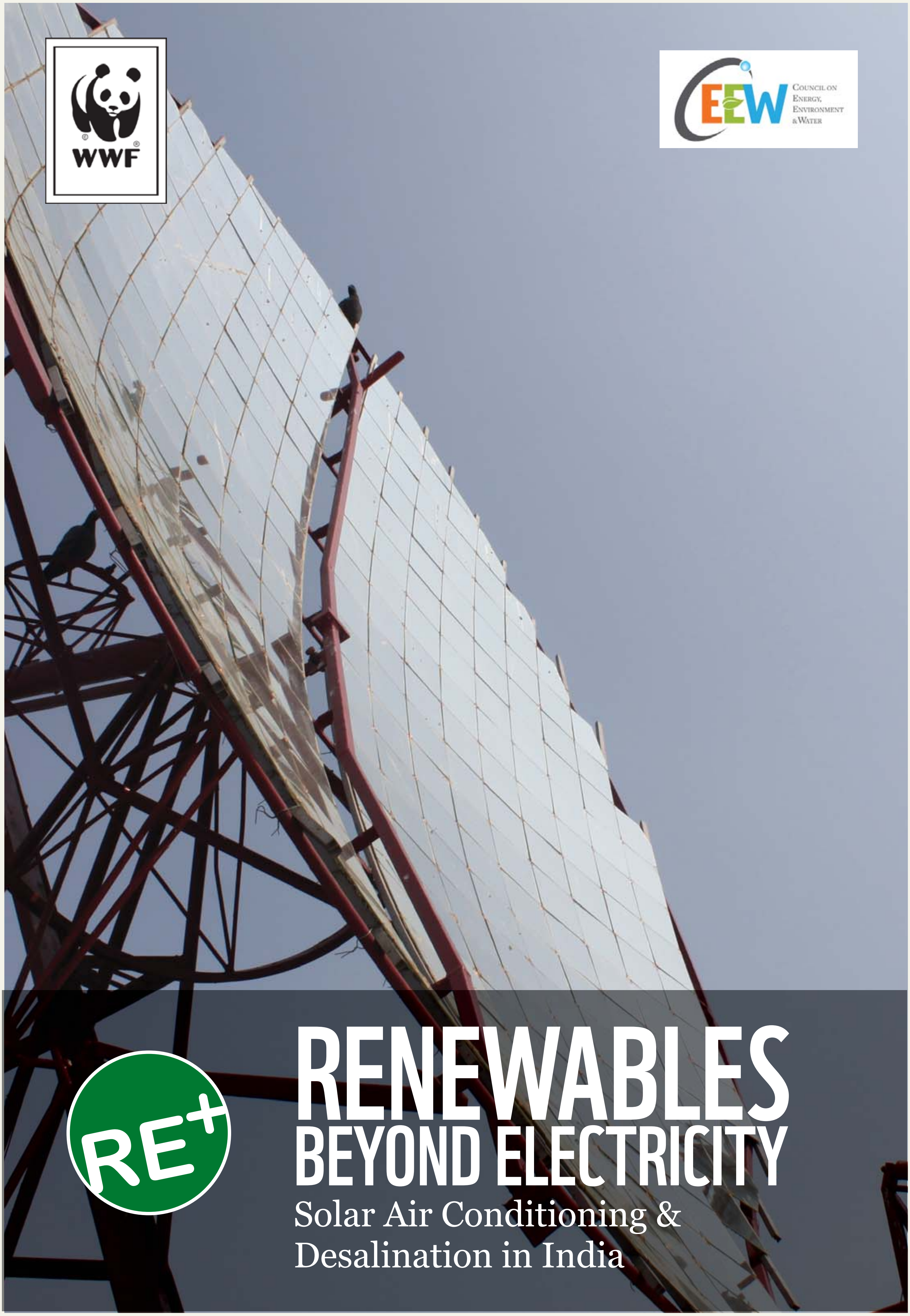

RENEWABLES BEYOND ELECTRICITY

Solar Air Conditioning & Desalination in India

Published by WWF- India and CEEW

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RENEWABLES BEYOND ELECTRICITY

Solar Air Conditioning & Desalination in India

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ACRONYMS AND ABBREVIATIONS

AC	Alternating Current
AHU	Air Handling Units
BARC	Bhabha Atomic Research Centre
BEE	Bureau of Energy Efficiency
BIS	Bureau of Indian Standards
BWRO	Brackish Water Reverse Osmosis
CCGT	Combined Cycle Gas Turbine
CEA	Central Electricity Authority
CEFC	Clean Energy Finance Corporation
CFA	Central Financial Assistance
COP	Coefficient of Performance
CSE	Centre for Science and Environment
c-Si	Crystalline Silicon
CSMCRI	Central Salt and Marine Chemicals Research Institute
CSP	Concentrated Solar Power
CSR	Corporate Social Responsibility
CST	Concentrated Solar Thermal
DC	Direct Current
DNI	Direct Normal Irradiation
DPR	Detailed Project Report
ECBC	Energy Conservation Building Code
ED	Electrodialysis
ESTIF	European Solar Thermal Industry Federation
ETC	Evacuated Tube Collectors
ETHP	Evacuated Tube Heat Pipe
FORRAD	Foundation for Rural Recovery and Development
FPC	Flat Plate Collector
GEDA	Gujarat Energy Development Agency

GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GoI	Government of India
GRIHA	Green Rating for Integrated Habitat Assessment
HVAC	Heating, Ventilation, and Air Conditioning
IGBC	Indian Green Building Council
IIT	Indian Institute of Technology
INCCA	Indian Network on Climate Change Assessment
InDA	Indian Desalination Association
INR	Indian Rupees
IPCC	International Panel on Climate Change
ITI	Industrial Training Institute
JNNSM	Jawaharlal Nehru National Solar Mission
KACST	King Abdulaziz City for Science and Technology
Kg	Kilogram
kW	Kilo Watt
LFR	Linear Fresnel Technology
LPD	Litre Per Day
LPG	Liquefied Petroleum Gas
MED	Multi-Effect Distillation
MEESE	Multiple Effect Evaporation with Solar Energy
MEH	Multi-Effect Humidification
MGD	Milion Gallons per Day
MNRE	Ministry of New and Renewable Energy
MoEF	Ministry of Environment & Forests
MSF	Multi-Stage Flash
Mt	Million Tonnes
MVC	Mechanical Vapour Compression
MW	Megawatt
NABARD	National Bank for Agriculture and Rural Development
NBC	National Building Code
NGO	Non-Governmental Organisation
NIOT	National Institute of Ocean Technology
O&M	Operation and Maintenance
ppm	Parts per million

PV	Photovoltaic
R&D	Research and Development
RE	Renewable Energy
REEEP	Renewable Energy and Energy Efficiency Partnership
RO	Reverse Osmosis
SAC	Solar Air-Conditioning System
SD	Solar Distillation
SEC	Solar Energy Centre
SVNIT	Sardar Vallabhbhai National Institute of Technology
SWCC	Saline Water Conversion Corporation
SWH	Solar Water Heating
SWRO	Seawater Reverse Osmosis
TDS	Total Dissolved Solids
TERI	The Energy and Resources Institute
TR	Tons Refrigeration
TVC	Thermal Vapour Compression
UAE	United Arab Emirates
UHCPV	Ultra-High Concentrator Photovoltaic
USA	United States of America
VAM	Vapour Absorption Machines
VC	Vapour Compression

CHAPTER 1

INTRODUCTION

With a significant and sustained economic growth in recent years, India now ranks fourth in the world in terms of primary energy consumption (USEIA, 2013). However, despite the overall energy demand and capacity augmentation, nearly 306 million Indians do not have access to electricity (IEA, 2013a). Presently, India's energy demand is primarily met through fossil fuels like coal, gas and oil (Planning Commission, 2012), with a substantial amount of these fuels being imported. India's fuel imports have been rising considerably over the last few years. For instance, coal import has doubled between 2010 and 2012 (68.9 Mt in 2010-11 and 145.8 Mt in 2012-13), resulting in broadening of the country's financial deficit (MoC, 2014). Increased reliance on fossil fuels means enormous costs in the form of subsidies and increased import dependence.

Thus, there is an urgent need for speeding up growth and large-scale deployment of renewable energy technologies in order to address India's energy security needs, bring down greenhouse gas (GHG) mitigation and moving towards low carbon development pathways. This critical issue has also been acknowledged by the Prime Minister's Council on Climate Change in the *National Action Plan on Climate Change* (MoEF, 2008). This can be gauged by the fact that a dedicated mission (Jawaharlal Nehru National Solar Mission) has been introduced in the action plan to promote renewable energy (solar) in India (MoEF, 2008). Under the aegis of the programme, India plans to deploy 20,000 MW of grid connected and 2,000 MW of off-grid solar power capacity by 2022. In addition, the programme targets to achieve 20 million m^2 of solar thermal collectors by the end of the final phase of the mission in 2022 (MNRE, n.d.[e]).

Being a tropical country, India has great potential for the effective use of solar energy. Most parts of India have between 300 and 330 sunny days in a year (equivalent to over 5,000 trillion kWh per year of energy), which can be harnessed through heat and electricity (MNRE, n.d.[a]). Likewise, several other renewable energy sources also have significant potential in India for power generation – wind (48,500 MW (MNRE, n.d.[b]) at 50 metres height and

1,02,788 MW at 80 metres height), small hydro (15,000 MW) (MNRE, n.d.[c]), biomass (23,000 MW[1]) (MNRE, n.d.[d]).

306 million

INDIANS DO NOT HAVE ACCESS TO ELECTRICITY

A report published by WWF-India and TERI, The Energy Report India – 100% Renewable Energy by 2050*, suggests that a sustainable and renewable energy-based economy could theoretically be achieved, where as much as 90 per cent of India's total primary energy supply could technically be based on renewable sources* (WWF-India and TERI, 2013).

Thus, renewable energy resources can offer environmentally and economically sustainable solution to deal with India's growing energy needs. However, accelerated deployment and mainstreaming renewable energy projects require proactive and coordinated intervention by various stakeholders, including the state governments, private sector, financial institutions and NGOs.

The potential of renewable energy is not only limited to electricity generation, but also for a variety of applications (heating, cooling, mechanical and cooking) spanning across several sectors (residential, commercial and industrial). With the objective to promote and create awareness about renewable energy applications, WWF-India and CEEW came out with a report titled *RE+: Renewables beyond Electricity*, which focused on the status and potential of 14 renewable energy applications (WWF-India and CEEW, 2013).

As a follow up to this study, WWF India and CEEW undertook a comprehensive analytical study of two renewable energy technologies, namely, solar air conditioning and solar desalination. Findings of these studies have been reported in this document with each application (solar air conditioning and desalination) being covered under separate chapters. These particular applications were selected based on their large potential, but limited existing installation, attractive payback yet significant financing challenges, interested stakeholders, environmental and social benefits, and government support, but limited awareness and market research.

Through primary survey and stakeholder interactions, the study highlights potential business opportunities in solar air-conditioning and solar desalination applications, analyses various factors or bottlenecks (technological, financial, market, regulatory and institutional), and lists a set of recommendations to overcome these barriers. Moreover, the study also tries to introduce readers (scientific as well as non-scientific) to the basics of these application technologies through a lucid description of various technical aspects (especially of processes and components).

Solar-energy applications like solar air conditioning and desalination have wide-ranging benefits. These technologies have high potential for applications across large parts of India. Further, solar technologies increases resilience against volatile and ever rising prices of conventional energy. With growing urbanization and demand for cooling, renewable energy application like solar air conditioning can play a significant role in reducing peak-load demand on the electrical grid, especially during the day time.

1 According to MNRE estimates, about 120–150 million metric tons per annum of surplus residue biomass is available (equivalent to 18,000 MW) from agricultural and forestry areas. Additionally, the country's 550 sugar mills can generate about 5,000 MW additional power through bagasse based cogeneration.

Though the variable nature of solar radiation is recognized, however progress on the technological front is being made to overcome the barriers, especially in terms of energy storage technology.

Apart from GHG mitigation and economic benefits, solar technologies also have many far reaching and significant benefits, such as provision of basic resources in remote areas and creation of regional and local level jobs. For example, low-cost solar desalination is being employed by local communities in arid regions of India to get clean and safe drinking water at low cost.

Thus, this study tries to identify areas of intervention and highlights major activities that are required to facilitate as well as accelerate large-scale deployment of solar desalination and air-conditioning technologies in India. The set of recommendations can possibly act as building blocks for future research, project implementation and policy interventions in India.

CHAPTER 2

SOLAR AIR CONDITIONING

2.1 BACKGROUND

Air conditioning is one of the most high energy intensive activities in the world. Conventionally, majority of cooling systems, from small scale (residential ACs) to large-scale (Heating, Ventilation and Air Conditioning (HVAC) systems in commercial and industrial sectors), run on grid provided electricity. The demand for cooling systems in India is poised to grow significantly in the coming decade, particularly due to expansion of India's population and growth of the economy, coupled with demand for housing and commercial spaces.[1] This will drastically scale up demands for electrically, which in turn will put enormous pressure on conventional grid provided electricity. Presently, cooling (fans, evaporative cooling and air conditioners) accounts for 45 per cent of the total energy consumption in the residential building sector; whereas HVAC consumes 55 per cent of the total energy utilized in commercial building sector (Planning Commission, 2011).

COOLING (FANS, EVAPORATIVE COOLING AND AIR CONDITIONERS) ACCOUNTS FOR **45%** OF THE TOTAL ENERGY CONSUMPTION IN THE RESIDENTIAL BUILDING SECTOR

At present, India's energy demand is primarily met by coal (54 per cent); gas (9 per cent) and oil (1 per cent) (MoP, 2012). The Planning Commission expects to have an installed capacity addition of 118,536 MW (including renewable energy sources) during the twelfth year plan (2012–17). Coal is likely to contribute around 59 per cent (69,280 MW) of the total installed capacity, thus clearly indicating a continued dominance of fossil fuels in the national energy mix in the coming years (Planning Commission, 2012).

Fossil fuel based power plants, although an important component of the national energy security and economic growth, have considerable negative impacts associated with them in terms of local ecology, public health as well as contribution to anthropogenic global warming. Since study by the Planning Commission (2011) clearly indicate that cooling systems consume the maximum energy required for a building – 55 per cent in commercial and 45 per cent in residential buildings – it is prudent to move towards renewable energy solutions to meet these demands. One such renewable energy solution is solar air conditioning, which can meet the growing cooling demand in India, in an ecologically sustainable manner.

Solar air-conditioning systems have a number of benefits compared to its conventional counterpart. Solar air-conditioning systems result in lower demand for grid electricity, lower operational costs and reduced environmental impacts, like GHG emissions, etc. Furthermore, solar air-conditioning systems work more efficiently during hot

1 Realty sector in India is already witnessing steep rise in the demand for new constructions. Based on the data by the Energy Conservation and Commercialization (ECO-III) estimates, as of 2010, the total commercial floor space in India is around 659 million m^2 (Kumar et al., 2010).

summer season when the requirement for cooling is maximum, thereby these systems can help in reducing electrical peak loads linked to conventional grid electricity based cooling systems. Large-scale deployment of solar air-conditioning systems can significantly lower the consumption of grid based electricity. At the same time it can also reduce the capital expenditure associated with transmission and distribution. Thermally driven solar air-conditioning systems have an added benefit, i.e., in places where the demand for cooling is not annual; these systems can provide hot water for utilization in other systems and processes.

Due to its seasonal nature of solar irradiation, these systems are less popular amongst consumers, but these shortcomings can be addressed by providing either an auxiliary system based on conventional fuel or thermal/electrical energy storage. Thus, a solar air-conditioning system needs to be well designed to meet the user's requirement and provide overall energy savings and environmental benefits.

Despite the multiple advantages of solar air-conditioning systems over conventional air-conditioning systems, it faces considerable technical, economical and policy barriers, which need to be overcome in order to scale up and realize untapped market potential. Although, the solutions for technical barriers are being developed, cost economics and policy push are two aspects that need equal attention to ensure large-scale deployment of solar air-conditioning systems.

In the last two decades, approximately one thousand solar thermal air-conditioning systems have been established globally, majority of which have been commissioned in Europe under the agenda of research and demonstration. But for past few years the market development and commercialization of solar air-conditioning has gained momentum in various sectors like residential and commercial buildings, and also in various industries. A detailed examination of this commercial market growth period indicates a significant potential for large-scale deployment of solar air-conditioning systems facilitated by technical efficiency improvements, market awareness, coupled with favourable government policies.

Ongoing interest in solar application for cooling requirements has resulted in a vast amount of literature ranging from lab-scale performance evaluation to case studies of successful implementation of solar air-conditioning projects. These studies look in detail into either a complete system or at a specific component of the system, like chiller, dehumidifier, etc. Most of these studies deal with the technical aspects of the system, but very few contain any detailed analysis of technology applications across different sectors, like industries, hospitality, residential, etc. In conclusion, literature on the potential and applicability of solar air conditioning in India is still very limited.

In order to overcome some of the existing knowledge gaps, this study aims to analyse and understand the 'ecosystem' of solar-assisted cooling applications in India. Ecosystem here refers to different aspects like finance, technology, human capital, policy and institutional mechanisms, which individually and along with other factors are likely to act as a barrier or provide opportunities for scaling up of solar air-conditioning application in India. The objectives of the study are:

- To understand the 'ecosystem' of solar air-conditioning application in India.
- To analyse and document the status, barriers and opportunities associated with solar air-conditioning application.

- To formulate a set of recommendations to promote large-scale deployment of solar air-conditioning application in the country.

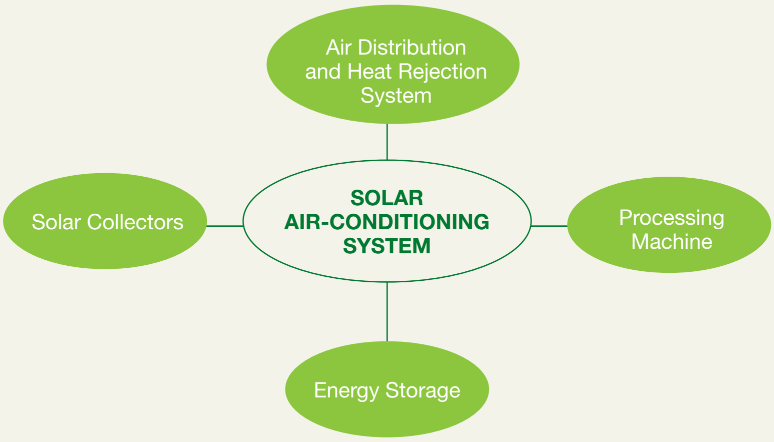
The data collection was done through primary survey as well as review of secondary literature. Primary data collection principally included questionnaire survey (electronic as well as telephonic), personal/group interviews with different stakeholders and site visits. The questionnaire for the primary survey was designed keeping in mind the needs of different stakeholders like manufacturers, industrial and institutional users, sector experts, civil society organizations and government officials, etc. Site visits were undertaken to gather first-hand information on multiple aspects of the operational renewable energy application. The data was then analysed, both quantitatively and qualitatively, to arrive at the study conclusions. This analysis tries to chart out the existing status, opportunities and potential of renewable energy applications in India. Recommendations for large-scale replication and deployment have been suggested so that this report can act as a building block for future research, project implementation and policy intervention. Furthermore, the report tries to introduce readers to the basics of solar air-conditioning technology through lucid description of various technical aspects like processes and components involved in solar air-conditioning systems.

2.2 TECHNOLOGY DESCRIPTION

Component wise a solar air-conditioning system can be divided into four basic parts, viz., (1) solar collectors (photovoltaic (PV) and thermal), (2) processing machine (cooling and dehumidification), (3) air distribution and heat rejection system, and (4) energy storage (see figure 2.1).

FIGURE 2.1

Components of Solar Air-Conditioning System



2.2.1 Solar Collectors

Solar collectors are employed to collect solar energy and to convert this energy into electricity or heat. Based on the output energy, the collector's used in the solar air-conditioning process can be classified in two categories, viz., (i) solar PV cells (ii) solar thermal collectors.

Solar PV cells: In Solar (photo voltaic) PV cells, DC (direct current) electricity is generated by the PV cells through transformation of incident solar radiation. To generate increased current, solar cells are connected in series and packed in a protective laminate, which is then referred to as solar panel or module. Following are two commercially available solar PV cells:

- Crystalline silicon (c-Si) modules constitute major share of the global annual solar PV market (85–90 per cent) (IEA, 2010). These are manufactured using silicon wafers (thin silicon slices or wafers are obtained by wire sawing block of metallurgical grade silicon). Sides of these wafers are then painted with different dopants, thereby creating P–N junction necessary for electrical generation. Crystalline silicon modules can be further subdivided into (a) mono crystalline (mono-Si), and (b) poly crystalline (poly-Si). Module efficiency of commercial crystalline silicon ranges between 13–19 per cent (IEA-ESTAP and IRENA, 2013).
- Thin films solar PV modules are manufactured by coating a thin layer of semiconductor material onto a substrate sheet (usually glass or steel). Thin film module manufacturing differs from crystalline silicon modules since it does not involves growing, treatment and slicing of a crystalline ingot. Thin film modules can be subdivided into three main categories: (a) amorphous (a-Si), (b) cadmium telluride (CdTe), (c) copper indium diselenide (CIS) and (d) copper indium gallium diselenide (CIGS) (IEA-ESTAP and IRENA, 2013). Commercial thin film module constitutes around 10–15 per cent of the global solar PV market (IEA, 2010), and has an efficiency ranging of 6–12 per cent (IEA-ESTAP and IRENA, 2013).

Solar thermal collectors: Solar thermal collectors utilize solar radiation to generate useful low and high temperature heat output. Solar thermal collectors can further be classified into non-concentrating and concentrating type of collectors. In non-concentrating type, the absorber area, i.e., area of the collector absorbing heat is equivalent to the collector area, i.e., the area that intercepts solar radiation. In the concentrating type collectors, the absorber area is smaller than the collector area (Norton, 2014). Commercially available non-concentrating type of collectors includes flat plate[2] and evacuated tube collectors (see figure 2.2). These collectors can achieve a temperature of around 100°C. In case temperature requirement is more than 100°C, concentrating solar collectors are used. In these technology, concentrators (mirrors or lenses) are arranged in a way (linear or point focus) to maximize and focus the incident sunlight on a small receiver end or absorber (see figure 2.3). The absorber then accumulates and transfers this heat through working fluid. Commercially available designs of concentrating collectors involve parabolic trough, dish type concentrating collectors and linear fresnel.

2 Flat Plate Collectors (FPCs) are the simplest non-concentrating solar thermal collector. FPC consists of a flat dark solar energy absorbing plate (made up of metal sheet or plastic) and is backed by a fluid tube with a glass or polycarbonate covering. The fluid is then circulated within these fluid tubes to absorb the heat from the absorber plate and deliver it to a storage tank. In case of Evacuated Tube Collectors (ETCs), they have several glass tubes that absorb solar energy, ultimately heating the working fluid. Evacuated tube (glass-metal) technology is manufactured by fusing glass tube to the heat pipe at the upper end in a vacuum condition. Evacuated tube (glass-glass) are manufactured by fusing double layer of glass together at one or both ends creating vacuum between layers.

FIGURE 2.2

Evacuated Tube Glass Heat Pipe Solar Thermal Collector at Mamta Machinery Pvt. Ltd., Ahmedabad

Source: Mamta Energy Pvt. Ltd., Ahmedabad

© Mamta Energy Pvt. Ltd., Ahmedabad

FIGURE 2.3

Dish Type (Scheffler) Concentrating Collectors Installed at Muni Seva Ashram, Vadodara

Source: Muni Seva Ashram, Vadodara

© Muni Seva Ashram, Vadodara

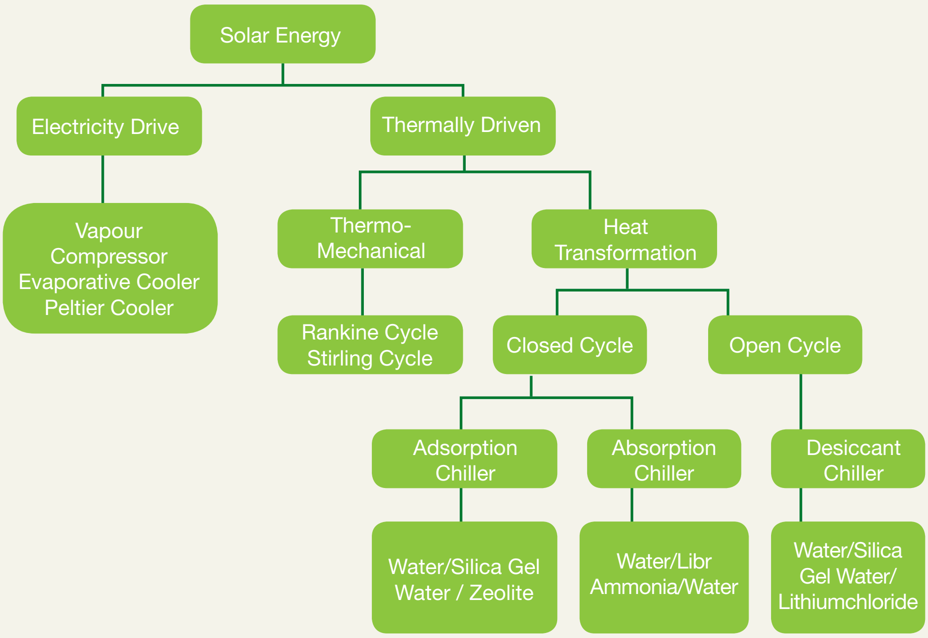
2.2.2 Processing Machine

Solar air-conditioning processing machines can be classified into two key groups, viz., (i) electricity (photovoltaic) driven system and (ii) thermally driven system (see figure 2.4). The thermal category can be further classified into, (a) thermo-mechanical driven system and (b) thermal/heat transformation driven system (Mittal, 2005).

