CHAPTER

5

SOLAR ENERGY APPLICATIONS: THE FUTURE (WITH COMPARISONS)

Luis A. Bon Rocafort and W.J. O'Donnell

5.1 HISTORY

5.1.1 Awakening

Solar energy can trace its roots to the early 19th century, when in 1838 French physicist Edmund Becquerel [1],[2] published his findings about the nature of materials being able to turn light into energy. He discovered the photovoltaic effect while experimenting with an electrolytic cell made up of two metal electrodes. Becquerel found that certain materials would produce small amounts of electric current when exposed to light. At the time this was an interesting discovery that was not appreciated.

Twenty years passed before Auguste Mouchout [1], a French mathematics teacher, designed and patented the first machine that generated electricity using the sun. Mouchout began his work with solar energy in 1860. He produced steam by heating water using a glass-enclosed, water-filled iron cauldron. Mouchout then added a reflector to concentrate additional radiation onto the cauldron, thus increasing the steam output. He succeeded in using his apparatus to operate a small steam engine.

At the 1878 Paris Exhibition, he demonstrated a solar generator that powered a steam engine, similar to the one shown in Figure 5.1. This engine included a mirror and a boiler that drove an ice-maker that produced a block of ice. Later in 1869, Mouchot wrote one of the first books devoted to solar energy: "Le Chaleur Solaire et les Applications Industrielles." Mouchout's work help lay the foundation for our current understanding of the conversion of solar radiation into mechanical power driven by steam.

The next promising discovery concerning solar technology came from an Englishman who while developing a method for continually testing an underwater telegram cable used selenium and noted that the conductivity of the selenium rods decreased significantly when exposed to strong light. Willoughby Smith [2], an electrical engineer, discovered the photoconductivity of selenium, which led to the invention of photoelectric cells.

Shortly after, William Adams [5], [6] wrote the first book about Solar Energy called: "A Substitute for Fuel in Tropical Countries." With the use of mirrors, Adams and his team were able to power a 2.5 horsepowered steam engine, bigger than Mouchout's 0.5 horsepowered steam engine. His design, known as the Power Tower concept is shown below in Figure 5.2 in a more current setting.

Charles Fritts [2] created the first working solar cell in 1883 turning the sun's rays into electricity. Fritts coated the semiconductor material selenium with a thin layer of gold. The resulting cells had a conversion efficiency of about 1% due to the properties of selenium, which in combination with the material's cost precluded the use of such cells for energy supply.

The first solar energy system for heating household water on rooftop was developed by Charles Tellier [2] in the late 1880's. This concept is shown in Figure 5.3. He used a non-concentrating solar motor for refrigeration much like a solar heat pump. The solar water heater that is employed today largely in warm climates originated in the late 19th century. Further advancements in solar refrigeration at that time were halted, Tellier's efforts concentrated on refrigeration while transporting across the oceans.

At the turn of the 20th century, in 1904, Henry Willsie recognized one of the fundamental limitations of solar power generation as being the inability to generate power without sunlight. He developed a concept to store generated power and use it at night. His method consisted keeping the water warm at night by storing it in an insulated basin. Tubes were then inserted into the heated water, and sulfur dioxide flowed through the tubes, transforming it into a high-pressure vapor, which operated an engine. Two small power plants were built using this method.

The next big advancement for solar energy came at the hands of Calvin Fuller, Gerald Pearson and Daryl Chaplin [2] of Bell Laboratories who accidentally discovered the use of silicon as a semi-conductor, which led to the construction of a solar panel with an efficiency rate of 6% in 1954. The first practical means of collecting energy from the sun and turning it into a current of electricity was at hand. The invention of the solar battery resulted in a major improvement in the ability to harness the sun's power into electricity.

In 1958, Vanguard I [8] was launched; it was the first satellite that used solar energy to generate electricity. Photovoltaic silicon solar cells provided the electrical power to the 6.4-inch, 3.5-pound satellite, demonstrating the potential for solar energy to generate reliable power. An illustration showing the solar cells used in the satellite is shown in Figure 5.4.

