application	
2	Iron- Chromium (ICB)	Has the potential to be very	Telecom back-up at the 5 kW
	Flow Batteries	cost effective at the MW –	– 3 hour scale and have been
		MWh scale	demonstrated at utility scale
3	Vanadium Redox (VRB)	Offers a relatively high cell	Commercial versions have
	Flow Batteries	voltage, which is favorable for	been operating on scale for
		higher power and energy	over 8 years
		density, Components are	
		comparatively expensive	
4	Zinc-Bromine (ZNBR)	Active cooling systems are	Tested on transportable
	Flow Batteries	needed to ensure stability and	trailers (up to 1 MW/3 MWh)
		safety of the system,	and for utility-scale
		Components are comparatively	applications mainly in
		expensive	Australia

Table 4.5. Flow Batteries: Types, comments and applications (EPRI, 2010 and ESA, 2016)

5. Nickel based batteries

Nickel–Cadmium batteries use nickel oxyhydroxide for the cathode and metallic cadmium as the anode with a potassium hydroxide as an electrolyte. These batteries have been superseded by Ni–MH due to inferior cycle life, memory effect, energy density and toxicity of the cadmium in Ni–Cd, compared to Ni–MH. Ni–MH also have the advantage of improved high rate capability (due to the endothermic nature of the discharge reaction), and high tolerance to over discharge (TIFAC, 2015). Different types of nickel based batteries are discussed in the below Table 4.6.

Types of Ni based batteries	Comments	Application
1. Nickel-cadmium (NiCd)	Rugged, high cycle count with	Airline industry
	temperature performance, Long	

Types of Ni based batteries	Comments	Application
	shelf life, Economically priced. The disadvantages are toxicity of	
	Cadmium, cannot be disposed easily and has Memory effect.	
2. Nickel-metal-hydride (NiMH)	Simple storage and transportation, environmentally friendly, wide temperature range. The disadvantages are limited service life, high self-discharge and Coulombic efficiency only about 65%	Rechargeable batteries for consumer use
3. Nickel-iron	Has Resistance to vibrations and high temperatures. The disadvantages are poor low- temperature performance, high self- discharge and high manufacturing cost	Mining, railroad signaling, forklifts and stationary applications

Table 4.6. Nickel Based Batteries: Types, comments and applications (Battery University, 2016)

6. Fuel cells / Hydrogen Storage

A fuel cell is an electrochemical cell, which can continuously and directly convert the chemical energy of a fuel and an oxidant to electrical energy by a process involving essentially electrodeelectrolyte system. The basic principles of a fuel cell are those of the electrochemical batteries. The big difference is that, in the case of batteries, the chemical energy is stored in the substances located inside them. When this energy has been converted to electrical energy, the battery must be thrown away or recharged appropriately. In a fuel cell, the chemical energy is provided by a fuel and an oxidant stored outside the cell in which the chemical reactions take place. As long as the cell is supplied with the fuel and oxidant, electrical power can be obtained (Venkatasubramanian, 2016).

In most of the fuel cells Hydrogen is used as fuel (Fuel Cell Today, 2012). This Hydrogen can be produced using excess energy available at any point of time and stored. This stored Hydrogen can be used as fuel and power can be generated from fuel cells when needed. Hydrogen storage combined with fuel cells can act as energy storage. Hydrogen can be generated from different materials. CH4-Steam reforming is the most cost competitive and energy efficient process, whereas water electrolysis and biomass gasification route is the most expensive and less efficient technologies. The storage and transportation of Hydrogen as a liquid also pose challenge as the boiling point of Hydrogen is -252.9 °C. Prof. S. N Upadhaya, BHU suggested that R&D should be pursued in partnership with industries in material development, reactors/fuel cells, and hydrogen storage vessels. He suggested that Centres of Excellence may be set up with focused R&D for long terms goals. In storage, he suggested the indigenous technology for storage of hydrogen needs to be encouraged on priority basis. This will promote the use of hydrogen

available from Chlor-alkali industries as surplus (estimated to be around 6600 tons annually) as well as from fertilizer units and refineries. (GOI, 2016)

Unlike other storage types, hydrogen can:

- Store large amounts of energy at reasonable costs compared to other emerging technologies
- Facilitate seasonal storage (weeks to months)
- Create cross-links from renewable electricity to other sectors (fuels, chemicals, automotive)(TIFAC, 2015, pp. 52)

Hydrogen based fuel cells (FCs) are considered a key future energy storage technology. The United States, Japan, Germany and South Korea are the leading countries in developing these technologies with established research and development (R&D) and market transformation programs and government-assisted projects to support emerging markets. During the past two to five years, tremendous progress has been made; stack and system costs have been lowered by a factor of two, and durability and efficiency are much improved. However, FCs are still not cost competitive with established technologies based on gas, oil or batteries. (TIFAC, 2015, pp. 53)

Mechanical Energy Storage

In Mechanical energy storage, energy is stored in the form of potential or kinetic energy. Flywheel is an example of kinetic energy storage. However, due to very short discharge time flywheel cannot be used for energy management. Compressed air storage and pumped hydro storages having longer discharge time can be used for energy management. They store energy in the form of potential energy.

4.2.3 Compressed Air Storage

CAES technology is another option based on conventional gas turbine technology which uses the elastic potential energy of compressed air. The energy is stored by compressing air in an airtight underground storage cavern. To extract the stored energy the compressed air is heated and then expanded through a high pressure turbine. The air is then mixed with fuel and combusted. The exhaust is then expanded through a low pressure gas turbine. These turbines are connected to a generator to produce electricity.

The world's first compressed air storage power station, the Huntorf Plant has been operational since 1978. The 290 MW plant, located in Bremen, Germany, is used to provide peak shaving,

spinning reserves and VAR support. Alabama's Electric Cooperative (AEC) has been running the world's second CAES facility since 1991. Called the McIntosh project, it's a 110 MW unit. This commercial venture is used to store off-peak power, generate peak power and provide spinning reserve (Gardner and Haynes, 2007).

The primary benefits of implementing a CAES system are ancillary services provided to the grid. Applications include: peak shaving; spinning reserve; VAR support; and arbitrage (Gardner and Haynes, 2007). Major disadvantages of this method are requirements for an underground storage and fossil fuels.

4.2.4 Pumped hydro storage (PHS)

Pumped hydro storage (PHS) is the only energy storage technology deployed on a Gigawatt scale worldwide. It offers quite reasonable cycle efficiency, sometimes exceeding 80% (TIFAC, 2015 p.52). In this Report we mainly focus on Pumped Hydro Storage as bulk energy storage system. Most of the PHSs are able to store energy for 8 hours and discharge in 6 hours (3 hours each in the morning and evening) which make them suitable for load levelling applications (KPCL, 2007). As the PHS is the most established bulk energy storage system, this chapter focuses mainly on PHS.

Operation

In a PHS the power is normally stored in the form of potential energy during late night or early morning (when there is excess generation mainly due to wind power and the demand is less) by pumping the water to a reservoir situated at a higher altitude and the water is taken out especially during the peak load hours through a turbine to produce electricity. Hence, we need to have two reservoirs at two different altitudes for this system to operate (See Figure 4.7). Environmental regulations may limit the use of PHS of large scale, but reservoir size can be two orders of magnitude smaller than conventional hydro-electric stations. However, in view of the high round trip efficiency, proven technology and low cost compared to other alternative technologies PHSs are still being installed at various new locations.



Figure 4.7: Pumped Hydro Storage Block Diagram

There are various types of PHS like pure pumped storage schemes (recirculation type, preferred in regions where hydro electric potential has already been developed to a large extent), mixed type pumped storage schemes (PHS combined with a conventional hydro plant), pumped storage schemes to supplement the storage capacity of conventional hydro power plants (without using a reversible pump turbine unit and hence, this plant can only store excess energy, but which would not supply additional peaking power) and underground pumped storage schemes (that preserve the natural landscape).

An economical option for installation of PHS is grafting a PHS in a conventional hydro plant. This would avoid the construction of one or both reservoirs. Bhira PHS (1 x 150 MW) of Maharashtra, India is an example of this type. This type of PHS development requires a close scrutiny of the capacity of the water conductor system of the existing plant and an extensive hydraulic study (CBIP, 1997).

Design Criteria for Economic Viability of PHS

Pumped hydro storage plants operate on the principle of power generation based on the exchange of water between upper and lower reservoirs. During lean load hours the excess energy is used to pump the water to the upper reservoir from the lower one and the opposite is done while generating energy. Even though the PHS is quite similar to normal hydro plants from working principle perspective, there are certain differences too. In PHS water flow is bidirectional having a major impact on the size and hydraulic characteristics of pumps/turbines. In PHS underground power house is preferred which makes the multiple surge tank stability problem more important. Therefore a more elaborate conceptual design study becomes necessary in case of PHS. The plant load factor of PHS is also very low compared to the normal hydro electric station as the PHS is used primarily to meet the peaking loads. While the plant

capacity of a normal hydro plant depends on the stream flow condition, the capacity and number of units of the PHS is decided based on power system requirement and specific site conditions. CBIP, 1997 report on Pumped Storage Schemes in India discusses the design criteria in detail.

The basic condition for undertaking PHS is availability of excess power. This can be determined by reviewing the daily, monthly and seasonal load curves. In all seasons except summer the Southern Region (SR) of India surrenders substantial amount of energy during off peak hours. This makes SR a preferred location for new PHS installations. (CBIP, 1997)

The initial viability of a PHS project is indicated by the L:H ratio in siting studies. L is the length of the waterway from the intake structure to the tailrace outlet and H is the net rated head available for energy production. Waterways entail a sizeable portion of the project costs; minimizing the length while maintaining a sizeable head difference is very important in having a viable project. Generally speaking, potential projects having an L:H ratio of less than 10 show promise as a pumped storage project as shown in Figure 4.8 below (MWH, 2009, p. 4-4). According to CEA (2013) Pelton wheel type hydro turbine is ideal for PHS since the generation from this type of hydro generator can vary easily from zero to full capacity.



Figure 4.8: Historical Capital Cost (2009\$/kW) vs L:H Ratio (Source: MWH, 2009, p.4.4)

Construction of a PHS involves creation of new weirs (albeit small). Even retrofitting existing hydro plants may require one of the reservoirs to be made additionally. As stated earlier, PHS plants need underground caverns for locating the reversible turbine and other electrical equipments. A green field or new PHS plant would need a new cavern. The retrofitted plants also may need some modification of the existing cavern as the size of a reversible turbine may change compared to the existing one. These activities have a certain impact on the local people and biodiversity. Most of the time the proposed sites are part of protected hill or forest region to satisfy the specific topological requirements of the PHS. Therefore, environmental clearance becomes a very essential step to build a PHS. These all require considerable amount of time and

resources. After approval of the project, it takes 3 to 5 years for a PHS to become operational. The time period varies depending on the type of PHS, i.e. new green field PHS or retrofitting existing hydro plant.

PHS is the most widely adopted bulk electricity storage technology in the world and has been deployed since 1890s in Alpine regions of Switzerland, Austria and Italy. The development of PHS remained slow until 1960 when many countries envisioned a dominant role of nuclear power and started installation of PHS plants to compliment nuclear power in providing peaking power. But the growth slowed down in 1990s when nuclear program was stalled in many countries and gas became cheap making open cycle gas turbines competitive for meeting peaking loads. With the increasing share of intermittent renewable energy sources like wind and solar in the energy mix, PHS is receiving renewed emphasis. According to Yang (2008), with reinforced attention for renewable energy, beginning from early 2000s, China, Japan and Europe revisited their PHS technology.

Along with storage facility, PHS provides ancillary services too. It stabilizes the grid through peak shaving, load balancing, frequency regulation and reserve generation. Increasing wind and solar installation in the grid has made these services essential for transmission system operators.

Forty three countries in the world have already adopted this mature technology for storing electricity in bulk. Table 7 lists the countries which have more than 2000 MW of PHS installation. The data is plotted in Figure 4.9.

It is evident from the data (Table 4.7 and Figure 4.9) that Japan is the world leader in PHS. Next two are China and the US. These three countries are far ahead of all other countries of the world in terms of PHS installed capacity. However, when we look at the PHS installation as percentage of total electricity generation capacity of a particular country, a different scenario emerges. The highest percentage of PHS is in Austria and the next is Switzerland. In all other countries the value is less than 10% of the total installed capacity.

Country	PHS Installation in GW	National Installed Capacity (IC) in 2014 in GW	% of PHS compared to National IC
Japan	27.43	311	9%
China	21.54	1223	2%
United States	20.85	1110	2%
Italy	7.07	114	6%
Spain	6.88	100	7%
Germany	6.38	181	4%
France	5.89	126	5%
India	5.07	270	2%

Country	PHS Installation in GW	National Installed Capacity (IC) in 2014 in GW	% of PHS compared to National IC
Austria	4.80	22.33	22%
South Korea	4.70	97	5%
United Kingdom	2.82	86	3%
Switzerland	2.68	20.49	13%
Taiwan	2.60	48.35	5%
Australia	2.54	62	4%

Table 4.7: Countries having PHS installation more than 2000 MWSource: Yang, 2008 and TSP data portal, 2015



Panel A. PHS installation in MW



Panel B. Percentage of PHS compared to total installed capacity

Figure 4.9: PHS installation in countries having capacity more than 2000 MW Source: Yang, 2008 and TSP data portal, 2015

Figure 4.10 shows the growth of PHS in the world. In Japan and the US major PHS plants started operation in 1960s. Although, China was late in installation, they have installed a huge amount of PHS within a very short period. As per their future plans of PHS installation, they would become world leader in PHS by 2018.



Figure 4.10: Growth of PHS installation in World Source: Global Energy Observatory

Novel Pumped Hydro Concepts

Variable Speed Motor-Generator System

A relatively new technology in this field is variable speed technology. This technology, as opposed to fixed-speed pump turbine, pioneered by Japan allows PHS to regulate frequency at both pumping and generating modes (Yang, 2008). In the generator mode, the capability of a variable speed machine is quite similar to a fixed speed machine, except that the operating efficiency can be optimized by adjusting the speed for the prevailing head and desired power output. It may also be possible to avoid the issues of operating in the so called "rough operating zone" that would exist for the synchronous speed unit. But in pumping mode adjustable speed machines can be effectively used to extend the single pump operating curve to a broad range of pumping operation, and provide positive control over the discharge and the required input power (MWH, 2009, pp.3-4).

The synchronous machines used as motor-generators at most of the PHS plants have a constant speed. This means that adjustment of the input power during pumping operation is not possible. Operation of conventional pumped storage units with constant power in pumping mode will mainly help to improve the energy balance of the system without contributing to the frequency control and the instantaneous power balance. One way of achieving controllability in pumping mode is by using several small pumps which can follow load in small steps. However, the most effective solution is to have a variable speed pump turbine assembly (Suul *et al*, 2008). This technology allows PHS facilities to regulate frequency in both pumping and generating modes (Nagura *et al*, 2010). With the aim of using pumping-mode operation to perform supply and demand power balancing during the night, Japan first started developing variable speed pump generator was the realization that significant quantities of oil burned in combustion turbines could be reduced by shifting the responsibility of regulation to PHS (NHA, 2012).

The development of variable speed pumped storage systems has been made possible by the development of high power semiconductors and power electronic drives, and several such units have been developed and put in operation during the last two decades (Suul *et al*, 2008). Two separate adjustable-speed pumped-storage generation systems with a world-largest capacity of 400 MW were commissioned in 1993 and 1995 respectively at the Kansai Electric Power's Okawachi Power Plant, and these have been operating reliably since then. (Nagura *et al*, 2010) Even though the variable speed turbine pump assembly may take a larger space and costs more than a conventional one, it has better efficiency, low response time and lot of other benefits like, absorbing short and long term grid fluctuations in pumping and generating mode, governor free operation in pumping and generating mode. Many European countries are planning to implement this technology in new plants, as well as retrofit the existing ones in coming years. Recently the power plant Goldisthal in Germany, with two 300 MW variable speed units, has

been put into operation (Mallick, 2015 and Suul et al, 2008). Many European countries have taken up R&D activities in areas related to retrofitting of the existing PHS plants. 'eStorage project' of Imperial College London is one of them which proposes to investigate and demonstrate the option of retrofitting existing PHSs with variable speed motor-generator. This proposition is especially attractive given that up to 30 GW of PHS capacities will need to be refurbished in any case by 2020. The variable speed technology would enable PHSs to continuously provide flexible balancing services both in generating and in pumping mode, thus replacing costly provision of these services by part-loaded conventional generators and most importantly greatly enhancing the ability of the system to absorb significant amounts of intermittent generation. The cost of retrofitting to variable speed is an order of magnitude lower than the construction cost of new plants. This is hence a very cost-effective approach of developing a new source of flexibility that would greatly enhance the ability of the EU system to absorb increased levels of intermittent renewables. Enhancing the capability of the existing PHSs also avoids the highly complex planning and environmental permitting procedures, making this option highly acceptable from the societal perspective. In a world's first, Le Cheylas pumped storage power plant, near Grenoble in France, is being converted from fixed to variable speed operation as part of this project. The refurbishment of Le Cheylas aims to demonstrate the cost-effectiveness of upgrading pumped storage plants to variable speed to meet changing operational requirements (Antheaume et al, 2015).

In India Tehri Stage I PHS (under construction) is implementing this technology. It is located in Tehri Garhwal district of State of Uttarakhand in India, on river Bhagirathi, about 1.5 km downstream of its confluence with river Bhilangana. The main feature of the Project is the large variation of about 90 m between the maximum and minimum head, under which the reversible units shall operate. The plant is using 4 x 250 MW variable speed vertical Francis type reversible turbines. The project will use Tehri Dam reservoir and Koteshwar Dam reservoir as upper reservoir and downstream reservoir respectively. These reservoirs are already commissioned as part of conventional hydro power project at Tehri (THDC, 2015).

Sea Water PHS

Sea water, underground and undersea PHSs are three other novel designs that are yet to be widely used worldwide. Tidal power plants also can be used as seawater PHS. The compressed air PHS is another promising alternative innovative design that can replace the upper reservoir in PHS with a pressurized water container that could potentially free PHS from the stringent geographical requirements. Renovation of the existing PHS facilities may increase the capacity by 15-20 % and efficiency by 5-10% (Yang, 2008).