In the electricity-driven system, solar energy is absorbed and converted into direct current (DC) by an array of solar cells known as a photovoltaic (PV) panel. This DC supply is then either used directly or converted into alternating current (AC) to run the compressor of a refrigerator (Sinha and Karale, 2013) (for details see the section on Solar Electric Air Conditioning).

FIGURE 2.4

Categorization of Solar Air-Conditioning Technologies



In case of thermally driven solar air-conditioning system, the collected solar energy is utilized either through solar thermo-mechanical[3] or thermal/heat transformation method[4] to provide cooling output (for details see the section on Solar Thermal Air Conditioning). Detailed technological information, working and efficiency of the process/systems have been explained in the following section.

I Electricity Driven Solar Air Conditioning

The solar electric air-conditioning system consists of a collection of solar PV cells, which convert solar energy into electrical energy to power electric heat pump(s) (see figure 2.5) (Rona, 2004). Photovoltaic cells are made up of semiconductor material which allows direct alteration of solar energy to direct current (DC). A DC-to-AC converter or an inverter is also required to convert DC supply from the solar PV cells to AC for powering the heat pump or it can be directly used in case of a DC-powered heat pump. To stabilize and smooth the generated current, a solar-charge controller consisting of a capacitor, sensors is required (Sinha and Karale, 2013).

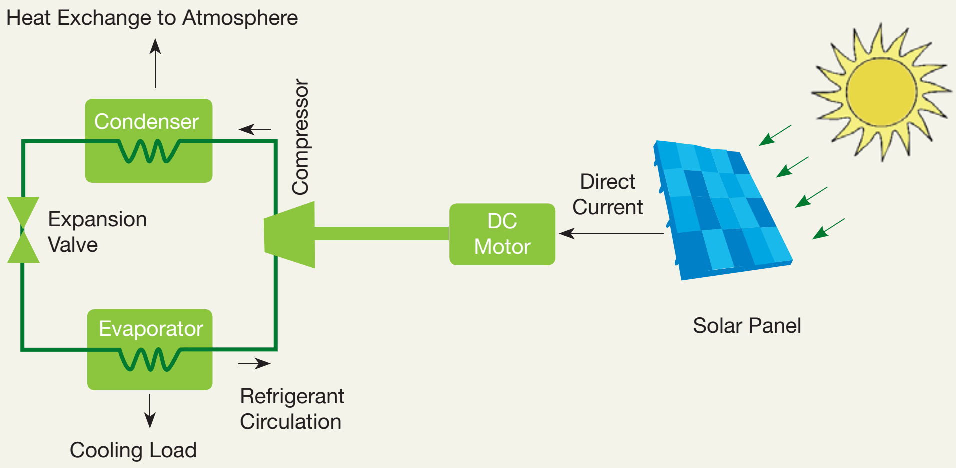
3 By employing Rankine cycle engine or Stirling cycle.
4 By employing processes like Diffusion absorption cycle, Open absorption cycle and Carre cycle, etc., (Pridasawas and Lundqvist, 2003; Rona, 2004).

One of the main advantages of this type of system is that an already operational operating conventional system, even if decentralized, can be easily transformed into a solar-powered system by simply adding solar PV panels to the internal grid.

FIGURE 2.5

Schematic Diagram of a Solar Electric Air-Conditioning System

Note: Adapted from Abu-Zour and Riffat, 2007



II Thermally Driven Solar Air Conditioning

In thermally driven solar air-conditioning systems, solar heat is utilized to produce cooling output rather than solar electricity. Solar energy captured by collectors is then used to drive “heat engine” or “chiller”, in turn generating cooling effect. Based on the mode of energy utilization, solar thermal air-conditioning systems can be further classified into, (a) solar thermo-mechanical air conditioning and (b) heat transformation air conditioning. These technologies have been explained in detail in the following section.

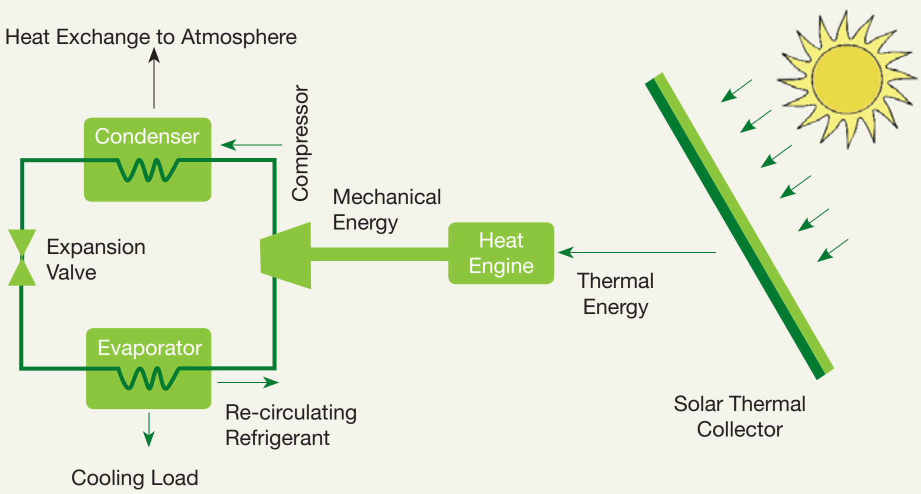
(a) Solar Thermo-Mechanical Air Conditioning

In the case of solar thermo-mechanical method, mechanical power necessary to run the compressor is produced by a solar-driven heat power cycle (Saitoh et al., 2007). The working fluid (liquid state) is vapourized at an elevated pressure in the boiler of the Rankine cycle by the solar energy collected (see figure 2.6). The generated high-pressure vapour is then transferred through a turbine or a piston expander, thereby leading to expansion of the vapour and drop in vapour pressure and temperature, resulting in the production of mechanical work. The mechanical work produced from the turbine is used to run the compressor of the vapour compression cycle. The condensed working fluid is exited from the turbine and pumped back to the boiler where it is again vapourized and the whole cycle is repeated.

The efficiency/COP of the Rankine cycle-based solar air-conditioning system increases with rising temperature of the vapourized working fluid used in the expander. While the operating fluid using the flat plate collector can generate temperatures in between 80°C and 120°C, the system cooling COP ranges between 0.2 and 1.50 (Sargent and Teagan, 1972).

FIGURE 2.6

Schematic Diagram of a Solar Thermo-Mechanical Air-Conditioning System



(b) Solar Thermal/Heat Transformation Air Conditioning

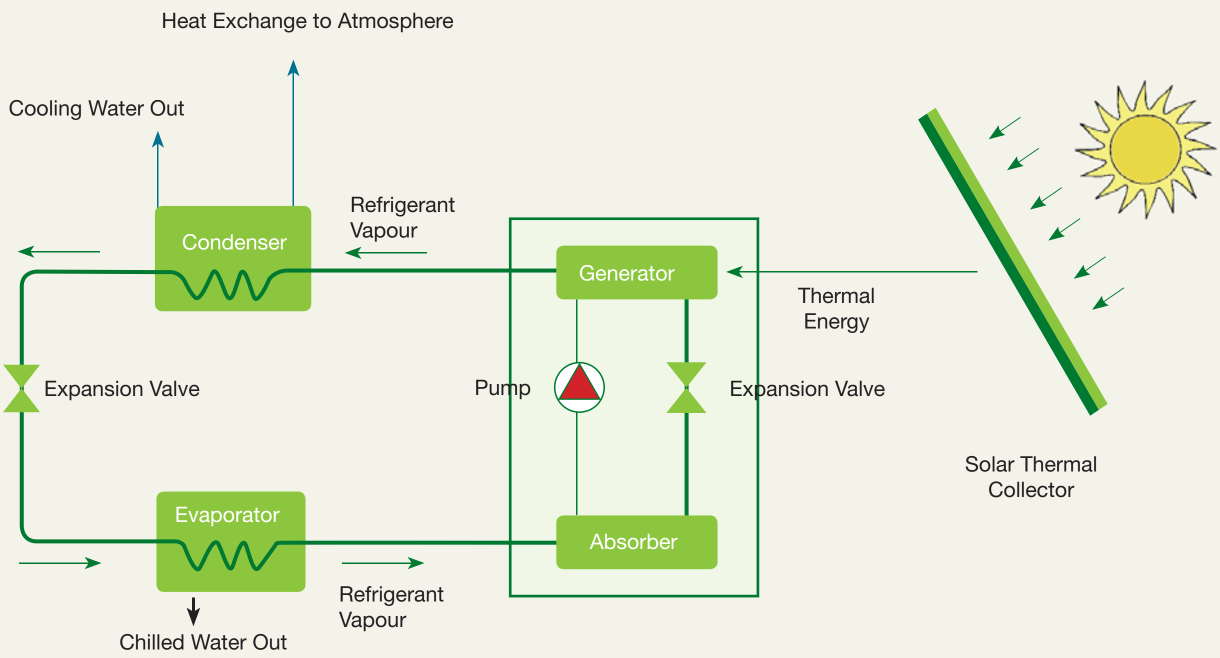
In solar thermal driven/heat transformation systems, cooling effect is produced using the expansion of refrigerant in closed-loop chillers at high pressure. This expansion of refrigerant is achieved through application of solar heat. The expanded refrigerant is then exposed to ambient temperature at low pressure thereby causing re-evaporation of the refrigerant and subsequent heat absorption. This phenomenon of heat absorption by condensing refrigerant results in the cooling effect (see figure 2.7). Re-condensed refrigerant is then circulated back in the loop thereby completing and restarting the cycle.

Currently there are two commercially available closed-loop chiller devices, i.e., absorption chillers and adsorption chillers. A third variety of chiller available is the desiccant chillers. Desiccant chillers are open type chillers in which fresh air stream is first dehumidified using the desiccant system and then dried air stream is cooled at required comfortable temperatures. In this type of open cycle, solar heat is required for dehumidification (removal of moisture) of the air stream. Thermal-driven chiller systems are operated at three different temperature strata. High temperature is required for driving the process, low temperature at which the process of chilling is managed and medium temperature range at which the driving heat and rejected heat from the refrigerant are removed by using the water cooling towers.

A characteristic solar thermal air-conditioning system comprises a solar collector, a thermal storage tank, a thermal refrigeration unit and a heat exchange system. The selection of the solar collectors is largely dependent on the temperature requirement for air conditioning and generally flat plate collectors are used where the temperature requirement is between 60 °C and 100°C, and in case of higher temperatures evacuated tube collectors or concentrating solar thermal collectors are employed (Sinha and Karale, 2013).

FIGURE 2.7

Schematic Diagram of a Solar Sorption Air-Conditioning System



Absorption Chillers: The vapour absorption system utilizes steam as its primary energy source for chillers. The vapour absorption system could be classified into either (1) indirect-fired, double-effect absorption chillers which require steam at around 190°C and 900 kPa, and (2) single-effect chillers that require hot water or steam at 75 °C to 132°C (USAID, 2009) (see figure 2.8).

In a vapour absorption cycle, the low-pressure vapour is absorbed into an absorber which is heated and pressurized to generate high pressure vapour (Abu-Zour and Riffat, 2007). Presently, two absorbent-refrigerant cycles are in use widely, viz., lithium bromide (LiBr)-water (aqueous) system (Chakraborty and Bajpai, 2013) and water (aqueous)-NH_3 system (Bajpai, 2012). In case of the LiBr system, lithium bromide is used as an absorbent whereas water is the refrigerant. In the NH_3 absorption system,

FIGURE 2.8

Single-Effect Absorption Chiller at Muni Seva Ashram, Vadodara

© Muni Seva Ashram, Vadodara

water is used as an absorbent and ammonia is the refrigerant. In the vapour absorption system, concentrated absorbent goes through the absorber, which is coupled to the evaporator (Wang and Chua, 2009). The refrigerant is then converted into high-pressure vapour and absorbed by the LiBr/water absorbent. The combination is then transferred to the generator where the refrigerant is evaporated using solar energy. The produced high-pressure refrigerant vapour then moves to the condenser from where heat is dispersed to the surroundings to condense the refrigerant back to liquid, thus completing the loop (Sinha and Karale, 2013). The cooling output for a single effect LiBr system is 4°C–38°C , COP[5] is in the range of 0.6–0.8 (Kedare, 2011) and 4°C–27 °C for a double-effect with COP achievable up to 1.2 (ESTIF, 2006). The cooling effect range is -51°C–4°C in the case of the aqueous ammonia refrigeration system (Kedare, 2011) with COP values ranging between 0.4–0.6.

The single effect absorption chillers can operate on hot water, or steam fired. While commercially available double effect absorption chillers operates either on direct heat or steam energy. In case of more efficient chillers (triple effect absorption chillers), these have just started to be commercially available for example Thermax an India based company has recently launched its pilot triple effect absorption system (see figure 2.9). But, this solar cooling chiller is going to be available in the project range of

5 The efficiency of an thermally-driven chillers is defined by the unit/figure, i.e., thermal Coefficient of Performance ($COP_{thermal}$), this unit is defined as the fraction of heat rejected from the chilled water cycle and the required driving heat, i.e., $COP_{thermal} = Q_{cold} / Q_{heat}$.

$COP_{thermal}$ is slightly different to the COP_{conv} of a conventional electrically driven compression chiller, defined by $COP_{conv} = Q_{cold}$ / Electric, where Electric represents the electricity consumption of the chiller.

The lower the value of COP means the more amount of driving input heat is required for the system and thus means the more rejected heat has to be removed through cooling towers. On the contrary systems/chillers with higher COP would mean reduced input, recirculation and rejection energy requirements.

100 kW to 3,000 kW catering to sectors like shopping malls, commercial complexes, office buildings, hospitals and industrial cooling requirements (Thermax, 2011).

With ongoing demand for low capacity absorption chillers, globally various companies have started to manufacture these small kits. But, despite these innovations and technical advancement small-scale chillers are presently available for single effect absorption cycles only. Table 2.1 gives an overview of some commercially available chillers and their capacities.

TABLE 2.1

Types of Commercial Chillers and Some Global Manufacturers

Chiller Type	Capacity	Material Pairs	Manufacturers
Absorption Chiller	10 kW –5 MW	H_2O/LiBr, NH_3/ H_2O, H_2O / LiCL	Yazaki, EAW Germany, Thermax, Pink, Climatewell, AGO Germany, Broad Air, Carrier, Voltas, York, McQuay, and Shuangliang Trane.
Adsorption Chiller	10 kW – 500 kW	H_2O/silica gel, H_2O / LiCL, H_2O/ zeolite	Mitsubishi, SorTech, Invensor, Mayekawa and SJTU.
Desiccant Chiller	20 kW – 350 kW	H_2O/silica gel, H_2O / LiCL	Imtech Drygenic, AIL Research, L-DSC Technology and Menerga.

FIGURE 2.9

Triple-Effect Absorption System Installed at the Solar Energy Center (SEC)

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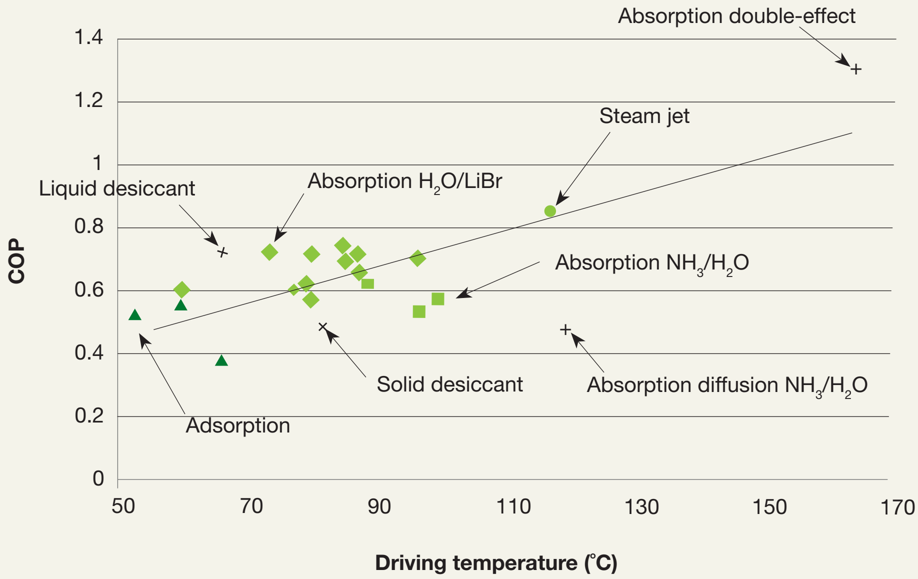
Adsorption Chillers: Adsorption chillers, as the name suggest, work on the principle of adsorption. These chillers use solid dry sorbent media like zeolite or silica gel as a sorption material in contrast to absorption chillers, which uses liquid solutions for sorption purpose. Commercially the available adsorption chillers use silica gel as sorbent and water as refrigerant (Choudhury et al., 2013). The adsorption chillers typically have two chambers or compartments one serves as an evaporator chamber and the other as a condensation chamber. The input driving heat energy produced from solar collectors is supplied to the sorbet material in the first compartment leading to heating up of water in the evaporator chamber resulting in the formation of water vapours. This generated water vapour is then adsorbed onto the sorbent material in the second compartment thereby resulting in the cooling effect.

FIGURE 2.10

Comparative Performance of Various Chiller Technologies

Source: Balaras et al., 2007



The sorbent is regenerated by heat application during the evaporation of water. Under normal conditions the adsorption chiller requires lower driving temperature (temperatures in the range of 60°C–80°C are sufficient) which could be met with flat plat and evacuated tube collectors. The COP of adsorption chillers are around 0.6 (see figure 2.10). The commercially available capacity of adsorption chillers ranges from 14 TR (50 kW) to 140 TR (500 kW) chilling power. However, recently companies like Mitsubishi (zeolite based compact adsorption chiller), SorTech (water/silica gel based) and SJTU (water/silica gel based) have launched adsorption chillers with less than 10 kW (3 TR) capacity (Mitsubishi Plastics, 2012).

TABLE 2.2

Comparative Assessment of Solar Cooling Technologies

Source: Adapted from Johnston, 2006

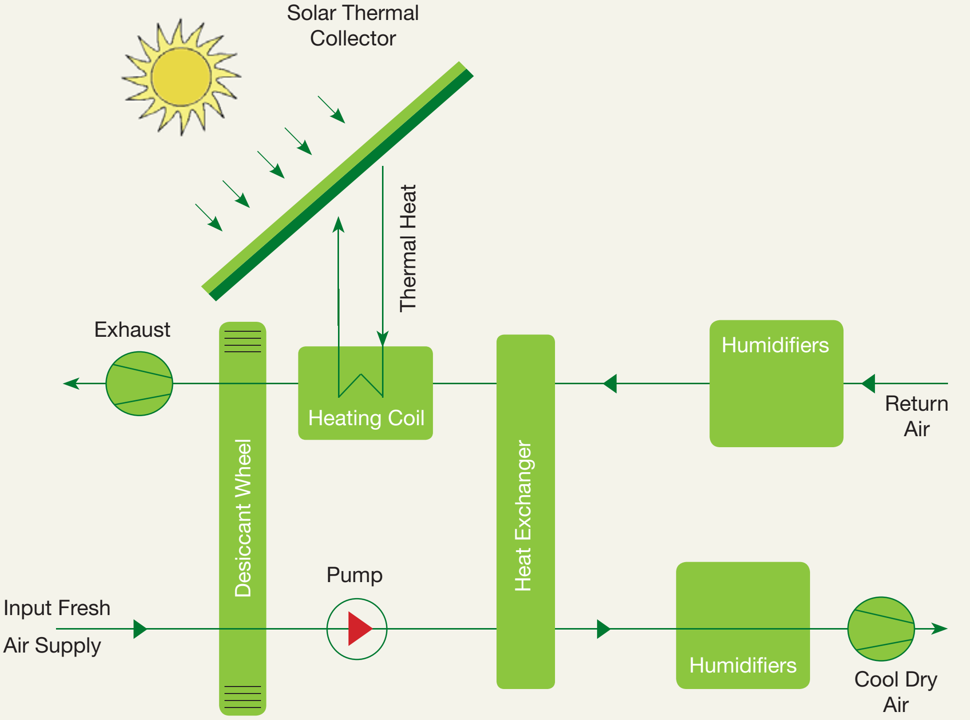
	Technology		
	Absorption Chillers	Adsorption Chillers	Desiccant Chillers
Benefits	Mature technology, constant output	Lower driving temperature requirement (temperatures in range of 60°C–80°C are sufficient)	Direct humidity treatment and can be integrated with an existing heating, lower temperature requirement (50°C–75°C) and ventilation system.
Drawbacks	Higher temperature collectors required (operate with temperatures of 90°C for single effect cycle to 150°C for double effect cycle)	Lower COP, typically heavier and expensive because high surface area is required for sorbent.	Sensible cooling best handled by second device, andrequires higher maintenance (due to rotating wheel).
Ideal Application	Radiant Cooling	Radiant Cooling	Humid environments, High volume of fresh air

Desiccant Chillers: Desiccant chillers are fundamentally an open cycle systems, wherein water is used as a refrigerant and which is in direct contact with fresh air (see figure 2.11). Desiccant chillers are an example of a thermally-driven cooling cycle which is an arrangement of air dehumidification by a desiccant dehumidifier material and evaporative cooling system or conventional cooling coil (ESTIF, 2006). The desiccant system is an open-cycle system, i.e., a cycle in which the refrigerant is expelled out of the process after providing the cooling effect. Thus in these type of chillers water is used a refrigerant. For the purpose of desiccant material both liquid and solid material can be used. At present commercially rotating desiccant wheels coated with solid and liquid sorption materials like silica gel or lithium-chloride are available.

FIGURE 2.11

Schematic Diagram of a Solid Desiccant Air-Conditioning System

Note: Adapted from ESTIF, 2006



In the desiccant chiller system, warm air from the surrounding atmosphere laden with moisture is introduced to the process side of the rotating desiccant wheel. This humid air is then dehumidified by sorption material and the latent heat is converted into sensible heat and thus results in increase of the dry bulb temperature of the inlet air. The processed dry and hot air is then cooled through indirect and direct evaporative cooling (Rona, 2004).

Afterwards, the air is humidified and additionally chilled by a controlled humidifier, according to the required heat and moisture of the delivered air stream. The air stream expelled from the rooms is humidified to the saturation point to take advantage of the full chilling potential. In the end, the desiccant sorption wheel is regenerated by applying heat produced by solar collectors in a relatively small temperature range from 50°C–75°C, to permit an uninterrupted functioning of the dehumidification process. At present desiccant chillers require larger-scale projects to be economically viable.

The COP values of desiccant cooling systems are between 0.5 to 1 (Kim and Ferreira, 2008). Desiccant cooling is operated at a higher temperature as compared to a typical conventional HVAC system. In so doing this system achieves a higher operating COP. Comparing COP of a solar PV driven vapour compression to a thermally driven vapour absorption chiller, it is observed that COP of a thermally driven chiller is low in comparison to a PV driven system, however Solar Cooling Efficiency (SCE)[6] of an absorption chiller is around 85 per cent whereas the same SCE value for vapour compression cycle is around 75 per cent (Sargon, 2011).

2.2.3 Air Distribution and Heat Rejection System

Post generation of chilled water or refrigerant, removal of heat (latent and sensible) from the room is accomplished through coils or air-conditioning units. These components and process along with piping and duct network are referred as air-distribution system. The cooling and dehumidification is achieved by supplying fresh air in the room which replaces the existing hot and moist indoor air. This process is referred as all in air system. Another process by which cooling is accomplished is by using the cold units inside the room (hydronic or decentralized systems) (Kim and Ferreira, 2008). In the hydronic system, the indoor air is cooled through transferring heat to the refrigerant via cold surface either through natural or forced convection. Fan coils and induction units are example of forced convection units (Feustel and Stetiu, 1995). A decentralized system involves packaging of various components like compressor, evaporator, condenser coils, fans and air filters in one unit. Window/room AC systems are a good example of decentralized systems.