Throughout history discoveries of little consequence have a way of becoming more as time passes on. Solar energy has been on a quest for a long time, to demonstrate to us as a society the potential there is in harnessing the sun's rays for power, and ultimately for our survival. Solar energy has to become part of our solution in the grand scheme of our energy supply make up.

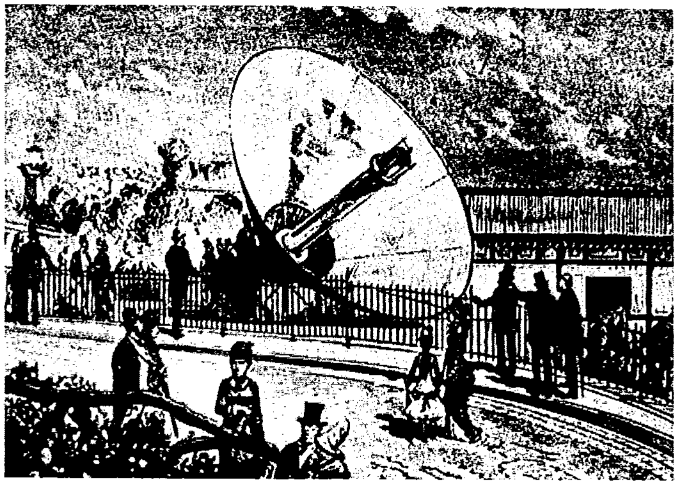

FIG. 5.1 SOLAR STEAM ENGINE [4]

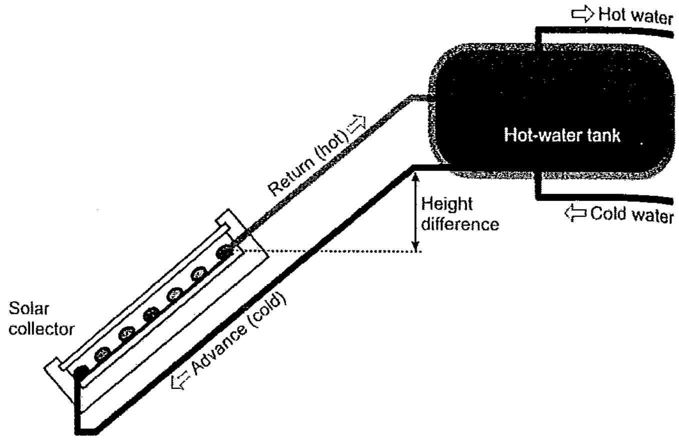

FIG. 5.3 ROOFTOP HOUSEHOLD WATER HEATER [7]

5.1.2 Revival

Every time a shortage of fuels is encountered, be it raw materials, processing capacity shortage, or transportation interruptions, a push for renewable energy sources and technologies emerge until the short term problem is solved. This cycle is not new, and will continue until permanent solutions are found. It seems that every time the cycle emerges, the duration of the push for new technology is prolonged. In the future, this cycle will be long enough to achieve a satisfactory solution that does not involve finite fuel resources.

The cost of producing energy using solar radiation has come down significantly over the last century, but the biggest hurdle, the availability of sunlight will always limit solar energy technology until an adequate advancement in energy storing technologies is found. Improving efficiencies in production, transmission and delivery systems, along with improvements on appliances and electrical equipment will help reduce our power needs. Using an improved infrastructure will help increase the efficiency and reliability of the power grid. Some reexamination of the traditional concepts concerning power generation and delivery must be revised in order to take advantage of the non-traditional methods of power generation (solar, wind, wave, etc.). Local on-site generation and storage must be a part of any plan that will succeed in the future. Better use of energy by appliances and other equipment must be implemented to reduce energy losses due to inefficiencies. Site specific power generation plans that take advantage of the local strengths available must be considered and a system designed that can help lower the load on the national grid system.