Although traditional PHS is a mature technology, it is expensive to construct and the payback periods are too long to motivate investment from private investors. Further, construction of both the upper and lower reservoirs from scratch poses threat to the natural environment and bio diversity. Japan has pioneered another new technology in PHS called Seawater PHS. Sea water Pumped Hydro Energy Storage is one option for providing the energy storage that will require construction of only one reservoir, i.e, upper reservoir. The sea is used as the lower reservoir, thereby reducing construction time and cost.

The Okinawa seawater PHS of Japan, commissioned in 1999, is the world's first seawater PHS. Its maximum output is 30 MW. The PHS uses the sea as lower reservoir while the upper reservoir is constructed at a height of 150 m above sea level with an effective head of 136m. Sea water PHS with a high flow rate and low head is technically and economically feasible for increasing the ability of national grids to allow high penetration of intermittent renewable energy. On the other hand, using low-head, high-flow seawater storage near the coast, greatly reduces the danger of contamination of inland freshwater supplies, thus reducing the environmental impact of pumped seawater energy storage. New saltwater projects have been proposed in Ireland, Greece, Belgium and the Netherlands (Lean et al, 2014). Another unusual approach called 'Energy Island' has been proposed by Dutch company DNV KEMA which also uses sea water for PHS. But the difference is that, the sea water is used as the upper reservoir and the lower reservoir is constructed 50m below sea level (Yang, 2008).

Tidal power plants also can be used as seawater PHS. One such example is La Rance tidal power plant in France. The turbines are reversible and can be powered by excess energy in the grid to increase the water level in the reservoir at high tide. This energy is more than returned during generation, because power output is strongly related to the head. If water is raised 2 ft by pumping on a high tide of 10 ft, this would have been raised by 12 ft at low tide. The cost of a 2 ft rise is returned by the benefits of a 12 ft rise. Unlike conventional PHS, in this kind of PHS, sometimes the cycle efficiency is more than one (Retiere, 1994).

Apart from these conventional energy storage technologies in the form of pumped hydro, compressed air energy storage, batteries, etc., flexible deployment of hydroelectric plants and gas turbines and to a lesser extent, coal and nuclear plants can also make the system flexible. Demand response in the form of smart grid technologies that can remotely manage demands like AC, heating, lighting, etc. as well as flexible thermal energy storage in room heaters, water heaters and air conditioning systems will also play an important role. Irrigation pumps, often energized only during nights, could be creatively used as a remotely managed flexible demand response to balance the variability in renewable power generation (Chakravarty and Ahuja, 2016).

4.3 Current Status in India

The total storage capacity of India is 5072 MW. Out of this 99% storage is built using PHS technology. The balance storages use three different technologies like sensible thermal energy storage, flow batteries and lead- acid batteries (Figure 4.11).



Figure 4.11: Energy storages in India Source: DOE Global Energy Storage Database, 2016

From both installation capacity and percentage of national installation perspectives India has room for improvement. Even though in terms of total PHS installation India is eighth, only about half of the total PHS capacity is operated as storage in India. The balance is used as a conventional hydro plant. Table 4.8 summarizes the present status of PHS in India. Only 5 out of 11 plants are operating in PHS mode. Balance plants are not being used in pumping mode due to various issues, like vibration problem in Kadana and non-availability of tail race pond for Nagarjuna Sagar, Sardar Sarovar and Panchet (Shukla, P.K., 2015).

In India, although the installation of PHS started in the year 1970 and the first plant, Nagarjuna Sagar came online in the year 1980, many PHS plants started operation much later in 2002-2006 (Figure 4.12). All these plants use reversible Francis turbines for electricity generation. There has been stagnation in PHS capacity addition from 2008. As per Central Electricity Authority the PHS potential of India is 96 GW (in 56 sites) and there are several new PHS planned for various states. Out of these, western region has the largest potential (about 41% of the total) for development of pumped storage plants. This is mainly due to the topographical features with steep gradients of the rivers originating from the Western Ghats (Shukla, P.K., 2015). However, only 2 of them, Tehri (1000 MW) and Koyena left bank (80 MW) are under construction. This may have been due to environmental issues related to creation of new weir or dam for PHS. Therefore, one needs to investigate the options where new PHS can be constructed with minimal damage to the environment. These options include retrofitting a conventional hydro power plant to operate as a pumped storage station or making the PHS power house completely underground.
Plant Name	Capacity in MW	Year of commissioning	Operation as PHS
Nagarjuna Sagar	7x100.8	1980-1985	Not working
Paithan	12	1984	Not working
Ujjain	12	1990	Not working
Panchet	1x40	1990-91	Not working
Kadana	4x60	1990-1998	Not working
Sardar Sarovar Dam	6x200	2006	Not working
Kadamparai	4x100	1987-89	Working
Bhira	1x150	1995	Working
Srishailam	6x150	2001-2003	Working
Purulia	4X225	2007-8	Working
Ghatghar	2X125	2008	Working

Table 4.8: Present Statuses of PHS plants in India (Source: Shukla, 2015)





4.4 Applicability in the Indian context

For PHS to be reliable and sustainable and thus enhance the grid's health, it ought to emerge into an economically viable and self sustaining value based asset. This has been widely recognised among the economies that are at the forefront in PHS technologies- Japan, the US and China. These economies are revising their regulatory frameworks and experimenting with new business models.

One of the first issues concerned with commercialisation of PHS is its definition based on its functional characteristics. Studies identify the confusion with respect to its definition. Yang (2008), argues that because the net electricity output of PHS operation is negative, a PHS facility usually cannot qualify as a power generator. Although their load-balancing and ancillary services to the grid are crucial and they reduce the needs for transmission upgrades, PHS facilities are not recognized as parts of the transmission infrastructure either. This confusion in business models has deterred the development of PHS in the United States. NHA (2012) puts forth similar argument and recommends that, since PHS has components of both generation and storage, they ought to be treated as a separate and distinct electricity infrastructure asset class. Associated issue which has been identified is the ownership of PHS. To tackle the issue of underutilisation of storage capacity due to oligopolistic market, Schill and Kemfert (2011) recommend that distribution of storage capacity to multiple market participants. Yang (2008), attributes the stable and predictable business environment favourable to the investments in PHS in Japan to vertically integrated regional electric power utilities, which build, own and operate the PHS facilities

NHA (2012), examining the case of the US, largely focuses on and makes recommendations for revision of regulatory framework and market incentives to promote pumped hydro storage systems. With respect to revision of regulatory framework, the study calls for easing the licensing system by bringing parity between federal and state requirements for setting up of pumped hydro storage systems. Further, low-impact and closed loop hydro storage systems that have very limited environmental impacts, ought to be considered separately to reduce the approval times for the systems. Owing to the potential pumped hydro systems have, not only as energy storage systems, but also in adding value through ancillary services, the study calls for a national policy to accommodate them in the established markets, and create market structures to ensure their commercial viability. Other recommendations include recognising regional differences in the generation portfolio- nuclear or renewables, and thus the role of pumped hydro storage in energy security.

Yang (2008) examined the differences in the frameworks in Japan, the US and China. The Chinese case is particularly interesting. Before 2004, most of the PHS facilities in China were built by local governments and local grid companies with diverse pricing models. In 2002, China restructured its power sector by separating them into two state-owned grid companies and five power generation corporations. In 2004, the National Development and Reform Commission promulgated a regulation which specified that PHS stations are transmission facilities and should be constructed and managed by the grid companies, and that the construction and operation costs of PHS should be incorporated into the operation costs of the grid companies. The decision to treat PHS as transmission facilities has contributed to the rapid expansion of PHS in China. Similar is the case with the US where generation and transmission was separated and PHS

is treated as a transmission asset. Overall, Japan, China and the US experiences show that the national regulatory and institutional environments have tremendous impacts on the deployment of PHS. Financing the PHS and the large lead time involved in appropriating the profits of the PHS are another drawback that discourages new investors. Similar is the case in India.

For commercial viability and economies of scale, studies recommended optimum utilisation of PHS and thus exploring their full revenue potential. To achieve this Ela et al (2013) suggests a mix of energy arbitrage and ancillary services. Electricity is a real-time commodity in which production and consumption occur simultaneously and production cost varies with consumption quantity. Therefore, PHS as a storage system can engage in energy arbitrage. This allows the PHS to charge storage at times when energy is plentiful and inexpensive and returning the energy to the power system when it is scarce and expensive. Further, PHS can also earn revenue through providing ancillary services like contingency reserves to tackle major disturbances, regulating and following reserves to compensate load variability and voltage support. In fact these services are already in place in countries like the US. Studies in the Indian context also recommend for similar market to be set up for PHS. Tongia (2015) argues for storage devices to participate in both sets of markets i.e., ancillary and demand response.

The scale and pace at which renewable energy is expected to be integrated into energy sector worldwide, is evident from the goals set for FY2022 in the Intended Nationally Determined Contributions (INDCs) at CoP21, Paris. Although the goals are ambitious they are not unachievable given the short installation time of solar and wind power plants. This would require manifold increase in the flexibility of the existing grid. Hence, if we wish to have a PHS down the line in FY2022 it is the high time to take action.

4.5 Recommendations

Funds Available for the Promotion of Pumped Hydro Schemes in India:

1. National Clean Energy Fund (NCEF):

By 2014-15 about Rs. 16,400 Crores has been collected as NCEF to support 'project/scheme relating to innovative methods to adopt clean energy technology and research and development'. The Ministry of Finance sets guidelines for projects and schemes for financing under the NCEF. "The projects relating to creation of power evacuation infrastructure for renewables" constitute one of the ten kinds of projects eligible for financing under NCEF. As evident from earlier discussion, PHS is a valuable transmission asset, where it takes un utilized energy and generates energy during peak time to reduce the loss of energy and balance the power system, it qualifies as 'power evacuation infrastructure'. In fact, states have already proposed development and promotion of PHS under NCEF.

2. Power System Development Fund (PSDF):

Power System Development Fund (PSDF), 2010 is one of the financial instruments set up by the CERC to take up and support various activities to strengthen the health of the grid. Given the benefits endowed by the PHS and their contribution to the total strengthening of the power system, PSDF can/should be channelized for financing PHS.

3. Renewable Regulatory Fund (RRF):

Renewable regulatory charges, operated through Renewable Regulatory Fund (RRF), are payable by the renewable energy generators for the unscheduled interchange caused due to their inability to forecast one-day-ahead schedule of renewable sources, like wind, with 70% accuracy and resulting imbalances caused in the grid. This fund is later used by RRFs to compensate the states for their losses. Since PHS can iron out some of the variability associated with renewable energies like wind and solar and thus reduce the overall cost, financial support to PHS through this channel is also warranted.

References

- 1) Antheaume S, Darona G, Houdeline J, Labrecque Y, and Laurier P (2015), Upgrading Two Pumped Storage Plants to Variable Speed
- Battery University 2016: Types of Lithium Ion Batteries, available at <u>http://batteryuniversity.com/learn/article/types of lithium ion</u> accessed on June 10, 2016
- Battery University 2016: Types of Nickel Based Batteries, available at <u>http://batteryuniversity.com/learn/article/nickel based batteries</u> accessed on June 10, 2016
- 4) Central Board of Irrigation and Power (CBIP), 1997: Pump Storage schemes in India
- 5) Central Electricity Authority, 2013. Large Scale Grid Integration of Renewable Energy Sources- Way Forward, available at http://cea.nic.in/reports/others/ps/pspa1/large_scale_grid_integ.pdf accessed on Nov 6, 2015
- Chakravarty S. and Ahuja D. R., 2016: Bridging the gap between intentions and contributions requires determined effort, Guest Editorial, Current Science, Volume 110, Number 4, 25.02.2016
- available at http://www.currentscience.ac.in/Volumes/110/04/0475.pdf accessed on Mar 1, 2016
- 8) Denholm P., Ela E., Kriby B. and Milligan M., 2010. The Role of Energy Storage with Renewable Electricity Generation, National Renewable Energy Laboratory.
- 9) DOE Global Energy Storage Database, 2016 available at <u>http://www.energystorageexchange.org/</u> accessed on June 21, 2016
- 10) Ela, E, Kirby, B, Botterud, A, Milostan, C, Krad, I and Koritarov, V 2013: 'The Role of Pumped Storage Hydro Resources in Electricity markets and System Operation', NREL/CP-5500-58655 available at <u>http://www.nrel.gov/docs/fy13osti/58655.pdf</u> accessed on 9.11.2015
- 11) Electric Power Research Institute (EPRI), 2010: Electricity Energy Storage Technology Options, available at <u>http://large.stanford.edu/courses/2012/ph240/doshay1/docs/EPRI.pdf</u> accessed on June 21, 2016
- 12) Energy Storage Association (ESA), 2010: Redox Flow Batteries, available at <u>http://energystorage.org/energy-storage/technologies/redox-flow-batteries</u> accessed on June 10, 2016
- 13) ETSAP-IRENA (2013):
- 14) Eurobat, 2010: Battery Technologies, available at <u>http://www.eurobat.org/battery-technologies</u> accessed on June 10, 2016
- 15) Fuel Cell Today, 2012: Fuel cell basics, May 2012 available at <u>http://www.fuelcelltoday.com/media/1637138/fc_basics_technology_types.pdf</u> accessed on June 21, 2016
- 16) Gardner J and Haynes T, 2007: Office of Energy Research, Policy and Campus Sustainability, Boise State University, Overview of Compressed Air Energy Storage, December 2007 available at <u>http://www.necec.org/files/compressedair.pdf</u> accessed on June 14, 2016
- 17) Global Energy Observatory, available at <u>http://globalenergyobservatory.org/</u>

- 18) GOI (2015a), 'Explanatory Memorandum on Introduction of Ancillary Services', available at <u>http://cercind.gov.in/2015/draft_reg/Ancillary_Services.pdf</u> accessed on 28.12.2015
- 19) GOI (2015b), 'CERC notification on Ancillary Services Operations', available at http://www.cercind.gov.in/2015/regulation/Noti13.pdf accessed on 7.1.2016
- 20) GOI, 2016: Government of India Ministry of New and Renewable Energy (R&D Coord. Group), Thrust Areas with Action Plan for RD&D" For Technology Development In New and Renewable Energy, April 2016
- 21) Imperial College, London, Estorage Project, Solution for cost-effective integration of renewable intermittent generation by demonstrating the feasibility of flexible large-scale energy storage with innovative market and grid control approach, available at <u>http://www.imperial.ac.uk/electrical-engineering/research/control-andpower/research/estorage/</u> accessed on June 23, 2016
- 22) KPCL, 2007: Karnataka Power Corporation Limited, Pre-feasibility Report, Kali Pumped Storage Scheme
- 23) Lean, E and Kearney, D (2014), An Evaluation of Seawater Pumped Hydro Storage for Regulating the Export of Renewable Energy to the National Grid, Energy Procedia, Vol 46. Pp 152-160
- 24) Mallick, P., 2015: 'Techno-economic perspective for pumped storage schemes', presented at Workshop on Pump-Storage Development and Integration of Renewable Energy, Central Board of Irrigation and Power, Delhi
- 25) MWH, 2009: 'Technical Analysis of Pumped Storage and Integration with Wind Power in the pacific Northwest' report prepared for US Army Corps of Engineers Northwest Division Hydroelectric Design Center.
- 26) Nagura O, Higuchi, M, Tani, K, Eng, D and Oyake, T (2010), Hitachi's Adjustable-Speed Pumped-Storage System Contributing to Prevention of Global Warming. Hitachi Review 59, pp. 99-105
- 27) National Hydropower Association (NHA), 2012: 'Challenges and Opportunities For New Pumped Storage Development' available at <u>http://www.hydro.org/wpcontent/uploads/2014/01/NHA PumpedStorage 071212b12.pdf</u> accessed on Nov 7, 2015
- 28) Retiere, C (1994), Tidal Power and the Acquatic Environment of La Rance, Biological Journal of the Linnean Society, Vol.51, pp 25-36
- 29) Schill , W-P, Kemfert, C. (2011): 'Practical Operation Strategies for Pumped Hydroelectric Storage: The Case of Pumped Hydro Storage in Germany', Energy Journal (32:3); pp.59
- 30) Shukla, P.K., 2015: 'Indian scenario of pumped storage hydro development', presented at Workshop on Pump-Storage Development and Integration of Renewable Energy, Central Board of Irrigation and Power, Delhi
- 31) Suul, J, Uhlen, K and Undeland, T(2008): 'Variable Speed Pumped Storage Hydropower for integration of wind energy in isolated grids-case description and control strategies' available at <u>http://www.elkraft.ntnu.no/eno/Papers2008/Suul-norpie08.pdf</u> accessed on Nov 10, 2015
- 32) THDC, 2015, available at http://www.thdc.gov.in/Projects/English/Scripts/Prj_Introduction.aspx?vid=145 , accessed on 9.11.2015

- 33) TIFAC (2015): Solar PV Technology Foresight for India, available at <u>http://tifac.org.in/images/publication/TIFAC%20Solar%20PV%20TF%20Report%20final%20version.pdf</u> accessed on June 21, 2016
- 34) Tongia, R (2015), Blowing Hard or Shining Bright?: Making Renewable Power Sustainable in India, Brookings Institution India Center.
- 35) TSP data portal (2015), available at <u>http://www.tsp-data-portal.org/TOP-20-</u> <u>Capacity#tspQvChart</u> accessed in November, 2015.
- 36) VENKATASUBRAMANIAN.V.,2016: Fuel Cell, IIT, Madras, available at <u>http://catalysis.chem.iitm.ac.in/fuelcell.pdf</u> accessed on June 21, 2016
- 37) Wikipedia, 2016: Lithium polymer battery, available at <u>https://en.wikipedia.org/wiki/Lithium polymer battery</u> accessed on June 21, 2016
- 38) Yang, C (2008): "Pumped Hydro Electric Storage." Climate Change Policy Partnership, Duke University. (Included in Energy Storage for Low-Carbon Electricity, edited by Chi-Jen Yang and Eric Williams)

5 Business Models and Policy

5.1 Introduction

In order to achieve the ambitious solar target of 100 GW by 2022, it is important for India to have a robust policy and regulatory framework that would create a vibrant market for solar applications in the country. Several states in India have already announced specific solar policies and regulations; however, there is a large variation in the content and structure of these guidelines. It is important for states to learn the success from other states and guard against possible failures that other states have already experienced. Such knowledge of both success and failures is extremely crucial to accelerate the market rapidly. Meanwhile it is also important to document and learn from international best practices from countries that are already in the lead in solar deployment. These learnings are crucial to India's clean development pathway as it helps us avoid costs associated with trials, experimentations and generic pilots. This section of the report aims to document existing solar policies across India, existing regulations for the solar market and business models that are applicable in the Indian context. This section also documents international best practices in each of the above sections that could be adopted into the Indian context.

