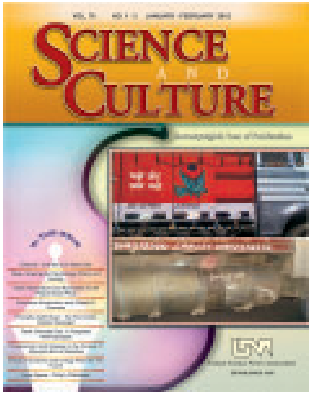
SCIENCE AND CULTURE

VOLUME 78 ❑ JANUARY-FEBRUARY 2012 ❑ NOS. 1–2

EDITORIAL

UNTIL THE SUN GETS COLD



The editorial published in the May-June 2011 issue of *Science and Culture* has generated sufficient interest amongst readers of the journal and I have received several phone calls requesting me to publish the current status and the roadmap of solar energy applications. Nature has provided us with solar radiation that is available freely and in abundance from time immemorial. It is also known that the sun is at the root of almost all energy that we consume. Auguste Mouchout, a French school teacher with remarkable foresight, realized in the mid-nineteenth century that coal (which fuelled the Industrial Revolution) would soon run out and one needed to plan ahead for alternate energy sources. He looked to the sun, and was inspired to make the first demonstrable design and patent of a steam engine operated by solar power. His research was initially supported by the monarch but could not be pursued as a long term project as coal was cheap and available in abundance at the time, and people did not dream of its present-day scarcity. The time is now ripe to explore all avenues to use the sun until it gets cold.

Serious attempts to harvest solar energy as a major source of power are relatively recent phenomena. Depleting fossil fuel, oil crisis and global environmental compulsions have alerted the whole world that current trends in energy supply and use are unsustainable—economically, environmentally and socially. In order to meet the greenhouse gas emission target we need an 'energy revolution' to develop efficient energy production on all fronts, to explore all types of renewable energy sources, to invent newer transport technologies, etc. This editorial deals primarily with the emerging technology of using solar radiation known as concentrated solar power (CSP) or concentrated solar thermal (CST) technology which holds much promise for a country like India that has plenty of sunshine and clear sky.

Sunlight reaches the earth's surface both directly and indirectly through numerous reflections and deviations. The amount of energy reaching the earth's surface perpendicularly at a distance of one astronomical unit (mean distance between the sun and the earth), known as solar constant, is about 1.4 kilowatts per square metre. The power received on one square metre surface area of the roof of a building is approximately equivalent to the energy required to run two refrigerators in a house. CSP, as the name suggests, concentrates the solar radiation on a small area using mirrors or lenses to heat a material to high temperature. This heat is first transformed into mechanical energy (by running turbines or other engines) and then to produce electricity. It is envisaged that CSP could provide about 10% of global electricity by 2050.

Unlike energies produced by solar photovoltaic (PV) technologies that use sunlight to produce electricity, CSP uses the heat of solar radiation and therefore has an inherent capacity to store heat energy which can be later used to produce electricity. CSP can therefore supply electricity to the grid when needed, including at a time after sunset or during the evening peak demand. All these features make the CSP a promising technology to help integrate large amounts of reliable renewable resources on grid, especially when compared to other sources such as photovoltaic or wind power. However, CSP plants would also need to be equipped with backup power systems for eventualities when CSP fails to provide power.

CSP is a proven technology. The first commercial plant started operating in California supported by federal and state tax incentives and mandatory long-term power purchase contracts during the period 1984 to 1991. After a brief hiatus, driven by the fall in fossil fuel prices, the technology has re-emerged in recent times as one of the major initiatives in more than a dozen countries including India. As of early 2010, the global stock of CSP plants was about 1 GW capacity which is expected to generate around 15 GW.

Sunlight varies from place to place due to variations in the composition of atmosphere and weather. Good direct normal incidence (DNI) is usually available in arid and semi-arid areas with reasonably clear skies, which typically lie at latitudes between 15^o and 40^o north or south. DNI is significantly better at higher altitudes because of low absorption and scattering of sunlight. The atmosphere is usually cloudy closer to the equator and at higher latitudes. As a result, most favourable areas for CSP are in North Africa, South Africa, the Middle East, north-western India, south-western United States, Mexico, Peru, Chile, western China and Australia. Other areas suitable for CSP are extreme south of Europe, Turkey, other southern locations of US, central Asian countries, places in Brazil and Argentina and other parts of China.