Heat rejection is an important step of any cooling and heating engine operation. Commonly, heat rejection is accomplished either through an air-cooled or a water-cooled system. In an air-cooled system, hot fluid is circulated through a condenser coil. The fluid temperature is brought down by heat transfer to ambient air; this process is further amplified using fans. In a water-cooled systems like water tower, evaporative condensation process occurs inside the heat exchanger. The heat absorbed by water is then rejected into the atmosphere. Wet cooled systems are smaller and compact in size than air-cooled systems, since the heat absorption capacity of water is greater than air.

2.2.4 Energy Storage

Though not directly involved in the cooling cycle, heat or electricity storage devices are crucial component of the solar cooling systems. Being a fluctuating source of energy across day and seasons, storage of generated heat/electricity becomes an important part which guarantees constant source of driving heat energy to run the cooling system for few hours and sometime for day’s altogether. Incorporation of storage units in the system increases its usability amongst consumers. Energy storage methods can be categorised into two primary types, viz., (i) electrical storage and (ii) thermal heat storage. **Batteries (electrochemical storage)** are one of the major technology used for storage of electrical energy. However, batteries used for storing PV electrical output differs lightly from conventional batteries since batteries used in PV applications

6 Solar Cooling Efficiency (SCE) is a product of radiation collection efficiency and cooling efficiency.

undergo both deep cycling and extended state of low charge during its daily normal operation. Lead acid batteries are a prominent example of a storage system for PV electricity.

In case of **thermal heat storage**, there are basically four types of thermal energy storage technologies available, as discussed below (see table 2.3).

TABLE 2.3

Comparative Assessment of Solar Thermal Energy Storage Technologies

Source: Adapted from Stryi-Hipp, 2012

Thermal Energy Storage Technologies			
Sensible heat storage	Latent heat storage	Sorption heat storage	Thermo-chemical heat storage
This type of storage systems uses the heat capacity of a material resulting in increased temperature of the material. e.g. hot/chilled water tanks, underground thermal energy storage	This type of storage systems uses the phase changing capacity (melting or evaporation) of a material. e.g. Ice storage, Phase change materials (PCM) panels and modules	This type of storage systems uses the sorption material (solid materials for adsorption and liquid material for absorption) for water vapour uptake.	This type of storage systems uses the chemical reactions to store energy. e.g. Silicagel/water, zeolite/water

However, to store solar electrical or thermal energy requires additional investment costs, space requirement and added electrical/thermal losses. As a result, one of the major challenges for front technology developers is to lower the solar energy storage costs, with a system design by optimizing storage volume and efficiency.

2.2.5 Technology Maturity of Solar Air-Conditioning Systems in India

Crucial components of any solar air-conditioning systems are the solar energy collector components (solar thermal collectors and solar PV panels), cooling subsystem (either thermally or electrically driven) and heat rejection part which rejects the waste heat generated from the thermally or electrically driven chiller and storage units.

Over the past few decades, solar PV technology and its auxiliary systems (energy storage units like inverters, etc.) have become common, technologically efficient and economically competitive (Green, 2000). These technologies and systems have realized a good status of technical maturity (IEA, 2010). Similarly, thermally driven solar air-conditioning systems which function below temperatures of 110°C (Evacuated Tube Collectors and Evacuated Heat Tube Pipe) and solar collectors with good supply chain, cost viability and efficiency are readily available in the market.

However, solar collectors to support thermally driven solar air-conditioning systems requiring high-driving temperature are still evolving. However, in the last few years, newer companies all over the world, including companies in India, like Clique Solar, Taylor made Solar Solution Pvt. Ltd., etc., (see figure 2.12) have entered the solar thermal market with solar concentrator technologies equipped with efficient tracking systems. Even so, solar collector systems with operating temperatures above 130°C along with tracking systems (single-axis and double-axis tracking) are still an evolving technologies, having broad scope for improvements.

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FIGURE 2.12

ARUN Dish at NTPC Energy Technology Research Alliance (NETRA), Noida

Solar electrical driven air-conditioning systems with the cooling subsystem, i.e., vapour compression chillers, is a mature technology. In comparison, large-scale thermally driven chillers and open sorption cycles have come into existence in the commercial market in the past few decades only. The main objective of these thermally driven chillers is to utilize waste heat generating from a co-generation system or industrial heating processing unit (IEA, 2013b; Xu et al., 2010). Characteristically, these chillers have been designed for providing base load cooling demands and not designed for in sync functioning with solar energy.

But growing interest in solar technology and fluctuating energy supplies have created a stimulating market for thermally driven chillers, especially small-capacity chillers. At present, various manufacturers across the globe are offering small-scale thermal-driven chillers in the market. Yet, most of these technology providers are small start-up establishments and would require significant support, both at the financial and policy levels, to set up a manufacturing facility on an industrial scale.

Lastly, the integration of buffer storage components is rapidly becoming common in solar air-conditioning systems. These storage components are sufficiently available in the market in different sizes ranging from small buffers for abatement of short-term fluctuations to bulky thermal storages that are used to accumulate solar heat for considerable number of hours.

Despite growing maturity and efficiency of the components, currently in terms of the technological aspect the major failing of a solar air-conditioning system is at the system stage. Many of the solar air-conditioning systems, due to poor designing and planning, do not succeed in accomplishing the intended energy and money savings, thus hampering large-scale deployment of the technology. Barriers related to technology are further discussed in this chapter.

2.3 APPLICATION MARKET

The significance and economical viability of solar air-conditioning systems is in those geographical areas and industrial sectors which have high demand for heating and cooling, located in high solar irradiation zones, and places with high cost of conventional energy/fuels, etc.

There is a good potential for installation of these systems across different sectors, since renewable energy applications can considerably reduce energy consumption and emissions. Table 2.4 highlights few such international case studies where solar energy is being used to meet process and comfort cooling demand.

Gradually the market for solar air-conditioning systems is picking up, with more and more companies, both small and large, entering the market. Based on stakeholder interactions during the course of the project, the following sectors were found to have a market potential for solar air-conditioning systems.

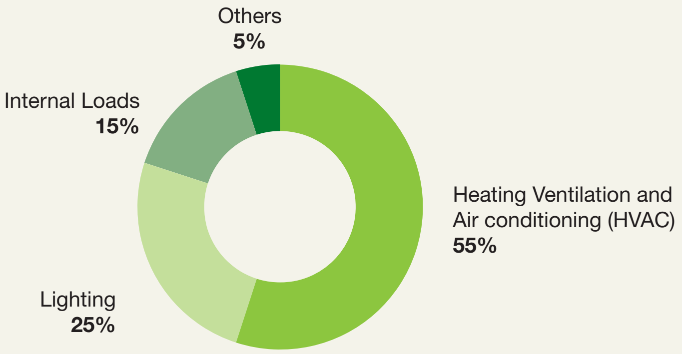
2.3.1 Commercial Building Sector

In India, building sector with its contribution of 5 per cent to the country's GDP is the second largest employment provider after the agricultural sector. The building sector is growing at a pace of 8 per cent to 10 per cent per year to meet the demand of the ever increasing urban population. The total floor area of the commercial building sector[7] is likely to be 19,861 million ft^2 in 2030 as compared to 2,900 million ft^2 in 2005 (Planning Commission, 2011).

FIGURE 2.13

Power Consumption Pattern in Indian Commercial Building Sector

Source: Planning Commission, 2011



7 Commercial building sector here includes Commercial Office Space, Hospitality and Retail

Likewise, the commercial building sector is one of the largest consumers of electricity and fuels. As per one estimate, per square meter electricity consumption in the commercial building sector is more than 200 kWh with air-conditioning and lighting services being the major power consuming applications. Commercial building sector accounts for 8 per cent of the total electricity consumption in India. This demand for energy is growing annually at a rate of 8 per cent (Planning Commission, 2011). Cooling activities (HVAC) in commercial buildings consume 55 per cent of the total energy utilized (see figure 2.13). Consequently, CO_2 emissions from conventional buildings in India were estimated to be 40,000 tonnes of CO_2 per million ft^2 in 2005. At this pace, emissions from the commercial building sector are projected to be 610 Mt of CO_2 in 2020 and 1,370 Mt of CO_2 in 2030 (Planning Commission, 2011).

As discussed in the technology section, commercially available solar air-conditioning systems are catering to high capacity cooling demand, and as such these systems are most well-matched to meet the cooling demands of commercial buildings such as retail malls, offices spaces, hospitals, convention centres, hotels, etc., which have high demand for cooling. Solar thermal driven air-conditioning systems could also help meet hot water requirement in these institutions during the winter season.

Hence, various on-ground installations evidently suggest that the commercial buildings sector is a lucrative market for solar air-conditioning systems. However, irrespective of these various benefits, solar air-conditioning systems are still a less popular alternative as compared to conventional HVAC systems due to their high upfront cost and nascent technology maturity stage. Apart from the cost and technology, another crucial barrier to these systems is the availability of sufficient roof top area for installation of solar PV panels or solar thermal collectors. Thus, in commercial places like supermarkets and convention centres with large amount of unused roof areas, solar air-conditioning systems can become a potential and viable option.

In hospital and hotels building where requirement of fresh cool air and hot water is more, solar air-conditioning systems can be a viable alternative. Another important characteristic of solar thermally-driven air-conditioning system is that these can be integrated with already installed conventional boiler systems as hybrid systems. For example, in Kailash Cancer Hospital and Research Centre (KCHRC), Vadodara, Gujarat, which is a 160-bed hospital established and run by Muni Seva Ashram (MSA), a hundred Scheffler dishes of $12.5m^2$ have been installed, each generating 400kg/hr of steam at $8.5kg/cm^2$ at 167°C. The steam is sent to a 100 TR LiBr-based vapour absorption chiller which supplements the installed bio-mass boiler based 500 TR vapour absorption chillers.

2.3.2 Residential Building Sector

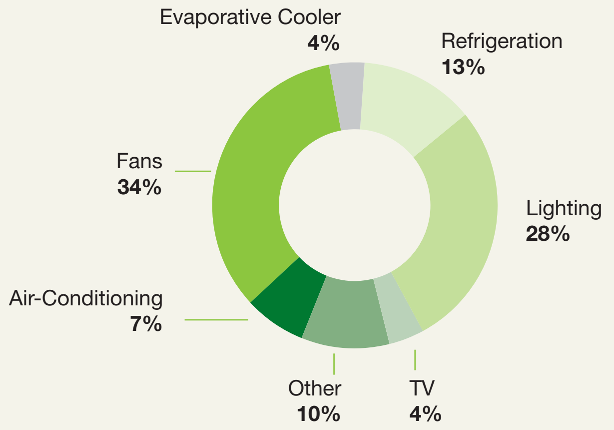
Cumulatively, residential and commercial building sectors accounts for 29 per cent (out of which the residential sector contributes 21 per cent) of the total electricity consumption in India.

With burgeoning urban population from 78.9 million in 1961 to 285.5 million in 2001, the demand for residential dwellings in urban areas is growing rapidly in India. The

FIGURE 2.14

Power Consumption Pattern in Indian Residential Building Sector

Source: Planning Commission, 2011



total floor area of the residential building sector is likely to grow from 16,300 million ft^2 in 2005 to 69,823 million ft^2 in 2030 (Planning Commission, 2011).

With growth of purchasing power of Indian households, there is an growing demand for cooling solutions like AC's, evaporative coolers and fans. At present cooling activities (fans, evaporative cooling and air conditioners) in residential buildings, account for 45 per cent of the total energy consumption (Planning Commission, 2011) (see figure 2.14). This consequently leads to a large amount of GHG emission from this sector.

Till now majority of the solar attuned chillers available in the market were of high capacity (>120kW), which are far bigger compared to the cooling demand of residential buildings. These systems owing to a small market and component capacities, required considerable amount of investment for installation. But, with growing interest in this market segment in the last decade, several companies have started manufacturing "solar kits" in the capacity range of 5–15kW. Also, solar PV based air-conditioning systems have started picking up in the market, but reliable information on its cost, performance and efficiency is still inadequate, at least for India.

Designing of solar air-conditioning system, either PV powered or thermally driven, apart from being cost viable also need to qualify in other aspects such as being low on maintenance, space requirement and noise. In addition, residential scale schemes like "combi-systems"[8] can be utilized for meeting the cooling demand. Such schemes are already operational in many European countries, but in India the potential for these systems is geographically limited.

2.3.3 Industrial Sector

Typically energy intensive industries require different kinds of energy sources like electricity, diesel, furnace oil, etc., for a variety of industrial energy demanding

8 Solar combi-system operates in the same way as a solar water heating system. It involves a large solar thermal collector area (which can either be a flat plate collector or an evacuated tube collector) and a complex system of piping/ducts (auxiliary units and a fan coil units) to transfer and distribute heat/hot water in the building. This heat can be then utilized for cooling purpose also.

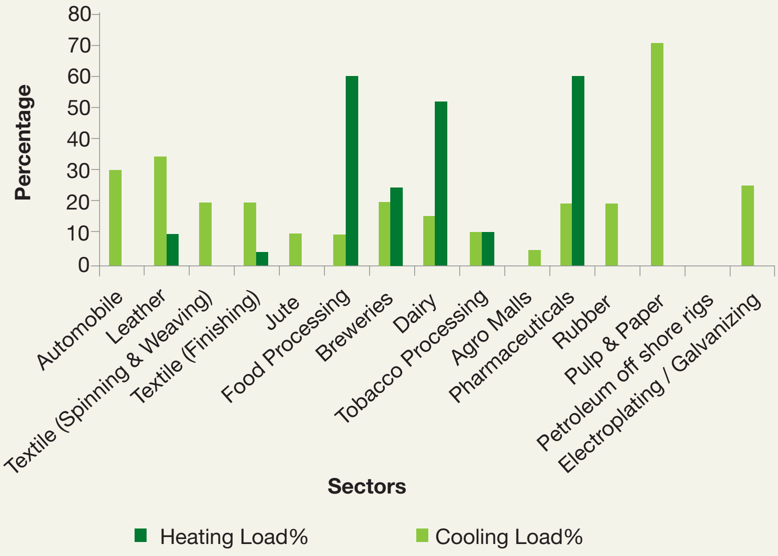
processes, such as process heat, comfort cooling, etc. In India, the industrial process heat requirement of many industries varies in the temperature range of 50˚C and 250˚C. Solar air-conditioning systems in industrial sector can be implemented to meet process cooling demand (for example, refrigeration and material preservation) as well as for providing comfort cooling. Thus, it significantly indicates the opportunity for implementation of solar application like solar-cooling systems. The following figures indicate the heating and cooling (see figure 2.15) demand of few industrial sectors in India.

As discussed earlier, various industrial sectors such as pharmaceuticals, chemical, food processing, etc., in order to meet their process chilling requirements, need chilled water at diverse temperatures ranges (for example, 8 to 10°C, sub zero temperature, etc.). In order to achieve this cooling demand industries use electricity generated from cogeneration or diesel generating sets. This electricity is then used through vapour compression chiller/vapour absorption chiller. However, the biggest hurdle in implementing solar application to meet these demand are the high upfront cost and round the clock availability of heat/electricity. In case of solar air comfort cooling demand, for installations like office buildings, laboratories, etc., typically centralized or package air-conditioning systems are installed at various industries.

FIGURE 2.15

Heating and Cooling Demand in Few Indian Industrial Sectors

Source: GIZ, 2011



Despite its vast potential, solar air-conditioning systems are finding it difficult to scale up their industrial segment. This is primarily because in industries the need for cooling is dependent on the process cycle and sometimes the requirement is round the clock. This uninterrupted demand is very difficult to meet through solar energy alone. Heat storage units can reduce this problem to some extent; however, this inflates the system cost. Furthermore, availability of mature air-conditioning technologies, like HVAC system and comparatively lower grid power tariffs increases the payback period for solar applications.

Solar application can be made attractive and economically viable by multiple utilization of the generated heat/energy. For example, many food industries require both refrigeration as well as dry heat air for drying products. These demands can be met by solar energy thereby making the payback period attractive and competitive with conventional solutions. One such installation has been done at Mahindra Vehicle Manufacturers Ltd., Pune, Maharashtra,wherein a group of 70 Scheffler solar dishes generate hot water which is used in VAM to provide process cooling. At the same time solar energy is also used for washing and degreasing of automobile components at the project site. Use of Scheffler dishes for thermal output reduces consumption of 1,476 tonnes of LPG per annum.

TABLE 2.4

Some Solar Air-Conditioning Systems that are Installed Globally

Parameters	Case Study 1	Case Study 2	Case Study 3	Case Study 4
Location	Ipswich Hospital Ipswich,Australia	"Rethimno Village" Hotel, Crete, Greece	"Iberotel Sarigerme Park"Hotel, Dalaman, Turkey	Head Offices of Inditex Arteixo - A Coruña, Spain
Application Type	Air conditioning	Air conditioning	Air conditioning and steam delivery for laundry	Air conditioning
Year of Application	2008	2000	2003	2003
Scale	300kWc	105kWc	140kWc	170kWc
Type of Chiller	Absorption	Absorption	Absorption	Absorption
Working Fluid	Thermic oil	Water	Water	Water
Type of Solar Collector	Parabolic trough	Flat Plate	Parabolic trough	Flat Plate
Collector Area	570m^2	448m^2	360m^2	1626m^2
Thermal Energy Output	360 MWh/annum	650-743 KWh/ annum	Appx. 590 kWh/day	Not Available
Cost	$6,000–9,000/ kWc	264,123 €	Not Available	900, 000 €

2.3.4 Current Installation of Solar Thermal Air-Conditioning Systems in India

According to one estimate, by 2011 globally around 700 solar air-conditioning systems have been installed (Stryi-Hipp, 2012) (see figure 2.16). These installations include systems with large as well as small capacities (Mugnier and Jakob, 2012). Estimates by IEA suggest that the solar air-conditioning installation around the world could be somewhere close to a thousand projects covering all types of technologies and sizes (IEA, 2011).However, compared to global figure of conventional air-conditioning units of 94.5 million units in 2011 (JARN, 2010), the number of solar air-conditioning installations seem significantly small. Recently, several large-scale solar air-conditioning systems have been installed or are under planning and development stages. An important trend in upcoming projects is that a large number of these are being developed and promoted by market forces and private investors without major governmental incentive or funding for financial sustenance.

At present, the HVAC market in India, in terms of volume, is estimated to get to around 5 million TR in 2015 (Buildo Tech Magazine, 2011). In case of the electricity demand from room AC systems (which constitute around 99 per cent of the annual air-conditioning systems sales), by 2030 it is expected to reach 239 TWh/yr, which equals to 143 GW of peak demand requiring almost 300 new coal fired power plants with individual capacity of 500 MW (Phadke et al., 2013).

The use of solar air conditioning is still a virgin area with a large untapped potential. In India, the expected market potential for solar air conditioning is about 0.75 million TR, and is increasing at the rate of around 17 per cent per annum (VSM Solar, n.d.).

The use of this technology is steadily picking up due to the introduction of favourable policies and incentives like the introduction of the National Solar Mission and provision of incentives and subsidies for procurement of solar equipments and so on. According to IEA, the global final energy demand for cooling by 2050 is likely to be 9 EJ, with solar cooling contributing to 1.5 EJ (1,000 GW_{th}, i.e., 17 per cent) of total energy use for cooling (see figure 2.17) (IEA, 2011). A market analysis by KPMG estimates the potential for solar cooling segment in India to be about 0.13 million m2 of collector area (~INR 2 billion) (KPMG, 2012). According to an recent estimate, by 2022 it is possible to achieve solar cooling capacity of about 25,000 TR in India (Singhal, 2014).

FIGURE 2.16

Estimated Globally Installed Solar Air-Cooling Systems

Source: Stryi-Hipp, 2012

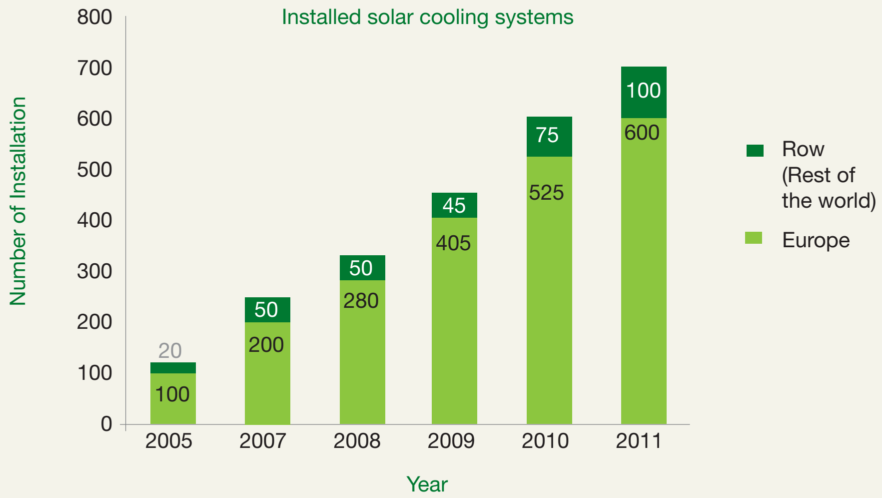
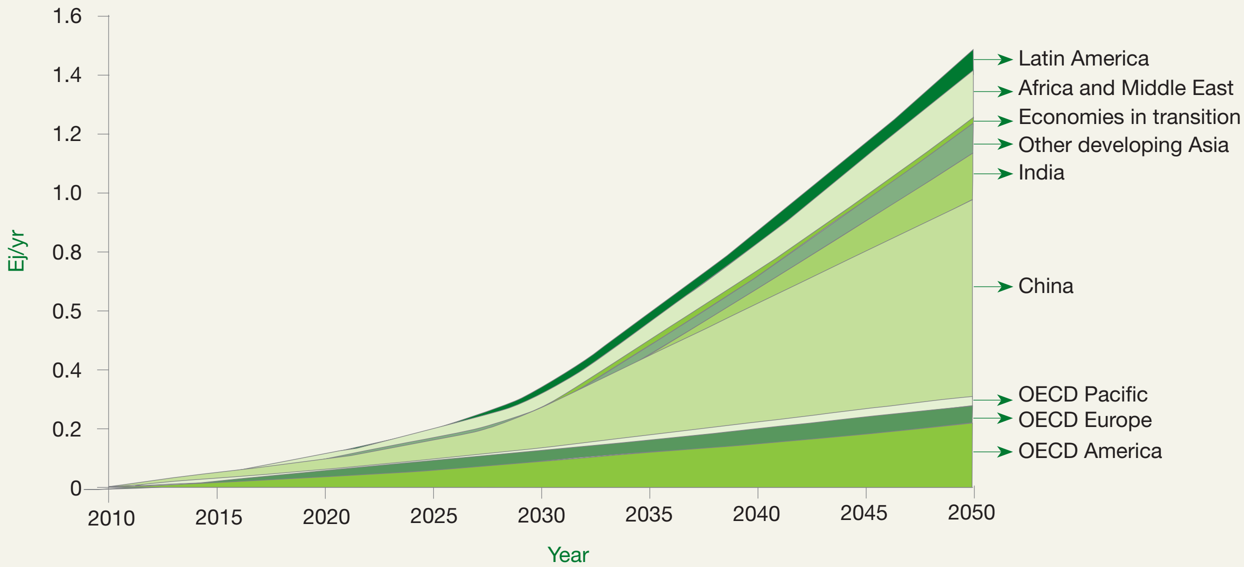


FIGURE 2.17

Projected Scenario for Solar Cooling (Exajoule/yr)

Source: IEA, 2012



Despite its vast untapped potential, still just a few companies exist in India that provide turnkey solar air-conditioning solutions. Most of the solar air-conditioning systems are installed by companies which puts together different components and subsystems as per their project requirements.

At present only a handful of successfully established installations of solar thermal air-conditioning systems are operational in India. Generally, these are in places where conventional boilers were already in used to generate steam for cooking/heating. Solar cooling systems have been integrated in a hybrid mode to the existing system. Along with commercial establishments, MNRE is also funding installation and R&D on these technologies, but at present the supply chain for the production and supply of the systems is still evolving in India. Few of these installations and manufacturers are mentioned below (see table 2.5).