An ideal and attractive policy is one that is well regulated, provides an opportunity to stakeholders to invest/install solar power plants under relevant business models. The purpose of a policy is to make the State's agenda known to the public and to provide a comprehensive framework for any given economic activity. A policy broadly serves two purposes: gives clarity to various departments on the action plan and direction of the State and provides clarity to the general public, investors, developers and other public and private stakeholders on the State's agenda. Framing a good policy is essential for any sector and more so for the solar sector that is still dependent on Government subsidies and frameworks in order to become economically viable.

A regulation is an attempt to control or influence private behaviour in the desired direction by imposing costs on or prescribing undesirable behaviour. Since regulation can have important consequences for economic efficiency and private incentives, it is usually justified only under special conditions. Regulation is of critical importance in shaping the welfare of economies. Regulations mainly help to prevent market failure, to check anti-competitive practices and to promote public interest (Singh and Mitra, undated). Important bodies jointly responsible for framing and better implementation of policies and regulations are the Central Government, Central Electricity Regulatory Commission, State Government, State Nodal Agencies and State Electricity Regulatory Commissions. A business model is a plan, implemented by a company or an organization, to deliver a value based proposition (product or a service or a combination of the two) to a Customer with the objective of earning revenues and profit. The business model formulates and communicates the logic behind the value created and delivered to the Consumers. In essence, a business model is a conceptual, rather than financial, model of a business. The company or the organization could be a Consumer, Utility, Developer, Financial institutions etc.

5.2 Jawaharlal Nehru National Solar Mission

The first state to announce a solar policy in India was Gujarat in 2009. This policy targeted towards installing 500 MW of solar PV. Witnessing Gujarat's success, the Central Government in January 11, 2010 launched the Jawaharlal Nehru National Solar Mission (JNNSM), under the carbon abatement initiative and the National Action Plan on Climate Change (NAPCC). The main target of the mission was to achieve 20 GW of solar power by 2022, which was later increased to 100 GW in 2015 in the Union budget of India. The objective of the JNSM is to establish India as a global leader in solar energy, by creating suitable policy conditions and rapid deployment of large-scale projects across the country.

The Mission has adopted a 3-phase approach: the last phase of the 11th Five Year Plan (2010-2012) and the first year of the 12th Five Year Plan (2012-2013) had been considered as Phase-I, the remaining four years of the 12th Plan (2013-17) are included in Phase-II, and in the 13th Five Year Plan period (2017-22) the country shall achieve its 100 GW target via various phases. The target shall be achieved by installing 60 GW of Utility power plants and 40 GW of rooftop power plants. The complimentary targets of this mission include achieving grid parity by 2022 and parity with coal based power generation by 2030.

Phase-I of NSM was announced with a target of 500 MW and the off-taker was NVVN (NTPC VidyutVyapar Nigam Limited). To achieve this target, Phase I was divided into two batches. Batch-I aimed at of 150 MW out of which 140 MW is commissioned. These projects were commissioned through a reverse bidding process. Batch-II announced a target of 350 MW out of which 340 MW was commissioned. The reverse auctions of Batch-II sent ripples in the international solar market. The lowest winning bid was 7.49 INR/kWh for a 5 MW plant by a French company, Solaire Direct. This established reverse bidding as a successful process of selection of developers, but with the risk of quoting so low that it could render the project unviable.

The Phase-II of NSM was announced with a target of 22,750 MW which has subsequently been revised to reflect the 100 GW target. With raised targets, Phase II required active government role in order to boost confidence of the investors which led to introduction of Viability Gap Funding (VGF) scheme. Under this financing option, bidders bid for viability gap funding

requirement in INR/ MW and the bidder with minimum VGF requirement is selected. The VGF would be provided in intervals to ensure successful completion of project. The projects are selected based on competitive bidding for viability gap funding to make generated solar power available at a pre-fixed levelized tariff.

The Phase-II was divided into 3 batches; Batch – I, II and III. Batch-I had a target of 750 MW, out of which 650 MW was commissioned. The off-taker of Batch-I was Solar Energy Corporation of India (SECI). Batch-II targets 15,000 MW which is further sub divided into three Tranches I, II & III with a target of 3,000 MW, 5,000 MW & 7,000 MW respectively. The off-taker of Batch-II is NVVN. Batch-III targets 2,000 MW which has been allocated to various states. The off-taker of Batch-III is SECI. This has been presented in Figure 5.1.



Figure 5.1 National Solar Mission: Phase wise depiction

Currently Batch-II and Batch-III of Phase-II are active. The Tranche-I of Batch-II which has a target of 3,000 MW is currently operative. The Off-taker of Batch-II is NVVN. Following projects are commissioned or under process under the Batch II Tranche I:

- Andhra Pradesh for Kurnool Solar Park had announced a tender of 500 MW under the open category. The lowest discovered tariff was 4.63 INR/kWh quoted by Sun Edison. Andhra Pradesh has also announced a tender under the open category for 350 MW and a tender for 150 MW under the DCR category. The lowest price discovered for the open tender was 4.63 INR/kWh quoted by SB Cleantech.
- Rajasthan for Bhadla Solar Park had announced tender for 420 MW under the open category. Rajasthan has also announced a tender for 130 MW under the DCR category with the lowest discovered tariff was 5.06 INR/kWh by Janardan Wind Energy Pvt. Ltd. Tender for 230 MW under the open category wherein, the lowest discovered tariff is 4.34 INR/kWh by Fortum Finnsurya Energy Pvt. Ltd.

• Karnataka for Tumkur Solar Park has announced a tender for 500 MW under the open category with a discovered tariff range from 4.78 to 4.80 INR/ kWh and tender for 100 MW under the DCR category which is yet to be allocated.

Batch-III of Phase-II will also be operated under VGF scheme. Under it, following projects are announced:

- Uttar Pradesh has announced a tender for 440 MW under the open category. The bid for 50 MW was made by Rattan India eligible for a VGF of 75,00,000 INR/ MW and for 75 MW made by Solaire Direct eligible for a VGF of 74,30,000 INR/MW. The rest of 315 MW has been re-tendered as of March 2016.
- Karnataka has announced a tender for 950 MW under the open category wherein 920 MW has been allocated to various bidders with the least VGF quoted by Hero Solar Energy Pvt. Ltd. 68,00,000 INR/MW. The tender also included 50 MW under the DCR category. The lowest tariff discovered was 4.43 INR/kWh.
- Chhattisgarh announced a tender for 100 MW under the open category with the lowest discovered tariff as 4.43 INR/kWh by Parampujya Solar Energy (an arm of Adani Green Energy Ltd.) eligible for a VGF of 59,00,000 INR/MW.
- Andhra Pradesh for Kadapa Solar Park has announced a tender of 500 MW. The Offtaker of Batch-III is SECI.
- Gujarat for Charanka Solar Park has announced a tender for 225 MW under the open category and a tender for 25 MW under the DCR category.

The Batch-IV of Phase-II would be undertaken by SECI. SECI has been designated as the implementing agency for selection of Grid-connected Special Purpose Vehicle (SPV) projects for a cumulative capacity of at least 5000 MW to be set up on 'Build-Own-Operate' basis through VGF mechanism. The Solar Projects under the State Specific VGF Scheme will be set up in the Solar Parks of various states to be developed through coordinated efforts of Central and State Agencies. However, as implementation of solar parks have begun recently, it could be possible that Solar Parks in some of the States may not be feasible because large tracks of land may not be available or do not become available soon. For such States, Solar Projects would be allowed to be located outside solar parks with land being provided either by the State Government, or arranged by the Solar Power Developers (SPDs).

5.3 Incentives for Solar Energy at the State Level: Policies, Regulations and Business Models

India has installed 7.8 GW of utility scale solar plants as of 24th July, 2016(MNRE, 2016). Since the announcement of the Gujarat Solar Policy in 2009 and the National Solar Mission in 2010, 118

several states have notified solar policies. See Figures 5.2 and 5.3 for state wise installed capacity of solar energy.



Figure 5.2 Solar Energy: Installed Capacity-I



Figure 5.3 Solar Energy: Installed Capacity-II

In order to achieve the revised target by 2022, majority of the states have declared their state specific solar policies with ambitious targets and attractive incentives. Some of the incentives offered are exemption of wheeling charges, exemption of electricity duty, exemption of banking charges and exemption of cross subsidy/additional surcharge; to name a few. The detailed description for each state policy is given below.

5.3.1 Rajasthan

Rajasthan experiences a good solar irradiation of 5.54 kWh/m2/day and the land prices in the state are comparatively low.

The energy requirement of the state is 65,717 MU and the available energy is 65,310 MU. The energy is deficit by 0.62%. At peak times, the power demand is 10,642 MW and the same is met by the state.

Rajasthan Solar policy

The Rajasthan solar policy was launched in July 2011. The policy targeted an allocation of 12 GW of solar power in the state by 2025. The policy was divided into two phases:

- Phase I: Up to 2013 200 MW
- Phase II: From 2013-2017 400 MW

As a part of its first phase the policy aimed to allocate 50 MW of rooftop, 100 MW each of PV and CSP projects. But there were a lot of delays in allocating the projects and signing Power Purchase Agreements (PPA) with the selected developers. This delay was largely attributed to the fulfillment of the state's Renewable Purchase Obligation (RPO) through projects allocated via the National Solar Mission (NSM).

After a prolonged delay for the phase I allocations, 100 MW was allotted in January 2015. Although the allocation target was 100 MW, only 75 MW of projects qualified. This is because all prospective bidders had to meet the lowest auction price (L1) of INR 6.45/kWh. Another major constraint for investors is the bankability of Rajasthan's distribution companies (DISCOMs). Table 5.1 presents bids by the bidders:

Company	Average Bid Price	Capacity Allocated (MW)
Essel Mining & Ind. Ltd.	6.45 INR/kWh	20 MW
Sidhidata Solar Urja Ltd.	6.78 INR/kWh	5 MW
Arjun Green Power Pvt. Ltd	6.95 INR/kWh	5 MW

Table 5.1 Solar Energy Installation in Rajasthan: Details of Bids

In June 2013, Rajasthan Renewable Energy Corporation Limited released draft RFP for setting up 50 MWs capacity of projects each of 1 MW capacity. Until date the state has commissioned only 35 MW of projects under the state policy. Rajasthan has also seen a large number of projects commissioned under the Renewable Energy Certificate (REC) Mechanism. The state has a total of 210.6 MW commissioned under this scheme.

Later in 2014 Rajasthan announced its updated solar policy in October. A lot of queries were sought out in the new policy and the state hopes for better implementation of projects under the state policy. This policy is currently active with allocations not being accepted at this moment.

Rajasthan Rooftop policy

The State will also promote development of rooftop PV solar power plants connected to LT under net metering scheme as per guidelines of RERC. The State Government shall allow the Net metering mechanism for grid connected system to the consumer(s) of the DISCOMs installing such systems subject to technical consideration and execution of net-metering agreement between such consumers and DISCOMs. The DISCOMs will develop a suitable and comprehensive consumer friendly IT application in this regard.

Type of The Plant	Tariff
Utility Scale Plants	
With Accelerated Depreciation	INR 6.10/kWh
Without Accelerated Depreciation	INR 6.74/kWh
Rooftop Solar Plants	
With Accelerated Depreciation	INR 6.10/kWh
Without Accelerated Depreciation	INR 6.74/kWh

Table 5.2 presents the current benchmark solar tariffs under the updated solar policy.

Table 5.2 Solar Energy Installation in Rajasthan: Current Benchmark tariff

The total installed capacity as on 31st March, 2016 by utilities is 1,291 MW and on roof top is 44.4 MW (Bridge to India, 2016).

Incentives and Subsidies

The possible business models for investors in solar energy are Feed in Tariff – Power Purchase Agreement, Open Access, REC, Captive Consumption, Rooftop / Net Metering. Table 5.3 presents the incentive and subsidy for investors for the same.

Type Of Incentive	Exempted (Yes/No)	Amount Applicable	Further Info. (If Any)
Transmission Charges	No	4.54 INR/Unit/Day – STOA 138.10 INR/Unit/month – MTOA/LTOA	-
Wheeling Charges	No	EHV - 0.01 INR/kWh 33kV - 0.11 INR/kWh 11kV - 0.32 INR/kWh	-
Cross Subsidy Charges (INR/kWh)	Yes	0.00	_
Wheeling Losses (%)	No	33kV> 5.80% 11kV> 15.60%	-
Transmission Losses (%)	No	4.15%	-
Banking	No	2% of banking energy in each month	Energy shall be allowed to be banked at consumption end for only captive consumption within the State for a period one month. Up to 10% of unutilized banked energy, the generator shall be entitled to get payment @ 60% of energy charges applicable for large industrial power tariff excluding full surcharge. Un-utilized banked energy in excess of 10% shall lapse.
Electricity Duty	Yes	0.00	-

Table 5.3 Solar Energy Installation in Rajasthan: Incentives and Subsidies

RPO targets for Rajasthan

Table 5.4 presents the RPO targets of the state.

Year	2015-16	2016-17	2017-18
RPO target	1.50%	5.00%	5.50%

 Table 5.4 Solar Energy Installation in Rajasthan: RPO targets

Additional Information

The PPA Signatories are the DISCOMS of Rajasthan based on the project location. The DISCOMS of Rajasthan are mentioned below:

- Jaipur VidyutVitran Nigam Ltd.
- Ajmer VidyutVitran Nigam Ltd.
- Jodhpur VidyutVitran Nigam Ltd.

The responsibility of transmission will be of the Developers, as approved by Rajasthan Vidyut Prasaran Nigam Limited.

The land can be procured either from the Government or from private parties. In case of Government lands, the State will allot the land as per provisions under Rajasthan Land Revenue Rules, 2007. Sub-leasing of the land by developers is allowed under this policy.

5.3.2 Gujarat

Gujarat is rich in solar energy resource with substantial amount of barren and uncultivable land. The solar irradiation on an average is 5.63 kWh/m2/day. With a potential of development of more than 10,000 MW of solar power generation, the state also has an extensive power network and utility with good operating efficiency.

The energy requirement of the state is 96,235 MU and the available energy is 96,211 MU. The energy is deficit by 0.2%. At peak times, the power demand is 13,603 MW and the demand met is 13,499 MW. The peak power deficit is 0.8%.

Gujarat Solar policy

Gujarat was the first state to announce a solar specific policy in 2009. It was the first state to introduce a solar policy, even before the Central Government. The Gujarat government had an initial target of 500 MW till 2014. But due to the keen interest among developers, 958.5 MW of solar power projects were allocated in the state.

The state has added close to 1105 MW of grid connected solar power, largely under its state policy. There have been very few projects under the National Solar Mission (NSM) allocated to Gujarat due to the developers preferring to set up projects in Gujarat under the state scheme. The state is also generating 65.6 MW of power from Roof top solar systems.

Gujarat has so far followed a fixed tariff mechanism and does not adopt reverse bidding to discover solar tariffs. Table 5.5 presents the tariff for most of the projects which are set up under the Gujarat Solar Policy 2009

Timeline	Tariff (Inr/Kwh)
Projects commissioned before 31.15.2010	15.00 (for first 12 years)
	5.00 (from 13^{th} to 25^{th} year)
Projects commissioned before 31.05.2014	15.00 (for first 12 years)
	5.00 (from 13^{th} to 25^{th} year)

Table 5.5 Solar Energy Installation in Gujarat: Tariff under Solar policy - 2009

Table 5.6 presents the revised tariffs of 2015.

	Levellized Tariff	Phased Tariff	
For Megawatt scale projects			
With accelerated depreciation benefit	INIP 10.27 /IW/h for 25 years	Year 1- 12: INR 11.50/kWh	
with accelerated depreciation benefit	in the 10.277 k will for 25 years	Year 13 to 25: INR 6.30/kWh	
Without accelerated depreciation benefit	INID 10.91 /LW/h for 25 years	Year 1- 12: INR 15.04/kWh	
without accelerated depreciation benefit	11NK 10.01/KW11101 25 years	Year 13 to 25: INR 6.84/kWh	
For Kilowatt scale projects			
With accelerated depreciation benefit	INR 15.49/kWh		
Without accelerated depreciation benefit	INR 15.14/kWh		

Table 5.6 Solar Energy Installation in Gujarat: Revised Tariff

The state has announced its new 'Gujarat Solar Power Policy – 2015' which will be operative till 2020. This policy is currently active, and allocations are not accepted at this moment.

Gujarat Rooftop policy

Rooftop Solar PV systems are also an integrated part of the new policy. The policy allows a rooftop PV system to be facilitated by net metering on Govt., residential, industrial and commercial buildings. The customer can also avail REC benefit. In addition to this, to boost Rooftop installations, the state nodal agency GEDA would provide an incentive of 10,000 INR per kW to private residential customers, with maximum limit of 20,000 INR per kW. Table 5.7 presents the current benchmark solar tariffs under the updated solar policy.

Period	July 1, 2015 To March 31, 2016	April 1, 2016 To March 31, 2017	April 1, 2017 To March 31, 2018
Levelized Tariff for Large Rooftop and M	legawatt-scale Photo	voltaic Power Plants (II	NR/kWh)
Without Accelerated Depreciation Benefit	6.77	6.30	5.86
With Accelerated Depreciation Benefit	6.17	5.74	5.34
Levelized Tariff for Kilowatt-scale Photovoltaic Power Plants (INR/kWh)			
Without Accelerated Depreciation Benefit	8.42	7.83	7.28
With Accelerated Depreciation Benefit	7.64	7.11	6.61

Table 5.7 Solar Energy Installation in Gujarat: Current Benchmark tariff

Gujarat is also the first state in the country to adopt the solar park concept. To overcome the challenges of land acquisition, grid infrastructure, water facility Charanka solar park came into

existence. The solar park is spread in an area of about 2,000 hectares which can occupy solar plants up to a capacity of 500 MW. As of July 2015 a total of 24 plants totaling 345 MW are operational in Charanka Solar Park.

