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SOLAR ENERGY – TODAY AND TOMORROW

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By

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1. GENERAL

Today no one can deny that our country is suffering from shortage of power, so badly needed for economic growth of the country, halting agriculture and industrial development.

To meet the shortage of power demand, we need to utilize all the available indigenous resources in Pakistan particularly Wind Mills, Hydel Potential, Thar Coal and Solar Energy, which has a great potential to meet our power demand and is emerging as the most potent source of renewal energy. Solar energy if sincerely exploited can bring a revolution in the very near future, and GoP must give due priority for its development in Pakistan to meet shortage of power.

2. SOLAR POWER

Solar Power is the conversion of sunlight electricity, either directly using photovoltaic (PV) or indirectly using concentrated solar power (CSP), so there are two major sources of solar power which will be discussed with respect to type of technology, application, economy, cost, their present and the future status.

i. Photovoltaic Cell (PV)

ii. Solar Thermal Power (CSP)

3. PHOTOVOLTAIC CELL

Broadly speaking photovoltaic cell technology can be classified into

- Traditional Crystalline Silicon Technology (SC)
- Thin Film Solar Cells (TFSC) technology

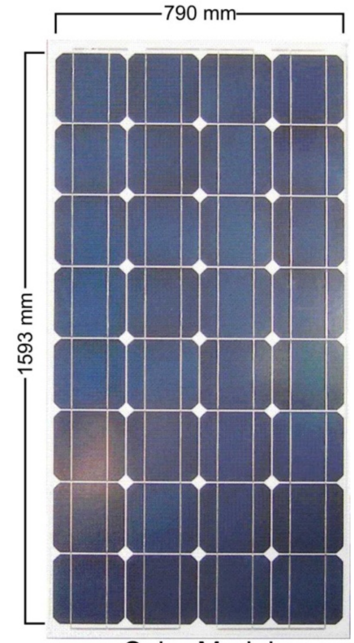
There are currently three different generations of solar cell. The first Generation (those in the market today) are made with crystalline semi conductor wafers, typically silicon. These are the SC's everybody think of when they hear "Solar Cell".

Second Generation Solar Cell are based on thin film technology. These Solar Cell focus on lowering the amount of material used as well increasing the efficiency.

The goal of third generation solar cells is to increase the efficiency using second generation solar cells (thin film) and using materials that are found abundantly on earth. This has also been a goal of the thin film solar cells. With the use of common and safe materials, third generation solar cells should be able to be manufactured in mass quantities further reducing the costs. The initial costs would be high in order to produce the manufacturing processes, but after that they should be cheap.

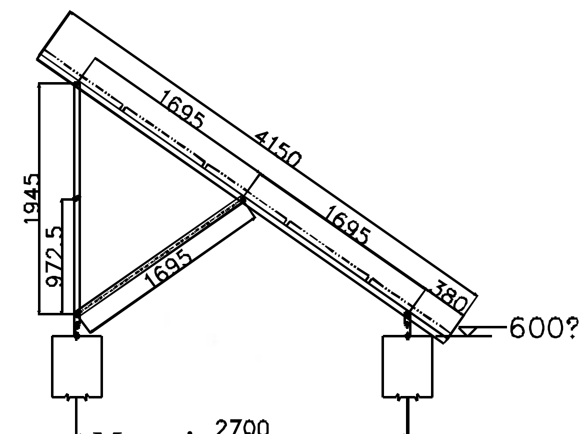
3.1 Silicon Technology

Traditional crystalline silicon technology uses photovoltaic modules using silicon. Nitride Mono or Multi Crystalline Silicon cells. Most of the today's manufacturers of photovoltaic models use this technology and have made investment worth of billion of dollars for establishment of factories and R&D. In this technology a relatively thick layer is deposited on substrate. The maximum efficiency achieved by use of this technology ranges between 8-15%. Data of one of the renowned Chinese manufacturer is enclosed for photovoltaic modules.