Solar electric systems are now used to power many homes, businesses, holiday cottages, even villages in Africa. Solar cells can be used to power anything from household appliances to cars and satellites. Solar technology is becoming increasingly cost-effective as more distributors enter the market and new technologies continue to offer more choices and new products. Technologies that can be used to advance solar energy into the future are discussed in the next section.

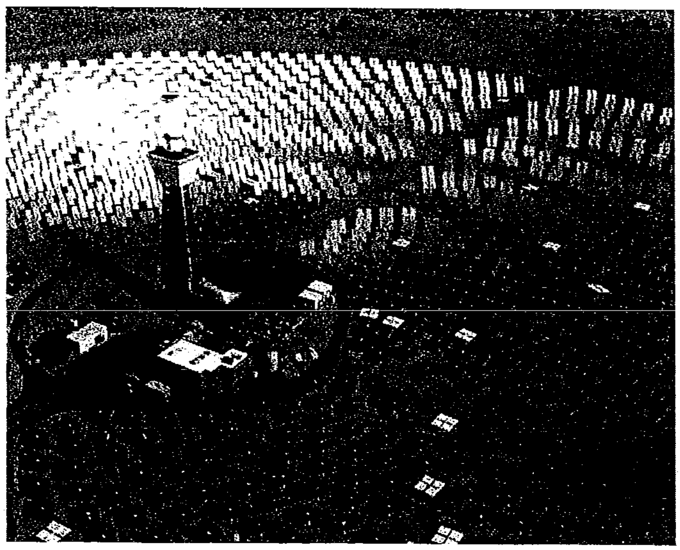

FIG. 5.2 POWER TOWER (Courtesy of DOE/NREL, Credit — Sandia National Labs)

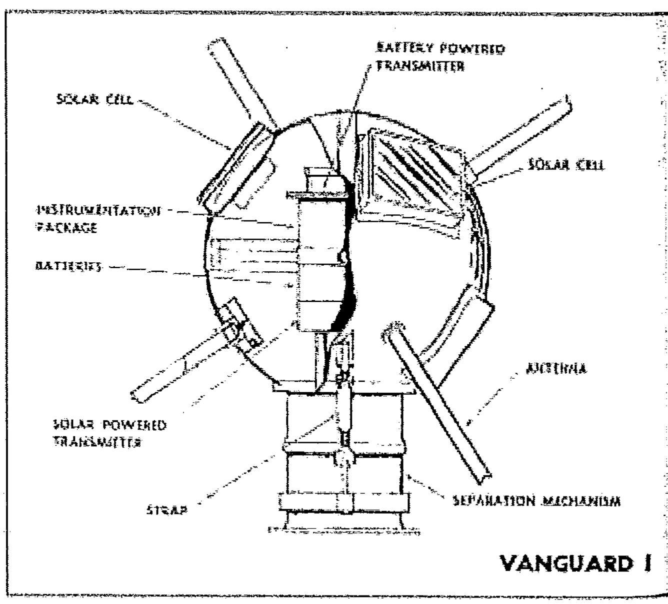

FIG. 5.4 VANGUARD I SATELLITE ILLUSTRATION

5.2 CURRENT TECHNOLOGIES

Solar technology can be divided into two categories; passive, and active. Passive technologies tend to rely on scientific concepts and phenomena to convert solar irradiation to power, while active technologies use mechanical systems to augment the power production. This enhancement can come at a cost to the efficiency of the system. Passive technologies use the sun's rays and scientific concepts of thermal heat and mass transfer to either cool or heat mediums like air or water. While the goal of active technologies is to produce measurable power, which can then be transmitted, used on demand, or stored in a battery for use when power can not be generated.