One of the major constraints in setting up CSP plants is the availability of land. A conservative estimate suggests that CSP plants require around 2 hectares per MW (1 hectare =10,000 sq. m.), depending on DNI and technology. It is estimated that CSP at south-western American states could produce more electricity than that is required in the entire United States; the Middle East and North Africa could produce about 100 times the current consumption of electricity in the Middle East, North Africa and European Union combined. Since most places in India receive more than 4 kWh/m^2/day, given an approximately 300 sunny days in a year, theoretical power potential for India is 5 trillion kWh/year, which is 10 times India's present energy consumption. However, CSP plants are not viable below a threshold of about 1,900 kWh/m^2/year, and other technologies such as photovoltaic (PV) are preferable. This means any place with DNI more than 6 kWh/m^2/day is suitable for CSP plant—the northwest of India is recognised as the best site for CSP.

> *One of the major constraints in setting up CSP plants is the availability of land. However, with our recent experiences in acquiring land for Tata Motors in Singur, Posco in Orissa and many other places, any land intensive project has lots of uncertainties. Even with the current proposal of purchasing land by the firm at market price instead of acquisition will also make the project costlier.*

The above is a theoretical estimate, but the biggest CSP project in the USA teaches us that the land requirement is about 6 to 10 acres per MW of electricity. According to this estimate, a small plant of 100 MW requires at least about 600 acres (2.4 km^2) of land. Some large projects have been proposed by the government under the Jawaharlal Nehru National Solar Mission and 35,000 km^2 area has been earmarked for CSP plant in the Kutch and Rajasthan desert which, according to this estimate, is sufficient to produce 1500 GW of electricity. However, with our recent experiences in acquiring land for Tata Motors in Singur, Posco in Orissa and many other places, any land intensive project has lots of uncertainties. Even with the current proposal of purchasing land by the firm at market price instead of acquisition will also make the project costlier.

Arid and semi-arid areas are suitable for CSP production because the availability of sunlight matches well with the peak electricity demand in daytime due to the use of air conditioners. All CSP plants have some ability to store heat energy which has been used to produce electricity in case of short-term variations of available sunlight due to clouds. During periods of maximum sunlight, the amount of heat generated in a solar field is more than what a turbine can utilize and therefore a CSP plant without storage needs to defocus some of the sunrays by adjusting solar collectors. In order to avoid this loss of energy as well as to supply electricity after sunset, CSP plants are equipped with thermal storage system. The idea of thermal storage systems is to store excess heat during the day in a storage material (usually molten salts) and use this stored heat after sunset to run the plant to produce electricity.

CSP plants with or without storage require fuel-powered backup systems to guarantee the smooth supply of electricity round the clock. Fuel burners using fossil fuel, natural gas, biogas, etc. also boost the conversion efficiency of solar heat to electricity by raising the working temperature level. The CSP plants built in California between 1984 and 1991 used natural gas to obtain year-round production of electricity. Typically the plant uses direct sunlight to produce electricity as well as to store heat, say, from about 7:00 am until sunset and then tap the energy from the storage system to produce electricity till midnight and then use the fuel backup system from midnight until the following morning (7:00 am). The amount of energy from fuel burners is thus about 15-20% of the primary energy.

Similar to thermal power generation plants, CSP also requires water for cooling and condensation processes. The water requirement in CSP plants is about 1.5 times more than that of a coal-operated thermal power plant of the same capacity. A typical estimate of water requirement for a CSP plant is about 3,000 litres/MWh. Accessing large quantities of water in arid and semi-arid areas is a challenge. From this point of view, Kutch (rather than the Rajasthan desert) would be a good choice to set up a CSP plant because of its access to sea water.

Just as people in different regions of the country consume different types of food (rice in the east and the south, wheat in the north and jowar in Rajasthan) resulting from the variation in capability of producing these grains (rice needs more water while jowar can be produced in arid areas), one has to similarly assess the availability of resources, need, cost-effectiveness and other associated parameters to decide on the appropriate technology suitable for a particular locality. It is time not to imitate but to explore all possible options with equal emphasis and understand their efficiency and limitations to arrive at the best suitable method of power production.