Incentives and Subsidies

The possible business models for investors in solar energy are Feed in Tariff – Power Purchase Agreement, Open Access, REC, Captive Consumption, Rooftop / Net Metering. Table 5.8 presents the incentive and subsidy for investors for the same.

Type Of Incentive	Exempted (Yes/No)	Amount Applicable	Further Info. (If Any)
Transmission Charges	No	2845.46 INR/MW/Day	
Wheeling Charges	No	11kV> 0.14 INR/kWh 400V> 0.51 INR/kWh	
Cross Subsidy Charges (INR/kWh)	Yes – Non REC Customer	REC Customer – 1.45 INR/kWh	
Wheeling Losses (%)	No	See Appendix- 5A	
Transmission Losses (%)	No	4.81%	
Banking		Charges exempted	Only for captive consumer availing non REC benefit and third party sale shall be eligible for banking of energy for one month period only. Any surplus energy of banked units in the given billing cycle available after set-off shall be considered as deemed sale to the concerned Distribution Licensees at Average Power Purchase Cost (APPC) rate determined by the Commission.
Electricity Duty	Yes	0.00	

Table 5.8 Solar Energy Installation in Gujarat: Incentives and Subsidies

Gujarat RPO targets

The state's solar policy (2009) had expired in 2014. The updated policy for solar energy in Gujarat was announced in August 2015 and the RPO targets were also revised. Table 5.9 presents the RPO targets of the state.

Year	2015-16	2016-17
RPO Target	1.50%	1.75%

Table 5.9 Solar Energy Installation in Gujarat: RPO Targets

Additional Information

The PPA signatory for the state is Gujarat Urja Vikas Nigam Limited. The solar policy of 2009 places the responsibility of developing the evacuation infrastructure for transmission lines on Gujarat Electricity Transmission Corporation Limited. It is the responsibility of the project developer to acquire the land required for the project as per the state solar policy. Alternatively, the developer may choose to set up a project in Charanka Solar Park by paying the necessary fees to GPCL.

5.3.3 Madhya Pradesh

The state is endowed with around 300 days of clear sun. The state offers good sites having solar radiation of 5.8 kWh/m2/day for installation of solar based power plants. The energy requirement of the state is 65,675 MU and the available energy is 70,890 MU. The state has surplus energy of 7.36%. At peak times, the power demand is 10,489 MW and the demand met is 11,672 MW. It has peak surplus of 11.3%.

Madhya Pradesh Solar policy

Madhya Pradesh is one of the fastest growing states for solar power in India. It announced its state policy back in 2015. The policy does not mention any specific targets, although the state shall be guided by the Renewable Purchase Obligations (RPO) announced from time to time by the Madhya Pradesh Electricity Regulatory Commission (MPERC). This policy is currently active with allocations being accepted at the moment.

The solar policy of Madhya Pradesh promotes solar projects under four specific categories

- Category I: Sale to DISCOMs via RFP issued from time to time
- Category II: Captive and Third Party Sale
- Category III: Projects under the REC route
- Category IV: Projects allocated under the National Solar Mission

The state has allocated three batches of solar projects since 2015. They are:

- RFP for 200 MW 2012
- RFP for 100 MW 2013
- RFP for 300 MW 2015

The state received record low solar bids under the latest RFP for 300 MW in July 2015. Table 5.10 presents the lowest solar tariffs discovered in the country as on date (July 2015).

Results Of Reverse Auction – RFP 300 MW	Bids (INR/kWh)
Lowest	5.05
Median	5.36
Highest	5.64

Table 5.10 Solar Energy Installation in Madhya Pradesh: Lowest tariff discovered

Madhya Pradesh has also attracted a significant share of projects under the National Solar Mission Phase 2 Batch 1. The state claimed 250 MW or 33% of all allocations.

The total installed capacity as on 31st March, 2016 by utilities is 767 MW and on roof top is 16 MW(Bridge to India, 2016).

Table 5.11 presents the current benchmark solar tariffs under the solar policy.

Type Of Plant	Tariff
Utility Scale Plants	INR 15.35/kWh
Rooftop Solar Plants	INR 15.49/kWh

Table 5.11 Solar Energy Installation in Madhya Pradesh: Current Benchmark tariff

No distinction has been made for projects that avail accelerated depreciation and projects that do not.

Incentives and Subsidies

The possible business models for investors in solar energy are Feed in Tariff – Power Purchase Agreement, Open Access, REC, Captive Consumption, Rooftop / Net Metering. Table 5.12 presents the incentive and subsidy for investors.

Type Of Incentive	Exempted	Amount Applicable	Further Info. (If Any)
	(Yes/No)		
Transmission Charges	No	0.64 INR/kWh	
Wheeling Charges	Yes	0.00	
Cross Subsidy Charges	Yes	0.00	
(INR/kWh)			
Wheeling Losses (%)	No	132kV(Including external	
		Losses)> 5.25%	
		33kV> 5.83%	
Transmission Losses (%)	No	5.82%	
Banking		2% of banked energy is to	Banking of 100% energy in every
-		be paid as banking charge	financial year is permitted

Type Of Incentive	Exempted (Yes/No)	Amount Applicable	Further Info. (If Any)
Electricity Duty	Yes	0.00	Exempted for a period of 10 years from date of Commissioning

Table 5.12 Solar Energy Installation in Madhya Pradesh: Incentives and Subsidies

RPO Targets of Madhya Pradesh

The RPO target for the year 2015-16 stands at 1.00% of the total energy requirement (~ 65,000 million kWh). This works out to a solar capacity of 433 MW for the year 2015-16. Table 5.13 presents the RPO targets of the state.

Year	2015-16	2016-17	2017-18	2018-19
RPO Target	1.00%	1.25%	1.50%	1.75%

Table5.13 Solar Energy Installation in Madhya Pradesh: RPO Targets

Additional Information

The PPA signatory for the state is Madhya Pradesh Power Management Company Limited. The developer of the plant shall be responsible to construct the evacuation infrastructure to the nearest 132/33 kV or 220/132 kV or 400/220/132 kV substation. The developer can either purchase land on their own or request for land allotment from existing Govt. land reserves. In case of Government land, the land leased to the developer shall be limited to 3.0 hectares per MW. 50% exemption on stamp duty in case of private land.

5.3.4 Maharashtra

Maharashtra has abundant solar potential available in the state, from which clean and non-polluting electricity can be generated on sustainable basis everywhere. The state receives global horizontal irradiance of 5.56 kWh/m2/day.

The energy requirement of the state is 1,34,897 MU and the available energy is 1,33,078 MU. The state is energy deficit by 1.35%. At peak times, the power demand is 20,147 MW and the demand met is 19,804 MW. The peak power deficit is 1.7%.

Maharashtra Solar Policy

Maharashtra is one of the only major states in the country that does not have a solar policy. The state has preferred to meet its Renewable Purchase Obligations (RPO) through a direct allocation of projects owned and operated by the State Government owned generating company, MAHAGENCO.

Recently the state announced its policy for grid connected solar projects as of July 2015. According to the policy, the state intends to come up with 7,500 MW solar projects out of which

2,500 MW will be developed under MAHAGENCO through the PPA method and the remaining 5,000 MW will be solar projects will be developed by other solar developers. In the capacity allocated under MAHAGENCO, ten percent shall be implemented at places available along the canals, lakes, water bodies of the water resources department of the local government bodies. This policy is currently active but allocations are not accepted at this moment.

Type Of Plant	Tariff
Utility Scale Plants	
With Accelerated Depreciation	6.13 INR/kWh
Without Accelerated Depreciation	7.15 INR/kWh
Rooftop Solar Plants	
With Accelerated Depreciation	6.63 INR/kWh
Without Accelerated Depreciation	7.65 INR/kWh

Table 5.14 presents the current benchmark solar tariffs under the solar policy.

Table 5.14 Solar Energy Installation in Maharashtra: Current Benchmark tariff

The total installed capacity as on 31st March, 2016 by utilities is 403 MW and on roof top is 65.3 MW (Bridge to India).

Incentives and Subsidies

The possible business models for investors in solar energy are Feed in Tariff – Power Purchase Agreement, Open Access, REC, Captive Consumption, Rooftop / Net Metering. Table 5.15 presents the incentive and subsidy for investors.

Type Of Incentive	Exempted (Yes/No)	Amount Applicable	Further Info.(If Any)	
Transmission Charges	No	0.29 INR/kWh	-	
Wheeling Charges	No	33kV - 0.11 INR/kWh 11kV - 0.22 INR/kWh LT – 1.03 INR/kWh	-	
Cross Subsidy Charges	No	33kV - 1.18 INR/kWh 11kV - 0.53 INR/kWh LT - 0.73 INR/kWh (above 20 kW)		
Wheeling Losses (%)	No	4.24%		
Transmission Losses (%)	No	33kV - 6% 22/11kV - 9% LT - 15.50%		
Banking	N.A	-	-	
Electricity Duty	N.A	-	-	

Table 5.15 Solar Energy Installation in Maharastra: Incentives and Subsidies

RPO Targets of Maharashtra

Table 5.16 presents the RPO targets of the state.

Year	2016-17	2017-18	2018-19	2019-20
RPO Target	1.00%	1.50%	5.00%	5.50%

Table 5.16 Solar Energy Installation in Maharashtra: RPO Targets

Additional Information

The PPA signatory for the state is Maharashtra State Power Generation Limited.

The responsibility of transmission will be the Maharashtra State Electricity Transmission Company.

The procurement of private land would be the developer's responsibility. Government wastelands can also be granted on lease hold basis, as per availability.

5.3.5 Karnataka

Karnataka is rich in solar resources and solar energy would complement the conventional sources of energy in a large way. The state of Karnataka has about 240 to 300 sunny days with solar radiation of 5.7 kWh/m2/day. The state has moderated potential of around 10,000 MW.

The energy requirement of the state is 62,643 MU and the available energy is 58,926 MU. The state is energy deficit by 5.93%. At peak times, the power demand is 10,001 MW and the demand met is 9,549 MW. The peak power is deficit by 4.5%.

Karnataka Solar Policy

In Phase 1 of the Karnataka state policy (2011-16), the target was to generate 200 MW of solar power and Government of Karnataka decided to allocate 40 MW each year. Under this policy the state had floated an RFP for 130 MW, but it could not be commissioned in due time.

The former policy of 2011-16 failed to envisage eventual technological advancements. So in May 2014, new solar policy for 2014-21 was announced. The targets for grid connected projects are 1600 MW and 400 MW for the rooftop solar PV. It also includes attractive provisions such as encouraging land-owning farmers to install solar power plants

As a measure of damage control Karnataka decided to keep the plant sizes smaller than the previous plan. The policy also targets building solar capacity for captive users and the merchant power projects that sell solar power directly to third party buyers through open access. The policy has opened this avenue to help users to quote and fulfill their RPOs and to also attract more investments. Karnataka had floated an RFP for the purchase of electricity for 500 MW solar PV projects through tariff based competitive bidding in June, 2014. It was necessitated

when after a few of the lowest winning bidders from the previous tendering process had declined to sign the Power Purchase Agreements (PPA) citing non-viability of their projects at the tariff that was quoted which was among the lowest in the country.

The collective bidding process did not prove to be fruitful since the lowest winning bid was declared to be INR 5.51/kWh and so the return of equity for the projects was not attributed to be attractive enough to justify investments. Even if the option of Accelerated Depreciation (AD) was availed it would only amount to an equivalent increase INR 1 to 1.5 in tariff, which would not prove beneficial for the developers.

Company	Bid Capacity	Avg. Bid Price
M/s. Today Green Power Pvt. Ltd.	20MW	INR 6.71/kWh
M/s. Asian Fab Tec Limited	10MW	INR 6.74/kWh
M/s. Today Green Power Pvt. Ltd.	20MW	INR 6.81/kWh

Table 5.17 & 5.18 present the summary of the winning bidders and price of the 500 MW RFP.

Table 5.17 Solar Energy Installation in Karnataka: Summary of winning bidders

Tariff	No. Of Projects
Between INR 6 and 7/ kWh	13
Above INR 7/ kWh	7

Table 5.18 Solar Energy Installation in Karnataka: Summary of price quoted

Karnataka Rooftop Policy

The 2014-21 solar policy promotes grid connected solar rooftop on public buildings, domestic, commercial and industrial establishments through net metering and gross metering methods based on tariff orders issued by KERC from time to time. In case of Rooftop PV system connected to the grid of a distribution company, the surplus energy injected shall be paid by the ESCOM at tariff determined by KERC from time to time.

Table 5.19 presents the current benchmark solar tariffs under the solar policy.

Type Of Plant	Tariff
Utility Scale Plants	6.51 INR/kWh
Rooftop and small solar PV plants	9.56 INR/kWh
Rooftop and small solar PV plants with 30% capital subsidy	7.20 INR/kWh

Table 5.19 Solar Energy Installation in Karnataka: Current Benchmark tariff

No distinction has been made for projects that avail accelerated depreciation and projects that do not. The total installed capacity as on 31st March, 2016 by utilities is 105 MW and on roof top is 47 MW (Bridge to India).

Incentives and Subsidies

The possible business models for investors in solar energy are Feed in Tariff – Power Purchase Agreement, Open Access, REC, Captive Consumption, Rooftop / Net Metering. Table 5.20 presents the incentive and subsidy for investors.

Type Of Incentive	Exempted (Yes/No)	Amount Applicable	Further Info. (If Any)
Transmission Charges	No	LTOA - INR 127400/MW/month STOA (12-24 hours) - 1047.13 INR /MW STOA (6-12 hours) - 525.56 INR/MW STOA (<6 hours) - 261.78 INR /MW	
Wheeling Charges	Yes	0.00	Exempted for plants commissioned by 31/3/18, for a period of 10 years.
Cross Subsidy Charges (INR/kWh)	Yes	0.00	
Wheeling Losses (%)	No	See Appendix- 5A	
Transmission Losses (%)	No	Range 5.27% to 5.67%	
Banking		NON REC Customer -Charges Exempted for plants commissioned by 31/3/18, for a period of 10 years.REC Customer – Not available	Banking of energy on monthly basis
Electricity Duty	-	-	-

Table 5.20 Solar Energy Installation in Karnataka: Incentives and Subsidies

RPO Targets of Karnataka

Table 5.21 presents the DISCOM wise RPO targets of the state.

Distribution Licensee	2015-2016	2016-2017	2017-2018
BESCOM	0.25%	0.5%	0.75%
MESCOM	0.25%	0.75%	1.0%
CESC	0.25%	0.5%	0.75%
HESCOM	0.25%	0.5%	0.75%
GESCOM	0.25%	0.5%	0.75%
HRECS	0.25%	0.5%	0.75%
Deemed Licensee	0%	0.5%	0.75%

OA and Grid-Connected Captive		
2015-16	0.00%	
2016-17	0.50%	
2017-18	0.75%	

Table 5.21 Solar Energy Installation in Karnataka: RPO Targets

Additional Information

The PPA signatory for the state is Karnataka Renewable Energy Development Limited.

The responsibility of transmission will be of Karnataka Power Transmission Company Limited.

According to clause 18 of the 'Karnataka Solar Policy for 2014-21', 'Government of Karnataka' will be responsible to dispense agricultural lands that will be converted and utilized by the developers to setup solar PV projects. These projects will be exempted from obtaining clearances from the pollution control board.

5.3.6. Tamil Nadu

Tamil Nadu has global horizontal irradiance of 5.71 kWh/m2/day with around 300 clear sunny days in a year. With substantial solar insolation, strong commitment of the state government and rapidly declining solar power costs, there are remarkable opportunities in the solar energy domain in the state.

The energy requirement of the state is 95,758 MU and the available energy is 92,750 MU. The state is energy deficit by 5.14%. At peak times, the power demand is 13,707 MW and the demand met is 73,498 MW. The peak power is deficit by 1.5%.

Tamil Nadu Solar policy

Tamil Nadu announced its solar policy in October, 2015. The key feature of the policy is the Solar Purchase Obligation (SPO) similar to the national Renewable Purchase Obligation (RPO). It had an ambitious target of 3,000 MW by 2015. With an initial target of 1,000 MW in December 2012, it planned to commission 1,000 MW each year till 2015. Table 5.22 presents the proposed 3000 MW which is to be achieved through utility scale projects, rooftop projects and projects under the REC mechanism.

	Utility Scale (MW)	Solar Rooftops (MW)	REC (MW)	Total (MW)
	(a)	(b)	(c)	(a) + (b) + (c)
2013	750	100	150	1000
2014	550	125	325	1000
2015	200	125	675	1000
Total	1500	350	1150	3000

Table 5.22 Solar Energy Installation in Tamil Nadu: RPO Targets

However due to lack of response from developers, the Letter of Intent (LOI) were only given to projects worth 700 MW. The entire state was caught in a fit due to regulatory uncertainties that included the striking down of the Solar Purchase Obligations (SPO) under the state policy by the Appellate Tribunal and lack of approval of the tariff for the PPA by State Electricity Regulatory Commission. In the year 2015, the state has allocated 2 GW of projects under a direct allocation route at a price of INR 7.01/kWh. This solar policy is currently active in the state, with allocations not being accepted at this moment.

Tamil Nadu Rooftop policy

The State will promote Solar Rooftops to domestic customers, by providing generation based incentive (GBI) of 2 INR/kWh for first two years, and 0.50 INR/kWh for subsequent years. It will also be promoted by installing solar home lighting for 3 lakh houses, energizing of street lights through solar energy. All new/existing Government/Local body buildings would be directed to install solar rooftops in a phased manner.

Table 5.23 presents the current benchmark solar tariffs under the solar policy.

Type Of Plant	Tariff
Utility Scale Plants	
Without Accelerated Depreciation	INR 7.01/kWh
With Accelerated Depreciation	INR 6.28/kWh
Rooftop Solar Plants	_

Table 5.23 Solar Energy Installation in Tamil Nadu: Current Benchmark Tariff

The total installed capacity as on 31st March, 2016 by utilities is 1,191 MW and on roof top is 85.4 MW (Bridge to India).

Incentives and Subsidies

The possible business models for investors in solar energy are Feed in Tariff – Power Purchase Agreement, Open Access, REC, Captive Consumption, Rooftop / Net Metering. Table 5.24 presents the incentive and subsidy for investors.