5.2.1 Passive

Passive solar energy technology uses sunlight to generate energy without the aid of a mechanical system. The main goal behind these types of technology is to convert sunlight or solar radiation into usable heat (water, air, thermal mass), causing thermally induced ventilation, or stored for future use. Passive solar technologies include direct and indirect solar gain for space heating, solar water heating systems based on the natural convection, use of thermal mass and phase-change materials for slowing indoor air temperature swings, solar cookers, the solar chimney for enhancing natural ventilation, and earth sheltering. Passive solar technologies also include the solar furnace and solar forge, but these typically require some external energy to power auxiliary systems that help align their concentrating mirrors or receivers, which has shown over time to be impractical and not cost effective for wide-spread use. Energy used for space and water heating, however, have demonstrated to be a good use of passive use solar energy.

5.2.1.1 Thermosiphon This method of passive heat exchange is based on natural convection. Natural convection causes the circulation of the fluid within a loop when the fluid is heated, which causes it to expand and become less dense. The denser fluid, the cool water, moves to the bottom of the loop, while the less dense fluid, the hot water, will rise to the top of the loop. Convection moves heated liquid in the system as it is replaced by cooler liquid returning by gravity. This type of system could be used in moderate temperature regions to pre heat incoming cold water for an instant water heater. This would reduce the electrical demand on the instant water heater and increase the overall efficiency of the system. A similar system is shown in Figure 5.3.

5.2.1.2 Thermal Collectors Solar collectors can be non-concentrating and concentrating. In non-concentrating collectors, the collector area is the same as the absorber area. In these types the whole solar panel absorbs the solar energy. Flat plate and evacuated tube solar collectors are two types of non-concentrating solar collectors that are used to collect heat for space heating or domestic hot water. Flat plate collectors consist of a dark flat-plate absorber, a transparent cover that allows solar energy to pass through but reduces heat losses, a heat-transport fluid (air, anti-freeze, or water) flowing through tubes to remove heat from the absorber, and an insulating backing. Fluid is circulated through the tubing to transfer heat from the absorber to an insulated water tank. This may be achieved directly or through a heat exchanger.

Evacuated tube collectors consist of evacuated glass tubes which heat up a fluid in order to heat water, or to provide space heating. The tubes are evacuated, that is under vacuum, such that convection and conduction heat losses are reduced. This allows them to heat up to temperatures that surpass those of flat plate collectors. Tube collectors have an advantage over flat-plate collectors with regards to the shape of the tube; since it is cylindrical the collector surface will always be perpendicular to the sun.

5.2.1.3 Thermal Mass A thermal mass is a solid or liquid body that has the capacity store heat during the day and then releases the heat slowly when the heat source is removed. The use of thermal mass has become popular in the world of building design as an alternative to passively heating an interior space. Using a thermal mass will prevent extreme temperature fluctuations during the day by serving as a thermal inertia, in other words, softens the temperature fluctuation experienced, by absorbing heat during the day, and slowly releasing this heat at cooler temperatures of the night, effectively heating the space. A thermal mass will absorb heat from the surroundings, as long as the surrounding temperature is hotter than the mass, once the temperature around the mass gets cooler, the thermal mass releases the stored heat to the surroundings. This phenomenon is illustrated below in Figure 5.5.

The use of thermal mass in building design, construction, and rehabilitation has increased due to renewed interest in green construction. Thermal masses can reduce the load on heating and cooling systems, while increasing individual comfort.

Leadership in Energy and Environmental Design (LEED [10]) is a rating system for buildings that use criteria such as energy savings, water management, among others to score how sustainable a building is. The LEED rating systems was created by the U.S. Green Building Council (USGBC), and are internationally accepted benchmarks for design, construction, and operation of high performance green buildings.

5.2.1.4 Solar Cooker A solar cooker is a cooking apparatus that uses sunlight to cook food. Solar cookers by nature require sunlight to perform and are usually reserved for outdoor use, but with careful planning and design could be adapted to be used indoors, concept shown in Figure 5.6.