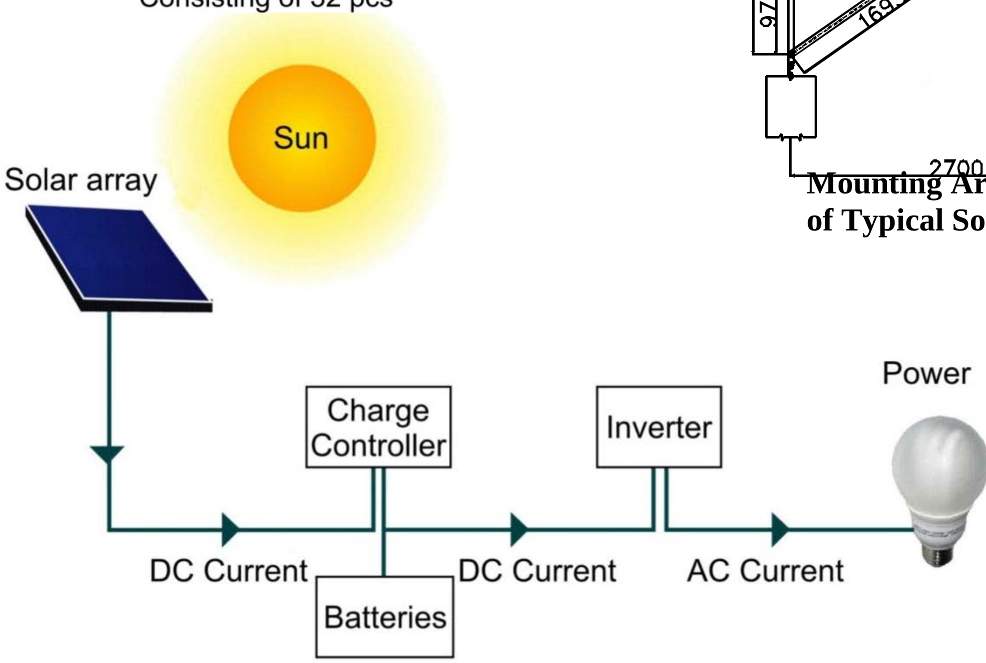


Solar Model
Consisting of 32 pcs

Solar Panels



Mounting Arrangement of Typical Solar Panel



General Layout of PV Station (System Configuration)

TYPICAL SOLAR PANELS (BRANDED) 3kW, 5kW AND 10kW SYSTEM CONFIGURATION AND ESTIMATED COST OF HIGH QUALITY PROJECT WITH 25 YEARS OF WARRANTY FOR SOLAR PANEL

Name of Equipments	Specification			Quantities/Cost U.S$		
	3kW	5kW	10kW	3kW	5kW	10kW
Solar panel	135W	160Wp	170W	24pcs/3000$	32pcs/5000$	63pcs/10,000$
Solar Array Support	3240/135-24			1set/500$	1set/800$	1set/800$
Charging Controller	60A/48V	5KW	15KW	1set/200$	1set/300$	1set/500$
Inverter	3000KVA	5KW	15KW	1set/300$	1set/500$	1set/1000$
Maintenance Free Deep Cycle Batteries (Average Life 10 Years)	1500AH	2500AH	5000AH	2,000$	3,300$	6,600$
Distribution Box / Anti-thunder Protector	Indoors			1set/200$	1set/300$	1set/500$
Installation Charges				300$	400$	500$
TOTAL COST				6500$	10800$	19,900$

PER WATT COST COMPARISON & SPACE REQUIREMENT

Description	Quality	3kW	5kW	10kW
Cost/Watt for 6 Hours Backup	High Quality Branded Products	2.2$	2.1$	2.0$
Cost/Watt for 12 Hours Backup	High Quality Branded Products	2.8$	2.7$	2.5$
Cost/Watt Without Batteries	High Quality Branded Products	1.5$	1.4$	1.35$
Cost/Watt for 6 hours backup	Commercial Grade	2.0$	1.9$	1.8$

ESTIMATED SPACE REQUIREMENT

Open Space Required for Panels		$30m^2$	$40m^2$	$60m^2$
Indoor Room Space for Batteries, Inverter etc.		$6m^2$	$8m^2$	$10m^2$

3.2 Thin Film Solar Cells (TFSC)

A thin-film solar cell (TFSC), also called a thin-film photovoltaic cell (TFPV), is a solar cell that is made by depositing one or more thin layers (thin film) of photovoltaic material on a substrate. The thickness range of such a layer is wide and varies from a few nanometers to tens of micrometers.