Type Of IncentiveExempted		Amount Applicable	Further Info. (If Any)
	(Yes/No)		
Transmission Charges	No	REC Customer:	
		LTOA/MTOA - 2903	
		INR/MW/Day	
		STOA - 120.97 INR/MW	
		NON REC Customer: 30%	
		of above mentioned charges	
		for respective category	
Wheeling Charges	No	0.1887 INR/kWh	
Cross Subsidy Charges	No	50% of open access customer	Open access regulation 13-3-
(INR/kWh)		_	2014(Page 268)

Type Of Incentive	Exempted	Amount Applicable	Further Info. (If Any)
	(1es/10)		
Wheeling Losses (%)	No	230kV> 0.80%	
		110kV> 1.90%	
Transmission Losses (%)	No	230kV> 0.76%	
		110kV> 1.94%	
		66kV> 0%	
Banking	-	-	The billing procedure
-			provides for a banking
			period of one billing cycle
Electricity Duty	No	0.00	Exemption up to 100% for
			self-consumption/sale to
			utility for 5 years

Table 5.24 Solar Energy Installation in Tamil Nadu: Incentives and Subsidies

RPO Targets of Tamilnadu

Table 5.25 presents the RPO targets of the state.

Year	2015-16	2016-17	2017-18
RPO Target	5.0%	-	-

Table 5.25 Solar Energy Installation in Tamil Nadu: RPO Targets

Additional Information

The PPA signatory for the state is Tamil Nadu Generation and Distribution Corporation under the Tamil Nadu Electricity Board. The responsibility of transmission will be of Tamil Nadu Transmission Corporation.

5.3.7 Kerala

Kerala receives good global horizontal irradiance of 5.40 kWh/m2/day. The state wants to ensure optimal usage of this available solar potential so that the usage of solar energy could be mainstreamed in the energy mix of the state.

The energy requirement of the state is 22,459 MU and the available energy is 22,127 MU. The state is energy deficit by 1.48%. At peak times, the power demand is 3,760 MW and the demand met is 3,594 MW. The peak power is deficit by 4.4%.

Kerala Solar policy

Kerala Solar Energy Policy' was announced on 25th November 2015. The policy targets to commission 500 MW by 2017 and 2,500 MW by 2030. The policy aims at installing off-grid

rooftop system in residential areas, grid connected small scale systems, installation of floating solar arrays over canals, reservoirs etc. However, there have been no allocations till date.

In 2014 Kerala announced its net metering policy. Both the Solar Energy Policy and the Net metering Policy are encouraging net metering for domestic and commercial buildings by providing better technology and highly incentivized schemes like Feed-In-Tariff, pooled cost. Kerala is also promoting the 'grid-tie' system that allows consumers having electric connections in different premises, owned by them, to be eligible to install a solar energy system in each premise and benefit from easy flow of electricity in all their premises.

In April 2015, the state commissioned 12 MW of solar rooftop on the Cochin International Airport, making it the first Indian state to have a "solar power neutral" infrastructure. The state intends to continue allocation of more capacity under the Solar Off-Grid Photovoltaic program of the Jawaharlal Nehru National Solar Mission (JNNSM) in the coming years. Table 5.26 presents the current benchmark solar tariffs under the solar policy.

Type Of Plant	Tariff
Utility Scale Plants	INR 6.86/kWh
Rooftop Solar Plants	_

Table 5.26 Solar Energy Installation in Kerala: Current Benchmark Tariff

No distinction has been made for projects that avail accelerated depreciation and projects that do not. The state solar policy is currently active and allocations are not accepted at this moment.

The total installed capacity as on 31st March, 2016 by utilities is 13 MW and on roof top is 19 MW (Bridge to India).

Incentives and Subsidies

The possible business models for investors in solar energy are Feed in Tariff – Power Purchase Agreement, Open Access, REC, Captive Consumption, Rooftop / Net Metering. Table 5.27 the incentive and subsidy for investors.

Type Of Incentive	Exempted (Yes/No)	Amount Applicable	Further Info.(If Any)
Transmission Charges (INR/kWh)	Yes	0.26	Applicable to captive consumers
Wheeling Charges (INR/kWh)	Yes	0.32	No OA charges for wheeling power within the state
Cross Subsidy Charges (INR/kWh)	Yes	0.50 (HT- Industry) 5.30 (HT- Commercial)	No CSS for wheeling of power within the state
Wheeling Losses (%)	Yes	4.50%	Wheeling charges and T&D losses will not be applicable to captive consumers
Transmission Losses (%)	Yes	_	Applicable to captive consumers

Type Of Incentive	Exempted (Yes/No)	Amount Applicable	Further Info.(If Any)
Banking	Yes	_	Conditional banking facility applicable to captive consumers after taking into account all possible constraints
Electricity Duty	Yes	_	_

Table 5.27 Solar Energy Installation in Kerala: Incentives and Subsidies

RPO Targets of Kerala

Table 5.28 presents the RPO targets of the state.

Year	2015-16	2016-17	2017-18
RPO Target	0.25%	0.25%	0.25%

Table 5.28 Solar Energy Installation in Kerala: RPO Targets

Additional Information

The PPA signatory for the state is Kerala State Electricity Board Limited. The responsibility of transmission will be of Kerala State Electricity Board Limited. The responsibility for identifying the land for solar projects shall be with the developers.

5.3.8 Andhra Pradesh

Andhra Pradesh is poised for rapid industrial growth driven by infrastructure investments and has also been selected by Ministry of Power as one of the pilot states for implementation of the 24x7 – Power for All (PFA) scheme. With good global solar irradiance of 5.58 kWh/m2/day, solar energy can become an important source in meeting the growing power requirements of the State.

The energy requirement of the state is 59,198 MU and the available energy is 56,163 MU. The state is energy deficit by 4.9%. At peak times, the power demand is 7,144 MW and the demand met is 6,784 MW. The peak power deficit is 5.0%.

Andhra Pradesh Solar Policy

Andhra Pradesh announced its solar policy on 26th September 2015. Under the policy the state targeted to install 1,000 MW by 2015. The government planned to proceed with L1 bidding process, for the final tariff determination. The state followed three business models REC, RPO and open access. The state gave incentives in the form of exemption from wheeling and transmission charges, exemption from cross subsidy charges, electricity duty and refund on

Value Added Tax (VAT) on plant components, stamp duty and registration charges for all projects commissioned by June 2014.

The state struggled on deciding the time period of PPA and after a few deliberations from the developers; the state extended the plant commissioning deadline to 12 months instead of six months earlier. Also the time duration for financial closure was extended to 210 days from 60 days. The state DISCOMs provided good bankability and proper management hence it received excess RFP applications from 184 applicants who bid for a total capacity of 1340 MW. The lowest bid was discovered at INR 6.58/kWh. Top three winning bidders were Sunborne Energy (25 MW) ACME Telepower Ltd (170 MW) and Alfa Infrapop (80 MW).

After the allocation of 1000 MW, Andhra Pradesh government in 2014 announced RFP for 500 MW for which the bidding capacity was a total of 1291 MW. The average bid price was of INR 5.25/kwh by First Solar Power India Ltd (80 MW) followed by Acme Clean Tech solution Ltd (160 MW) and Waneep Solar Pvt. Ltd (50 MW). Table 5.29 presents the bids received by the state.

Results Of Reverse Auction – RFP 500 MW	Bids (INR/kWh)
Lowest	5.05
Median	5.36
Highest	5.64

Table 5.29 Solar Energy Installation in Andhra Pradesh: Bids received

Due to bifurcation of the state, Andhra Pradesh announced its new solar policy in 2015. The state targets 5,000 MW of solar projects by 2020 mostly through private investment. The state also is giving a thrust to large scale production via solar parks. The state has three solar parks at Kurnool, Anantpur, and Kadapa.

The solar policy of Andhra Pradesh promotes solar projects under four specific categories

- Category I: Sale to DISCOMs via RfP issued from time to time
- Category II: Captive and Third Party Sale
- Category III: Projects under the REC route
- Category IV: Projects allocated under the National Solar Mission

This policy is currently active and allocations are not accepted at this moment.

Andhra Pradesh Rooftop Policy

The state will also promote installation of solar rooftop systems on public buildings, domestic, commercial and industrial establishments on gross and or net meter basis. The consumers are free to choose either net or gross meter option for sale of power to Discoms under this policy.

The applicable tariff for either of the cases shall be equal to the average cost to serve of the Discom which will be determined by APERC every year. For example, the average cost to serve approved by APERC for FY 2013-14 is Rs. 5.25 per unit. This facility shall be extended for a period of 25 years for Eligible Developers who set up solar rooftop projects within the Operating Period of the policy. Table 5.30 present the current benchmark solar tariffs under the solar policy:

Type Of Plant	Tariff
Utility Scale Plants	INR 6.49/kWh
Rooftop Solar Plants	_

Table 5.30 Solar Energy Installation in Andhra Pradesh: Current Benchmark Tariffs

No distinction has been made for projects that avail accelerated depreciation and projects that do not.

The total installed capacity as on 31st March, 2016 by utilities is 571 MW and on roof top is 36 MW (Bridge to India).

Incentives and Subsidies

The possible business models for investors in solar energy are Feed in Tariff – Power Purchase Agreement, Open Access, REC, Captive Consumption, Rooftop / Net Metering. Table 5.31 presents the incentive and subsidy for investors.

Type Of Incentive	Exempted (Yes/No)	Amount Applicable	Further Info. (If Any)
Transmission Charges	Yes	0.00	
Wheeling Charges	Yes	0.00	
Cross Subsidy Charges (INR/kWh)	Yes	0.00	Exempted from date of commissioning for a period of 5 years.
Wheeling Losses (%)	Yes		Exempted for all Solar Power Projects injecting at 33 kV or below.
Transmission Losses	No	4.01%	
Banking		2% of banked energy is to be paid as banking charge	Annual banking facility available, Drawls from banked energy shall not be permitted during five month period from 1st April to 30th June and 1st February to 31st March of each Financial year.
Electricity Duty	Yes	0.00	

Table 5.31 Solar Energy Installation in Andhra Pradesh: Incentives and Subsidies

RPO Targets of Andhra Pradesh

Table 5.32 presents the RPO targets of the state.

Year	2015-16	2016-17	2017-18	2018-19
RPO Target	0.25%	0.25%	0.25%	0.25%

Table 5.32 Solar Energy Installation in Andhra Pradesh: RPO targets

Additional Information

The PPA signatory for the state is Transmission Corporation of Andhra Pradesh.

The developer of the plant shall be responsible to construct the evacuation infrastructure to the nearest 132/33 kV or 220/132 kV or 400/220/132 kV sub station

The developers can either purchase land on their own or request for land allotment from existing Govt. land reserves. In case of Government land, the land leased to the developer shall be limited to 5.0 hectares per MW. There is a 50% exemption on stamp duty for the purchase of private land being given as an incentive.

5.3.9 Telangana

Telangana has a vast solar potential with global horizontal irradiance of 5.5 kWh/m2/day for 300 sunshine days. Government of Telangana intends to make use of the positive environment in solar market and push given by Government of India for substantially harnessing the solar potential in the state of Telangana.

The energy requirement of the state is 43,337 MU and the available energy is 40,644 MU. The state is energy deficit by 6.21%. At peak times, the power demand is 7,884 MW and the demand met is 6,755 MW. The peak power is deficit by 14.32%.

Telangana Solar policy

Telangana announced its solar policy in July, 2015, which provides framework for its RfS allocation plans. The state of Telangana announced a Request for Selection (RFS) for 2,000 MW on 1st April 2015. This is the second RFS that follows an earlier RFS of 500 MW announced in September 2014. It was the single largest allocation by any state in the country till date. The lowest bid was a record at INR 5.17/kWh (lowest at that time). This policy is currently active and allocations are not accepted at this moment.

Telangana Rooftop policy

The Government of Telangana is committed to promotion of solar rooftop systems on public buildings, domestic, commercial and industrial establishments. All incentives provided by the GOI/MNRE under the NSM or other schemes and incentives provided by state government from time to time shall be extended to grid connected SRPs as well as off grid SRPs. The consumers are free to choose either net or gross meter option for sale of power to the DISCOMs under this policy. The tariff applicable for units generated under gross metering at 11 KV and below would be average cost of service of the DISCOM as determined by TSERC. The tariff applicable for units under net metering would be average pooled power purchase cost. Projects under both gross and net metering would be subject to monthly billing and settlement.

Table 5.33 presents the current benchmark solar tariffs under the solar policy.

Type Of Plant	Tariff
Utility Scale Plants	INR 6.72 INR/kWh
Rooftop Solar Plants	-

Table 5.33 Solar Energy Installation in Telangana: Current Benchmark Tariff

No distinction has been made for projects that avail accelerated depreciation and projects that do not. The total installed capacity as on 31st March, 2016 by utilities is 433 MW and on roof top is 37 MW (Bridge to India).

Incentives and Subsidies

The possible business models for investors in solar energy are Feed in Tariff – Power Purchase Agreement, Open Access, REC, Captive Consumption, Rooftop / Net Metering. Table 34 presents the incentive and subsidy for investors.

Type Of Incentive	Exempted (Yes/No)	Amount Applicable	Further Info. (If Any)
Transmission Charges	No	144 INR/KW/Month	
Wheeling Charges		33 kV – 16.63 INR/kVA/month 11 kV – 191.53 INR/kVA/month LT – 406.84 INR/kVA/month	
Cross Subsidy Charges (INR/kWh)	Yes	0.00	Exempted from date of commissioning for a period of 5 years.
Wheeling Losses (%)	No	See Appendix- 5A	
Transmission Losses (%)	No	4.01%	

Type Of Incentive	Exempted (Yes/No)	Amount Applicable	Further Info. (If Any)
Banking		2% of banked energy is to be paid as banking charge	Annual banking facility available, Drawls from banked energy shall not be permitted during five month period from 1st April to 30th June and 1st February to 31st March of each Financial year.
Electricity Duty	Yes	0.00	

Table 5.34 Solar Energy Installation in Telangana: Incentives and Subsidies

RPO Targets of Telangana

Table 5.35 presents the RPO targets of the state.

Year	2015-16	2016-17	2017-18
RPO Target	0.25%	-	-

Table 5.35 Solar Energy Installation in Telangana: RPO Targets

Additional Information

The PPA signatory for the state is Southern Power Distribution Company of Telangana Limited.

The responsibility of transmission will be of Telangana State Transmission Corporation, Southern Power Distribution Company of Telangana Limited and Northern Power Distribution Company Limited of Telangana. The responsibility for identifying the land for solar projects shall be with the developers. Land acquired for grid-connected SPPs for sale to DISCOMs/ captive use/ third party sale or for Solar parks shall be deemed to be converted to Non-agricultural land status on payment of applicable conversion charges to the SPC and no further conversion procedures need to be followed by the developers in respect of such land [Agricultural Land (Conversion for Non-agricultural Purposes) Act, 3 of 2006].

5.3.10 Odisha

Of the few renewable energy resources that are fast advancing towards grid parity solar energy no doubt is the frontrunner. Odisha receives global horizontal irradiance of 5.2 kWh/m2/day with around 300 clear sunny days every year. The feasible potential for power generation in the Solar Photovoltaic and the Solar thermal routes have been roughly estimated as 8000 MW and 2000 MW respectively.

The energy requirement of the state is 26,482 MU and the available energy is 26,052 MU. The state is energy deficit by 1.62%. At peak times, the power demand is 3,920 MW and the demand met is 3,892 MW. The peak power is deficit by 0.7%.
Odisha Solar Policy

Odisha announced its solar policy in July 2013 estimating to generate 8,000 MW from solar energy. The policy was announced to cater to the problem of energy security in the state. The state intends to put up 135 MW cumulative capacity additions through Solar Purchase Obligation (SPO) till FY 2015-2016. But until now the state has not achieved much. At present there are two projects in the pipeline:

• 5 MW Bhubaneswar – Cuttack Rooftop solar power project under state Government of Odisha with Green Energy Development Corporation of Odisha Ltd (GEDCOL) as the Nodal agency.

• 20 MW PV based solar power plant at Manmunda under NSM Phase-II, Batch-I under the Viability Gap Funding Scheme. This project is allotted to GEDCOL by Solar Energy Corporation of India Ltd. (SECI).

Apart from the ongoing projects, the state does not plan to come up with any other projects at the moment. This policy is currently active and allocations are not accepted at this moment.

Roof Top Policy

With the objective of decreasing the day time peak power requirement, reducing losses and improving the voltage Rooftop Solar PV will be promoted by the state. Small grid interactive roof top solar power projects connected to LT Grid with individual capacities ranging from 0.5 KW to 500KW and Stand-alone projects with storage batteries can cater to power requirements of a facility during day as well as night time. The primary objective of these projects would be to use the solar power within the institution/household during the day in tandem with grid power and export excess power, if any, or the power generated during holidays and other off days to the grid at tariffs determined by OERC.

Table 5.36 presents the current benchmark solar tariffs under the solar policy.

Type Of Plant	Tariff
Utility Scale Plants	
Without Accelerated Depreciation	9.51 INR/kWh (for first 12 years) 6.81 INR/kWh (for next 13 years)
With Accelerated Depreciation	11 INR/kWh
Rooftop Solar Plants	-

Table 5.36 Solar Energy Installation in Odisha: Current Benchmark Tariff

The total installed capacity as on 31st March, 2016 by utilities is 78 MW and on roof top is 12 MW (Bridge to India).

Incentives and Subsidies

The possible business models for investors in solar energy are Feed in Tariff – Power Purchase Agreement, Open Access, REC, Captive Consumption, Rooftop / Net Metering. Table 5.37 presents the incentive and subsidy for investors.

Type Of Incentive	Exempted (Yes/No)	Amount Applicable	Further Info.(If Any)
Transmission Charges (INR/kWh)	No	0.0625	_
Wheeling Charges (INR/kWh)	No	CESU - 0.7382 NESCO - 0.8419 WESCO - 0.6476 SOUTHCO - 0.9405	-
Cross Subsidy Charges (INR/kWh)		CESU - 1.44 (EHT) & 0.786 (HT) NESCO - 1.32 (EHT) & 0.585 (HT) WESCO - 1.27 (EHT) & 0.66 (HT) SOUTHCO - 5.04 (EHT) & 1.29 (HT)	-
Wheeling Losses (%)	No	8.00%	-
Transmission Losses (%)	No	5.75%	-

Table 5.37 Solar Energy Installation in Odisha: Incentives and Subsidies

RPO Targets of Odisha

Table 5.38 presents the RPO targets of the state.