TABLE 2.5

Some Installed Solar Thermal Air-Conditioning Systems in India

S. No	Installed At	Manufacturer	Capacity	Technology	Year of installation
1	Mamata Energy Plant, Ahmedabad	Mamta Energy Pvt. Ltd., Ahmedabad	25 TR	Vapour absorption chiller	2006
2	Chhatrapati Shivaji Hospital, Thane	Sharda Inventions Pvt. Ltd., Nashik	212 TR	160 TR vapour absorption cooling and 52 TR desiccant cooling	2011
3	Solar Energy Centre (SEC), MNRE, Gurgaon (demonstration project)	Thermax, Pune	28.5 TR	Triple-effect vapour absorption chiller	2011
4	NTPC Energy Technology Research Alliance (NETRA), Noida	Clique Solar, Mumbai	50 TR	Vapour absorption cooling	2012
5	Mahindra Vehicles Manufacturers Ltd., Pune	Thermax, Pune	120 TR	Vapour absorption cooling	2010
6	Turbo Energy Ltd. (TVS group) Chennai	Clique Solar, Mumbai	50 TR	Vapour absorption cooling	2011
7	Muni Seva Ashram, Vadodara	Gadhia Solar	100 TR	Vapour absorption chiller	2008
8	Magneti Marelli, Manesar	Thermax, Pune	30 TR	Vapour absorption cooling	2010
9	NPCIL (Nuclear Power Corporation of India Limited), Kota, Rajasthan	Thermax, Pune	100 TR	Triple effect vapour absorption chiller	2013
10	Honeywell Techbologies, Hyderabad	Thermax, Pune	100 TR	Triple effect vapour absorption chiller	2013

Based on stakeholder discussions, it was observed that solar air-conditioning technology in India is evolving for solar thermal driven. In case of solar PV, it is still at a nascent stage. Hence, there is no steady market demand for the systems. Manufacturing companies in India thus cater to industrial and commercial clients on project-by-project basis aiming to meet the cooling demand of the clients. Since the technology ecosystem for solar cooling is still focusing on R&D, demonstration project and awareness creation, hence, companies have not yet started on developing dedicated business models to promote solar cooling. Rather these companies are focusing on individual projects most of which are not on turnkey basis. Table 2.6 lists key stakeholders that currently influence this market segment in India.

TABLE 2.6

Key Stakeholders in Indian Solar Air-Conditioning Market

Stakeholder		Role
Companies	Sharada Inventions, Surya Shakti Pvt. Ltd., Arka technologies Pvt. Ltd., First Esco (India) Pvt. Ltd., VSM Solar Pvt. Ltd., Thermax Ltd., Clique Developments Ltd., Mamta Energy Pvt. Ltd., Energetic Consulting Pvt. Ltd., SLT Energy Ltd., Taylormade Solar Solutions (TSS) Pvt. Ltd.	These companies provide solar air-conditioning systems
	Thermax Ltd., Kirloskar Pneumatic Company Ltd. (KPCL), Voltas Ltd.	Vapour absorption chillers
Government	Ministry of New and Renewable Energy (MNRE)	Initiates policy actions, co-funds, facilitates execution of demonstration projects
	Bureau of Indian Standards (BIS)	Involved in standardization, certification and quality of solar energy collectors and components.
	Bureau of Energy Efficiency (BEE)	Mandated to put into action national programmes on energy efficiency and conservation in industries and buildings
	Ministry of Environment and Forests (MoEF)	Focal point for GEF (Global Environment Facility) funded solar projects in India
	Solar Energy Centre (SEC)	Involved in testing of products/ technologies (solar PV and thermal) as well as promoting them through outreach activities.
	State Nodal Agencies (SNAs)	Translating MNRE's mandate at the state level. Fund disbursement,project monitoring and evaluation.
Consultants/ Associations	Indian Green Building Council (IGBC)	Promotes green buildings in India, including use of renewable energy as one of the interventions.
	Individuals and consultants like Price water house Coopers India (PwC), World Institute of Sustainable Energy (WISE), and Dr Ajay Chandak	To evaluate and promote CST based projects under UNDP-GEF scheme.
Research & Development	APITCO, Hyderabad	Under the UNDP-GEF project APITCO has been mandated with performance evaluation of existing CST based project (include cooling system)
	Indian Institute of Technology (IIT), Bombay, Madras and Delhi	Working towards improvements in CST's and allied applications.
	GK Energy Pvt. Ltd., Thermax Ltd., Akson Solar Equipments Pvt. Ltd., and University of Pune	Development of performance standards, test procedures, and protocols for CST systems
	Thermax Ltd.	Involved in in-house research and development on absorption chillers

	The Energy and Resources Institute (TERI)	Involved in development of biomass, solar hybrid process cooling system
	Sardar Patel Renewable Energy Research Institute (SPRERI)	Has targeted to develop solar thermal medium pressure steam and heat pumping for power and space cooling systems
Financial Institutions	Indian Renewable Energy Development Agency (IREDA)	Mandated to promote and extend financial assistance to renewable energy projects in India. Presently promoting solar off-grid programme under the JNNSM.
	National Bank for Agriculture and Development (NABARD)	Provides capital subsidy-cum-refinance for setting up solar off-grid (PVand thermal) projects under the JNNSM.
Bilateral/ Multilateral Organizations	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)	Under the ComSolar (Commercialisation of Solar Energy in Urban and Industrial Areas) project, promoting awareness, developing and testing of business models to make solar energy commercially viable in urban and industrial areas.
	UNDP-GEF	Mandated to promote and commercialize the use of CSTs for industrial process heat applications through demonstration and replication project. Also, developing knowledge documents, test standards and test protocols to promote scaling up.

2.4 COST ESTIMATES

The true market cost of investment for solar air-conditioning systems are difficult to assess, both at the global as well as national levels. This is particularly because solar air-conditioning technology is still evolving and only limited installations have been executed. Another important observation here is that, most of the projects are either demonstration or pilot level projects supported by the government, developmental agencies and R&D institutes, etc.

The initial level of investment required to install[9] a solar air-conditioning system is significantly higher in comparison to conventional cooling systems. According to IEA this investment in solar air-conditioning systems could be 2 to 5 times more than the conventional cooling systems with similar capacity (IEA, 2011). The upfront cost of solar air-conditioning systems could vary depending on the geography and existing market base for demand and supplying capacity. Despite the higher initial investment cost, maintenance and operation of a solar air-conditioning system is fairly economical when compared to conventional cooling systems. For example, in case of desiccant cooling chillers maintenance majorly involves changing of filters (IEA, 2012).

9 Investment cost includes planning, assembly, construction and commissioning.

Globally, estimated investment cost for solar thermal cooling system ranges between $\$1{,}600/\text{kW}_{cooling}$ to $\$3{,}200/\text{kW}_{cooling}$ for medium to large capacity systems (IEA, 2012). Component-wise cost of a double effect LiBr chiller costs around € 1,200/$\text{kW}_{cooling}$ and single effect LiBr chiller costs around €1,000/$\text{kW}_{cooling}$.

With more recent advances in the solar cooling market, "pre-engineered" solar kits are quickly becoming available for the consumers. Though mainly these systems are available in European markets, potential for these "solar kits" could be significant in developing countries like India. The prices of these kits is expected to be somewhere near to € 3,000/$\text{kW}_{cooling}$, and these system are developed in 35 kW cooling capacity so as to maximise the target market base (IEA, 2011).

The cost of a conventional air-conditioning HVAC system ranges between INR 0.05 million and 0.1 million per TR, while the cost of installation of a solar air-conditioning system is about INR 0.15 million per TR (Business Standard, 2006). The operation and maintenance requires negligible running cost, but the solar heat collectors need to be changed every four to five years and cost about 10 per cent of the system cost.

Thus, the total payback period without depreciation and subsidy benefits offered by government is estimated to be four to five years. The average life span of an average size (25TR) solar air-conditioning system is about 25 years (Mamta Energy).

FIGURE 2.18

Vapour Absorption Cooling System at NTPC Energy Technology Research Alliance (NETRA), Noida

To promote solar air-conditioning systems in India, MNRE has fixed benchmark costs for concentrated solar thermal (CST) systems. A CST system with manual tracking cost of INR 7,000/m^2; a CST system with single axis tracking has a benchmark cost of INR 18,000/m^2 of dish area and INR 20,000 has been fixed for two axis tracked systems. In the case of flat plate collector, MNRE has defined a benchmark cost of INR 8,500/m^2 for the domestic user and INR 8,000/m^2 for the commercial user. Evacuated tube collectors have a benchmark cost of INR 11,000/m^2 for non-commercial users and INR 10,000/m^2 for commercial consumers. MNRE provides 30 per cent capital subsidy on the benchmark cost or loan at 5 per cent interest on 50 per cent of the benchmark cost to all the beneficiaries in the general category states. This subsidy goes up to 60 per cent in the special categories states like Himachal Pradesh, Jammu & Kashmir, Uttarakhand and the north eastern states including Sikkim.

A crucial impetus that is required to significantly scale up solar air-conditioning systems is to make them economically viable. However, economic viability and payback time of these systems depends heavily on geographical location, technology availability and local application “ecosystem”. Following are few interventions that could lower down the payback period in case of solar air-conditioning systems:

- Co/Poly-generation, wherein output energy from one phase is utilised as input energy source for the second phase process (e.g., steam and waste heat) can be utilized for several functions like process heating and cooling, etc. This mode of energy generation and utilization could lower down the payback period.
- Designing and planning of the cooling system should be as per the needs of the clients so as to reduce wastage of energy and money.
- Technology improvements in the solar collectors, chiller units and storage components can also reduce payback period significantly.
- Large-scale manufacturing of small and medium sized solar air-conditioning systems and related components.

2.5 POLICY SCENARIO

The Ministry of New and Renewable Energy (MNRE) under the Jawaharlal Nehru National Solar Mission (JNNSM) provide incentives and capital subsidies for solar thermal and solar PV equipments and machinery. At present, there is subsidy of INR 5,400/m^2 for concentrating systems if it has single axis tracking and INR 6,000/m^2 if it has double axis tracking. The solar air-conditioning system based on solar thermal collectors like FPC or EPC are also subsidised by MNRE. Under the Phase II of JNNSM, the government has a target of at least 200 systems, 30 TR each on an average (60,000m^2) for air-conditioning/refrigeration systems by 2017 (MNRE, 2012).

In addition to the above, demonstration projects (see table 2.7) for solar thermal air-conditioning systems have been installed and commissioned at the MNRE’s Solar Energy Centre (SEC).

TABLE 2.7

Demonstration Projects Installed at SEC, Gurgaon

S No.	Capacity	Technology	Solar collector area
1	$100kW_{thermal}$	LiBr vapour absorption systems	$288m^2$ collector area (48 parabolic trough concentrators (PTC)
2	$15kW_{thermal}$	LiBr vapour absorption systems	$96m^2$ collector area (16 parabolic trough concentrators (PTC)
3	$5kW_{thermal}$	LiBr vapour absorption systems	$31.5m^2$ collector area (30 parabolic trough concentrators (PTC)
4	$15kW_{thermal}$	Zeolite based vapour absorption systems	$61.38m^2$ collector area (18 parabolic trough concentrators (PTC)

FIGURE 2.19

PTC-Based Solar Air-Conditioning System at SEC, Gurgaon

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To encourage and commercialize the use of CSTs for industrial process heat applications, MNRE has started the implementation of UNDP-GEF project – "Market Development and Promotion of Solar Concentrator Based Process Heat Applications in India". Under this umbrella project, MNRE is trying to augment awareness and build up of technical capabilities of different stakeholder like manufacturers, installers and concentrating solar heat (CSH) users. Under this programme, various applications including solar process cooling and comfort cooling in the industrial sector are being promoted through interventions such as developing demonstration and replication projects. As a target, this project aims at facilitating installation of 30 CST demonstration projects and at least 60 replication projects.

Apart from execution of on ground installations, this project is also working towards removal of barriers (economic, technical and institutional) by developing knowledge documents, market assessments, test standards and test protocols to promote CST applications in industries. The project term is from 2012 to 2017 with a total project budget of $23,750,000 which is currently being funded by grants from the Global Environmental Facility (GEF). During the project period, the CST sales in India are likely to grow to 15,000m^2 per year by 2016, and over the life period of the project installations (i.e., 20 years) nearly 315,000 tonnes of CO_2 emissions will be abated.

FIGURE 2.20

Double-Effect Vapour Absorption Chiller (15kW) at SEC, Gurgaon

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Following are the few interventions being carried out under the aegis of UNDP-GEF project to promote CST in India (Sun Focus, 2014):

- Providing additional financial support to CST projects under the ESCO model.
- For demonstration project of 250m² and above, facility to avail 15 per cent of system benchmark cost to a maximum of INR 75 lakh with online performance monitoring, O&M expenses, feasibility report/DPR, etc. Similar support is available for projects of 150 m² and above with dual axis tracking system.
- By providing performance/fuel saving data, O&M expenses data, etc., replication projects of 250m² and above can avail INR 5-10 lakh incentive under this project.
- Under the repair and renovation scheme, 10 per cent of the project cost with a maximum ceiling of 15 lakh is paid to the developer, subject to equal or more finance being invested by the developer himself.
- Preparation of training manuals for maintenance, troubleshooting and operation of CST systems.
- Empanelment of consultants (PwC, WISE, and Dr Ajay Chandak) for promoting and creating awareness about CST applications.
- National level independent study to evaluate the CST ecosystem and performance of installed systems.
- Through the consortium of GK Energy, Thermax Ltd., Akson Solar and the University of Pune, performance standards, test procedures and protocols for CST systems are being developed.
- Performance evaluation of existing CST based project (include cooling system) under the UNDP-GEF project in India is being carried by APITCO, Hyderabad.

Apart from subsidies and incentives, there are policy mechanisms like standards and codes that directly influence building energy conservation and efficiency. Standards and codes like the National Building Code (NBC) and Energy Conservation Building Codes (ECBC) provide broad-spectrum guidance on possible energy efficiency aspects like daylight integration, artificial lighting requirements and heating, ventilating and air conditioning (HVAC) design standards for commercial buildings (Tathagat, 2011). Various market-driven voluntary green building rating programmes such as Indian Green Building Council (IGBC) programmes – LEED, TERI-GRIHA and Eco-housing – are also promoting the integration of renewable energy-based technologies in building operations.

2.6 BENEFITS

India's economy has witnessed unprecedented growth over the last decade, making India the 10th largest economy in the world (IMF, 2014). The changing social scenario (urbanization and lifestyle changes) has resulted in sharp increase in the energy and power demand in the country, despite having one of the lowest per capita power consumption in the world (which is around 880kWh) (CEA, 2013a). Presently, India's demand of domestic power was reported to be 918 billion units in 2012 (energy gap between supply and demand was -8.7 per cent and peak shortage was -9 per cent (CEA, 2013b). According to Greenpeace domestic power demand is likely to be 1,640 billion units by 2020, calculated on the basis of an annual growth rate of 9.8 per cent (Greenpeace, 2013). Considering the steeply increasing domestic power demand, the Planning Commission in its Integrated Energy Policy report suggested that by 2031–32 power generation capacity must increase to nearly 800 GW (Planning Commission, 2011) as compared to the present scenario of 234 GW (MOSPI, 2013).

As per available national GHG emission data, the total GHG emissions from the energy sector was around 58 per cent in which contribution of electricity generation in 2007 was 719.31 million tonnes CO_2eq. (INCCA, 2010). This estimate includes both grid and captive power generation. The GHG emissions eq. from electricity generation was 65.4 per cent of the total CO_2 eq. emitted from the energy sector. Furthermore, refrigerants currently being used in conventional vapour compression systems also have negative externalities on the ecosystem. The refrigerants, CFC (Chloro-Flouro-Carbon) and HCFC (Hydro-Chloro-Flouro-Carbon) are ozone depleting substances and are highly potent global warming gases.

The manufacturing of various solar air-conditioning systems are such that harmful refrigerants such as CFC, HCFC or HFC are not used. Furthermore, solar air-conditioning system has multiple direct and indirect benefits ranging from GHG emission reduction to employment generation and green image. Traditionally, HVAC uses conventional fossil energy sources to generate steam in the boilers which in turn is passed through the process "path" to achieve air conditioning. Using the solar air-conditioning system considerably reduces the use of conventional fuel such as electricity, wood, natural gas, furnace oil and so on. For example, 100TR solar air-conditioning system installed at Kailash Cancer Hospital and Research Centre (KCHRC), Vadodara, Gujarat, abates approximately 330,000kg of CO_2 per year and

1,000 kg/day of wood. Also large-scale deployment of solar air-conditioning system can reduce the peak demand deficient.

Promoting solar air-conditioning systems directly incur economic benefits to the user by reducing conventional fuel consumption and indirectly the heavy expenditure on fossil fuel imports. Solar air-conditioning systems (thermally driven) can also be integrated in the existing industrial installation which produces waste heat. Some other indirect benefits include employment generation and green image creation for the technology user.

2.7 BARRIERS AND OPPORTUNITIES

Solar air-conditioning system is a promising technology, which can considerably contribute in meeting the demands of residential, commercial and industrial stakeholders in a sustainable manner. Yet, despite these positive aspects deployment of solar cooling technology in India is still in a nascent stage due to various factors. This section highlights the barriers based on feedback received through stakeholder interaction across different sectors and levels.

2.7.1 Technological Challenges

During the course of interactions with different stakeholder it emerged that in terms of execution of solar air conditioners, technology is not the major barrier. Nonetheless, there are known technical problems that are restricting the scaling up of solar air-conditioning systems. Majority of the technical problems are solvable and many of these issues have already being researched. The technical aspects heavily impact the cost economics of the system; hence improving efficiency will significantly remove economic barriers for deployment.

- **Performance of absorption, adsorption and desiccant chillers**

  The performance (COP) of the solar energy compatible chillers, like absorption, adsorption and desiccant ranges between 0.4–1.4 as compared against 2–5 for conventional vapour absorption chillers with similar capacity. This significant gap in the efficiency leads to extra investment thereby making the solar air-conditioning systems unattractive for users.

- **Lack of small capacity solar air-conditioning units**

  One of the primary technical barriers towards the spread of solar air-conditioning systems in India is the lack of small-size units. Majority of the cooling demand in India is from the residential sector. Also,within the commercial sector, there is demand for small cooling units as well. Thus, in the absence of commercially available small cooling units, either the user opts for higher capacity systems leading to increased investment cost and payback period or goes for conventional cooling systems. Lack of small package solar air-conditioning systems hampers increased deployment, since installation of solar collectors require large area, which for majority of industries is difficult to part with.

- **Quality and consistency of cooling output**

  Another major issue with respect to solar air conditioning is the consistency of cooling output. Presently solar cooling systems are being promoted as the technology that can deliver high cooling need when the heat is the maximum (summer season). Air-conditioning systems based on the solar thermal driven chillers need initial few hours in the morning to generate sufficient heat and steam to run the system. But, one must also consider the fact that in offices and other commercial institutions the demand for comfort cooling starts in the morning.

  Also, seasonal intermittency of solar irradiation hampers the all year round operation of solar air-conditioning systems, thereby many of the users with process cooling needs in the industry prefer conventional systems.

- **Performance of system components**

  From the component point of view, non-availability of low-cost commercial thermal energy storage with low heat loss (in case of sensible thermal energy) and large system size (in case of latent heat storage and thermo-chemical heat storage systems) is still a major barrier. The storage component is also crucial in terms of delivery of cooling output. Storage units constitute around 20–30 per cent of the total system cost.

- **Limited technology maturity**

  Large-scale thermally driven solar air-conditioning system technology is already available and is ideal by economies of scale (at least single effect sorption systems). However, small capacity “solar kits” technology is slowly picking up in the global market. Yet, these technologies are still at the development stage. In comparison, conventional cooling systems have been in the market for quite a few decades and the technology is mature. Household-level cooling systems are much more mature with “fix and forget” facility for users, whereas solar air-conditioning technologies lag behind in this issue. Therefore, solar air-conditioning systems are finding it difficult to form a stronghold in the Indian cooling market.

2.7.2 Limited Information and Awareness

- **Limited demonstration and replication projects**

  MNRE along with various research institutes and companies is at present working towards promoting solar air-conditioning system in India. However, there are only a handful of demonstration projects installed in India (mainly based on solar thermal driven systems). Further, in the case of solar PV installations, hardly any detailed database for installed systems is available. This lack of information on systems track record creates low confidence and high-risk perception amongst potential users, financial lending institutions, etc.

- **Lack of information on technology, performance and government support**

  There are around 10 existing solar-driven air-conditioning system projects installed in India. Yet, inclusive system performance evaluation of these projects and careful analysis highlighting the factors for success of the project or otherwise are in dearth. In case of solar PV based systems, documentation regarding current technology available in India, its performance, cost and installation status is further lacking. For a non-technical user, there is limited clarity and transparency in terms of information on subsidies and incentives provided by government as well as the process of availing financial support. Enhanced and demystified information on subsidies, awareness creation by government agencies and other stakeholders could stimulate market development of and investments in solar air conditioning.

- **Public perception of solar being a complex and auxiliary system**

A large number of users from the industrial, residential and commercial sectors in India currently use conventional fossil fuel and electricity for meeting their cooling requirements. Based on stakeholder discussions, one of the primary barriers observed was the general perception that solar air conditioning is a complex, risky and intermittent system requiring frequent maintenance. Thus, most users see these systems only as auxiliary components or demonstration projects to showcase the institutional "green" image.

2.7.3 Limited Skilled Manpower and Training

- **Limited knowledge and experience of solar cooling technologies and systems amongst technical companies**

Dissatisfaction occurs when the installed system despite using quality collectors and components, performs inefficiently. This usually happens as a consequence of the lack of proficiency, knowledge and practical experience of planning and designing companies. It leads to designing of systems which are often either under designed or over designed in meeting the client's cooling needs.

India has a vast pool of technical manpower to drive the market for solar applications. However, being a new technology there are very few consulting companies which can deliver efficiently designed solar cooling systems in India. At present there is a significant gap in technical knowledge for solar cooling, resulting in delays in executing project or installation of poorly designed systems.

- **Inadequate accessibility of technical human capital (skilled and semi-skilled)**

In Indian solar-air conditioning market, technical consultants/companies, which offer solar cooling systems are mostly small in size having limited resources for R&D, demonstration, manufacturing, installation, commissioning and post-sales servicing network. All these stages of project realization require both skilled as well as semi-skilled technical manpower. This unfortunately is limited at the moment resulting in delayed project execution, post-sale servicing problems, and issues with operation and maintenance of the system.

- **Limited solar air-conditioning research infrastructure**

MNRE under various schemes and programmes has initiated few demonstration and research projects in collaboration with various research agencies across the country (see table 2.6). However, upon discussions with various stakeholder and sector experts it was observed that India with its vast potential for solar cooling has limited research infrastructure for this sector. In addition, various small R&D institutes and companies still find it difficult to get access to government research grants due to factors such as inadequate infrastructure, lack of manpower, etc. This has led to polarization of technology wherein big companies have funds for research and the small companies are becoming mere executors at project sites.

2.7.4 Policy Issues

- **Subsidy disbursal mechanism**

  To promote solar applications in India, MNRE under the JNNSM has started subsidy and incentive disbursement mechanism amongst the project developers. The subsidy disbursal mechanism in case of solar off-grid application involve manufacturer who on behalf of the user submits the proposal to MNRE. The installed system is then reviewed along with specifications and a 15-day performance appraisal evaluation by a third party and the State Nodal Agency (SNA). Following successful appraisal, the subsidy amount is given to the project developer. However, discussions with solar air-conditioning users revealed that the rate of subsidy disbursal by MNRE was rather slow, which acted as a barrier to the penetration of solar applications in the country.

- **Lack of standards and measures for quality assurance**

  At present, solar air-conditioning systems in India lacks standardized performance evaluation standards and protocols[10] for off-grid solar thermal applications. In the absence of these guidelines, measuring the performance of solar air-conditioning systems and comparing them with other technologies and applications become difficult. This further restricts interventions like performance-based incentives for projects, etc.

- **Need for more focus on solar PV in addition to promoting only thermal systems**

  Most of the MNRE schemes presently focus on solar collectors and solar thermal driven cooling applications at a large scale. However, solar PV driven air-conditioning systems have not received much attention. Considering the potential it has to meet the cooling demand for India's growing urban population in a sustainable manner, government agencies must promote solar PV driven cooling systems.

- **Existing subsidised power tariffs**

  Currently power tariffs and select fuels in India are highly subsided and underpriced. This situation of lower baseline fuel charges provides very little incentive for a user to shift from conventional air-conditioning system to solar-based cooling system. It is therefore a prominent deterrent for deployment of solar air-conditioning systems in the country.

10 MNRE has formulated standards for solar PV systems and FPC/ETC based SWH systems.

2.7.5 Cost Aspects

- **Lack of strong market base**

  Being a technology which currently has evolving market base in India, there are not many dedicated manufacturers of solar air-conditioning systems in India due to which the supply chain for equipments becomes constrained. This is more evident in the case of PV driven solar air conditioning systems.[11] Furthermore, there are only a few types of solar collectors that can deliver the temperatures required by the vapour absorption machines. Also, due to the lack of pre-packaged air-conditioning systems (with range of capacities), most of the project are custom designed to meet the needs of individual clients. Although this process helps in designing effective systems, it however also increases the cost. A small supply base, often results in recurrent delays in the installation and commissioning of projects. Not only supply of equipments, but also post-installation servicing is also an issue for the clients/ users which further discourages other potential users.

- **Higher initial investment costs**

  For any project to be feasible, one of the primary criteria is its financial viability. The major issue with solar cooling systems is the higher initial investment cost. Stakeholders consultations revealed that users hope for simple paybacks of 2 to 4 years for their investments whereas solar air-conditioning systems offer a payback period somewhere in range of 4–8 years[12] (with inclusion of government subsidies and accelerated depreciation reimbursement). Though the thermal driven cooling systems have negligible running costs but the mirrors for the collectors need to be changed every four or five years and comprise 10 per cent of the system cost. Thus, higher financial investment is a key barrier to deployment of solar air-conditioning technology in India.