According to the Indian Renewable Energy Status Report published in October 2010, the cost of energy production per unit (kWh) from coal plant is the lowest (Rs. 1-2 when indigenous coal is used) and that from the photovoltaic is the highest (Rs. 12-20). The estimated cost of energy production in CSP plants is between Rs. 10 to 15 per kWh. Currently, wind, small hydro, and biomass are the most cost-competitive renewable options. Solar technologies, including CSP and PV, are the least competitive but offer the greatest opportunity for growth because of their high potential among all renewable energy sources.

India has abundant untapped renewable energy resources, including a large land mass that receives high solar radiation, a long coastline and high wind velocities that provide ample opportunities for both land-based and offshore wind farms. It is also blessed with significant production of biomass, and has numerous rivers and waterways that have potential for hydropower. In India about 64% of energy comes from fossil fuel powered plants (coal, gas and diesel), 23% from hydro power, 3% from nuclear power and approximately 10% of India's total installed electric generating capacity comes from renewable energy source. Of renewable energy projects, India's position in wind power generation is commendable being the fifth largest installation on wind capacity globally, only behind the United States, China, Germany, and Spain. India's current wind capacity totals 12,000 MW representing 70% of India's total renewable energy capacity. Based on an estimate that 1% land area of the potential nine states will be available and that each megawatt of wind capacity requires 12 hectares of land, India's total wind potential works out to be 48,561 MW. More systematic assessment of wind power capacity is needed. It is to be noted that the efficiency of India's existing wind plants is lower than that of many other countries leading in wind power, such as Germany. With improved wind power technology the estimated wind power capacity could go upto 60,000 to 70,000 MW. The cost of energy production per unit is also competitive (Rs. 3-4). India has installed 2,767 MW of small hydro plants (less than 25 MW each), 1,412 MW of grid-connected cogeneration from bagasse, and 901 MW of biomass-based power from agro residues. Waste-to-energy projects have an installed capacity of 72 MW. Cumulative installed capacity of solar PV in India has reached 15.2 MW, of which 12.3 MW is grid-tied and 2.9 MW is off-grid, which is about 1% of total renewable energy resources. With the introduction of CSP, JNNSM aims to have 500 MW of electricity by 2013 and 10,000 MW by 2022.

Although CSP is accepted as a proven technology globally, India has no CSP plants as yet (there is 351 MW approved CSP plants in Gujarat and another 30 MW in Rajasthan) and does not have any experience in this field.

With the constraints of land, water, cost, skilled manpower[1] and experience it will be prudent to enter into CSP business cautiously.

The present power-generating capacity is insufficient to meet our current demand, and in 2009–2010 India experienced a generation deficit of approximately 84 TWh ($1T=10^{12}$). India's frequent electricity shortages are estimated to have cost the Indian economy 6% of gross domestic product (GDP) during the financial year 2007–2008. With the currently targeted economic growth, it is estimated that India will need to double its installed generating capacity to over 300 GW by 2017. Given the performance record of different energy producing sectors in the last five year plan (2002-2007), the situation is not at all encouraging and there is no reason to believe that India will meet its target in the 11th or subsequent Five Year Plans. Nuclear power achieved 90% of the target, while thermal and hydro power generation met about 50%. In order to meet the projected power needs of the future, India should concentrate on full utilization of all existing and proven technologies, including nuclear, till CSP and other minimal carbon-dioxide emitting technologies start producing electricity to meet our demands of the future.

With 78 million Indian households (more than 44%) and 1,25,000 villages without electricity, India's goal should not be restricted to central grid and large-scale generating facilities for industrial growth but also to provide electricity to 400 million citizens without electricity. Emphasis should be placed on off-grid renewable energy obtained from all possible sources (PV, biomass, solar heater, etc.) as a practical cost- effective method of providing electricity catering to smaller blocks of remote villages where expansion of the grid system will require substantial investment of time and money. Just as people in different regions of the country consume different types of food (rice in the east and the south, wheat in the north and jowar in Rajasthan) resulting from the variation in capability of producing these grains (rice needs more water while jowar can be produced in arid areas), one has to similarly assess the availability of resources, need, cost-effectiveness and other associated parameters to decide on the appropriate technology suitable for a particular locality. It is time not to imitate but to explore all possible options with equal emphasis and understand their efficiency and limitations to arrive at the best suitable method of power production. ❒

S.C. Roy

[1] I have noted, after writing of this editorial, in the recent issue of Times of India that a research institute solely devoted to solar research has been established in West Bengal to produce skilled manpower.