Many different photovoltaic materials are deposited with various deposition methods on a variety of substrates. Thin-film solar cells are usually categorized according to the photovoltaic material used:

- Amorphous Silicon (a-Si) and other Thin-Film Silicon (TF-Si)
- Cadmium Telluride (CdTe)
- Copper Indium Gallium Selenide (CIS or CIGS)
- Dye-sensitized Solar Cell (DSC)
- Plasmonic Solar Cell (PSC)

The silicon is deposited on glass, plastic or metal which has been coated with a layer of transparent conducting oxide (TCO).

Since the invention of the first modern silicon solar cell in 1954, incremental improvements have resulted in modules capable of converting 12 to 18 percent of solar radiation into electricity. The performance and potential of thin-film materials are high, reaching cell efficiencies of 12–20%;

Most popular Thin Film technologies are Plasmonic Solar Cells (PSC) and Dye-Sensitized Solar Cells (DSC). Dye-sensitized Solar Cells are likely to reduce cost and space requirements and its under development is discussed here:

3.2.1 Dye-Sensitized Solar Cell

A dye-sensitized solar cell (DSSC, DSC or DYSC) is a low-cost solar cell belonging to the group of thin film solar cells. It is based on a semi conductor formed between a photo-sensitized anode and an electrolyte, because it could potentially be made of low-cost materials, and does not require elaborate apparatus to manufacture, this cell is technically attractive. Likewise, manufacture can be significantly less expensive than older solid-state cell designs. It can also be engineered into flexible sheets and is mechanically robust, requiring no protection from minor events like hail or tree strikes. Although its conversion efficiency is less than the best thin-film cells, in theory its price/performance ratio should be high enough to allow them to compete with fossil fuel electrical generation by achieving grid parity.

Advantages

DSSCs are currently the most efficient third-generation solar technology available. Other thin-film technologies are typically between 5% and 13%, and traditional low-cost commercial silicon panels operate between 12% and 15%. This makes DSSCs attractive as a replacement for existing technologies in "low density" applications like rooftop solar collectors, where the mechanical robustness and light weight of the glass-less collector is a major advantage. They may not be as attractive for large-scale deployments where higher-cost higher-efficiency cells are more viable, but even small increases in the DSSC conversion efficiency might make them suitable for some of these roles as well.

Disadvantages

The major disadvantage to the DSSC design is the use of the liquid electrolyte, which has temperature stability problems. At low temperatures the electrolyte can freeze, ending power production and potentially leading to physical damage. Higher temperatures cause the liquid to expand, sealing the panels and causing a serious problem.

Replacing the liquid electrolyte with a solid has been a major ongoing field of research.

Latest Developments

A group of researchers at Georgia Tech made dye-sensitized solar cells with a higher effective surface area by wrapping the cells around aquartz optical fiber and claimed that a sun-tracking system would not be necessary for such cells, and would work on cloudy days when light is diffuse.