Use of optics and appropriate materials can ensure every home in the future can prepare meals using this form of passive solar

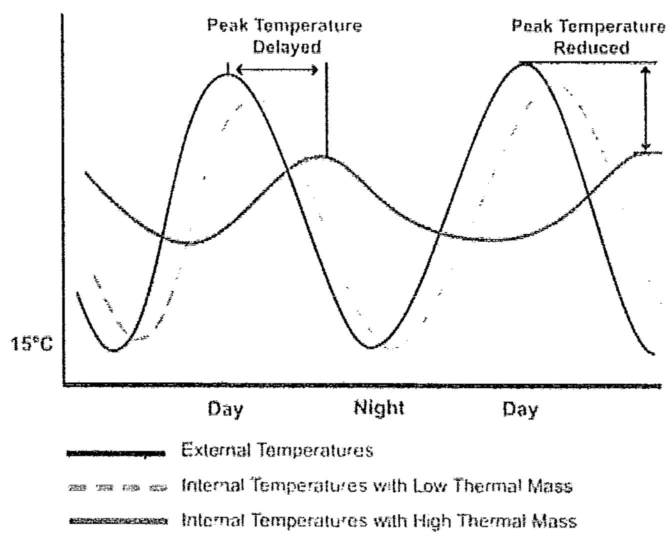

FIG. 5.5 THERMAL MASS TEMPERATURE FLUCTUATION [9]

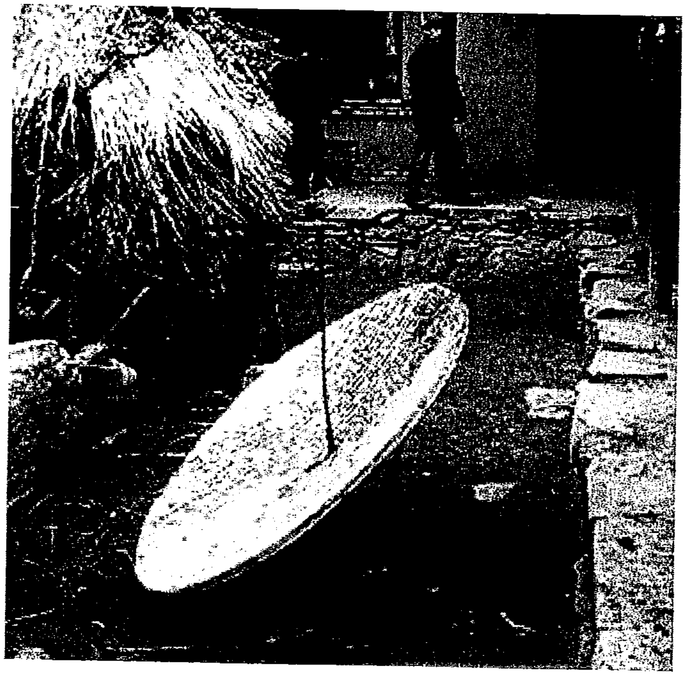

FIG. 5.6 **INDOOR SOLAR COOKER DESIGN** (Courtesy DOE/NREL, Credit — Tsuo, Simon)

technology whenever possible, reducing the demand on the electrical grid as well as on natural gas.

In order for a solar cooker to perform satisfactorily, they must use some form of concentrated sunlight, by way of mirrors or reflective metals, to direct the energy used to the cooking area. They must also convert sunlight to usable heat. A solar cooker must also be thermally insulated, that is once the heat is trapped inside the cooker, and it should be insulated so that the heat does not escape.

Solar cookers can reach temperatures of 300°F. Although this is significantly less than what can be achieved with your stovetop, or conventional oven, it will still cook food. The catch is that it takes longer to cook the food. Improvements in concentrating materials and amplification of the suns rays could reduce the amount of time required to cook the food using a solar cooker. Another limitation is that the cooker must be used around the times when the sun is highest in sky to take full advantage of the solar power.