- **Limited financial support from government**

  MNRE has been actively promoting solar energy based applications (both thermal as well as PV), through provision of subsidies and incentives. However, this financial support is only available for the solar component (collectors) of the installations (on an average solar component constitutes around 30 per cent of the total cost of a system) thereby leaving substantial remainder amount to be financed by the project developer. Thus, it makes installation of solar air-conditioning projects financially unattractive amongst many users.

- **Limited avenue for finance accessibility**

  In India, solar air conditioning, being a new and emerging technology accessing finance from banks and Development Finance Institutions (DFIs) is still a difficult process. Banking and other financial institutions perceive solar energy as a risky business; therefore lending finance for such projects is still limited. However, with the onset of JNNSM, banks have started to show interest in solar projects, though majority of this interest lies in the solar PV market which is comparatively mature

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11 During stakeholder interactions it was observed that solar PV based air-conditioning systems in India are either completely being imported or are being assembled by companies. There are no dedicated manufacturers for these systems.

12 This payback period can vary based on system specification, geography, local market, state policies etc.

and has reliable prospects for banks (with significant on ground performance records). In case of solar cooling projects, banks and DFIs would first like to see a similar project and its performance in India. Even if the project developer is able to secure finance, it has to be taken on higher lending rates.

- **Lack of financial support based system performance**

  As mentioned earlier, MNRE's subsidies and incentives for solar air conditioning systems are only available for solar components. The available support is based on the benchmark cost of solar collector's area. Due to this mechanism, low cost and low efficiency are getting promoted whereas the critical systems components like process chillers and backup storage units are not considered. MNRE subsidy scheme, in general, does not consider on ground project realities like need for adoption of high energy efficiency chillers (double and triple effect) or the thermal energy storage units with long buffering period. Thus, it renders many potential projects as economically unviable.

2.8 RECOMMENDATIONS

Table 2.8 outlines some of the recommended interventions in overcoming the barriers hindering the spread of solar air-conditioning systems in the country.

TABLE 2.8

Barriers and Associated Recommendations

Barrier	Recommendations
Technological challenges	Improvement in component design, system technology and materials, and solar collector efficiencies.
	Promoting cost-effective, compact energy (especially heat) storage equipments
	Design and development of small scale solar air-conditioning systems
Limited information and awareness	Need to develop new and innovative business models
	Promotion and dissemination of information through dedicated e-portals
	Documentation of project information and performance
Limited skilled manpower and training	Using existing infrastructure (vocational training centres and industrial training institutes) for creating skilled and semi-skilled workforce.
	Innovative collaborations between various stakeholders like government, training centres and companies to create necessary human capital
	Enhanced interface between research agencies and on ground implementing companies
	Decentralization of solar air-conditioning research activities
Cost aspects	Creation of market demand through government initiatives
	Employing co/poly generation interventions
	Performance based subsidy and financial support
	Tapping alternative funding sources like CSR and NCEF funds

Barrier	Recommendations
Policy issues	Developing standards for solar air-conditioning components and high-grade solar collectors
	Transparent and efficient subsidy disbursal mechanism
	Increased support for dedicated solar air-conditioning research
	Creating opportunities and platforms for sharing of knowledge, technology and best practices amongst national and international stakeholders

2.8.1 Reducing Technological Challenges

There is a considerable potential for further development of solar air-conditioning systems in terms of energy and cost efficiency, particularly at the system stage. Since solar air-conditioning technologies are still relatively unfamiliar as compared to electrical driven vapour compression, the investment cost of solar air-conditioning systems could be reduced through technological development in component design, system technology and high-performance materials.

This intervention will necessitate R&D into new heat and mass transfer systems, advanced sorption materials and innovative sorption material coatings for heat exchange surfaces. Promoting the use of technically efficient multi-effect chillers with significantly better COP (desiccant, double effect and triple effect cycles) will ensure wider adoption of solar cooling technologies by different end users.

There is a need to develop energy efficient cooling towers (dry and wet) for heat rejection. Technological development is required to minimize the auxiliary power required for waste heat rejection in case of thermally driven air-conditioning systems thereby decreasing the payback period of the complete system.

Scaling up of solar air-conditioning technology in India would also require new, cost-effective, compact energy (especially heat) storage equipments. Advanced materials and storage technologies would be required to meet these needs. Furthermore, storage components would also cater to medium-temperature storage. Energy storage systems catering to medium temperature range (between 100°C and 300°C) will enable the incorporation of solar air-conditioning systems into larger-base industrial processes.

Given that cooling demand by various users differ in terms of cooling output, temperature and quantum of cooling air, air-conditioning units are especially cost viable at scale. However, since presently majority of the demand for air-conditioning systems is in small to medium range residential and commercial units, design and development of small-scale cooling systems becomes crucial. Small-scale cooling units "solar kits", with standardized capacities, compact design, and higher efficiency as well as "fix and forget" mechanism needs to be developed and field tested within the next few years.

2.8.2 Facilitating Enhanced Awareness and Information Dissemination

Apart from technical barriers, deployment of solar air-conditioning systems is also hindered by various non techno-economic barriers. Limited awareness of solar air-conditioning technologies, low priority to solar energy application for energy reduction, perception of solar air-conditioning systems as being a complex system must be addressed by using multi-facet interventions like collation of available information and wide spread dissemination of this information.

There is a significant need to develop new and innovative business models like RESCO[13], which are already being implemented on ground for Solar Water Heaters (SWHs) in India[14]. Promoting and creating awareness about these innovative and low-risk business models can enhance the confidence of both the user as well as lending institutions, thus stimulating the growth of solar air-conditioning systems.

Further, MNRE can also promote and disseminate information through e-portals, which can be easily integrated in existing web infrastructure such as MNRE website, etc. The web portal can display useful information about solar air conditioning such as case studies, analysis, available subsidies, list of manufacturers and suppliers, etc. The portal could also help in aggressively promoting small solar air-conditioning units especially PV driven systems amongst commercial and residential users. Such measures would increase confidence and clarity on the technology, finance, and other aspects of solar air-conditioning systems.

2.8.3 Creating Pool of Skilled Manpower

One of the primary reasons that solar air conditioning at the moment is finding it difficult to secure a market of its own is that the technology of HVAC system is mature and the industry has adequate skilled and semi-skilled manpower to cater to post-sales operations, and monitoring and maintenance of the systems. Thus, creation of a broad base of trained skilled and semi-skilled individuals will be necessary, not only for solar air-conditioning project execution but also for their operation.

To create skilled manpower, there should be more emphasis on imparting solar energy technology related knowledge in technical course curriculum. Semi-skilled workforce can be trained for operation and maintenance of solar energy systems at vocational training centres and industrial training institutes (ITIs). Thus, a push is required from the government and leading institutions in the solar industry to develop and incorporate the already existing chain of training centres in India into the emerging solar industry. This can ensure a steady stream of skilled as well as semi-skilled workforce to cater to the rising solar market in India. Innovative collaborations could

13 Under the RESCO model initial capital cost is not completely borne by the user, but it is either partially or fully invested by the installing company. Consumers have to pay an agreed percentage of finance back to the company based on energy savings and the agreement period.

14 Aspiration Energy Pvt. Ltd. in India is offering SWH for users on “PAYS model” (a model similar to the RESCO mechanism).

also be formulated between various stakeholders like the government, training centres and companies to create necessary human capital.

Lastly, solar research in India, especially on solar air-conditioning technology is limited. A review of the existing infrastructure, ongoing projects and stakeholder interactions showed that currently the limited research on solar air conditioning is happening primarily in academic institutes and few companies. Further, the focus of this research is more on large-scale thermal-base cooling systems. The interface between these research agencies and on ground implementing companies is inadequate and it is difficult for small companies to avail financial support from funding agencies. Thus, there is need for a more decentralised research network, wherein some portion of the research grant can be disbursed amongst small-scale companies which usually lack strong financial base. Decentralization can foster the development of low-cost and small-scale solar air-conditioning units that are more in demand from clients with limited cooling requirements. Similarly, there should be more focus on interface between governments, research agencies as well as large and small companies to share ideas and knowledge.

2.8.4 Making Solar Air-Conditioning Cost Effective

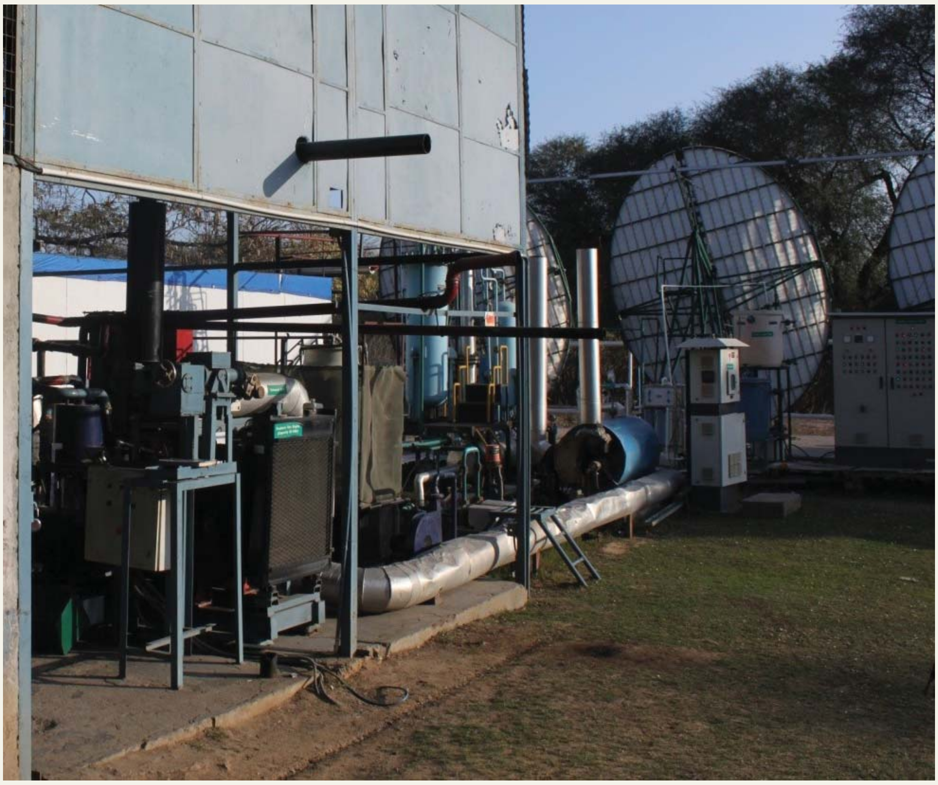
Primary intervention that is required at the moment is to create demand. The solar air-conditioning technology in India is still evolving and small-scale units are entering the market. Therefore, government support is needed to create the initial stimulus that would encourage the system demand and market base. For example, large-scale deployment of solar PV projects under the JNNSM has resulted in creation of strong market base and reduction of cost for solar PV panels in India.

“Poly” generation in the installation could lower down the payback period. Poly generation would principally be similar to co- and tri-generation systems in which output energy from one phase is utilised as input energy source for the second phase. Similar installations could be the use of output hot water for both processes – cooling as well as processing heating requirements. For example, the cold storage system developed by TERI and supported by MNRE includes, a 15kW Vapour Absorption Machine (VAM), $50kW_e$ Biomass Gasifier system and an array of solar concentrating collectors (see figure 2.21). The synthesis gas produced from the biomass gasifier is then used to operate engine-generator producing electricity. The residual waste heat from the gasifier along with the thermal energy from the solar CST system is used by the VAM to generate refrigeration output (Kumar, 2012).

Greater awareness and promotion of innovative business models like RESCO could increase the confidence not only of users but also of financial lending institutions. Furthermore, government intervention in facilitating easy loan availability from financial lending institutions, performance-based subsidy and financial support on complete system (not just the solar component) could provide a needed incentive for users to install solar air-conditioning systems. In a recent announcement, the government plans to utilize around INR 108 crore from NCEF to provide subsidy to target SWH installations (4,00,000 m^2) in industries and commercial sectors (MNRE, 2014). Similar fund allocation from NCEF can also be made to promote solar air-conditioning systems. Similarly, tapping into Corporate Social Responsibility (CSR)

FIGURE 2.21

Solar Biomass Hybrid Cold Storage System at SEC, Gurgaon



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funds could be one of the avenues to promote solar air conditioning in the industrial sector.

2.8.5 Creating Conducive Policy Environment

At the moment BIS certification is available for FPC and ETC based solar collectors. Developing similar standards for solar air-conditioning components and high-grade solar collectors can generate interest and confidence amongst consumers. At the same time policy intervention is required to foster the market for small-scale solar air-conditioning units and solar PV based systems. These can be achieved through increased support in R&D activities and by creating trained manpower through the existing infrastructure of training centres.

MNRE needs to create a transparent and efficient subsidy disbursal mechanism. Efforts are also needed to gradually shift from the existing 'subsidy driven' towards a 'market driven' approach so that the technology and its ecosystem gradually become self-sustainable. MNRE also needs to shift its role to be a supporting and regulatory authority. This transition can be achieved in the longer term through creating policies that foster innovative market mechanisms and transfer funds to create local demand and manufacturing capacity. This could help in creating lower system prices and simultaneously stimulating demand in the country.

Market and technology development in solar air conditioning cannot happen in isolation. Thus, the government need to facilitate wide ranging interface amongst diverse local stakeholders. These interfacing programmes could engage local stakeholders with various international funding, research agencies and companies, especially from the European Union, where solar air-conditioning systems have achieved market and technological maturity. Such interfaces are being promoted by the government for the solar water heater system in India. This intervention could provide a necessary platform for exchange of financial support for demonstration projects, and sharing of technology and best practices.

In India, which receives significant amount of sunlight for major portions of the year, solar air-conditioning systems have substantial potential. Thus, it is important that interventions throughout solar air-conditioning 'ecosystem' and not just technical innovations are required for its wide scale application and acceptability. Effective and large-scale implementation of solar air-conditioning systems can make crucial contribution in meeting India's cooling demand and low carbon development goal.


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ग्राम-भोपा की ढ़ाणी जिला अजमेर, वर्ष-2011

CHAPTER 3

SOLAR DESALINATION

3.1 BACKGROUND

Seawater desalination has been recognized as a potential solution to India's limited freshwater reserves and an ever-increasing demand for it by the country's burgeoning population. Limited availability of fresh water is witnessed in many parts of India, varying in scale and intensity at different times of the year. Seven states (Haryana, Punjab, Delhi, Rajasthan, Gujarat, Uttar Pradesh and Karnataka) are underlain by brackish ground water affecting 42 million people. Around 25 per cent of the population of India resides along the coast having easy access to seawater that can be treated / desalinated to produce potable drinking water (Abraham and Luthra, 2011). Coastal areas in particular are struggling with severe salinity ingress due to excessive extraction of groundwater and limited recharge of aquifers. A large section of India's urban and rural population reportedly consume water with TDS (total dissolved solids) levels of about 1,500 to 2,000 mg/L (milligram per litre) which is well above permissible limits (as specified by the Bureau of Indian Standards – BIS) (TERI).[1] Excess fluoride levels (causing salinity) in water impose health implications such as digestive disorders, skin diseases, dental fluorosis and skeletal fluorosis (on prolonged exposure).

Desalination is a process by which dissolved minerals (including salts) are removed from seawater or brackish water.[2] Although, the well-established and proven conventional desalination processes (powered by fossil fuel) can be employed to produce enormous amounts of safe and potable drinking water, the main drawback is that it is highly energy intensive causing large-scale greenhouse gas (GHG) emissions. Ramping up the number of fossil fuel powered desalination plants in the country to fulfil fresh water needs would jeopardise chances to meet demand for conventional fuels in other competing sectors of power, agriculture, industries and so forth. This demonstrates that water and energy are interconnected and interdependent and that choices made and actions taken in one domain can significantly impact the other. The process of desalination can become sustainable if dependence on fossil fuels as its energy source can be overcome by integration with renewable resources like solar energy.

Several remote areas in arid locations as well as coastal villages and islands struggling with scarcity of safe drinking water are heavily dependent on fresh water transported from neighbouring areas using tankers. Furthermore, these places often lack access

1 Water is fresh when its TDS concentration is below 500 mg/L as per BIS specifications. Salinity, in some cases, is expressed by the water's chloride concentration, which is about half of its TDS value.

2 Seawater has a TDS concentration of about 35,000 mg/L and brackish water has a TDS concentration range between 1,000 and 10,000 mg/L.

to electricity or are subjected to intermittent power supply. Therefore, coupling solar with desalination systems is the most promising option particularly in remote and arid regions which lack access to grid electricity or face severe power outages.

The study found that solar desalination solutions are yet to reach commercial scale in the country. There have been efforts to set up demonstration solar desalination plants in the country with the help of government funding and donor finance / CSR funds. For example, KGDS Empereal solar thermal desalination plant in Ramanathapuram, Tamil Nadu, funded by the Department of Science and Technology and six solar photovoltaic-reverse osmosis (solar PV-RO) plants, each with a capacity of 5,000L/day, implemented in Rajasthan by NGOs – Manthan, Prayatna and Foundation for Rural Recovery and Development (FORRAD), and financed by the Coca-Cola Foundation.[3] The desalination market also consists of manufacturers providing small-scale solar-RO systems for water purification, such as Jakson Power Solutions and solar stills manufacturers such as Kotak Urja. There have also been cases wherein successful pilot projects faced challenges in scale-up. For example, Gerindtec's (Indo-German EPC) pilot scale 1,000 L/day MiniSal plant in Chennai was successful, but faced administrative and financing challenges during scale-up in Lakshwadeep.

At present, several R&D efforts in solar desalination technologies, with the support of Indian R&D institutions such as Central Salt & Marine Research Institute (CSMSCRI), National Institute of Ocean Technology (NIOT), as well as international institutions/ donors (outlined in table 3.1) are being undertaken across the country in an effort to commercialize solar desalination technologies. Table 3.1 outlines some of the key players in solar desalination in India.

TABLE 3.1

Key Players/Actors in Solar Desalination

Source: CEEW compilation

Category	Key players
Strategic players	Ministry of New and Renewable Energy (MNRE); National Bank for Agriculture and Rural Development (NABARD)[4]
Private companies/ manufacturers of solar desalination units	**Solar PV desalination technologies:** Jakson Power Solutions; Saurya Enertech; NRG (U.S.)
	Solar thermal desalination: KG Design Services (KGDS) & Empereal Inc; Taylormade Solar Solutions (TSS) Pvt. Ltd; Gerindtec; Clique Solar; Kotak Urja Pvt. Ltd.; Aqua-Aero Water Systems (Netherlands); Mage Water Management (Germany)
Philanthropic organizations	Barefoot College/Manthan (Indian arm of the Barefoot College)/Prayatna Sansthan (sister NGO of the Barefoot College); Foundation for Rural Recovery and Development (FORRAD); Jal Bhagirathi Foundation; the Coca-Cola Foundation
R&D institutions	**Indian:** Central Salt & Marine Chemical Research Institute (CSMCRI); Bhabha Atomic Research Centre (BARC); Department of Science & Technology (DST); National Institute of Ocean Technology (NIOT); The Energy and Resources Institute (TERI); Solar Energy Centre (SEC); IIT, Madras; IIT, Delhi; Sardar Vallabhbhai National Institute of Technology (SVNIT); Hindustan Institute of Technology, Chennai **Overseas:** Fraunhofer Institute; Heriot Watt University, UK

3 Barefoot College is registered under the Friends of Tilonia Inc., a US-based 501(c) 3 charitable organization which helps to support sustainable development programmes of the Barefoot College; Manthan and Prayatna Sansthan are affiliated centres of the Barefoot College in Rajasthan.

4 NABARD disburses loans for off-grid decentralised energy applications to banks. On receipt of subsidy from NABARD, the bank disburses the loan directly to the manufacturers.

Category	Key players
Donors/ financiers (Indian and overseas)	UNDP; Renewable Energy and Energy Efficiency Partnership (REEEP); GIZ; Acumen Fund
Industry Association	Indian Desalination Association (InDA)

3.2 TECHNICAL DESCRIPTION

All desalination processes contain three liquid streams – the saline feed water which is the brackish water or seawater; the low salinity product water; and brine (also called reject water).[5] Currently available conventional desalination technologies can be categorized as follows (see table 3.2):

TABLE 3.2

Conventional Desalination Technologies

Source: Gude et al., 2010

Technology	Process	Principle
Solar distillation (SD);multi-effect distillation (MED); multi-effect humidification (MEH); multi-stage flash distillation (MSF); mechanical vapour compression (MVC) and thermal vapour compression (TVC)	Phase change / thermal processes	Involves distillation process involving heating the feed (seawater, brackish water or other impaired waters) to boiling point at the operating pressure to produce steam, and condensing the steam in a condenser unit to produce freshwater.
Electrodialysis (ED) and reverse osmosis (RO)	Non-phase change / membrane processes	Involves separation of dissolved salts from the feedwaters by mechanical or chemical / electrical means using a membrane barrier between the feed (seawater or brackish water) and product (potable water).
Membrane distillation (MD); RO combined with MSF or MED processes.	Hybrid processes	Involves combination of phase change/thermal processes (e.g. MSF) and non-phase change/ membrane techniques (e.g. RO) in a single unit or in sequential steps to produce pure or potable water. Hybrid desalination enables efficient utilization of electrical power to produce water from the RO process (requires electricity to operate) when demand for electricity is low and full utilization of waste heat for producing water in the MSF or MED desalination plant (requires steam to operate) when power demand is high. Advantages of the hybrid process include higher energy efficiencies resulting in lowering of cost of desalinated water, when compared with "standalone" desalination processes and improved operating flexibility due to quick response time of the SWRO desalination plant to produce water.

5 Brine is a concentrated salt solution (with more than 35,000 mg/L dissolved solid) that must be disposed carefully.

Note: The **Multi Stage Flash (MSF)** process is divided into sections or stages in which saline water is heated at the boiling temperature between 90°C and 110°C, with decreasing pressure through the stages.

Similar to MSF, **Multi Effect Distillation (MED)** is a multi-stage process variant in which vapour from each vessel (stage) is condensed in the following vessel and vaporized again without the need to supply additional heat unlike MSF. A lot of the large-scale conventional desalination plants in India deploy MED technology.

Multiple Effect Humidification (MEH) involves use of heat from highly efficient solar thermal collectors to induce multiple evaporation / condensation cycles. This process can occur in a single chamber and is a highly energy efficient process (Gerindtec's MEH technology requires only 120kWh of thermal energy to produce 1 cubic meter of fresh water).[6]

In **Vapour Compression (VC)** distillation process, the heat for water evaporation comes from compression rather than from direct heating. This process is generally used in combination with other processes (MED) to improve overall efficiency.

In the **Reverse Osmosis (RO),** the seawater pressure is increased above the osmotic pressure, thus allowing the desalinated water to pass through the semi-permeable membranes, leaving the solid salt particles behind.

Electrodialysis technology is usually limited to brackish feedwater.

3.2.1 Integrating Solar into Desalination

Conventional fossil-fuel driven desalination systems can be coupled with solar energy in the form of solar PV or solar thermal energy. The best coupling of solar energy with desalination systems is determined by various criteria, such as the required quantity of potable water (plant capacity); feedwater salinity; remoteness; radiation (such as direct normal irradiation in case of solar thermal); geographical conditions (such as wind speed and temperature); the system's efficiency; investment and operational cost; affordability of disposal; as well as availability of support organizations/personnel to handle O&M; land efficiency / land requirement; the possibility for future increase of the system's capacity and so forth.

Various combinations of solar energy and desalination systems have been mentioned in detail below. Solar PV systems can only be integrated with electricity-driven membrane desalination processes such as reverse osmosis (RO). Solar thermal systems, on the other hand, can generate both steam and electricity, and can therefore be coupled with both steam driven phase change/thermal technologies (e.g., MED, MEH) as well as electricity driven membrane processes (e.g., RO).

3.2.2 Various Solar Driven Desalination Technologies

I. Solar PV Modules

Photovoltaic systems can be used to power RO or ED desalination processes, which are based on electricity as the input energy (IEA-ESTAP and IRENA, 2012). Conventional/ fossil fuel based RO is a dominant technology for desalination in India. "RO is a pressure-driven membrane process where feed water flows under high pressure through a semi-permeable membrane, separating two aqueous streams, one rich in salt and the other poor in salt". Due to the hydrophilic nature of membranes, only water

6 CEEW-Stakeholder conversation

is allowed to pass through leaving impurities and salts behind. Recovery/conversion rate of feed water to product is lower for RO systems when compared to thermal desalination processes and gets further reduced in case of high salinity/TDS values. The RO membranes are susceptible to membrane fouling, thus requiring pre-treatment of feedwater and regular cleaning with chemicals, thereby, adding to operational costs. It is noteworthy that higher TDS not only leads to more wastage of water but also frequent membrane fouling (caused by deposition of salt/organic matter and so forth).