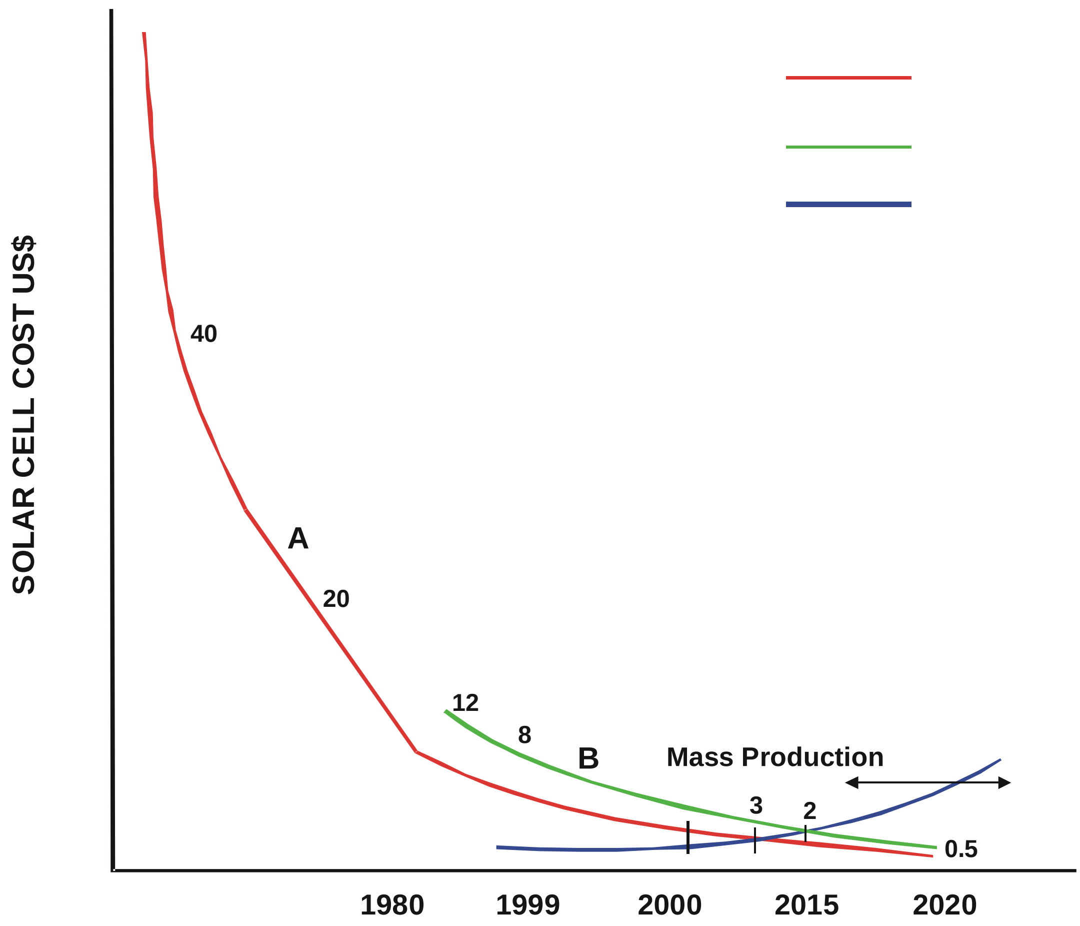
Dyesol and Tata Steel Europe announced in June 2011 the development of the world´s largest dye sensitized photovoltaic module, printed onto steel in a continuous line and targeted development of Grid Parity Competitive BIPV solar steel that does not require government subsidised feed in tariffs.

4. PRODUCTION AND COST OF SOLAR CELLS

Thin-film producers still enjoy in 2009 price advantage as its production cost is 20% less than that of silicon modules. It is expected that the production cost of thin-film will continue dropping (40% less than silicon), as Chinese producers are now putting more resources into R&D and partnering with manufacturing equipment suppliers. Out of several photovoltaic materials used, Dye-Sensitized Solar Cell is likely to be commercialized in the near future being light weight and cheaper in cost.

In recent years, the manufacturers of thin-film solar modules are bringing costs down and gaining in competitive strength through advanced thin film technology. However, the traditional crystalline silicon technologies will not give up their market positions for a few years because they still hold considerable development potential in terms of the cost.

The need for cheaper and more efficient solar cells is huge. In order for solar cells to be considered cost effective, they need to provide energy for a smaller price than that of traditional power sources such as coal and gasoline. The movement toward a more green world has helped to spark research in the area of plasmonic solar cells. Currently, solar cells cannot exceed efficiencies of about 30% (First Generation). With new technologies (Third Generation), efficiencies of up to 40-50% can be expected. With a reduction of materials through the use of thin film technology (Second Generation), prices can be driven lower. Solar manufacturing equipment suppliers intend to score cost of below US$1/W. The below graph shows how the cost of solar cell has reduced over the last four decades. It is expected with the present trend of research and development, solar energy is likely to be the cheapest source of energy by the year 2015, when mass production will start, beating all other power sources. It is estimated that solar panel cost which is about US$1.5/Watt today will come down to US$0.5/Watt by the year 2020.