The cooker can be used to warm food and drinks and can also be used to pasteurize water or milk. Unlike cooking on a stove or over a fire, which may require more than an hour of constant supervision, food in a solar cooker is generally not stirred or turned over, both because it is unnecessary and because opening the solar cooker allows the trapped heat to escape thereby slowing the cooking process. Air temperature, wind, and latitude also affect cooking efficiency. Careful planning must be used when using a solar cooker to ensure the food is prepared properly as to take advantage of the cooking method.

5.2.1.5 Solar Chimney Using passive solar energy, improvements can be made to the natural ventilation of buildings through the use of convection heat transfer concepts. A solar chimney uses solar energy to accomplish this. The solar chimney is not a new concept, it is not even recent, and it has been implemented in the past by Persians and Romans.

A solar chimney works by absorbing solar energy during the day and heating the chimney and the air in it. This heated air wants to move to higher elevations creating an updraft through the chimney (similar to a thermosiphon). The movement of the air in the chimney can be used to suck in air at the base of the chimney, which would cause air drafts along the building to which the chimney is attached. This can be used to circulate cooler air inside the building, as shown in Figure 5.7. Although this system is not ideal in every location or climate, its concept can be applied on most new construction to improve natural ventilation using simple heat convection concepts.

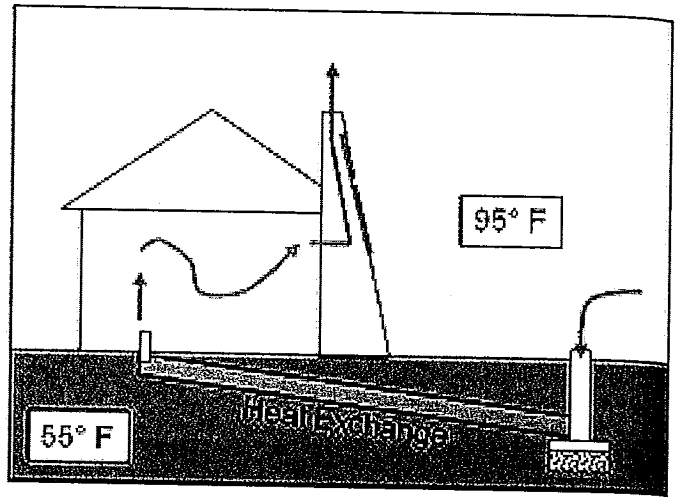

FIG. 5.7 **SOLAR CHIMNEY [11]**

A solar chimney can also be used in colder climates to circulate hot air inside the building by reversing the flows into the structure, or even devising a closed loop system that will help reduce the load on your heating appliance. In hotter climates combining the solar chimney technology with water can increase the cooling effect by using evaporation cooling.

5.2.1.6 Solar Furnace A solar furnace is a structure used to harness the rays of the sun in order to produce high temperatures, usually for industrial applications. This is achieved using a parabolic reflector, concentrating direct sun light, also known as direct insolation, onto a focal point. The solar furnace consists of an array of plane mirrors which in turn reflects sun light onto a large curved mirror. After the rays bounce off both set of mirrors they are then focused onto a small area that can reach more than 6,000°F, useful for some industrial processes. The solar furnace at Odeillo in the Pyrenees-Orientales in France is shown in Figure 5.8.

5.2.2 Active

Active solar technologies are used to convert solar energy into light, heat, ventilation, cooling, or to store heat for future use. This type of solar energy generation uses electrical or mechanical equipment, i.e., pumps and fans, to increase system efficiencies. Solar hot water systems that use pumps or fans to circulate a working thermal fluid through solar collectors are one type of active solar technology. Another type of active solar technology used to convert sunlight to electric power is by use of photovoltaic, or with concentrating solar power. The latter focuses the sunlight to boil water which is then used to provide power. Another concept that uses concentrating solar power is the Stirling engine dishes which use a Stirling cycle engine to power a generator.