Year	2015-16	2016-17	2017-18	2018-19
RPO Target	0.50%	1.50%	5.00%	4.50%

Table 5.38 Solar Energy Installation in Odisha: RPO Targets

Additional Information

The PPA signatory for the state is Grid Corporation of Odisha. The responsibility of transmission will be of Odisha Power Transmission Corporation Limited. The responsibility for identifying land required for the project as per the state solar policy shall be with the developers.

5.3.11 Chhattisgarh

The state of Chhattisgarh is blessed with high global horizontal irradiance of 5.41 kWh/m2/day and high rainfall with capacity for large solar energy generation. Chhattisgarh has the potential to evolve as a major solar generation center in India.

The energy requirement of the state is 21,499 MU and the available energy is 21,230 MU. The state is energy deficit by 1.25%. At peak times, the power demand is 3,817 MW and the demand met is 3,638 MW. The peak power is deficit by 4.7%.

Chhattisgarh Solar policy

The Govt. of Chhattisgarh released the solar energy policy on 20th November 2012 and will be operative till 31st March 2017. This policy is aimed at achieving a target solar power generation capacity between 500MW to 1,000 MW by March 2017. Some of the incentives offered are:

- Exemption of VAT by the Commercial Tax Department for all equipment/materials required for solar power project.
- Charges for Open Access and losses shall be applicable as approved by the CSERC/central regulatory body for third party sale outside the state
- Wheeling and transmission charges as per CSERC regulations.
- Cross subsidy surcharge shall not be applicable for Open Access obtained for the Third Party Sale within the state subject to the industries maintaining their demand within the contracted range.
- Energy banking facility allowed at mutually agreed terms and wherever necessary approval of appropriate electricity regulatory commission shall be obtained.

Azure Power has commissioned 30 MW in Durg, Chhattisgarh; three months in advance of the contracted scheduled date. The power plant installation is divided into three phases of 10 MW each.

The state acknowledges Rooftop PV solar projects as an important emerging area and the state government will initiate a pilot project in association with Government of India. Incentives provided by MNRE will be made available to eligible project developers under the solar policy.

This policy is currently active and allocations are not accepted at this moment.

Table 5.39 presents the current benchmark solar tariffs under the solar policy.

Type Of Plant	Tariff
Utility Scale Plants	INR 7.74/kWh
Rooftop Solar Plants	_

Table 5.39 Solar Energy Installation in Chhattisgarh: Current Benchmark Tariff

The total installed capacity as on 31st March, 2016 by utilities is 103 MW and on roof top is 30 MW(Bridge to India).

Incentives and subsidies

The possible business models for investors in solar energy are Feed in Tariff – Power Purchase Agreement, Open Access, REC, Captive Consumption, Rooftop / Net Metering. Table 5.40 presents the incentive and subsidy for investors.

Type Of Incentive	Exempted (Yes/No)	Amount Applicable	Further Info.(If Any)
Transmission Charges (INR/kWh)	No	0.28	-
Wheeling Charges (INR/kWh)	No	0.24	A grant of 4% in terms of energy injected will be provided to developers
Cross Subsidy Charges (INR/kWh)	No	EHV - 0.89 HV - 1.18	-
Wheeling Losses	No	6.00%	-
Transmission Losses	No	4.20%	-
Transmission Charges (INR/kWh)	No	0.28	-
Wheeling Charges (INR/kWh)	No	0.24	A grant of 4% in terms of energy injected will be provided to developers

Table 5.40 Solar Energy Installation in Chhattisgarh: Incentives and Subsidies

RPO targets of Chhattisgarh

Table 5.41 presents the RPO targets of the state.

Year	2015-16	2016-17	2017-18
RPO Target	1%	-	-

Table 5.41 Solar Energy Installation in Chhattisgarh: RPO Targets

Additional Information

The PPA signatory for the state is Chhattisgarh State Power Distribution Company Ltd.

The responsibility of transmission will be of Chhattisgarh State Power Transmission Company Ltd.

The responsibility for identifying land required for the project as per the state solar policy shall be with the developers.

5.3.12 Jharkhand

Jharkhand offers good site with global horizontal irradiance of 5.23 kWh/m2/day and has close to around 300 sunny days. The state intends to harness it to support the energy requirement of state.

The energy requirement of the state is 7,599 MU and the available energy is 7,390 MU. The state is energy deficit by 5.75%. At peak times, the power demand is 1,075 MW and the demand met is 1,055 MW. The peak power deficit is 1.9%.

Jharkhand Solar policy

The state of Jharkhand recently notified its solar power policy in August 2015 and will remain in operation till the next five years or until any change comes in the recent document, whichever is recent. The minimum capacity of putting a MW scale project shall be 1 MW and for rooftop solar PV power plant at a single location shall be 1 KW. The state wishes to do 2,100 MW grid connected MW scale PV projects till 2020 and 500 MW of rooftop solar PV projects till the same time period. The state will allow business models like Sale to DISCOMs, Sale to third party via Open access and captive consumption under net metering. Till now although the state has not been active enough in putting any solar power plants. This policy is currently active and allocations are accepted at this moment.

Rooftop policy for Jharkhand

The state will encourage implementation of Rooftop solar PV power plants. The state shall promote deployment of solar PV power plants on the government organizations; government owned or aided hospitals, research/education institution, government residencies/colonies, etc. In addition to this, private institutions, commercial buildings will be encouraged to install Rooftop PV plant. The customer can install and operate the plant by captive consumption and injecting of surplus energy to grid or by sale of energy to DISCOM/Third Party. Eligible Developers are allowed to avail the relevant subsidies & incentives from MNRE under NNSM scheme. Table 5.42 presents the current benchmark solar tariffs under the solar policy.

Type Of Plant	Tariff
Utility Scale Plants	INR 7.97/kWh
Rooftop Solar Plants	_

Table 5.42 Solar Energy Installation in Jharkhand: Current Benchmark Tariff

No distinction has been made for projects that avail accelerated depreciation and projects that do not. The total installed capacity as on 31st March, 2016 by utilities is 18 MW and on roof top is 10.5 MW (Bridge to India).

Incentives and Subsidies

The possible business models for investors in solar energy are Feed in Tariff – Power Purchase Agreement, Open Access, REC, Captive Consumption, Rooftop / Net Metering. Table 5.43 presents the incentive and subsidy for investors.

Type Of Incentive	Exempted (Yes/No)	Amount Applicable	Further Info.(If Any)
Transmission Charges (INR/kWh)	No		
Wheeling Charges (INR/kWh)	No		The govt. of Jharkhand will provide a grant of 4% of wheeling charges in terms of energy injected.
Cross Subsidy Charges (INR/kWh)	No		Exempted for third-party sale required the source of power from the solar plant has to be in the state.
Wheeling Losses (%)			
Transmission Losses (%)			
Banking	Yes	Charges shall be adjusted in kind @ 2% of the energy delivered at the point of withdrawal	Permitted for all the Open access/ scheduled and captive consumers.
Electricity Duty	Yes	Will be exempted for 10 years from the date of commissioning	Source of power has to be from the solar plant within the state

Table 5.43 Solar Energy Installation in Jharkhand: Incentives and Subsidies

RPO Targets of Jharkhand

Table 5.44 presents the RPO targets of the state.

Year	2015-16	2016-17	2017-18	2018-19	2019-20
RPO Target	1.00%	1.50%	5.25%	5.25%	4.50%

Table 5.44 Solar Energy Installation in Jharkhand: RPO Targets

Additional Information

The PPA signatory for the state is Jharkhand State Electricity Board.

The responsibility of transmission will be of Jharkhand Bijli Vitran Nigam Limited.

5.3.13 Uttar Pradesh

The State of Uttar Pradesh is endowed with vast potential of solar power receiving global horizontal irradiance of 5.05 kWh/m2/day. The Government is keen to tap this resource to improve the availability of power in the State by promoting the establishment of solar energy

based power projects, both grid connected and off-grid type, so that the energy requirements of the state can be met.

The energy requirement of the state is 1,03,179 MU and the available energy is 87,062 MU. The state is energy deficit by 15.62%. At peak times, the power demand is 15,670 MW and the demand met is 13,003 MW. The peak power deficit is 17%.

Solar Policy for Uttar Pradesh

Uttar Pradesh is one of the states with good performance in solar generation. On one hand, the time frame of PPA being short can bring in developers; yet the solar targets being conservative could be an obstacle for the state – in reaching its RPO. This policy is currently active and allocations are not accepted at this moment.

Uttar Pradesh announced its policy in 2015. Under the state policy, 130 MW was allotted in August 2013 and PPA was signed for 110 MW in December out of which 42 MW is commissioned as of July 2015.

Uttar Pradesh Rooftop Policy

Uttar Pradesh announced its Rooftop Solar Policy in 2014 in order to implement grid connected rooftop solar photovoltaic power plants for captive or self-consumption on net energy metering/net energy billing mechanism. Rooftop Solar Photovoltaic Power Plants are proposed to be promoted under Net energy metering mechanism up to 50 KW and Net energy billing mechanism above 50 KW. The state has an objective of achieving 20 MW by FY 2016-17. Table 5.45 presents the current benchmark solar tariffs under the solar policy.

Туре	Year Of Commissioning				
	FY 14-15	FY 15-16	FY 16-17	FY 17-18	FY 18-19
New Solar large scale Grid Connected PV Projects	8.91	8.64	8.37	8.11	7.84
Total Tariff – Solar Rooftop New Projects (up to and including 50 KW)	15.71	15.28	11.85	11.43	11.00
Total Tariff – Solar Rooftop New Projects (more than 50 KW)	8.91	8.64	8.37	8.11	7.84

Table 5.45 Solar Energy Installation in Uttar Pradesh: Current Benchmark Tariff

The total installed capacity as on 31st March, 2016 by utilities is 122 MW and on roof top is 45.4 MW(Bridge to India).

Incentives and Subsidies

The possible business models for investors in solar energy are Feed in Tariff – Power Purchase Agreement, Open Access, REC, Captive Consumption, Rooftop / Net Metering. Table 5.46 presents the incentive and subsidy for investors.

Type Of Incentive	Exempted (Yes/No)	Amount Applicable	Further Info.(If Any)
Transmission Charges (INR/kWh)	No	0.13	-
Wheeling Charges (INR/kWh)	Yes	0.62	-
Cross Subsidy Charges (INR/kWh)	No	1.82	-
Wheeling Losses (%)	No	11 kV - 8.00% > 11 kV - 4.00%	-
Transmission Losses (%)	No	5.59%	
Banking	Yes	2% of energy banked on Financial Year Basis	Banking allowed for all project categories
Electricity Duty	No		

Table 5.46 Solar Energy Installation in Uttar Pradesh: Incentives and Subsidies

RPO targets of Uttar Pradesh

Table 5.47 presents the RPO targets of the state.

Year	2014-15	2015-16	2016-17
RPO Target	1.50%	1.75%	5.00%

Table 5.47 Solar Energy Installation in Uttar Pradesh: RPO Targets

Additional Information

The PPA signatory for the state is Uttar Pradesh Power Co-operation Ltd.

The responsibility of transmission will be of Uttar Pradesh Power Co-operation Ltd.

According to the policy, responsibility of acquiring the land is in control of the state government or its agencies.

5.3.14 Uttarakhand

Uttarakhand is richly endowed with natural renewable resources for generating electricity. The entire state on an average receives global horizontal irradiance of 4.98 kWh/m2/day. The Government of Uttarakhand wants to promote the harnessing of solar energy in the state to meet the energy requirements of the state.

The energy requirement of the state is 12,455 MU and the available energy is 12,072 MU. The state is energy deficit by 3%. At peak times, the power demand is 1,930 MW and the same is met by the state.

Uttarakhand Solar Policy

Uttarakhand is one of India's only hill states that have announced both policies for both utility scale systems as well as rooftop systems. The state had announced its utility scale policy in June, 2015. This policy is currently active and allocations are accepted at this moment.

Despite the inherent limitation of rough terrain and a lack of an investment climate, the state had floated 30 MW RfP in the month of August 2014 for procurement of solar power through tariff based competitive bidding. Many companies had participated in this bid with a wide range of proposed capacity. Like the previous state/ center bids, results of this bid is depicting almost same pattern. Lowest bid was relatively competitive, however, most of the successful bidder bids at a very close price.

In the bid, Redwoods Projects Pvt. Ltd was identified as most competitive bidder with a bid of 6.85 INR/kWh. Highest winning bid price 7.98 INR/kWh, was quoted by Asun Solar & Co. Maximum capacity was won by Madhav Infra Project (12 MW). UJVNL, a government body, had also won 5.864 MW capacity and Purshotam Ispat had won 4 MW (4*1) capacity. Table 5.48 presents the bids received during the process.

Company	Average	Bid Price	Bid Capacity
Redwoods Projects Pvt. Ltd	6.85 IN	R/kWh	2 MW
Advika Energies Energy (P) Ltd.	7.56 INR/kWh		1 MW
Purshotam Industries Ltd.	7.71 INR/kWh		1 MW
Bid Capacity		,	Tariff
Between INR 6 and 7/kWh			3
Between INR 7 and 8/kWh			11
Between INR 8 and INR 10/kWh			4

 Table5.48
 Solar Energy Installation in Uttarakhand: Bids received

In September 2015, Uttarakhand Renewable Energy Development Agency (UREDA) invited bids of projects for 170 MW at a minimum capacity of 100kW and a maximum of 50MW, under 25-year power purchase agreements (PPAs) with the state utility Uttarakhand Power Corporation Limited (UPCL). Table 5.49 presents the current benchmark solar tariffs under the solar policy. The total installed capacity as on 31st March, 2016 by utilities is 5 MW and on roof top is 12 MW(Bridge to India).

Type Of Plant	Tariff
Utility Scale Plants	
Without Accelerated Depreciation	INR 7.20/kWh
With Accelerated Depreciation	INR 6.60/kWh
Rooftop Solar Plants	
Without Accelerated Depreciation	INR 6.05/kWh

Table 5.49 Solar Energy Installation in Uttarakhand: Current Benchmark Tariffs

Incentives and Subsidies

The possible business models for investors in solar energy are Feed in Tariff – Power Purchase Agreement, Open Access, REC, Captive Consumption, Rooftop / Net Metering. Table 5.50 presents the incentive and subsidy for investors.

Type Of Incentive	Exempted (Yes/No)	Amount Applicable	Further Info.(If Any)
Transmission Charges (INR/kWh)	No	0.27	-
Wheeling Charges (INR/kWh)	Yes	0.23	A grant of 4% in terms of energy injected will be provided to developers
Cross Subsidy Charges (INR/kWh)	Yes	-	_
Wheeling Losses (%)	Yes	-	-
Transmission Losses	No	4.30%	
Banking	Yes	2% of energy banked on Financial Year Basis	Banking allowed for all project categories
Electricity Duty	Yes	0.00	
VAT	Yes	-	

Table 5.50 Solar Energy Installation in Uttarakhand: Incentives and Subsidies

RPO Targets of Uttarakhand

Table 5.51 presents the RPO targets of the state.

Year	2015-16	2016-17	2017-18
RPO Target	0.10%	1.50%	5.50%
_			

 Table 5.51 Solar Energy Installation in Uttarakhand: RPO Targets

Additional Information

The PPA signatory for the state is Uttarakhand Power Corporation Ltd.

The responsibility of transmission will be of Power Transmission Corporation of Uttarakhand Ltd.

The permission to use government land will be given to the developer at 5.5 hectare per MW and at a long term lease of 30 years. If the developer is buying a private land, they will be given 50% exemption on the stamp duty. For setting up solar plants on agricultural land, the developer will be exempted from paying any conversion fee.

5.3.15 Delhi

The Government of NCT of Delhi (GNCTD) considers solar power to be the most viable form of green energy in Delhi. With global solar irradiance of 5.01 kWh/m2/day, the state can easily lower the state's expenditure on energy by harnessing solar power.

The energy requirement of the state is 29,213 MU and the available energy is 29,106 MU. The state is energy deficit by 0.43%. At peak times, the power demand is 6,006 MW and the demand met is 5,925 MW. The peak power deficit is 1.3%.

Delhi Solar policy

In September, 2014, Delhi Electricity Regulatory Commission issued the DERC (Net Metering for Renewable Energy) Regulations, 2014 to promote use of Renewable Energy Generation for Self-Consumption. For effective implementation of these Regulations, the Commission has formulated guidelines elaborating minimum transformer level capacity that must be offered for connectivity, procedural requirements for obtaining connectivity, technical requirement of the Renewable Energy System, mechanism for billing, accounting adjustment (both in terms of net off as well as in financial terms). Under the Delhi Solar Energy Policy, 2015 announced in September 2015; the state aims to install 1,995 MW by the end of FY 2025. Table 5.52 presents the breakup of the target.

Fiscal Year	New Solar Energy (Mw)	Cumulative Solar Energy (Mw)
FY 16	35	35
FY17	84	119
FY 18	193	312
FY 19	294	606
FY 20	385	991

Fiscal Year	New Solar Energy (Mw)	Cumulative Solar Energy (Mw)
FY 21	285	1276
FY 22	228	1503
FY 23	187	1690
FY 24	161	1850
FY 25	145	1995

 FY 25
 145
 1995

 Table 5.52 Solar Energy Installation in Delhi: Breakup of the target

Along with a sound emphasis net metering, the state intends to promote a robust investment climate that enables multiple financial models, from self-owned (CAPEX) to third-party owned (RESCO) models. Also facilitate access to loans at preferential interest rates through various schemes that may be introduced from time to time, whether through public or private channels. This policy is currently active and allocations are not accepted at this moment.

Delhi Rooftop policy

The State shall promote the development of grid-connected solar plants on rooftops for meeting own electricity needs and injecting surplus electricity into the distribution grid. The customer can choose Group Net Metering or Virtual Net Metering. The State shall encourage implementation of grid connected solar plants to Government/public institutions, Commercial and Industrial establishments and Residential customers. All grid connected solar plants should comply with applicable CEA (Grid Standards) Regulations, 2013 and other applicable rules, regulations, and guidelines as amended from time to time.