5. APPLICATIONS

5.1 In Global Scenario

i. Solar cells have a great potential to help rural electrification. An estimated two million villages near the equator have limited access to electricity and fossil fuels and that approximately 80% of people in the world do not have access to electricity. When the cost of extending power grids, running rural electricity and using diesel generators is compared with the cost of solar cells, many times the solar cells win. If the efficiency and cost of the current solar cell technology is decreased even further, then many rural communities and villages around the world could obtain electricity when current methods are out of the question. Specific applications for rural communities would be water pumping systems, residential electric supply and street lights.

ii. Low cost solar panels and batteries will be provided to poor communities in 14 countries in Africa and Asia in the next four years under U.N Development Programme. A total of 33 million people in 14 countries will be able to make use of Solar Energy for commercial, business and economic development. This will save 520 million dollars annually spend on purchase of Kerosene or biomass fuel in low income villages. Similarly in Bangladesh, millions of houses have been electrified by solar panels.

5.2 Applications in Pakistan

i. We should make maximum use of solar panels without batteries, as batteries are the weakest link in the solar power system. Maintenance of batteries is not only difficult but also cost expensive. Here some situations are given under where no back up is required or utility supply can be used as stand by power.

ii. Thousand of tubewells in Sind and Punjab Provinces are not functioning due to non availability of power supply thus badly effecting production of agriculture. In Sind Province thousands of additional tubewells are also needed to lower the underground water level which will also boost crop production and will have great socio-economic impact on life of people. In these areas solar powered tubewells can be installed without provision of batteries, which will substantially reduce the cost of solar power supply system and will also make the system maintenance free.

iii. Solar power can be installed for running small industries, factories, in commercial areas and even to meet domestic loads particularly air conditioning loads during the day time in summer season with backup power supply, from Distribution Companies

iv. Power Supply with backup to Remote Areas

v. In addition Distribution Companies instead of expending their power supply network to far flung areas, should install solar power to supply electricity to individuals or communities. It will be more economical to install solar power in these areas as it will hardly cost US$2.0/Watt against fuel based power supply cost of US$2-3/Watt in addition to meeting 24% - 30% line losses and expensive fuel supply cost of Rs.10-15/Unit. Hydel power which is the cheapest source of power supply cost US$1.2 – 1.5/Watt. Adding transmission & distribution cost of network line losses and maintenance cost of network, the overall cost works out to US$2.0 to 2.5/Watt, which is quite compatible to solar photovoltaic cost of today. It is estimated that a solar P.V station will recover its cost within 8-10 years at the average generation cost of today in Pakistan.

5.3 Large Plant Applications

There are also large plant based on solar cell technology in the World. Since 1997, PV development has accelerated due to high increase in prices of oil & gas, global warning concerns. Photovoltaic production growth has average of 40% per year since 2000 and installed capacity reached to 39.8GW by end of 2010. Following is the list of largest photovoltaic power plants under construction & commissioned in the World.

List of Large Under Construction Projects

Sr #	Project	Country	DC Power (MW)	Status
1.	Desert Sunlight Project	California USA	550	Under Construction
2.	Topaz Solar Farm	California USA	550	Under Construction
3.	Blythe Solar Power Project	California USA	550	Under Construction
4	California Valley Solar Ranch	California USA	250	Under Construction
5.	Antelope Valley Solar Ranch	Antelope Valley USA	230	Under Construction
6.	Gujrat Solar Park	Patan District, India	210	April, 2012

List of Large Completed Projects

Sr #	Project	Country	DC Power (MW)	Completion Date
1.	Golmud Solar Park	China	200	2011
2.	Sarnia Photovoltaic Power Plant	Canada	97	2009–2010
3.	Montalto di Castro Photovoltaic Power Station	Italy	84.2	2009–2010
4.	Finsterwalde Solar Park	Germany	80.7	2009-2010
5.	Okhotnykovo Solar Park	Ukraine	80	2011
6.	Solarpark Senftenberg	Germany	78	2011
7.	Lieberose Photovoltaic Park	Germany	71.8	October 2009
8.	Rovigo Photovoltaic Power Plant	Italy	70	November 2010
9.	Olmedilla Photovoltaic Park	Spain	60	September 2008
10.	Strasskirchen Solar Park	Germany	54	December 2009
11.	Puertollano Photovoltaic Park	Spain	50	2008

6 SOLAR THERMAL ENERGY

i. Solar thermal energy (STE) is a technology for harnessing solar energy for thermal energy(heat). Solar thermal collectors are classified by the United States Energy Information Administration as low-, medium-, or high-temperature collectors. Low-temperature collectors are flat plates generally used to heat swimming pools. Medium-temperature collectors are also usually flat plates but are used for heating water or air for residential and commercial use. High-temperature collectors concentrate sunlight using mirrors or lenses and are generally used for electric power production.