Reverse osmosis technology can be used both for brackish water reverse osmosis (BWRO) and seawater reverse osmosis (SWRO). However, experts consider solar PV powered RO plants to be more suited for desalinating brackish water and not water with very high TDS values.[7] This could be due to a range of factors such as: (i) seawater has higher osmotic pressure as opposed to brackish water and therefore requires higher energy for desalination, and, inevitably, a larger PV array; (ii) RO systems for desalinating seawater would require mechanically stronger components to withstand higher pressures and therefore, the total cost of water from seawater PV-RO will be higher than that from brackish water (Abraham and Luthra, 2011). There were no installations of PV-seawater RO systems in the country as of January 2014.

(a) Solar RO plants installed in the country

Solar powered RO plants in Rajasthan – Barefoot College in collaboration with CSMCRI, FORRAD and the Coca Cola Foundation under Project Santushti: An exemplary case of successful community managed solar water desalination plant.

Villages around Sambhar Lake in Rajasthan struggle from lack of safe drinking water because of drought conditions and saline groundwater which is exacerbated by excessive groundwater pumping. In light of this, Manthan, Prayatna Sansthan and FORRAD implemented solar PV powered RO plants in six villages around Sambhar Lake – Kotri (2006); Sinodiya (2010); Bhopa ki Dhani (2010); Jhag (2011); Mordi (2012); and Solawata (2012). Prior to the installation of these solar PV-RO plants, villagers either shared water (local water bodies – "*talaabs*") with cows, goats and camels or relied on private tankers.

FIGURE 3.1

Solar PV-RO Plant at Mordi, Ajmer District, Rajasthan

Source: CEEW site visit

© Poulami Choudhury / CEEW

7 CEEW – Stakeholder interaction.

The solar-RO plants under Project Santushti was funded by the Coca Cola Foundation and implemented by Manthan/Prayatna Sansthan (affiliated centres of Barefoot College) and FORRAD. The desalination unit was designed and installed by the Central Salt and Marine Research Institute (CSMCRI). Each of the six RO plants have a capacity to generate around 5,000 LPD (400–800 L/hour) of desalinated water and utilizing electricity generated by a 5kW solar PV plant mounted on the roofs of the building housing the desalination unit. The plants can treat water with salinity ranging from 2,000 to as high as 8,000 parts per million (ppm) (during summer months). Feedwater is sourced from borewells; nearby wells; or transported from catchments through pipes. Figure 3.1 represents solar PV-RO plant operational at village Mordi in Rajasthan.

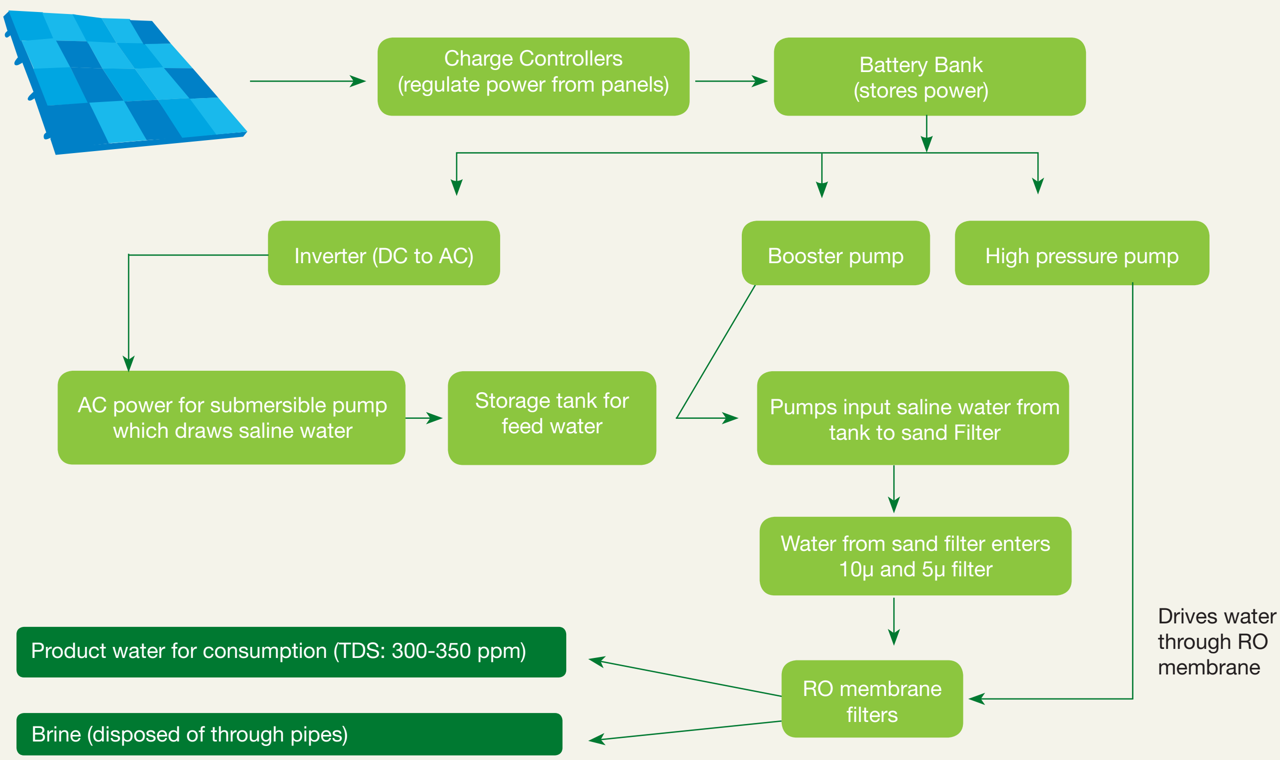
The plant comprises the following components: solar PV modules (48 panels power a single 5kW plant); battery bank (tubular gel batteries); charge controllers; submersible pump; inverter which converts direct current (DC) to alternating current (AC); overhead storage tank (storing product water/desalinated water); a booster pump, a high pressure pump, a sand filter, DC motor, pressure gauges, valves, 5μ and 10μ filters and the RO membrane. Figure 3.2 illustrates the working of a solar PV-RO plant.

Solar energy captured by solar panels is regulated by charge controllers and stored in battery banks for powering the RO plant (see figure 3.4). After the feedwater has passed through the sand filter and 10μ and 5μ filters for pre-treatment, a high-pressure pump is utilized to force the pre-treated feedwater to flow across the membrane surface. Electricity from solar PV modules powers both the booster pump and high pressure pump. Excess electricity is converted to AC power by an inverter and utilized to run Prayatna's (NGO that implemented the plant) office appliances and solar workshop.

FIGURE 3.2

Working of a Solar PV Powered RO Plant Implemented in Rajasthan by Barefoot College

Source: CEEW



Regular O&M entail cleansing of the RO membrane on a daily basis and once in a month with chemicals. Regular O&M is carried out by local residents who are in-charge of overseeing the functioning of the plant with the help of training from Barefoot Power personnel who also take care of any major faults. The membranes are sent to CSMCRI for replacement every year as it treats water with high TDS of the order of 5,000–8,000 ppm. The successful operation of the Kotri solar-RO plant encouraged Barefoot College, CSMCRI and the Coca Cola Foundation to implement similar plants in the surrounding villages.

The villages with solar RO plants instituted *Pani Samiti*s to collect a one-time deposit of INR 500 per family and charge a monthly maintenance fee which is then used to pay the personnel in-charge of overseeing plant operations.

FIGURE 3.3

Solar PV-RO Purifier (10 L/h), Jakson Solar Solutions

Source: CEEW Site Visit

© Poulami Choudhury / CEEW

(b) Solar RO for water purification[8]

Smaller capacity solar driven RO systems can be designed to purify water to cater to drinking water needs of around 2–3 families. For instance, Jakson Solar Solutions' 10 L/h solar PV-RO system developed under technology transfer from BARC can purify water having salinity of up to 2,000 ppm. Recognising intermittency of solar energy as one of the bottlenecks, Jakson has introduced a separate chamber in the RO plants if consumers wish to house a battery in order to counter intermittent nature of solar energy (see figure 3.3).

The decline in cost of PV modules coupled with the significant improvement in RO technology makes it an attractive option for desalination (Gude et al., 2010). However,

8 Scientifically, there is no difference between desalination and purification. Generally speaking, when the salinity level is low (less than 5000 mg/L) and a number of other impurities are also present, water needs "purification". When the salinity is as and removing salt to make the water usable is the primary objective (for example seawater), water needs "desalination".

operational costs associated with running an RO plant, especially those treating water with higher salinity remains a hindrance. This strengthens the case for adoption of solar thermal technologies for treating water with high TDS values.

(c) Solar-RO systems for water purification – Implemented by Saurya EnerTech with funding from UNDP-ACE and REEEP – Project Swajal

Swajal project was initiated in 2011 as a survey project. Based on poor drinking water quality, the towns of Noida and Ghaziabad and villages of Khoda and Behrampur were chosen for a detailed study. It was found that residents restricted their daily water intake due to high charges and/or resorted to unsafe drinking water. Swajal plans to implement a commercial system based on a solar powered RO water purifier, linked to a chain of small franchised centres (purification centres) that provide clean drinking water at an affordable price (REEEP, n.d.).

II Solar Thermal Technologies

Solar distillation: The simplest direct solar distillation process deploys solar stills which mimic the natural hydrological cycle. A solar still comprises an air-tight triangular basin made of concrete, galvanized iron sheet or fibre reinforced plastic which collects feedwater/salty water for distillation (Ali, Fath and Armstrong, 2011). The bottom of the basin is painted black for effective heat absorption and the basin's top is covered with a transparent glass tilt to ensure the passage of maximum solar radiation for evaporating water. The condensed water is then collected at the lower end of the cover. The outlet is connected with a storage container as shown in figure 3.4 (GEDA)[9]

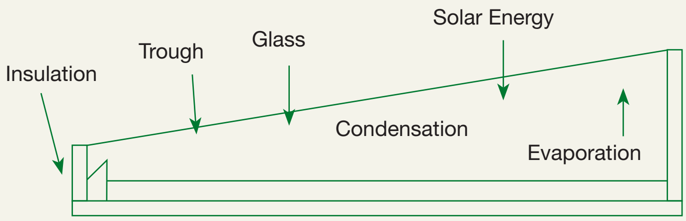
Both small and large-scale solar distillation plants deploying solar stills have been implemented in the country since the 1970s and have also undergone series of technological improvements since then (Arjunan et al., 2009). The construction of a solar still is simple and involves low operation and maintenance rigours. Typical still efficiency of 35 per cent with a low productivity of 3–4 L/m² and large area requirements are two factors that prevent large-scale applications of solar stills (Gude

FIGURE 3.4

Solar Stills

Source: (SolAqua)[10] (GEDA)[11]

© SolAqua - Gujarat Energy Development Agency (GEDA)



9 http://geda.gujarat.gov.in/applications_solar_stills.php
10 http://www.solaqua.com/solstilbas.html
11 http://geda.gujarat.gov.in/applications_solar_stills.php

et al., 2010). It is noteworthy that productivity of solar stills can be improved by integrating them with non-concentrating or concentrating solar collectors (e.g., single basin coupled with flat plate collectors) (Arjunan et al., 2009).

Solar thermal collectors/concentrated solar power (CSP):[12] Solar collectors capture solar irradiation and can be classified into two categories based on concentration ratios, viz., (i) non-concentrating type primarily used for low temperature applications such as space/water heating (e.g., flat plate collectors are often used for distillation) and (ii) concentrating type solar collectors (e.g., parabolic troughs or dish, such as the Scheffler dish, ARUN concentrators; heliostat collectors are used in CSP for power generation). Concentrated solar power plants have the advantage of being integrated either with RO (utilize electricity) or thermal desalination units (e.g., MSF and MED that utilize steam) (Gude et al., 2010). The CSP-MED combination is especially attractive because it can be used in dual configuration mode, producing both power and desalinated water. Furthermore, CSP can be coupled with thermal storage, and/or hybridized with coal/natural gas/biomass which enables them to operate in limited or in the absence of solar radiation. Such features make CSP plants a viable alternative for seawater desalination (IEA- ETSAP and IRENA, 2012). Table 3.3 provides the possible combinations of solar collectors with various desalination technologies (Gude et al., 2010).

TABLE 3.3

Possible Combinations of Solar Collectors with Desalination Technologies

Source: Gude et al., 2010; CEEW compilation

Type of solar collector	Source of salt water	Desalination process
Direct solar	Seawater, brackish water	Solar stills
Flat panel collectors	Seawater	MED
Evacuated tube collectors	Seawater	MSF/TVC
Scheffler dish	Seawater	MEH
ARUN concentrator	Seawater	MEH; MED
Parabolic trough collectors	Seawater	MED
Photovoltaic thermal collectors	Seawater, brackish water	MED

Thermal storage and hybridization: Thermal storage of solar energy is imperative to counter intermittent nature of solar radiation that can adversely affect working of a solar thermal plant. Thermal storage aids in countering plant shutdown and sudden output fluctuations. For example, Gerindtec’s solar thermal desalination technology integrating solar thermal panel with multi-effect humidification (MEH), utilizes pressurized water as the storage material to store sun’s energy which can then be used to run the plant during night or in conditions of low solar radiation. However, it is important to note that integrating thermal storage with solar thermal/CSP can increase the the overall costs of the system. Hybridization of solar with biomass/natural gas to produce steam throughout the day (e.g., KGDS plant in Ramanathapuram) could be a more cost-effective approach for large-scale CSP desalination.

12 CSP plants use collectors to concentrate (focus) irradiation/heat and convert it into steam that drives a turbine for generating electrical power.

Brief description of solar thermal desalination technologies available in the Indian market

(a) *Linear Fresnel Reflector based Hybrid CSP Demonstration Plant in Ramanathapuram*

The first in the country: In October 2012, KG Design Services (KGDS) together with Empereal Inc. and the National Institute of Ocean Technology (NIOT) commissioned India's first CSP-powered desalination plant using Linear Fresnel technology in Ramanathapuram district of Tamil Nadu (see figure 3.5). Discussions with both KGDS and DST suggest that the plant is designed to generate both power and desalinated power. The CSP plant is integrated with biomass which makes it run round-the-clock thus producing electricity and potable water for around 7,500 residents in the village of Narippaiyur, Ramanathapuram.

KGDS and Empereal Inc. consider Linear Fresnel technology suitable for solar thermal applications like desalination, especially in the Asian and Indian context due to factors such as: simple and reliable system because of the single axis tracking of reflectors and fixed receivers; cost-effectiveness and land-efficiency. These advantages drive the selection of Linear Fresnel technology for applications ranging in output temperature from 110˚C to 450˚C (Muirhead, 2012).[13] The plant produces desalinated water at the rate of 6,000 L/hour reducing salinity from 26,000 ppm to 2 ppm. The seawater is sprinkled onto the series of tubes inside the MED-thermo vapour compressor (TVC) system where the steam produced by the LFR runs through the series of tubes and converts seawater into vapours which is then condensed, cooled and re-mineralized for consumption.

FIGURE 3.5

CSP-MED Seawater Desalination Plant in Ramanathapuram District of Tamil Nadu, Based on Linear Fresnel CSP Technology

Source: Muirhead, 2012

© CSP Today

(b) ***ARUN concentrator:*** During the course of this study it has been found that manufacturers of Scheffler dish and ARUN concentrator in India are trying to make

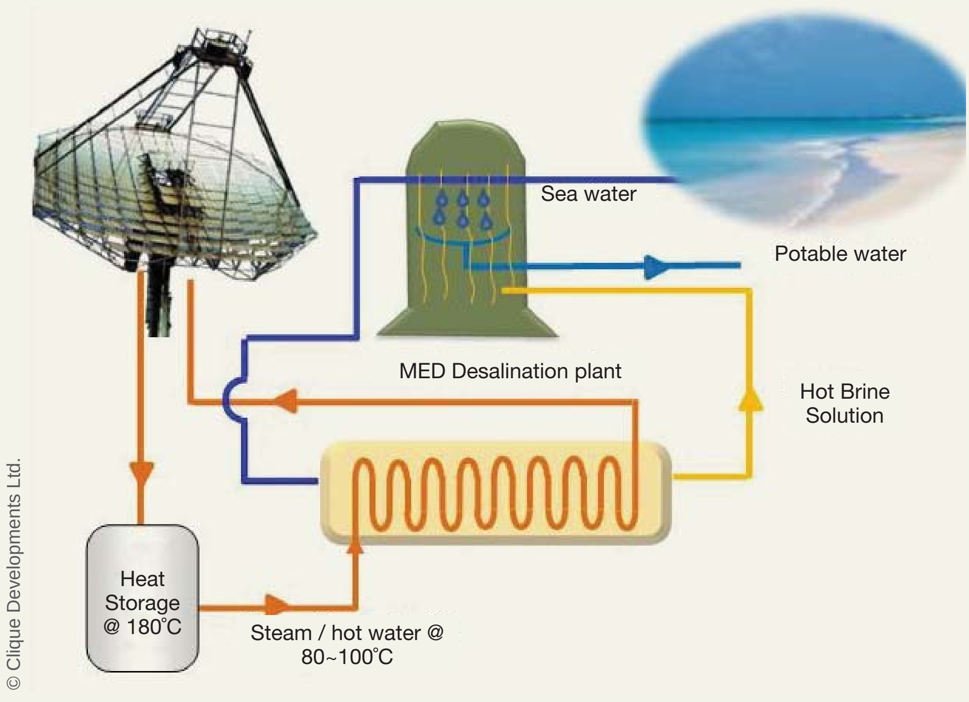
13 http://social.csptoday.com/emerging-markets/executive-viewpoint-manoj-divakaran-president-coo-empereal-inc#sthash.nHIKT0ny.dpuf

inroads into the solar thermal desalination space. ARUN concentrator integrated with a typical multi-effect distillation (MED) system is depicted in figure 3.6. ARUN concentrator supplies heat in the form of steam or pressurized hot water at about 150–180°C which is then stored in the storage tank for the operation during non-solar hours. The desalination plant typically requires heat at 80–120°C, which is supplied through heat storage. The heat storage at higher temperatures reduces the storage size significantly which helps reduce the cost of storage as well as thermal losses.

FIGURE 3.6

ARUN Concentrator Integrated with MED Unit

Source: Clique Solar, 2013



(c) ***Scheffler dish:*** TSS Pvt. Ltd. manufactures both Scheffler dish and multi-effect evaporation units for desalination purposes. The TSS desalination process is based on evaporation of salt/waste water and the subsequent condensation of the generated steam. This proprietary process is referred to as Multiple Effect Evaporation with Solar Energy (MEESE). In the process, seawater, industrial wastewater or other salty water (salt lakes, waste, fossil brackish water) is heated through special parabolic concentrators. The heated salty/waste water enters an evaporation chamber produced from corrosion free materials where it evaporates and the produced steam is transported to the condenser in a second step without any additional energy demand. During condensation, the main part of the energy used for evaporation is regained, applying materials with extremely low heat flux resistance. The key to this system is the reduced energy demand through effective re-use of energy, which otherwise would be wasted during condensation. Compared to a conventional solar distiller where solar energy requirement is in the order of 500 KWh/m^3 of distillate, TSS system's energy demand is only of the order of 120 KWh/m^3. The most efficient of solar distillers developed until now, can produce distillate of maximum 6 L/m^2 area of the collector's surface, whereas the TSS system, in conjunction with parabolic concentrators can be designed to produce 25 L/m^2 of solar parabolic concentrators (TSS, n.d.). Table 3.4 summarises the solar PV and soar thermal desalination technologies.

TABLE 3.4

Summary: Solar PV and Solar Thermal Desalination

Source: CEEW compilation

	Solar PV powered desalination	Solar thermal desalination
Application	• Solar PV driven RO plants in India include plants for community use (500–800 L/hour) as well as portable systems for water purification used for individual use (10L/h).	• CSP can be used to drive both MED (thermal) and RO (electricity) processes. Solar thermal processes for desalination can include – solar stills (individual households); and concentrating solar collectors (e.g., Linear Fresnel Reflectors based 6,000L/hour desalination plant at Ramanathapuram, Tamil Nadu).
Advantages	• Water does not require remineralization after undergoing desalination • Successful pilots of solar PV-RO plants exist in India – based on model of community participation • Modular design • Solar PV RO purification units (700-800 L/day) are available in the Indian market • RO is more evolved than thermal technologies	• Higher conversion rate as compared to solar-RO systems (upto 90 per cent); brine generated is less compared to solar-RO plants • Generated highly concentrated brine; minimising disposal concerns • Modular design • No pre-treatment is required • Does not require skilled personnel–more suitable for remote regions • Involves lower operational costs
Disadvantages	• Lower recovery/conversion rate from feedwater to product water (30–60 percent) • Generation of waste stream/brine increases with increased salinity • Adequate pre-treatment – sand filters; bag filters is necessary • Higher operational costs – membrane replacement; chemicals for purification • Solar PV-RO not considered viable (by experts) for large-scale seawater desalination[14] • Requires skilled personnel for operation	• Solar concentrators generate demineralized water which might make the taste less palatable; requires additives/remineralization • Solar thermal technology is still at a nascent stage in India

3.2.3 Overseas Case Studies on Solar Desalination

Various solar desalination projects in the countries of United Arab Emirates (UAE), Australia and the United States of America (USA) are described below. The commitment to adopt solar desalination by these countries dovetails into the broader goal of promoting renewables for reducing energy intensity and progress towards a green and sustainable future.

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OVERSEAS CASE STUDIES ON SOLAR DESALINATION

King Abdullah Initiative for Seawater Desalination – Solar Powered Desalination Plant at Al-Khafji (30,000 m^3/day) in Saudi Arabia

Saudi Arabia is the largest producer of desalinated water in the world, accounting for at least 17 per cent of the total world output. Around 27 desalination plants operate in Saudi Arabia that consume around 1.5 million barrels of crude oil every day making solar based desalination a much needed solution due to both concerns for climate change and economical viability (Muirhead, 2013). King Abdullah's initiative for Solar Water Desalination in Saudi Arabia was announced in 2010 with the launch of its first phase. The first phase of the initiative included construction of a solar desalination plant at Al-Khafji that can produce 30,000m^3 of desalinated water to meet drinking water needs of 100,000 dwellers of Al-Khafji City (Arabian Gulf) and construction of a solar energy station with a capacity of 10 MW. Software giant – IBM has collaborated with the King Abdulaziz City for Science and Technology (KACST) to construct the plant that will be powered by ultra-high concentrator photovoltaic (UHCPV) technology – a system with a concentration greater than 1,500 suns. The IBM-KACST team is working towards improving nano-membrane technology that filters both salts and potentially harmful toxins in water while using less energy as opposed to other forms of water purification such as RO and thermal technologies (Gizmag, 2010).

The first phase of the project started in 2010 and has resulted in two solar energy plants being constructed in Al-Khafji and Al-Oyainah, located 35km from Riyadh, both of which will cumulatively generate 10 MW of solar power for the Al-Khafji desalination plant (KACST). The second phase aims to build another 30,000 m^3/day capacity solar desalination plant. The third phase would involve construction of several solar desalination plants throughout the country. The target of this initiative is to bring down the production cost of desalinated water to \$0.4/m^3 as compared to the current cost which ranges from \$0.67 to \$1.67 (UNWAP, 2014).

By 2020, the King Abdullah Initiative for Solar Desalination envisions to gradually make all desalination plants run on solar power (Muirhead, 2013).

Commitment towards Solar Powered Desalination

The Saline Water Conversion Corporation (SWCC), an entity under the authority of Ministry of Water and Electricity responsible for operating the country's publicly owned desalination plants has committed to establishing solar powered desalination plants in Haqel, Dhuba and Farasan by 2018, after the successful commissioning of the Al-Khafji solar desalination plant (Arab News, 2012). These plants will produce water at a cost under \$0.40/m^3.

UAE Awaits World's Largest Solar Desalination Plant

The UAE in 2013 announced its plans to establish world's largest solar-powered desalination plant at Ras Al Khaimah emirate which is estimated to produce more than 22 million gallons of potable water per day (MGD) utilizing the most advanced RO and filtration technologies which is expected to drive down the per unit production rate of water. The plant will be implemented by private service utility and solutions provider Utico Middle East and would also generate 20 MW of electricity (Economic Times, 2013).