Table 5.53 presents the current benchmark solar tariffs under the solar policy.

Type Of Plant	Tariff
Utility Scale Plants	
Without Accelerated Depreciation	INR 6.86/kWh
With Accelerated Depreciation	INR 6.20/kWh
Rooftop Solar Plants	—

 Table 5.53 Solar Energy Installation in Delhi: Current Benchmark Tariffs

The total installed capacity as on 31st March, 2016 by utilities is 5 MW and on roof top is 32 MW(Bridge to India).

Incentives and Subsidies

The possible business models for investors in solar energy are Feed in Tariff – Power Purchase Agreement, Open Access, REC, Captive Consumption, Rooftop / Net Metering. Table 5.54 presents the incentive and subsidy for investors.

Type Of Incentive	Exempted (Yes/No)	Amount Applicable	Further Info.(If Any)
Transmission Charges (INR/kWh)	Yes		There shall be no Open Access Charges during the Operative Period of the Policy if the solar electricity is generated and consumed within the State.
Wheeling Charges (INR/kWh)	Yes		There shall be no wheeling charges for solar
Cross Subsidy Charges (INR/kWh)	Yes		Period.
Wheeling Losses (%)	-		
Transmission Losses (%)	-		
Banking	Yes		There shall be no banking charges for solar plants commissioned during the Operative Period.
Electricity Duty	_		

Table 5.54 Solar Energy Installation in Delhi: Incentives and Subsidies

RPO Targets of Delhi

Table 5.55 the RPO targets of the state.

Year	2015-16	2016-17	2017-18
RPO Target	0.30%	0.35%	-

 Table 5.55 Solar Energy Installation in Delhi: RPO Targets

Additional Information

The PPA signatory for the state are state DISCOMS

- Tata Power Delhi Distribution Limited
- BSES Yamuna Power Limited
- BSES Rajdhani Power Limited
- NDMC New Delhi Municipal Council

The responsibility of transmission will be of Delhi Transco Limited.

This land procurement will be guided by the CERC guidelines. The Commission decided to retain the proposed land cost at Rs. 25 Lakh/MW (Rs. 5 Lakh/Acre * 5 Acre/MW) for Solar PV projects.

5.3.16 Haryana

The state is blessed with global horizontal irradiance 5.12 kWh/m2/day. The state also has more than 300 days of clear sunlight and seeks to harness the untapped and inexhaustible solar energy potential in the state.

The energy requirement of the state is 46,615 MU and the available energy is 46,632 MU. The state is energy deficit by 0.4%. At peak times, the power demand is 9,152 MW and the same is met by the state.

Haryana Solar Policy

The Haryana solar power policy was announced in 2014. According to the policy, the state shall require an installed capacity of 1,300 MW solar power plants till 2025. By March 2017, the State Renewable Energy Development Agency had intended to install 100 MW scale grid connected solar power in two phases. The first phase of 50 MW was announced in April 2014 but no projects have been commissioned yet. The government also announced another RfP for 150 MW in May 2015 which was scheduled to be commissioned by May 2016.

Since the state ran into several delays in its state scheme programs and due to this uncertainty in the policy the state was able to install a capacity of 15.8 MW only. This commissioned capacity was under various central policy schemes for solar PV, CSP and small solar PV rooftop plants. Hence the state Government announced a new policy with improved implementation schemes and a detailed approach. Haryana will be installing a total capacity of 3,200 MW till 2021-2022 to reach its RPO target of 8%. This policy is currently active and allocations are not accepted at this moment.

Haryana Rooftop Policy

The state will also generate solar power through installation of rooftop solar power plants in the State. Accordingly the installation of 1kWp to 1 MWp of capacity Grid connected & up to 50 KWp of capacity off-grid Solar roof-top Power Plants on the rooftops of Industries, Public and Private Institutes, Schools, Colleges, Commercial& Social Institutions/Establishments, Charitable Trust Bhawans, Hospitals and Residential Buildings etc. shall be promoted for their captive use/net meter as per the State Govt. Regulation. For installation of rooftop solar power plants the State Government shall provide capital /generation subsidy/ incentives. A capacity of 1600 MW rooftop solar power plants shall be added by the year 2021-25.

Table 5.56 presents the current benchmark solar tariffs under the solar policy.

Type Of Plant	
Utility Scale Plants	
Solar PV Crystalline – Levelized tariff (INR /kWh)	7.45
Solar PV Thin Film – Levelized tariff (INR /kWh)	7.20
Rooftop Solar Plants	
Levelized tariff (INR /kWh)	7.19

Table 5.56 Solar Energy Installation in Haryana: Current Benchmark Tariffs

The total installed capacity as on 31st March, 2016 by utilities is 24 MW and on roof top is 35 MW(Bridge to India).

Incentives and Subsidies

The possible business models for investors in solar energy are Feed in Tariff – Power Purchase Agreement, Open Access, REC, Captive Consumption, Rooftop / Net Metering. Table 5.57 the incentive and subsidy for investors.

Type Of Incentive	Exempted (Yes/No)	Amount Applicable	Further Info.(If Any)
Transmission Charges (INR/kWh)	No	0.29	-
Wheeling Charges (INR/kWh)	No	0.74	Including distribution losses i.e. 6%
Cross Subsidy Charges (INR/kWh)	No	5.02	-
Wheeling Losses (%)	No	0.0%	
Transmission Losses (%)	No	5.5% (intra-state)	
Banking	Yes	Banking facility allowed for a year by the licensees/utilities withdrawal of banked power should not be allowed during peak time of the day.	Banking allowed for MW scale power plant developers and rooftop grid interactive SPV developers.
Electricity Duty	No	-	-

Table 5.57 Solar Energy Installation in Haryana: Incentives and Subsidies

RPO Targets of Haryana

Table 5.58 presents the RPO targets of the state.

Year	2015-16	2016-17	2017-18
RPO Target	0.75%	1.00%	1.25%

 Table 5.58 Solar Energy Installation in Haryana: RPO Targets

Additional Information

The PPA signatory for the state is Haryana Power Purchase Centre.

The responsibility of transmission will be of Haryana VidyutPrasaran Nigam.

Panchayat lands will be made available for setting up to 50 MW solar plant capacity. The Panchayat lands will also be made available on lease and the farmers shall be paid as per the prevailing state policy. The bidders will be selected via reverse bidding on the basis of the maximum discount offered on the levelized tariff fixed by HERC.

5.3.17 Punjab

Punjab receives global horizontal irradiance of 5.05 kWh/m2/day, and has close to 300 days of clear sunlight. The state wants to make optimal usage of this available solar potential so that the energy demands of the state could be met.

The energy requirement of the state is 48,629 MU and the available energy is 48,144 MU. The state is energy deficit by 1.00%. At peak times, the power demand is 11,534 MW and the demand met is 10,023 MW. The peak power deficit is 15.1%.

Punjab Solar Policy

The state of Punjab announced its solar policy in December 2012 under the name of "New and Renewable source of Energy policy-2012". The policy includes solar, wind, biomass, hydro etc. wherein solar policy targets for 1,000 MW of solar installation till 2025. Following the announcement, Punjab Electricity Development Agency (PEDA) released an RfP for 300 MW as part of phase I of the policy. The power generated is sold on APPC/Open access mechanism. The 300 MW solar capacity is divided into two categories namely: newly incorporated and existing companies; in order to encourage entrepreneurship in the solar business. Table 5.59 presents the details of the eligibility criteria.

	Category 1	Category 2	
Eligibility	Newly incorporated/existing	Existing companies	
75 . 1 . 1	companies		
I otal Allotment	50 MW	250 MW	
Minimum Capacity	1 MW	5 MW	
Maximum Capacity	4 MW	30 MW	
Individual Project Size	Multiples of 1 MW	Multiples of 5 MW	
Technical QualificationNo prior experience in solar requiredShould have installed and comm least one single grid-connected p MW or higher, which is operation 1 year, anywhere in the world		Should have installed and commissioned at least one single grid-connected project of 5 MW or higher, which is operational for at least 1 year, anywhere in the world	
Financial Qualification			
Internal Resource	Not required	INR 75 Lakh/MW computed as 5 times the	
Generation(The formula	*	maximum internal resources generated during	

	Category 1	Category 2	
is given in the RfP)		the past 5 years	
Net Worth Criteria	INR 2 Crore/MW	INR 1 Crore/MW	
Annual Turnover	Not required	INR 3 Crore/MW for the past 3 years	
Table 5.59 Solar Energy Installation in Punjab: Eligibility Criteria			

The bid range announced in the RFP was quite high as compared to other states. Out of the 200 MW allocations, 139 MW projects in Phase I are already commissioned. As a part of Phase II of the Punjab solar policy the government invited proposals for 250 MW divided into 3 categories presented by Table 5.60.

	Category I	Category II	Category III
Eligibility	Newly incorporated/	Newly incorporated/	Newly incorporated/
	existing companies	existing companies	existing companies
Total Allotment	50 MW	100 MW	100 MW
Minimum Capacity	1 MW	5 MW	25 MW
Maximum Capacity	4 MW	24 MW	50 MW
Individual Project Size	Multiples of	Multiples of	Multiples of
	1 MW	5 MW	5 MW
Number of projects			
per bidder/company in	One	One	One
each category			

 y
 Image: Comparison of the second system

 Table 5.60 Solar Energy Installation in Punjab: Phase II Categorization

On June 2015, Punjab Energy Development Agency (PEDA) invited proposals for allocation of solar PV projects under Phase III of its state new and renewable policy for 500 MW. This Policy is currently active and allocations are not accepted at this moment.

Punjab Rooftop Policy

On 5th November, 2014 Government of Punjab launched its policy on net metering for grid interactive Rooftop Solar PV plants. Under this policy, all the consumers of state DISCOM are allowed to install Rooftop Solar plant ranging from minimum 1KWp to 1MWp (AC side). The maximum capacity of the plant shall not exceed more than 80% of the sanctioned connected load or contract demand of the consumer. To boost the number of installations, the consumer shall be exempted from banking and wheeling charges, losses, cross subsidy and additional surcharge etc. Table 5.61 presents the current benchmark solar tariffs under the solar policy.

Type Of Plant	Tariff
Utility Scale Plants	
Without Accelerated Depreciation	INR 7.04
With Accelerated Depreciation	INR 6.35
Rooftop Solar Plants	
Without Accelerated Depreciation	INR 7.04
With Accelerated Depreciation	INR 6.35

Table 5.61 Solar Energy Installation in Punjab: Current Benchmark Tariffs

The total installed capacity as on 31st March, 2016 by utilities is 367 MW and on roof top is 55 MW (Bridge to India).

Incentives and Subsidies

The possible business models for investors in solar energy are Feed in Tariff – Power Purchase Agreement, Open Access, REC, Captive Consumption, Rooftop / Net Metering. Table 62 presents the incentive and subsidy for investors.

Type Of Incentive	Exempted (Yes/No)	Amount Applicable	Further Info.(If Any)
Transmission Charges (INR/kWh)	No	LTOA/MTOA - 68,313 INR/MW/month STOA – 0.19 INR/kWh	
Wheeling Charges (INR/kWh)	No	LTOA/MTOA – 3,53,010 INR/MW/month STOA – 1.08 INR/kWh	
Cross Subsidy Charges (INR/kWh)	No	For Industry – 0.89 INR/kWh For Commercial - 1.07 INR/kWh	
Wheeling Losses (%)	Yes	66/33 kV - 5.03% 11 kV - 5.42%	
Transmission Losses (%)	Yes	220/132/66/33/11 kV - 5.5%	
Banking	Yes	The banking facility for the power generated shall be allowed for a period of one year by the PSPCL/LICENSEE/PSTCL.	The energy banked during non-paddy season and non-peak hours will not be allowed to be drawn during paddy season and peak hours respectively
Electricity Duty	Yes	100% exemption	-

Table 5.62 Solar Energy Installation in Punjab: Incentives and Subsidies

RPO Targets of Punjab

Table 5.63 presents the RPO targets of the state.

Year	2015-16	2016-17	2017-18
RPO Target	1.00%	1.30%	1.80%

Additional Information

The PPA signatory for the state is Punjab State Power Corporation Limited.

It is the responsibility of the bidder or project developer to obtain grid connectivity with PSPCL/PSTCL sub-station.

The Bidder / Solar Power Developer (SPD) can setup the Solar PV projects on Panchayat Lands/Private lands on lease hold basis. The bidders are required to submit the land documents in the form of registered land deed /registered lease agreement in the name of the bidding company / SPD.

5.4 International Best Practices

It is important for India to imbibe a global clean energy deployment pathway and learn from those countries that are in the advanced stages of implementation of their Solar PV power projects and other renewable goals. In this regards, this section specifically examines following policy interventions and/or business models:

5.4.1 Utility Based Policy Interventions

Virtual Net Metering

In multi-tenant building with individual electric meters for each tenant, there were difficulties installing distributed solar PV systems because of the problem of assigning the benefits of the generation to each occupant. A system could easily be connected to a common area load or to an individual tenant, but if it was connected directly to multiple loads, there would be no way of ensuring equitable distribution of the generation. Some tenants would benefit more than others. Installing multiple systems, one for each tenant or load in the building, is cost prohibitive.

Virtual Net Metering allows the tenants and owner to install a single solar system to cover the electricity load of both common and tenant areas connected at the same service delivery point. The electricity does not flow directly to any tenant meter, but rather it feeds directly back onto the grid. The participating utility then allocates the kilowatt hours from the energy produced by the solar PV generating system to both the building owners and tenants' individual utility accounts, based on a pre-arranged allocation agreement. The intent of Virtual Net Metering is to help low income multifamily residents receive direct benefits of the building's solar system, rather than all of the benefits going to the building owner (Figure 5.4).



Figure 5.4: Flow chart for Virtual Net Metering

Group Net Metering

Group net metering, simply put, allows the value of surplus power to be shared with other electric utility account holders. The best example is a company that has two buildings with two separate meters: a storage facility with great potential for solar but that uses little energy and a factory with little solar potential but a big electric bill. Now the two buildings (and more importantly the two meters) can share in the benefit of Group net metering, meaning the building with more energy requirement (i.e. industry) can use the energy generated by the storage facility.

Utilities are required to allow customers to use group net metering. All the customers and the solar array availing group net metering benefit have to be connected to the same utility. The credit sharing for the energy generated from the array depends on specifics of the group arrangement. If the array is connected through the account of one of the group members, then the net metering credit is first applied exclusively to that account. If there is credit remaining after that account has been fully covered for the month, then that surplus credit is shared out among the other group members. Customers using this arrangement are allowed to share credit between family members, say where the trackers are installed in the field of one of the family members. If instead, the array directly connects to the utility grid, then pretty much all of the credit generated is surplus, and it is all available to be shared among the group members. This concept is generally followed for Solar Parks (Figure 5.5).



Figure 5.5: Flow chart for Group Net Metering

Delhi was the first state in India, which has announced both Virtual and Group Net metering. This announcement was made in Delhi Solar Policy-2015. The state will mandate deployment of solar plants with net metering on all the existing/upcoming government organizations. The state will also encourage Commercial and Residential customers to install solar plants with net metering. The state will offer a limited-time Generation Based Incentive to Domestic /Residential Customers of 2 INR/kWh from 1st January 2016 to 31st December 2018. The customers shall be exempted from paying Electricity Duty, Open Access charges, VAT, Entry Tax, Wheeling charges and Banking charges. Despite of such attractive policy, the real implementation of both Group net and Virtual Metering is yet to start. The State government is to work with DERC to approve Group Net Metering for non-government customers and Virtual Net Metering for all customers by 1st April 2017.

For India to achieve its rooftop target of 40 MW by 2022, it is imperative for the states to adopt and implement such attractive policies.

5.4.2 Utility-based Business Models

Utility involvement in the solar rooftop market was initially limited to being a facilitator. The Utility mainly provides the broad framework for gross/ net metering and interconnections. Some Utilities also retail solar PV systems and provide system rebates, but this is limited to Municipal Utilities. However, a growing number of Investor-owned Utilities have recently taken up a more active role in encouraging the development of solar rooftop installations due to a number of developments in the market.

The Utility business model is undergoing the most significant change since its development. Utilities, which were used to operating in a very benign environment have now had to face a more uncertain future due to a number of technological and economic developments like falling costs of distributed energy generation technologies; increasing Customer, regulatory, and political interest in demand side management (DSM) technologies and climate change considerations.

New disruptive technologies (solar PV, battery storage, fuel cells, etc.) are today becoming more and more competitive with Utility based energy services. As their cost curves improve, these technologies will force Utilities to change the way they deliver energy. Keeping the impact of disruptive technologies like rooftop solar in mind, the Utilities have also started working towards active participation in these emerging segments. Utility-based solar business models have started emerging wherein Utilities are now actively involved in innovating on the rooftop business model front in order to capture value from these solar markets. The Utilities involvement in the solar PV rooftop business model space has been limited to four broad areas which have been highlighted in below:

a.) Utility Ownership

Utilities are becoming more and more aggressive in owning rooftop systems as it allows them to claim tax credits and at the same time ensure that they make a healthy rate of return on the power generated from these installations while also ensuring that Consumers with rooftops do not transit out (partially or fully) of the Utility's eco-system.

A number of Utilities ranging from San Diego Gas and Electric, Southern California Edison to Western Massachusetts Electric Company (WMECO) are aggressively developing rooftop installations on customer sites.

Ownership of solar PV assets by the Utilities has been pioneered by Utilities like Southern California Edison, Duke Energy and Arizona Public Service. The overriding reason behind this model is the regulated rate of return that is available for these Utilities for the capital investment in rooftop installations.

b.) *Utility Financing*

Another route in which Utilities are encouraging the deployment of solar rooftop installations is by financing Consumers. Utility and public financing programs have been launched by a number of Utilities and Local Governments across the United States to facilitate adoption of solar PV. These financing options aim to address two broad aims of (a) covering Rooftop Owners who do not have access to traditional financing options (self/ Third Party) and (b) enhancing affordability of systems by reducing interest rates and upfront fees and relaxing lending guidelines. Two broad types of loans are available through Utility-based financing: (i) Utility Loans: These are loans which are targeted at Utility Customers and administered by the Utility at the local, municipal or the state level. These programs are structured so as to be either cash flow positive or neutral, in order to make electricity savings equal to or greater than the cost of the loan. Utility loans are either linked to the Consumer (bill financing) or linked to the property (meter secured financing).