ii. Concentrating Solar Power (CSP) systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. The concentrated heat is then used as a heat source for a conventional power plant. A wide range of concentrating technologies exists; the most developed are the parabolic trough, the solar power tower. Various techniques are used to track the Sun and focus light. In all of these systems a working fluid is heated by the concentrated sunlight, and is then used for power generation or energy storage.

iii. Where temperatures below about 95 °C are sufficient, as for space heating, flat-plate collectors of the nonconcentrating type are generally used. Because of the relatively high heat losses through the glazing, flat plate collectors will not reach temperatures much above 200 °C even when the heat transfer fluid is stagnant. Such temperatures are too low for efficient conversion to electricity.

iv. The efficiency of heat engines increases with the temperature of the heat source. To achieve this in solar thermal energy plants, solar radiation is concentrated by mirrors or lenses to obtain higher temperatures – a technique called Concentrated Solar Power (CSP). The practical effect of high efficiencies is to reduce the plant's collector size and total land use per unit power generated, reducing the environmental impacts of a power plant as well as its expense. Up to 600 °C, steam turbines, standard technology, have an efficiency up to 41%. Above 600 °C, gas turbines can be more efficient.

The most popular Solar Thermal Plant are parabolic through Solar System and Tower Solar Plants commonly known as “heliostat”.

6.1 Parabolic Trough Designs

Parabolic trough power plants use a curved, mirrored trough which reflects the direct solar radiation onto a glass tube containing a fluid (also called a receiver, absorber or collector) running the length of the trough, positioned at the focal point of the reflectors. The trough is parabolic along one axis and linear in the orthogonal axis. For change of the daily position of the sun perpendicular to the receiver, the trough tilts east to west so that the direct radiation remains focused on the receiver.

Full-scale parabolic trough systems consist of many such troughs laid out in parallel over a large area of land. Since 1985 a solar thermal system using this principle has been in full operation in California in the United States. It is called the SEGS system. Other CSP designs lack this kind of long experience and therefore it can currently be said that the parabolic trough design is the most thoroughly proven CSP technology.

6.2 Power Tower Designs

Power towers (also known as 'central tower' power plants or 'heliostat' power plants) capture and focus the sun's thermal energy with thousands of tracking mirrors (called heliostats) in roughly a two square mile field. A tower resides in the center of the heliostat field. The heliostats focus concentrated sunlight on a receiver which sits on top of the tower. Within the receiver the concentrated sunlight heats molten salt to over 1,000 °F (538 °C). The heated molten salt then flows into a thermal storage tank where it is stored, maintaining 98% thermal efficiency, and eventually pumped to a steam generator. The steam drives a standard turbine to generate electricity. This process, also known as the "Rankine cycle" is similar to a standard coal-fired power plant, except it is fueled by clean and free solar energy.

The advantage of this design above the parabolic trough design is the higher temperature. Thermal energy at higher temperatures can be converted to electricity more efficiently and can be more cheaply stored for later use. Furthermore, there is less need to flatten the ground area.

In principle a power tower can be built on a hillside. Mirrors can be flat and plumbing is concentrated in the tower.

6.3 Storage of Energy

Solar energy is not available at night, making energy storage an important issue in order to provide the continuous availability of energy. Research is going on to develop new techniques to store energy.

6.3.1 Molten Salt Storage

A variety of fluids have been tested to transport the sun's heat, including water, air, oil, and sodium, but molten salt was selected as best. Molten salt is used in solar power tower systems because it is liquid at atmospheric pressure, it provides an efficient, low-cost medium in which to store thermal energy, its operating temperatures are compatible with today's high-pressure and high-temperature steam turbines, and it is non-flammable and non-toxic.

The uniqueness of this solar system is in de-coupling the collection of solar energy from producing power, electricity can be generated in periods of inclement weather or even at night using the stored thermal energy in the hot salt tank. Normally tanks are well insulated and can store thermal energy for up to a week. As an example of their size, tanks that provide enough thermal storage to power a 100-megawatt turbine for four hours would be about 9 m (30 ft) tall and 24 m (80 ft) in diameter.