Solar Desalination Plants in Port Augusta, Australia – Exploring the Breadths of Possibilities

a. Point Paterson Desalination Plant – Combining Power, Water and Salt

The Point Paterson Desalination Plant is Australia's first solar-powered desalination plant, established seven kilometres from Port Augusta in South Australia developed by Acquasol Infrastructure Limited. The plant envisions integrating power generation, desalination and commercial salt production to alleviate the environmental impacts associated with desalination processes such as GHG emissions and brine disposal. The Point Paterson facility will produce 200 MW of electricity – 50 MW solar thermal and 150 MW combined cycle gas turbine (CCGT) in addition to producing 5.5 gigalitres of water per year – enough for 34,000 people. The plant will deploy parabolic trough concentrators, combined cycle gas turbines and multi-effect distillation (MED). The captured heat will be used to generate steam to drive electricity production and desalination, with excess heat going into thermal storage. The cost of setting up the plant was around A$370 million (US$340 million) (Acquasol, 2007). The plant is designed in a way that will enable expansion for annual production of more than 45 gigalitres of water (Acquasol, 2007). As the facility is built on the site of a salt pan, brine from the desalination process is diverted to land based holding ponds for salt harvesting rather than dumping into the sea (Energy Matters, 2013).

b. Sundrop Farms' Solar Desalination – Greening the Greenhouses

The Australian Government's Clean Energy Finance Corporation (CEFC) which initiated investing in renewables in 2013 is co-financing the expansion of Sundrop Farm's solar desalination greenhouse operation near Port Augusta, South Australia with a capacity to produce 10,000 litres of desalinated water per day (Margolis, 2012). Sundrop Farms is in the process of constructing a 20-hectare greenhouse facility which will produce over 15,000 tonnes of tomatoes a year for metropolitan markets across Australia using solar-thermal technology to desalinate seawater to provide irrigation, heating and cooling for its greenhouses (see figure 3.7). It is believed that once operational (by mid-2015), this project would employ 200 people and prove exemplary in its worldwide demonstration of sustainable horticulture practices that address growing food insecurity, water and clean energy challenges (National Centre for Excellence in Desalination, 2013). The total project cost will be about A$100 million (US$92 million). CEFC will provided A$40 million (US$36.9 million) in senior debt finance which was crucial in getting other investors on board (CEFC).

FIGURE 3.7 Sundrop Farms' Solar Desalination Plant

Source: Radio Australia, 2012

WaterFX's Solar Desalination Solution – An Answer to California's Water Woes?

Several parts of California, for instance, near the San Joaquin Valley are drought prone where availability of fresh water supplies and highly saline water has been a constant cause of worry affecting even farm productivity. WaterFX, a California based start up, offers a solar desalination system – the Aqua4 – which deploys 400kW parabolic troughs and multi-effect evaporating unit for desalinating water. The system is modular and can therefore be used for both small and large-scale applications. WaterFX's test facility, which started operations in 2013, has shown promising signs by successfully producing up to 14,000 gallons of fresh water a day. The plant costs $1 million and was financed by the Panoche Water District with state funds (NY Times, 2014). The success of the pilot initiative has led WaterFX to plan the expansion of the demonstration project to increase its capacity to 65,000 gallons a day over the same 6,500ft^2 area (Guardian Professional, 2014). The plant produces desalinated water priced at $450 per acre-foot which is a quarter of conventionally desalinated water costing $2,000 per acre-foot.[15]

KEY TAKEAWAYS

- Government's commitment to invest in solar desalination technologies is crucial for wider uptake – e.g., in Australia and Saudi Arabia
- Promotion of pilot projects
- Exploration of various applications of solar desalination – e.g., in Australia

3.3 APPLICATION MARKETS

Solar desalination plants are most ideal for locations that are either not connected to grid power or have intermittent access to it. India's geographical location resulting in abundant sunshine, its enormous seawater resources and problems of brackish groundwater in several parts call for implementing solar desalination technologies. India is located in the equatorial sun belt of the earth, thereby receives abundant radiant energy from the sun. The solar radiation received in most parts of India ranges from 4 to 7 kWh/m^2/day and clear sunny weather is experienced for 250 to 300 days in a year (Abraham and Luthra, 2011). Most places in India that suffer from salinity lie in high-radiation zones – 5.4 to 6.4 kWh/m2 (annual average) (Abraham and Luthra, 2011). Parts of Rajasthan, Gujarat, Andhra Pradesh, Maharashtra, Madhya Pradesh and Tamil Nadu receive very high annual global radiation which is conducive for solar technologies.

Potential uses of solar desalination

- Purification
- Brackish water desalination
- Seawater desalination
- Industrial wastewater treatment
- Agriculture

India has a 7,000 km coastline which is home to around 25 per cent of the country's population indicating a huge potential for seawater desalination (Abraham and Luthra, 2011). Several regions of India are affected by coastal and inland ground water salinity problems. Intensive irrigation for agriculture and extensive sand mining (e.g., in Kerala) has worsened the problem even further. Some of the states affected with brackish water that can act as potential sites for solar desalination include: Rajasthan, Gujarat, Tamil Nadu, Odisha, Andhra Pradesh, Maharashtra, Uttar Pradesh, Haryana and Punjab.

15 An acre-foot is 325,000 gallons, or the amount of water it takes to cover an acre at a depth of one foot

Solar PV-RO systems can serve well for rural areas or smaller towns with brackish water and limited access to energy. Higher TDS values (e.g., greater than 8000 ppm) lead to frequent membrane fouling and covering annual O&M costs generated by RO membrane replacements after the expiry of the warranty period is a cause of concern. Against this backdrop, it can be said that solar thermal driven desalination units which entail negligible O&M costs, do not require skilled personnel for operation. These units generate a fairly concentrated brine (as waste product and in the process allaying worries related to disposal of wastewater/brine) and are well suited for seawater desalination, process industries, common effluent treatment plants (CETPs) and in community plants for treatment of brackish water. Not every part of India can benefit from a CSP solution because locations need to have adequate direct normal irradiation (DNI) levels. Affordability of reuse/disposal is also an important factor that should be taken into account.

Table 3.5 shows the number of research that are being undertaken and pilot projects that are being implemented in India, in an effort to improve, reduce costs and commercialize desalination through solar thermal multi-effect humidification (MEH), solar stills and solar PV powered RO.

TABLE 3.5

Status of Solar Desalination Technologies/Projects in India

Source: CEEW compilation

Solar Desalination Technologies/Projects	Project Implementers	Capacity	Status
Solar PV-RO without battery	Jakson Solar Solutions Pvt. Ltd. (technology transfer from BARC)	700–800 L/day	Project in planning stage
Solar PV-RO plant in Kotri, Rajasthan	Manthan (Indian arm of Barefoot College)	5,000 L/day	Operational
Solar PV-RO plant at Sinodiya, Rajasthan	Manthan	5,000 L/day	Operational
Solar PV-RO plant at Jhag, Rajasthan	Manthan	5,000 L/day	Operational
Solar PV-RO plant at Silowata, Rajasthan	Prayatna Sansthaan (affiliated centre of Barefoot College)and Manthan	5,000 L/day	Operational
Solar PV-RO plant at Mordikala, Rajasthan	Prayatna Sansthan and Manthan	5,000 L/day	Operational
Solar PV-RO plant at BhopakiDhani, Rajasthan	Manthan	5,000 L/day	Operational
Swajal Aqua pilot project using solar RO purification technology in villages of Khoda and Behrampur, U.P.	Saurya Ener Tech (funding from REEEP and MNRE)	10,000 L/day	Operational
Solar stills with better efficiency and increased output	CSMCRI	7 L/day	Not commercialized yet; trials to be conducted in remote areas of Rajasthan, Madhya Pradesh, Gujarat, Rameshwaram, Sunderbans and northern regions of India. CMSCRI has filed for a provisional patent

Water Pyramid in Kutch (Gujarat) and Roopji Raja Beri in Barmer district, Rajasthan, based on solar stills principle (structure made of uniquely designed inflated foil)	Aqua-Aero Water Systems BV (Netherlands); Acumen Fund (US) and Jal Bhagirathi Foundation	1000 L/day	Operational
Solar thermal (multi-effect humidification) pilot plant in Chennai (MiniSal 1000 project)	Was implemented by Gerindtec and Mage Water Management with solar thermal panel from Tinox	10,000L/day	Decommissioned
Solar thermal (Linear Fresnel) demonstration plant in Ramanathapuram district, Tamil Nadu	KG Design Services and Empereal Inc.; NIOT with funding DST	6000 L/hour	Awaiting government clearance before commencing operations (as of February 28, 2014)[16]
Solar powered RO plant at Sardar Vallabhbhai National Institute of Technology (SVNIT), Surat	SVNIT, NRG	100,000 L/day	Under planning
Multi-stage evacuated solar desalination system	Under testing by IIT Madras and Heriot Watt University, UK	Not known	Experimental stage

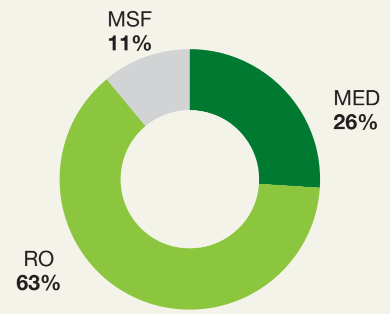
3.3.1 Feasibility of Integrating Solar into Fossil-Based Desalination Plants – Reduce Carbon Footprint of Conventional Desalination

It may be worthwhile to explore the idea of running conventional plants as hybrid units partly running on solar to reduce power cost and carbon footprint. There exist around 1,000 desalination plants in India with most of the plants using RO technology (see figure 3.8). However, it is MED and not RO which generates the highest share of desalinated water (71 per cent) by virtue of being used in bigger capacity plants in the country. Gujarat (47 per cent of the total plants) and Tamil Nadu (37 per cent of the total plants) have been more active in setting up desalination plants in comparison to other coastal states in India (Abraham and Luthra, 2011).

FIGURE 3.8

Technology used in Current Desalination Plants in India (Total Plants: 1,000)

Source: Frost and Sullivan, 2009



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In principle, a solar field/solar thermal concentrators could be added to an existing desalination plant, similar to other solar steam augmentation projects, as long as the plant has a useful life of at least 15 to 20 years. However, the available land next to the existing power and desalination plants is usually limited; which lowers the potential for such projects. Furthermore, there could be contractual and regulatory challenges that need to be overcome (Muirhead, 2013). Our discussion with experts suggest that existing desalination plants (using RO technology) can be run on solar power if issues related to motor (requirement of DC motor) can be sorted out.

Table 3.6 illustrates the business models of few of the private players (inclusive of both solar PV and solar thermal) that are trying to make a mark in India's solar desalination market. The analysis covers companies manufacturing small scale solar desalination (RO) systems (e.g., Jakson Power Solutions) to those manufacturing units with higher capacities (such as TSS Pvt. Ltd). Few of the companies interviewed in the study endorsed the idea of indigenization of technology and in-house manufacturing (e.g., of modules) can reduce costs even further and also ensure quality assurance. During the course of our stakeholder interactions, it emerged that most of the projects implemented or currently in the pipeline greatly depend on donor funding, but few players are also keen on adopting toll-based model (user charges) for treating brackish/saline water for industrial customers.

TABLE 3.6

Business Models of Existing Solar Desalination Players

Project Implementer	Jakson Solar Solutions Pvt. Ltd.	Manthan	Taylormade Solar Solutions (TSS) Pvt. Ltd.
Technology	Solar PV-RO (without battery)	Solar PV-RO (with battery bank)	Solar thermal – Scheffler dish technology
Business Model	Donor/CSR based (at present); Plans to charge upfront cost to consumers – educational institutions; hospitals	Donor/CSR based	Donor/CSR and toll based or fee-for-service
Capacity	10 L/hour	400–600 L/hour	Under planning; not known
Scale of use and status	Serves 3–4 families; targeted at small towns/villages with limited access to electricity; planning stage	Village level (at least 50 families); operational (6 plants in the villages of Jaipur and Ajmer districts, Rajasthan)	Villages and industries; planning underway for desalination project in eastern India
Solar component suppliers + Desalination Unit	Technology Transfer from BARC PV modules – outsourced – Webel Solar; plans to manufacture its own in the future: RO membrane; motor; filter are outsourced; fabrication by Jakson	PV modules – outsourced – REIL; Solar unit set up by Manthan Desalination unit (RO membrane; sand filter; accessories) provided by CSMCRI	Solar thermal component – In-house MED unit – Manufactured in-house

Financing	At present state renewable agency had agreed to finance the solar-RO units; otherwise, upfront cost to be borne by the consumers; minimal inclination to utilising subsidies	Funded by the Coca Cola Foundation (financed the desalination unit); Barefoot College (solar component) and the village itself (building space to house the plant); User charges levied (on residents of six villages) varies from INR 30–50 each month and is decided by the village panchayat	TSS plans to go ahead with a toll-based model where it will collect user fees (example- from industries) for treating water also plans to use subsidies and external funding
O&M	Jakson plans to provide O&M through its channel partners	Regular cleaning and maintenance by Manthan and the local population; membrane replacement/ motor repair by CSMCRI	Under planning; not known

3.4 COST ESTIMATES

The economics of a solar desalination system differ from conventional plant economics which is almost entirely based on the fixed costs of the system. Site-specific aspects, which also have a significant impact on final costs, include feedwater supply/ transportation and storage, freshwater delivery to end-users, brine disposal and the size of the plant. In general, solar desalination is expensive as compared to conventional desalination because of high capital costs. It is noteworthy that there are no fuel costs for the system.

With the rapid decrease of cost of PV panels, technical advances (exploring possibilities of cogeneration/polygeneration through CSP) and increasing number of installations, cost of renewable desalination is likely to reduce significantly in the near future (Muirhead, 2012).

3.4.1 Cost and Payback of Solar PV-RO Purification/Desalination Units

Solar-RO purification systems: Capital cost is higher for solar PV-based desalination compared to conventional desalination, even more so as salinity of water rises.[17]
The upfront (capital) costs of battery-less standalone solar PV-RO units by Jakson Power Solutions cost around INR 40,000 which is three fold higher than the cost of conventional RO purifiers. Jakson is targeting to sell its product in smaller towns and villages with limited access to electricity that will ensure a faster payback period for users. The high costs of this product can also be attributed to the fact that components of the solar-RO unit are outsourced. According to Jakson, costs can be driven down if it begins manufacturing solar PV panels in-house. The payback period for Jakson's solar RO purifiers is believed to be within 5 years.

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Community solar RO desalination plants: The first solar PV-RO unit installed by Barefoot College/Manthan in Kotri in 2006 cost around INR 15–16 lakh (see figure 3.9). However, recent Barefoot College installations of solar PV-powered RO units in villages of Solawata and Mordi in Rajasthan in 2012 cost around INR 35 lakh.[18] This included cost of solar components (such as PV panels, battery bank, charge controllers, inverter); RO desalination unit; housing space for the desalination unit; and other accessories such as submersible pumps, storage tank, overhead tank and so forth. A major proportion of the financial burden was borne by the Coca Cola Foundation (financed the RO desalination unit) as part of CSR and Barefoot College, USA (financed the solar unit). It is noteworthy that the village panchayat funded the construction of the housing space for the solar RO unit.

Although, the O&M costs are currently minimal as replacement of RO membrane and other repairs are undertaken by CSMCRI free of charge under the warranty period,[19] these costs will have to be borne either by Barefoot College or the Coca Cola Foundation post expiry of the warranty period. Frequent replacement of RO membrane is the largest contributor towards O&M expenses, considering that each membrane costs around INR 30,000–35,000. The user charges collected by Manthan and Prayatna Sansthan (affiliated centres of Barefoot College) across the six villages range from INR 30–50, and are decided by the village panchayat. Further, every family using water from the unit paid a one-time deposit of INR 500.

FIGURE 3.9

Barefoot College's Solar RO Desalination Unit at Kotri, Rajasthan

Source: CEEW

© Poulami Choudhury / CEEW

18 The RO unit costs INR 12 lakh and the overall cost of the solar components is Rs 16-18 lakh. The rest 2–5 lakh was spent on constructing the housing unit.

19 Installations at Jhag; Solawata; Mordi; Sinodiya and Bhopa ki Dhani are recent and fall under CSMCRI's warranty period.

3.4.2 Cost and Payback: Solar Thermal Desalination Units

Solar thermal desalination units possess greater merit when salinity of water is high. Another key learning from stakeholder engagement is that there is no single thumb rule for determining the cost effectiveness and payback period of solar desalination plants – both hinge on a combination of several factors, such as electricity prices, capacity, type of conventional system/fuel to be replaced (diesel or electricity) and so forth. Calculating the payback period of solar-thermal units could be a little more challenging as these solutions need to be tailored/optimized according to the geography, direct normal irradiation (DNI), ambient temperature, latitude (higher latitude gives a higher output for parabolic troughs), etc. Furthermore, solar thermal units may entail higher payback period as the technology is still evolving. However, it scores over solar RO and conventional technologies due to minimal O&M costs.

Solar stills: Solar stills for individual use are the cheapest amongst solar desalination technologies. Basin-type solar stills with an output of 2.0–2.5 litres of water at a time cost INR 5,000. The solar desalination plant – "Water Pyramid" – in village Roopaji Raja Beri having a capacity of 1,000 L/day costs INR 1.5 lakh (Sebastian, 2009).

Solar thermal Scheffler dish powered desalination: The unit cost of producing desalinated water using the Scheffler dish (solar thermal) technology is around INR 1.25. Interestingly, discussions with stakeholders revealed that the cost of producing desalinated water using conventional fossil fuel is INR 2/L which is higher than the cost of solar desalinated water. The higher per unit cost of water desalinated using conventional fuels is attributed to expenditure incurred on procuring fossil fuel required in operating the plant.[20]

Concentrated Solar Power (CSP) driven desalination – hybrid CSP desalination plant: It is important to note that intermittency of solar radiation can also have an impact on costs. The overall production cost of desalinated water increases if plants run for a few hours. Therefore, hybridizing solar thermal desalination plants with conventional fossil fuel or an alternative fuel source having high availability near location of the plant (such as biomass availability in village Narippaiyur, Ramanathapuram) is required to counter intermittency and increasing the operating hours of the plant.[21] The KGDS Empereal's hybrid CSP – MED-TVC desalination plant at Ramanathapuram integrates biomass generated steam along with steam from the solar CSP component which ensures that the plant operates 24x7, generating both power and desalinated water. This brings down the overall cost of desalinated water to INR 0.06/L.[22]

Engagement with few of the existing solar thermal players interested in implementing solar thermal desalination plants, such as Gerindtec and TSS Pvt. Ltd. revealed their inclination in leveraging the CSR model in combination with subsidies for financing such projects. Further, rather than trying to sell solar thermal desalination plants with high upfront costs, solar thermal desalination players (such as TSS Pvt. Ltd.) are planning to charge consumers (primarily industries) a fee for producing desalinated

20 Project developers were not well placed to share detailed cost related information as projects were still in the planning stage.
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water after treating industrial wastewater. The business model is to retain ownership of solar thermal plants and charge users/industries for the services.

Various avenues for cost reduction could include design improvements, optimization of solar thermal plants, polygeneration/co-generation of power and desalinated water (using spent steam) in CSP-MED combination, hybrid desalination plants (to counter intermittency) and indigenization of technologies introduced by overseas players.

3.5 POLICY SCENARIO

MNRE under the purview of scheme on "Off-Grid and Decentralized Solar Applications" of the JNNSM provides subsidies to both solar PV RO and solar thermal desalination systems. However, it must be noted that the subsidy is applicable only to the solar component (and not to the desalination unit, e.g., the MED/RO membrane) of both PV and thermal desalination plants.

3.5.1 Subsidies Applicable for Solar PV Powered RO Plants

Under the "Off-Grid and Decentralized Solar Applications" scheme, MNRE would extend financial assistance under JNNSM through a combination of 30 per cent capital subsidy only to the solar component of the solar PV-RO units catering to individual, non-commercial and industrial/commercial entities. Table 3.7 illustrates the boundary conditions for provision of financial assistance by MNRE for "Off-Grid and Decentralized Solar Applications" under the JNNSM scheme. The current benchmark cost for PV with and without battery banks is outlined in table 3.8.

Under the "off-grid and decentralized solar applications scheme", subsidies are also extended to mini-grids that power solar PV-based RO plants (SPV plant of maximum capacity of 250Wp each) that may constitute as one of the components of the total electrical load of a village. The entire funding under this scheme is project-based and requires submission of a detailed project report (DPR) to avail capital subsidy. The Ministry of New and Renewable Energy provides a combination of 30 per cent capital subsidy of the benchmark cost to the eligible project (MNRE).[23] Capital subsidy of 90 per cent of the benchmark cost is available for special category states, i.e., those in the northeast, Sikkim, Jammu & Kashmir, Himachal Pradesh and Uttarakhand.

TABLE 3.7

Subsidies Applicable for Solar PV Component of Solar Desalination Plants

Source: CEEW-stakeholder interaction

	Type of Application/ User	Capacity	Subsidy
A	Individual	5kWp	Capital subsidy
B	Non-commercial	100kWp	Capital subsidy
C	Commercial/Industrial	100kWp	Capital subsidy

23 http://mnre.gov.in/file-manager/UserFiles/jnnsm_spv_mini_grid_plants.pdf

TABLE 3.8

Benchmark Costs Applicable in case of Solar PV Unit of Solar Desalination Plants

Source: MNRE, 2013

SPV System	Capacity	Benchmark Cost (INR/Wp)
SPV power plants (with battery bank) with DC motor (in case of AC motor, there is a reduction of 15 per cent in the benchmark cost)	> 300 Wp–1kWp	210
	> 1kWp–10kWp	190
	> 10kWp–100kWp	170
SPV power plants (without battery backup)	Up to 100kWp	100

3.5.2 Subsidies Applicable for Solar Thermal-Based Desalination Plants

Capital subsidies applicable to solar thermal desalination units have been outlined in table 3.9. It must be noted that the financial assistance is confined only to solar component. The capital subsidy/unit collector area is based on 30 per cent of the benchmark costs or INR/m^2 of the installed concentrator area, whichever is less. Capital subsidy would be computed based on the applicable type of solar collector, multiplied by the collector area involved in a given project.

Apart from the capital subsidy, the pattern of support could include a soft loan at 5 per cent interest, inter alia, for balance cost, which may include installation charges, cost of civil work for large systems and costs of accessories (e.g., insulating pipeline, electric pump, controllers and valves, and so forth).

TABLE 3.9

MNRE Subsidy on Solar Thermal Systems

Source: MNRE, 2013a; 2013b; NABARD, 2013 It is noteworthy that MNRE has not received any applications for CFA for solar desalination plants so far.[24]

Type of System	Category	Benchmark cost INR/m^2	Subsidy (30 per cent of the benchmark subject to a maximum of INR
Evacuated tube collector (ETC)	Domestic	8,500	2,550
	Commercial	8,000	2,400
Flat plate collector (FPC)	Domestic	11,000	3,300
	Commercial	10,000	3,000
Concentrator with manual tracking	-	7,000	2,100
Concentrator with single axis tracking (Scheffler dish)	-	18,000	5,400
Concentrator with double axis tracking	-	20,000	6,000

Notes: 1. Systems below 500 L/day are categorized as domestic systems and those above 500 L/day are categorized as commercial systems.
2. States under the special category receive 60 per cent subsidy. They are Himachal Pradesh, Jammu & Kashmir, Uttarakhand, and the north eastern states including Sikkim.

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3.5.3 MNRE's Efforts to Propel R&D in Solar Desalination

It is important to note that MNRE has not received any applications from private companies regarding disbursal of subsidies for solar desalination plants.[25] However, it is funding various R&D projects in solar-powered desalination projects undertaken by various research institutions. For instance, it has recently sanctioned a loan of INR 23 lakh to Hindustan Institute of Technology, based in Chennai, which had floated a proposal for designing a triangular solar desalination plant for domestic use.

3.5.4 Pilot Projects

In addition to providing financial support for R&D in solar water desalination, MNRE is promoting renewable powered desalination technologies through pilot demonstration projects. For example, it has been one of the funders for Saurya EnerTech's Swajal Project on pilot solar PV-powered RO water purification systems in Khoda and Behrampur villages, initiated in 2011.[26]

As part of the ComSolar Project, MNRE in collaboration with GIZ as one of the funders, and Gerindtec as the technology provider had planned to undertake a demonstration pilot project to set up a 10,000 L/day solar water desalination plant at Bitra Island of Lakshadweep which is facing a severe shortage of drinking water for its small population.[27] It was envisaged that MNRE, GIZ and the Lakshwadeep administration would each be shouldering one-third of the project costs. However, it took three years (from 2009) for taking the decision to commission the project. The foreign exchange rates (INR to Euro) witnessed a major fluctuation within this period, which eventually stalled the project as additional funding could not be obtained to cover the increased costs.[28]

3.6 BENEFITS

3.6.1 Environmental and Long Term Economic Benefits

The most vital impact of desalination on the environment is that it reduces consumption of conventional water resources and emission of GHG. Solar-powered desalination systems can offset costs of transporting fresh water to water thirsty remote areas. For example, solar PV-RO installation by Manthan in Bhopa ki Dhani in Rajasthan offsets cost incurred on importing large amounts of fresh water from neighbouring areas. The villagers were paying a monthly charge of INR 400 prior to the installation of the solar RO pant, after which they are required to pay only INR 30 a month for safe drinking water.

25 Telephonic conversation with MNRE
26 http://www.reeep.org/projects/business-model-clean-drinking-water-using-solar-ro-indian-industrial-belt
27 ComSolar Project aims to enhance cooperation between German and Indian project developers to demonstrate business models for commercialization of solar technologies in India, and technology transfers through public private partnerships
28 CEEW-stakeholder interaction

Additional power produced from solar-powered desalination plants can also be used for other purposes such as lighting, running computers and so forth (see figure. 3.10).