(ii) Revolving Loans: Revolving loans finance Rooftop Owners directly through public sources such as appropriations, public benefit funds, alternative compliance payments, environmental noncompliance penalties, bond sales or tax revenues. Rooftop Owners prefer these as they come at low interest rates, have relaxed lending guidelines and extended tenors. The Montana Alternative Energy Revolving Loan Program is one such example.

c.) *Community-shared or Customer programs*

Community Share Solar programs provide Energy Consumers the option of utilizing the benefits of solar generation without actually installing on-site renewable generation or making high upfront payments required for the development of such projects. These plants are usually set up by Community-owned Utilities or Third Parties in partnership with Investor-owned Utilities.

They provide options for Customers to participate in and receive proportional benefits through virtual net metering or fixed price contracts. The Community Share program allows Utilities to develop larger program and projects while providing expanded options to more Customers at lower costs. The key challenge in this approach remains the need to ensure a compelling value proposition to Consumers. The broad outline of a community shared solar project model has been highlighted below.



Figure 5.6 Community owned business model

The advantage of community-based solar rooftop models for the communities is that they avoid the need to assess feasibility of solar rooftop installations, develop these installations and then monitor operation and maintenance. The community members who sign up for these projects receive solar benefits without paying upfront capital cost, installation or the O&M.

d.) *Energy Purchases*

A number of Utilities are also entering the market with the objective of procuring energy directly from Third Party or Rooftop Owners by offering feed-in tariffs. The use of energy purchases allows the Utilities to buy all the energy generated by the rooftop at a flat price under a long term power purchase, the cost of which is passed onto the consumers as part of its annual revenue requirements while at the same time retaining the Customers on whose rooftops these systems have been set up.

5.4.3 Key Challenges and Considerations

While the Indian Power Sector provides a number of opportunities for a host of Developers/ Investors to come in and develop business models, however business model design and implementation in India still remains a challenge, especially for Third Party Developers who want to bring in greater scale and efficiency into the rooftop development market. Solar rooftop projects suffer from a number of commercial, policy and regulatory, technical and financing challenges which are being addressed as the market grows. However there is still a concerted effort required from Policy-makers, Regulators, Financers and above all the Utilities and the Developer community for all of these challenges to be appropriately addressed and the market to scale up.

Following are some of the key challenges associated with solar PV rooftop business model design:

a.) **Contract Sanctity:** One of the major challenges that Developers face in the Indian market are those related to contract sanctity. This essentially means according due recognition to the contractual framework which embodies the understandings between parties with appropriate legislative and legal back up in order that the protection of rights of any of the parties and enforceability are not eroded or taken away. Third Party Developers have to enter long term contracts with Rooftop Owners which are mostly backed up by Letters of Credit for one month's billing and with limited long term payment security.

Contracts need to be easily enforceable, provide remedies for payment defaults, and buy out clauses/ appropriate compensation framework in case of building redevelopment or relocation. The Developers as well as the financial institutions need to champion the development of these frameworks.

b.) Availability of Financing (especially project financing) and capacity of Financial Institutions to evaluate rooftop projects: Access to project financing and consumer financing is one of the key requirements for scale up the solar rooftop sector. Banks and Financial Institutions are still in the process of putting in place consumer financing products (loans) and guidelines which allow access to debt for Rooftop Owners. In case of Third Party Developers, especially in the commercial and industrial space, banks and financial institutions still lack appropriate tools and expertise to evaluate these projects especially from a long term risk perspective. As new business models come into the market, Banks and Financial Institutions will have to also increase their capacity to analyze and finance these models.

c.) *Solar Equipment Leasing*: One of the key fiscal incentives used to bring down the cost of solar in markets like the United States is of depreciation or accelerated depreciation (AD) in the case of India. However many Developers use new Special Purpose Vehicles (SPV) for developing projects which in turn are unable to leverage this incentive mechanism due to no profits in new SPVs. The AD benefit can be utilized through Investors who have book profits and this would require these Investors owning the equipment and leasing the same to Rooftop Owners and Developers. These Investors would then be eligible for Accelerated Depreciation on the investment upfront.

While this does provide upfront relief in terms of lower costs, the Developers/ Rooftop Owners leasing the equipment need to pay a service tax (14 percent) on the leased rental. The Net Present Value of the Service Tax paid by the Developer turns out to be higher than the tax savings from AD (for the Investor to make a 16% return on investment).

d.) **Rooftop Leasing**: Access to the rooftops for the life of the solar rooftop project remains another key challenge. A number of situations may arise where the Developer may not have access to the rooftop for the full life of the project due to either reconstruction or expiry of the lease. Most private sector institutions have leases which run up to 10 years and developing rooftop projects on buildings with 10 year leases becomes risky in case the building owner does not agree to become a part of the solar PV rooftop power sale and lease agreement and continue with the agreement with the new tenants once the building lease with the present ones is over.

In other cases Rooftop Owners are skeptical about leasing the rooftops for 25 years as they might want to construct more floors or in some cases reconstruct the whole building. This case has come to light in the New Delhi area where a number of institutions are not ready for rooftop solar despite a very competitive tariff and adequate space for rooftop systems have not agreed to the development of these systems.

e.) **Role of Utilities:** challenges and facilitation required: One of the biggest challenges facing the solar rooftop space is the limited capacity of the Utilities in understanding the solar PV rooftop space including the business models as well as developing a framework for their deployment. Interconnection process is slowly being specified and in some case is long and

cumbersome allowing only a few Contractors/ Developers to commission projects creating oligopolies.

A need exists for streamlining the interconnection process, making this time bound and transparent with a focus on achieving required quality standards. Utilities also need to be provided performance parameters for interconnection processes, which make them liable for ensuring time bound implementation. One example of where this is being attempted is the case of BESCOM in Karnataka where an open sourcing framework has been developed and Developers need to adhere to national and international standards while deploying systems and interconnecting them to the grid.

f.) *Match between incentive mechanisms and needs of the market:* The policy makers and regulators have chosen the net metering framework for promoting solar PV rooftop development in India. While this framework has a number of advantages, three basic disadvantages it suffers from are: (1) rooftop projects become attractive only for the commercial and industrial sector as these two pay the highest consumer tariffs, (2) Utilities end up losing their high-paying Customers, and (3) development of solar rooftop projects is not based on the optimal utilization of rooftop space.

The focus on Net Metered Consumers leaves out a large number of Consumers like schools, hospitals, and storage facilities etc. which have large rooftop space but do not have the financial justification of adopting net metered solar rooftop business models. A regulatory framework needs to evaluate the target market and reach of the business models which can work and aim for optimal rooftop utilization and penetration.

5.4.4 International Best Practices: Few Examples

- 1. To encourage Americans to use solar power, the Environmental Protection Agency and the Department of Energy runs the Energy Star program, which, among other projects, offers tax credits for solar-powered systems.
- 5. If a customer installs 'Energy Star-approved' solar-power systems before the end of 2016, they can claim 30% of the cost as a tax credit for the year they installed it. As a credit, they can take the amount directly off their tax payment, rather than a deduction from the taxable income. The federal tax credit is a one-time credit but it may be carried forward (and possibly back) if not completely usable in the system installation tax year. One can claim the credit for their primary residence, a vacation home and for either an existing structure or new construction. Other than the cost of the system, there's no limit to the dollar amount of the credit. Other than tax credits, various other schemes provide upfront incentive for Rooftop systems varying from 1 \$/Watt to 5.80 \$/Watt rebate, which results in 20-50% reduction of landing cost of the system. Say, for California, the

residential sector would be provided with an incentive of 1.25 \$/Watt for installing a Solar PV system on their Rooftop. (Anaheim Public Utilities - PV Buydown Program)

- 5. 'SolarCity' is one of the largest solar lease companies operating in the United States. SolarCity provides residential solar leases, which are financed by Financial Institutions like Morgan Stanley, Equity Investors who claim the Income Tax Credit (ITC) and depreciation benefits. SolarCity offers its Customers a variety of lease structures, including zero down payment options. The lease payments cover the cost of the system and the cost of monitoring, maintenance, and repair, including inverter replacement, if necessary. SolarCity also guarantees a minimum level of electricity output (in kilowatthours) from the rooftop PV system.
- 4. San Diego Gas & Electric's (SDG&E), under its Sustainable Communities Programme encourages development of solar rooftop installations, owned by them and installed on leased rooftops of customers. The systems installed at customer sited rooftops are installed, owned, maintained and operated by SDG&E. SDG&E is also responsible for the design, installation and maintenance work which is usually contracted out. The rooftops of the participating consumers are leased by SDG&E, generally for 10 years, with a possibility of two five-year extensions. The rooftop systems are connected to the utility-side of the meter and the electricity flows right into the grid using a gross metering format. The customer does not earn any energy credits nor is there a decrease in their bill. However, the Rooftop Owners can use the presence of the rooftop systems for obtaining 'Leadership in Energy and Environmental Design' (LEED) credits. SDG&E obtained permission for a US\$ 4.3 Million investment from the regulators.
- 5. An on bill financing was offered by Powder River Energy Corporation of Wyoming to its Residential Customers wherein they could take loans up to US\$ 2500 at a 0% rate of interest and repay the loan by up to 36 months. The Public Service Electric and Gas Company (PSE&G) of New Jersey also offers utility-based loans at 6.5% for up to 10 years and covers around 40% to 60% of the installed system cost. The solar system owner also has the option of repaying the loan by signing over solar renewable energy certificates to PSE&G.
- 6. In 2010, 'Colorado Utilities' the Municipal utility serving the city of Colorado offered its customers the chance to invest in community solar gardens. Under this scheme, the customers could lease panels from one of two community Solar Project Developers, Sunshare or Clean Energy Collective with a minimum solar garden interest of 0.4 kW. All customers who subscribed to the program received a fixed credit of \$0.09 /kWh on their electric bill for their share of the power generated by the panels they had leased. The consumers could either lease or purchase panels at varying rates depending on the project. The pilot run by the program was for 2 MW of installations. As of October 2012, the utility had 288 residential and 1 education consumers participating in its

program and has a pipeline of another 51 residential and 3 educational consumers waiting to be connected.

- 7. Gainesville Regional Utilities' (GRU), a municipal Utility in Florida, offers a FIT as an alternative to the rebate programme. As a result of the FiT, GRU does not lose Utility Customers as it would have in a net metered programme, rebates can be spread over longer periods (five or ten years) instead of being offered up-front, the contracting is actually performance-based which in turn provides a greater leverage than the rebate programmes. This mechanism provides a very transparent yet simple mechanism for the purchase of both solar generated power and the accompanying renewable energy credits.
- 8. In Germany incentive are provided in form of Feed-in tariffs. These tariff decrease in regular intervals to exert cost pressure on energy generators and technology manufacturers. The decrease (called "degression") applies to new plants. Thus, it is hoped, technologies are becoming more efficient and less costly. Germany also provides grid Feed-in tariffs incentive to every company involved in the renewable energy generation business, especially for small and medium-sized energy firms This encourages them to invest in developing and generating renewable energy systems, to decrease initial market entry barrier for these businesses, and to reduce the costs of renewable energy systems for production and consumption over a period of time.

5.5 Applicability in Indian Market & Recommendations

Based on our study of existing policies and business models and international best practices, we found the following recommendations applicable for India:

Stringent check on RPO targets

Although the solar deployment in India has progressed with considerable pace in the last few years, it is found that the RPO implementation has been inadequate. The demand for solar power plants is largely a function of adherence to RPO by obligated entities. It is therefore imperative that the RPO targets are strictly enforced by the respective State Electricity Regulatory Commissions (SERC). This non-compliance to RPO targets is reflected in the poor demand for Renewable Energy Certificates (REC).

Adoption of reverse bidding for project allocation

Reverse bidding for solar project allocations have been very successful in bringing down the cost of solar power through competitive market dynamics. It has also increased transparency and provided a level playing field for any developer that intends to enter the Indian solar market. Some states such as Tamil Nadu have not adopted reverse bidding. This has led to a higher purchase price of solar energy on behalf of the government and has also unfairly favoured certain parties. It is therefore recommended that all solar allocations in India be conducted via reverse bidding.

Implementation of Virtual and Group net metering

Delhi was the first state in India to announce Virtual and Group net metering in 2016. However the implementations of these schemes have not yet begun. Virtual and Group net metering are a perfect solution in India's crowded urban centers. Most of Indian cities are vertical in nature because of which rooftop space availability is severely limited. Group net metering allows residential societies and high-rise apartments to set up a common solar power plant and share the benefits. This is an effective way to accelerate rooftop solar deployment in India in order to meet the ambitious goal of 40 GW.

Disbursement of capital subsidy for rooftop market

Currently the Ministry of New & Renewable Energy (MNRE) offers 30% upfront capital subsidy for rooftop solar installations on institutional and residential buildings. This subsidy is channelized through a system of authorized channel partners in coordination with the state nodal agencies. It is found that this process has led to an increase in prices for the end consumer and unwanted delays. It is therefore recommending that the MNRE develop a mechanism to disburse subsidy on a running basis (ex. GBI) or directly transfer the subsidy to the end user. The government may draw parallels to the LPG subsidy that is directly transferred to the beneficiary's bank account.

Utility owned business model

One of the major hindrances to the deployment of solar systems (especially rooftop) is the resistance from the utility company. Solar power represents a threat to the utility's traditional business model since it reduces the revenues for the company. This is where utility owned business models ensure that utility's interests are protected while deploying solar systems across the country. Utilities can be involved in promoting rooftop solar similar to National LED Programme (UJALA Scheme).

Appendix- 5A

State	Discom	Wheeling Losses		
	UGVCL	Injection Point	11kV	400 V
GUJARAT	PGVCL	Drawl Point		
	MGVCL	11,22 & 33 kV	10%	15.98%
	DGVCL	400 V	-	9.55%
		Injection Point	ΗT	LT
		Drawl Point		
	BESCOM	HT - 5.3/4.6/11 kV & 50 kW	5.68%	11.92%
		LT - 400V 3 Phase or	11.020/	0.240/
		230V 1 Phase	11.9270	0.2470
		Injection Point	ΗT	LT
		Drawl Point		
		HT - 5.3/4.6/11 kV & 50 kW	4.36%	9.91%
	MESCOM			
		LT – 400V 3 Phase or 230V 1 Phase	9.91%	5.61%
KARNATAKA				
		Injection Point	ΗT	LT
	HREC	Drawl Point		
		HT - 5.3/4.6/11 kV & 50 kW	6.72%	15.35%
		LT – 400V 3 Phase or 230V 1 Phase	15.35%	6.62%
	HESCOM	Injection Point	ΗT	LT
		Drawl Point		
		HT - 5.3/4.6/11 kV & 50 kW	5.90%	15.15%
		LT – 400V 3 Phase or	15 150/	0.240/
		230V 1 Phase	13.1370	9.2470
	GESCOM	Injection Point	ΗT	LT
		Drawl Point		
		HT - 5.3/4.6/11 kV & 50 kW	7.80%	15.06%
		LT - 400V 3 Phase or	15.06%	7 26%
		230V 1 Phase	15.0070	7.2070
		Injection Point	ΗT	LT
	CESC	Drawl Point		
		HT - 5.3/4.6/11 kV & 50 kW	5.77%	11.80%
		LT - 400V 3 Phase or	11 80%	8.03%
		230V 1 Phase	11.0070	0.0070
		Injection Point	33 kV	11 kV
TELANGANA	TSNPDCL TSSPDCL	Drawl Point		
		33 kV	4.00%	8.06%
		11 kV	8.06%	8.06%

References

- Ministry of New and Renewable Energy, http://www.mnre.gov.in/
- Solar Energy Corporation of India Limited, http://www.seci.gov.in/
- MNRE Best Practices Manual for Implementation of State-Level Rooftop Solar Photovoltaic Programmes In India.
- Bridge to India,2016 : India Solar Handbook 2016, available at http://www.bridgetoindia.com/
- Rajasthan Renewable Energy Corporation Limited (RRECL): Rajasthan Solar Policy, available at http://www.rrecl.com/Index.aspx
- Gujarat Energy Development Agency: Gujarat Solar Policy, available at http://geda.gujarat.gov.in/
- Madhya Pradesh New & Renewable Energy Department: Madhya Pradesh Solar Policy, available at http://www.mpnred.com/Home/Index.aspx
- Maharashtra Energy Development Agency: Maharashtra Solar Policy, available at http://www.mahaurja.com/
- Karnataka Renewable Energy Development Ltd.: Karnataka Solar Policy, available at http://kredlinfo.in/
- Tamil Nadu Energy Development Agency: Tamil Nadu Solar Policy, available at http://teda.in/
- Agency for Non-conventional Energy and Rural Technology: Kerala Solar Policy, available at http://www.anert.gov.in/
- 15. New & Renewable Energy Development Corporation of Andhra Pradesh Ltd.: Andhra Pradesh Solar Policy, available at http://nredcap.in/Default.aspx
- 15. Telangana New & Renewable Energy Development Corporation Ltd.: Telangana Solar Policy, available at http://tnredcl.telangana.gov.in/SolarEnergy.aspx
- 14. Odisha renewable Energy Development Agency: Odisha Solar Policy, available at http://www.oredaodisha.com/
- 15. Chhattisgarh Renewable Energy Development Agency: Chhattisgarh Solar Policy, available at http://www.creda.in/
- 16. Jharkhand Renewable Energy Development Agency Ltd: Jharkhand Solar Policy, available at http://www.jreda.com/
- 17. Uttar Pradesh New & Renewable Energy Development Agency: Uttar Pradesh Solar Policy, available at http://www.upneda.org.in/
- 18. Uttarakhand Renewable Energy Development Agency: Uttarakhand Solar Policy, available at http://www.ureda.uk.gov.in/
- 19. Department of Environment, Delhi: Delhi Solar Policy, available at http://www.delhi.gov.in/wps/wcm/connect/Environment/environment/home

- 20. Department of Renewable Energy, Govt. of Haryana: Haryana Solar Policy, available at http://hareda.gov.in/
- 21. Punjab Energy Development Agency: Punjab Solar Policy, available at http://www.peda.gov.in/main/
- 25. Singh and Mitra, undated: Singh V.V. and Mitra S., Regulatory Management and Reform in India, Background Paper for OECD, undated.