The Andasol power plant of 150MW in Spain is the first commercial solar thermal power plant to utilize molten salt for heat storage and night time generation. It came online on March 2009.

Heat Transfer

Molten salt coolants are used to transfer heat from the reflectors to heat storage vaults. The heat from the salts are transferred to a secondary heat transfer fluid via a heat exchanger and then to the storage media, or alternatively, the salts can be used to directly heat graphite. The graphite is located on top of the tower. Heat from the heliostats goes directly to the storage. Heat for energy production is drawn from the graphite. This simplifies the design. Graphite is used as it has relatively low costs and compatibility with liquid fluoride salts. The high mass and volumetric heat capacity of graphite provide an efficient storage medium.

Cost

A cost/performance comparison between power tower and parabolic trough concentrators is estimated that electricity could be produced from power towers for 5.47 ₡/kWh and for 6.21 ₡/kWh from parabolic troughs. The capacity factor for power towers was estimated to be 72.9% and 56.2% for parabolic troughs. There is some hope that the development of cheap, durable, mass producible heliostat power plant components could bring this cost down.

6.3.2 Requirement of Water

A design which requires water for condensation or cooling may conflict with location of solar thermal plants in desert areas with good solar radiation but limited water resources. A good suitable location for CSP Plants is where sufficient heat radiation and plenty of good quality water is available.

6.4 Application in the World

Commercial concentrating solar thermal power (CSP) plants were first developed in the 1980s. The 354 MW SEGS CSP installation is the largest solar power plant in the world, located in the Mojave Desert of California. Other large CSP plants include the Solnova Solar Power Station (150 MW), the Andasol solar power station (150 MW), and Extresol Solar Power Station (100 MW), all in Spain. The 370 MW Ivanpah Solar Power Facility, located in California's Mojave Desert, is the world's largest solar thermal power plant project currently under construction. 553MW new capacity is proposed in Solar Park, California.

Morocco is building five solar thermal power plants. The sites will produce about 2000 MW by 2012. Over ten thousand hectors of land will be needed to sustain all of the sites.

In July 2011, Iran inaugurated Iran's biggest solar power plant in Mashhad which produces 72,000 kilowatt-hour electricity per year. Following are the few CSP plants installed:

Capacity (MW)	Name	Country	Location	Notes
354	Solar Energy Generating Systems	USA	Mojave Desert California	Collection of 9 units
150	Solnova Solar Power Station	Spain	Seville	Completed 2010
150	Andasol solar power station	Spain	Granada	Completed 2011, with 7.5h thermal energy storage
100	Extresol Solar Power Station	Spain	Torre de Miguel Sesmero (Badajoz)	Completed December 2010
75	Martin Next Generation Solar Energy Center	USA	Florida	steam input into a combined cycle
64	Nevada Solar One	USA	Boulder City, Nevada	

DATA OF TYPICAL SILICON NITRIDE MONOCRYSTALLINE SILICON PANELS

These Panels are normally manufactured in the range of 75Watt to 250Watt but herein performance characteristics of three models are given:

Performance			
Rated Power (P_{max})	135W	160W	170W
Power Tolerance	$\pm$3%	$\pm$3%	$\pm$3%
Nominal Voltage	12V	24V	24V
Warranty	25 Years	25 Years	25 Years
Qualification Test parameters			
Temperature Cycling Range	-40^{0}C to +80^{0}C		
Damp Heat Test	85^{0}C, 85% relative humidity		
Front and Rear Static Load Test (eg: Wind)	2,400 Pa (50psf)		
Front Load Test (eg: Snow)	5,400 Pa (113psf)		
Hailstone Impact Test	25mm □(1 inch) at 23m/s (52mph)		
Typical Electrical Characteristics			
Rated Power (P_{max})	135W	160W	170W
Voltage at P_{max} (V_{mp})	17.4V	35.1V	35.6W
Current at P_{max} (I_{mp})	7.8A	4.6A	4.8A
Open Circuit Voltage (V_{DC})	22.1V	44.2V	44.3V
Mechanical Characteristics			
Dimensions (L x W x D) mm	1510x674x50	1593x790x50	1593x790x50
Weight	12 kg	15 kg	15 kg
Cells	36	72	72