FIGURE 3.10

Additional Power from Solar Panels Used to Run Prayatna's Solar Workshop at Silowata and the Office Computer in Kotri, Rajasthan

Source: CEEW

© Poulami Choudhury / CEEW

3.6.2 Health and Socio-Economic Benefits

Solar desalination plants can bring a wide array of social and economic benefits, especially in rural and remote areas with limited energy access. Operation of the solar-RO plants has not only resulted in monetary savings but has also ensured that villagers lead a healthy life, which in turn increases their economic productivity. Consumption of saline water led to skin and stomach ailments and stunted growth in children. Solar RO plants installed by Barefoot College reduce salinity levels/TDS from 4,000–6,000 ppm to only 300–400 ppm, making water clean and safe for consumption. Residents endorse these installations and firmly believe that it can "extend their life-expectancy by providing safe drinking water".[29] The social benefits of solar desalination projects, especially in water scarce areas with poor income households is also brought out in Roopaji ki Beri where villagers no longer face the ignominy of stealing water from neighbouring villages after the installation of 'water pyramid' (Sebastian, 2009).

29 CEEW-stakeholder interaction

I. A Potential Vehicle for Community/Women Empowerment

In village Mordi in Rajasthan, women in-charge of Prayatna Sansthan's day-care centres are successfully operating and maintaining a 5,000 L/day capacity solar RO desalination system installed in 2012. These women have received O&M training from officials of CSMCRI, which has designed and installed this solar RO plant, and Barefoot College, Tilonia. Support for complex repair and replacement of the plant is provided by Manthan, Prayatna Sansthan and CSMCRI.

The solar desalination plant housed within the day-care centre premises is run daily for three hours in the afternoon (12 p.m. to 3 p.m.) to produce potable drinking water for around 30 families. Moreover, this harmonizes well with the day-care centre's timing, thus preventing women from spending additional time to operate the solar-RO plant.

This is an exemplary case that illustrates how women with the support of dedicated local institutions can successfully manage perceived complex solar RO systems, thus ensuring long term sustainability of such installations. This is also contrary to the popular perception that CSR funded decentralized renewable energy projects in rural areas are difficult to sustain owing to dearth of skilled personnel (see figure 3.11). Local community members stationed at the solar desalination plant in Bhopa ki Dhani offer regular O&M services free of charge (see figure 3.12).

FIGURE 3.11

Solar-RO Plant Operated by Women (Village Mordi, Rajasthan)

Source: CEEW

© Poulami Choudhury / CEEW

FIGURE 3.12

Voluntary Services Offered by the Community in Regular O&M of the Solar Desalination Plant in Village Bhopa ki Dhani, Rajasthan

Source: CEEW

© Poulami Choudhury / CEEW

3.7 BARRIERS AND OPPORTUNITIES

There are several challenges that currently hamper scale-up of solar desalination technologies in the country, such as high costs and limited access to finance, nascent technology, lack of awareness, dearth of skilled personnel in remote areas, and absence of conducive policies and policy advocacy (see table 3.10)

TABLE 3.10

Solar Desalination: Overview of Barriers and Potential Opportunities

High costs and limited access to finance	Nascent technology	Lack of awareness/ access to information	Lack of skilled personnel	Lack of conducive policies and confidence in subsidies
• Indigenization and in-house manufacturing of both solar components and materials for desalination unit (can bring down the upfront cost and establish quality control) • Co-generation/ Poly-generation in case of CSP driven desalination	• Collaboration with R&D institutes and overseas players • Implementation of pilot projects • Research into cost-effective thermal storage technologies	• Periodic mapping of solar desalination projects and stakeholders • Information exchange between related government bodies (MNRE; R&D institutes like DST; NABARD; State Nodal Agencies)	• Engagement with local level organizations for long-term oversight of installations	• Inclusion of solar driven desalination within the scope of other ministries

3.7.1 High Costs and Limited Access to Finance

One of the biggest roadblocks hindering wider implementation or penetration of solar desalination technology remains its high upfront cost (as outlined in the section on "Costs") and payback period compared to conventional desalination technologies. Stakeholder interactions led us to believe that indigenization and in-house manufacturing can play an important role in driving down the overall costs of solar desalination solutions. For example, one of the primary reasons for the high cost of Gerindtec's solar desalination solution was the greater degree of imports involved. Gerindtec was required to import solar thermal panels with Tinox coating and materials for the desalination unit from Germany. Recognising this, Gerindtec had to carve out plans to indigenize the technology (components of desalination unit in particular) to cut back on import costs. Likewise, in-house manufacturing of solar components (e.g., solar panels) rather than sourcing from external suppliers can not only reduce the upfront cost of the product but also act as a means to ensure quality control.

Limited access to finance is also a key challenge encountered by solar desalination project developers. Due to high costs, most firms have initially adopted or are keen to adopt the CSR model. However, firms, especially solar thermal technology manufacturers have experienced difficulties in convincing the corporate to look beyond the upfront costs and take long-term economic, social and environmental benefits into account.

One of the avenues highlighted by R&D experts that can lead to cost reduction for CSP-based desalination includes exploring possibilities of cogeneration and poly-generation wherein electricity, steam and waste heat generated from a CSP plant can be utilized for several purposes – electricity generation, cooling and desalination.[30]

3.7.2 Technology

Nascent Technology: A major factor that makes RO technology lot more attractive or favourable is the fact that it is quite developed as opposed to solar thermal solutions, which are still undergoing development and constant improvement. However, it is essential to note that the solar PV-RO technology is not considered appropriate for desalinating water with very high salt concentrations (greater than 8000-9000 ppm) because of high operational costs (frequent replacement). Solar thermal desalination solutions are a lot more complicated to design as it requires optimization with respect to radiation, geography and environmental factors. Manufacturers/project developers often run the risk of installing a solar thermal desalination plant without considering various factors for optimizing the output which, in turn, can have an overall impact on the economic and operational success of the plant. Collaboration with R&D centres (Indian and overseas) and overseas international companies working in the space of integrating solar energy into desalination technologies to implement research and demonstration projects will aid in commercialising these technologies.

Intermittent nature of solar energy: Continued research and awareness regarding cost-effective thermal and battery storage solutions for integration with solar desalination

30 CEEW-stakeholder interaction

plants is important to counter the intermittent nature of solar resource which ultimately hampers productivity.

Disposal of brine: Disposal of brine/wastewater from RO desalination plants is a major cause of concern, which can be avoided by selecting a solar thermal technology that has a higher conversion rate of about 90 per cent as opposed to RO that can only achieve conversion rates of up to 60–65 per cent. Another operational constraint of solar RO technology is frequent membrane fouling, particularly in areas with high salinity. Solar thermal desalination processes involving minimal maintenance can help in overcoming this challenge.

3.7.3 Lack of Awareness or Access to Information

Lack of awareness was observed on various levels during the course of this study. The biggest misperception among project implementers was non-availability of government subsidies for solar desalination solutions, whereas, in reality, discussions with MNRE suggested that it is open to subsidising such projects wherein the financial help would be confined to the solar component.

One-on-one interactions unravelled that few firms have also experienced challenges in accessing information regarding subsidies applicable to solar desalination systems from government bodies like NABARD which is responsible for disbursing loans related to off-grid applications.[31] This signals to the need for putting in place measures that would ensure information exchange between various government institutions or departments (e.g., between MNRE and NABARD) that are involved in promoting uptake of solar applications, including solar PV-RO purification/desalination systems.

It was also seen during the interactions that project implementers (including both private manufacturers and not-for profit organizations) are at a loss due to lack of information on interested donor agencies/funders, R&D institutes that can provide technical support, social organizations/NGOs working to provide safe drinking water, and supply chain actors such as manufacturers of DC pumps. Access to such information can help them better access the market and also operate plants more successfully. The government and other research organizations must take the lead in showcasing potential of solar desalination solutions in the public domain.

3.7.4 Lack of Skilled Personnel

It is believed that solar RO may not be a feasible solution in remote areas such as islands or villages where there is lack of potential labour/personnel to maintain such a system. However, in the case of the solar desalination project operated in the villages discussed above, the concerted efforts of the Barefoot College, CSMCRI scientists and the local community became the primary reason for the successful sustenance of the solar desalination units.

31 NABARD disburses loans (including capital subsidies) for off-grid decentralised energy applications to banks. On receipt of the subsidy from NABARD, the bank shall disburse the loan directly to the eligible manufacturers.

FIGURE 3.13

Classroom (left) and On-Field O&M Training (right) Imparted by CSMCRI Officials

Source: FORRAD, 2012

Local representatives from Manthan and Prayatna Sansthan as well as village residents (in-charge of daily maintenance) from the village community were imparted O&M training by CSMCRI scientists (see figure 3.13).

Both Manthan and Prayatna have been pivotal in promoting active community engagement, convincing village panchayats in financing construction of the building for housing the plant and training local residents in regular O&M of the installations.

The Manthan example highlights the opportunity of engaging civil society organizations/NGOs that support long-term viability of solar desalination installations. However, an important thing to note here is that in remote areas where such dedicated support organizations/NGOs may not be present to drive the overall O&M efforts, it would be incorrect to expect locals to oversee functioning of solar RO desalination plants on a continued basis. For instance, MNRE did not find it feasible to install solar PV-RO desalination plant in Lakshwadeep, which required skilled personnel for regular maintenance, and instead decided to implement solar thermal desalination (the project did not take off due to financial issues) that does not require skilled labour for O&M. During the course of our conversations stakeholders indicated that solar PV-RO plants can often fail in remote areas due to lack of technical help for addressing O&M issues. This opens up a whole new opportunity to explore solar thermal desalination solutions that can serve these areas lacking such support institutions.

3.7.5 Lack of Conducive Policies and Confidence in Subsidies

Although MNRE only extends subsidies to solar component of the solar desalination plants, there are few firms reluctant to develop business models that are heavily reliant on government subsidies citing poor disbursal regimes. The stakeholder discussions also revealed that firms often do not receive an encouraging response from NABARD with respect to clarity on subsidies for solar desalination solutions. Such experiences coupled with previous instances of delayed subsidy disbursal (in case of solar lighting solutions and so forth) have eroded confidence in the subsidy route. It was observed that government departments (responsible for approving loans for solar applications) are often unaware of the various schemes/policies supporting this technology.

During the course of our discussions, stakeholders endorsed the viability of integrating solar energy into existing fossil powered desalination plants, but emphasized that realising this would require a greater initiative on the part of policymakers. Stronger policy advocacy measures by R&D institutions, policy advocacy organizations and private companies could help strengthening the case for more demonstration projects exhibiting viability of running conventional plants with solar.

3.8 RECOMMENDATIONS

Table 3.11 highlights the recommended interventions targeted at alleviating a range of challenges hampering wider uptake of solar desalination technologies.

TABLE 3.11

Barriers and Associated Recommendations

Source: CEEW

Targeted Barriers	Recommendations
High costs and limited access to finance	• Unlock CSR funds • Disseminate information on solar desalination success stories to build investors' confidence • Pitch for funding from various ministries (such as the Ministry of Drinking Water and Sanitation) • Leverage the National Clean Energy Fund (NCEF) • Promote indigenization of components of the solar desalination plant to drive down the capital cost • Engage local-level organizations for overall plant oversight to promote confidence amongst CSR funders
Technological Constraints	• Establish pilot projects utilizing National Clean Energy Fund (NCEF), especially for the less-evolved solar thermal based desalination technologies • Explore the breadth of support from R&D institutes, for example, in order to optimize solar thermal desalination systemsfor maximum output • Promote international cooperation
Lack of awareness or access to information	• Bridge the information gap by documentation and dissemination of information in the public domain • Promote subsidy discourse with NABARD and state nodal agencies which in turn can provide accurate information to companies on government schemes for desalination • Leverage industry associations, for example, InDA to disseminate information
Lack of skilled personnel	• Engage grassroots organizations capable of mobilizing community for overall implementation and maintenance of solar desalinations systems
Lack of conducive policies and confidence in subsidy regime	• Foster synergies between government bodies such as the Ministry of Drinking Water & Sanitation, and Central and State Pollution Control Boards could trigger strategies/policies that can integrate solar energy into desalination applications • Explore solutions to contractual and regulatory challenges associated with retrofitting existing fossil based desalination plants with solar concentrators

3.8.1 Building Synergies between Different Government Ministries

The idea behind promoting solar-driven desalination technologies is not just restricted to reducing greenhouse emissions and obtaining fuel savings. The broader goal is to provide access to safe drinking water to residents in rural and remote districts, especially at places where people struggle with highly saline water and as a result face severe health and economic issues. For example, residents of village Bhopa ki Dhani in Rajasthan, which was one of the villages surveyed in this study, were found to pay an exorbitant monthly fee (INR 400/household) for consuming water transported from neighbouring areas. This amount was reduced drastically after implementation of the solar PV-RO plant.

Thus, in order to realize the full potential of solar desalination in India, it may be essential that various government ministries/bodies aside from the MNRE are taken on board to pitch for greater uptake of solar desalination technologies across sectors like drinking water and health. These ministries could include State Renewable Energy Development Corporations, Ministry of Drinking Water and Sanitation, Central and State Pollution Control Boards and Ministry of Health. Leveraging national level drinking water programmes such as the Rajiv Gandhi National Drinking Water Mission to include solar desalination as one of the focus areas, could also act as an impetus to popularize this technology. These government ministries can allocate funds for implementing solar desalination projects, thereby, alleviating challenges related to access finance. Further, the guidelines of the Central Pollution Boards could include solar desalination solutions as one of the possible technologies for wastewater treatment in industries.

As has been witnessed in the case of Saudi Arabia and Australia (elaborated in the section on international case studies on solar desalination), a greater commitment from the government towards greening the energy-intensive desalination processes is the need of the hour if solar desalination technologies are to succeed in the country.

It is important that policymakers explore possibilities of integrating/retrofitting conventional desalination plants with solar PV or solar thermal/CSP technologies by way of introducing favourable guidelines or incentives to eliminate contractual and regulatory challenges.

3.8.2 Pilot Projects Might Hold the Key

Pilot projects are essential, in particular, for solar thermal technologies to obtain a better understanding of local solar radiation and haze factors at sites, before embarking on commercial scale projects.

Solar PV-RO plants implemented by the Barefoot College and CSMCRI offers a prime example of how pilot projects are an effective tool for replication and promoting scale-up of a technology. Community feedback for the first of the six solar-powered RO plant installed in 2006 in Kotri, led CSMCRI to introduce improvements in its other solar PV-RO installations at Sinodiya, Jhag, Bhopa ki Dhani, Silowata and Mordi. These include bag filters (10μ and 5μ) with stainless steel housing for more efficient filtration, three membrane elements (see figure 3.1 and figure 3.9) instead of one for higher flow velocity and minimum concentration gradient, and increased capacity of high pressure and booster pump.

The National Clean Energy Fund (NCEF), formed from clean energy cess on coal, can be utilized to mobilize investments into R&D in solar desalination technologies and deployment of pilot projects. It is noteworthy that the primary objective of NCEF is to promote R&D in clean energy technologies but it has been utilized for regular projects as well. For example, The Ministry of Drinking Water and Sanitation has thus far been allocated 221 crore from the NCEF, which was used to provide solar energy powered dual pumped piped water supply in 74 backward districts (Paliwal and Goyal, 2013). The NCEF, however, has recently come under the scanner for its ineffective utilization as only 45 per cent of the total sum of INR 81.79 billion accumulated in NCEF was allocated to projects as of March 2013 (Ganesan, Choudhury, Palakshappa, Jain and Raje, 2014). Ministries such as the MNRE and the Ministry of Drinking Water and Sanitation can be allocated funds from NCEF to implement solar desalination projects. In addition, continued research into effective solar thermal storage technologies is crucial to overcome challenges pertaining to intermittent solar energy.

3.8.3 Bridging the Information Gap

Since the market for solar desalination in India is still in its infancy, there is very little awareness and access to updated information on the various projects that are operational, supply chain actors, potential users, support organizations that are currently active or interested to implement solar desalination projects as well as potential financiers who could fund such endeavours. The following can help provide an impetus to promote information flow and creation of awareness about solar desalination.

- *Documentation of the existing solar desalination landscape:* There is a dearth of documentation or case studies on solar desalination plants implemented across the country that could be presented in the public domain. There is opportunity need for an in-depth research on the current market, projects and potential of solar desalination. It is also important to disseminate information about ongoing research projects in the space of solar thermal storage technologies, which can be integrated with solar desalination plants.
- *Subsidy discourse with NABARD and state nodal agencies:* MNRE needs to engage NABARD and state nodal agencies and update them about subsidies applicable to solar desalination. Along with financing renewable power generation, banks and public sector enterprises must be made aware to finance solar desalination technologies (could be under CSR).
- *Information dissemination by other government ministries:* Various government ministries like the Ministry of Drinking Water and Sanitation could publish information highlighting the importance of solar-desalination and its successful models across the country.
- *Leveraging industry associations:* The Indian Desalination Association (InDA) can engage its members and update them of the potential of solar desalination

technologies. The InDA website could act as a vital tool to disseminate progress and relevant information about solar desalination projects and the technology in general. InDA could also facilitate organising dedicated seminars to provide a platform to solar desalination players across the board (R&D institutes, private manufacturers, NGOs active in drinking water and sanitation sector) to share their experiences in implementing solar desalination technologies.

3.8.4 Community Participation: Engaging Local Level Institutions (NGOs)

Likewise in any solar installation (home-lighting systems, mini-grids), lack of dedicated skilled personnel is a major impediment for ensuring long-term maintenance of a solar desalination installation. The successful community managed solar desalination plants in Rajasthan implemented by Manthan and Praytna Sansthan demonstrates that engagement of local organizations working in the realm of drinking water, watershed and solar lighting solutions could act as the vital backbone to demystifying the technology to communities, and promoting community participation for long-term maintenance of the installation. The successful model of integrating community empowerment and drinking water provision that dictates sustainability of such projects could also serve to attract CSR funding for such projects. Annexure 2 enlists few local institutions working in the field of drinking water that may serve as potential partners for solar desalination projects.

Another example of how local experience of grassroots organizations (active in watershed management and water conservation) can aid solar desalination projects in rural is showcased by NGOs such as Manthan and Praytna Sansthan in Rajasthan. In order to reduce feedwater salinity, Manthan mixes underground water (with very high salinity) with water from the watershed (stores non-saline rainwater) prior to the

FIGURE 3.14

Manthan's Watershed Project Provides Feedwater for Jhag Solar-RO Plant

© Poulami Choudhury / CEEW

treatment by Jhag solar RO plant (figure 3.14). This was helpful as feedwater with high salinity reduces efficiency of the process and leads to frequent membrane replacement. Likewise, when operations of the Silowata RO plant were discontinued due to repair works, Prayatna Sansthan ensures that village consumers are provided with potable water from wells located in nearby areas. This helps to retain trust of local residents in the solar desalination technology.

3.8.5 Transforming Corporate Perceptions: Seizing the CSR Opportunity

Our stakeholder interactions suggest that access to CSR funding for setting up solar desalination projects has been a tough task for project developers, particularly solar thermal developers. They often had to counter rigid corporate perceptions that draw comparisons between capital costs and payback of solar desalination solutions with conventional desalination technologies, thus failing to see the bigger picture which entails significant reductions on O&M costs, GHG emissions and fossil fuel.

The government might want to play a facilitating role in organization dedicated events that can trigger interactions and information exchange amongst donors/CSR funders, various private firms and not-for-profit organizations, R&D institutions, and so forth. As mentioned earlier, NCEF can be an important source of finance for R&D and pilot projects in solar desalination.

Private players who have previously been unsuccessful in obtaining CSR funding for solar thermal desalination projects emphasized that corporate focus on reducing GHG emissions and environmental implications of conventional desalination plants as opposed to supporting short-term economic gains has played a major role in spurring adoption of solar desalination technologies in the Middle East, particularly in countries like Saudi Arabia. This could serve as a key takeaway for Indian corporate as well who are not willing to look at the long-term environmental, social and cost benefits of solar desalination technologies.

Rather than focussing on the capital costs of solar desalination plants, it is essential that financiers consider unit cost of producing desalinated water using solar power.

3.8.6 Exploring the Breadth of Support from R&D Institutes

CSMCRI's commendable effort in providing technical support to Barefoot College in successfully implementing and operating solar RO plants is a model that ought to be adopted by other R&D institutes working in the space of solar desalination technologies. Private firms, especially solar thermal desalination players must make an effort to seek technical advice from R&D institutions regarding optimizing the technology so as to gain higher output and cost-effectiveness. Solar thermal desalination technology is still at an evolving stage. It is thus essential that R&D institutions provide their invaluable technical expertize in making pilots and commercial installations a success.

3.8.7 Promote International Cooperation and Indigenization

It is noteworthy that despite Geridntec's (Indo-German EPC) successful pilot demonstration of the 1,000 LPD (MiniSal 1000) at Chennai, its efforts to replicate the same technology on a larger scale (10,000 LPD) in Lakshwadeep failed owing to bureaucratic delays, which ultimately made the project financially unviable. As solar desalination is still at a nascent stage, it is vital to make the policies and bureaucratic processes more amenable for increased participation by experienced foreign players looking to implementing such technologies in the country.

Also, it is important that the overseas players promote indigenization of various components of the desalination unit to the maximum extent possible, which will enable cost minimization by driving down costs associated with imports of either solar and desalination components. One of the interviewed solar desalination companies endorsed the need for in-house manufacturing to decrease costs and ensure quality control of systems.

ANNEXURE I

STAKEHOLDER INTERACTIONS

Organizations/Individuals
Arka Technologies Pvt. Ltd.
Prof. Ajay Chandak
Clique Developments Ltd.
Central Salt and Marine Chemicals Research Institute (CSMCRI)
Claro Ventures
Department of Science and Technology (DST)
Gerindtec
Jakson Power Solutions Pvt Ltd
Mamata Energy Pvt. Ltd.
MNRE (Ministry of New and Renewable Energy)
Muni Seva Ashram
MNRE
Manthan
MNRE
NTPC Energy Technology Research Alliance (NETRA)
Prayatna Sansthan
Saurya Enertech
Sharada Inventions Pvt. Ltd.
Solar Energy Centre (SEC)
Taylormade Solar Solutions Pvt. Ltd. (TSS Pvt. Ltd.)
Thermax Pvt. Ltd.
Turbo Energy Ltd. (TVS group)

ANNEXURE II

POTENTIAL SOLAR DESALINATION COLLABORATIONS

Organisation	Role
Yatn	NGO
Arghyam	NGO
Water Aid	NGO
Boond	NGO
Barefoot –Tilonia	NGO
Social Awareness Newer Alternatives (SANA)	NGO
Ion Exchange	NGO
LEAD-Chennai	NGO
Navdanya	NGO
Hitachi	Company
Hyflux	Company
Boond	Social Enterprise
Schneider Electric	Training provider in solar technologies
Shri Ratan Tata Trust and Navajbai Ratan Tata Trust	NGO

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ABOUT WWF-INDIA

WWF-India is one of the largest conservation organizations in the country dealing with nature conservation, environment protection and development-related issues. Established as a Charitable Trust in 1969, it has an experience of over four decades in the field. Its mission is to stop the degradation of the planet's natural environment, which it addresses through its work in biodiversity conservation and reduction of humanity's ecological footprint.

WWF-India works across different geographical regions in the country to implement focused conservation strategies on issues like conservation of key wildlife species, protection of habitats, management of rivers, wetlands and their ecosystems, climate change mitigation, enhancing energy access, sustainable livelihood alternatives for local communities, water and carbon footprint reduction in industries, and combating illegal wildlife trade. WWF-India is actively engaged in promoting renewable energy uptake, enabling energy access, demonstrating renewable energy projects in critical landscapes, and overall promoting clean energy solutions.

WWF-India has been working on issues related to biodiversity conservation, sustainable livelihoods and governance, and climate change. The Climate Change and Energy programme of WWF-India is working towards a climate resilient future for people, places and species that support pathways for sustainable and equitable economic growth. Low carbon development and renewable energy at scale are the thrust areas of climate change and energy programme.

ABOUT CEEW

The Council on Energy, Environment and Water (CEEW) is an independent, not-for-profit, policy research institution. CEEW works to promote dialogue and common understanding on energy, environment and water issues in India, its region and the wider world, through high quality research, partnerships with public and private institutions, engagement with and outreach to the wider public.

CEEW's work covers all levels of governance: at the global/regional level, these include sustainability finance, energy-trade-climate linkages, technology horizons, and bilateral collaborations with China, Israel, Pakistan, and the United States; at the national level, it covers resource efficiency and security, water resources management, and renewable energy policies; and at the state/local level, CEEW develops integrated energy, environment and water plans, and facilitates industry action to reduce emissions or increase R&D investments in clean technologies. For more information, visit http://www.ceew.in

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