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REVIEW ON SOLAR FUELS

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ABSTRACT

The world relies on energy to power industry, move people and products, and keep us safe and comfortable. Fossil fuels, including coal, natural gas, and petroleum; provide much of the energy, we use today. However, their supply is inherently and geographically limited, and there are significant environmental impacts to the continued and increased conventional use of fossil fuels. To address social equity, global climate change, urban air pollution, energy security through diversity, and economic growth issues, new energy solutions are needed. Scientists and engineers are pursuing many pathways to clean and sustain energy systems.

Conversion of solar energy into chemical fuels is an attractive method of solar energy storage. Solar fuels, such as hydrogen, can be used for upgrading fossil fuels, burned to generate heat, further processed into electrical or mechanical work by turbines and generators or internal combustion engines, or used directly to generate electricity in fuel cells and batteries to meet energy demands whenever and wherever required by the customers. The challenge is to produce large amounts of chemical fuels directly from sunlight in robust, cost-effective ways while minimizing the adverse effects on the environment. The success of solar thermal power generation-known as 'concentrating solar power' (CSP), which use mirrors or lenses to concentrate a large area of sunlight, or solar thermal energy, onto a small area. Nevertheless, solar fuels are among the most promising technologies to curb the growing demand for fossil fuels and to mitigate the effects of climate change.

Key words: Environment, Solar fuels, Concentrated solar power (CSP).

INTRODUCTION

Sunlight is by far the most abundant energy resource on earth. However, solar energy is intermittent and does not necessarily match the variations in demand.[1] If it is to become a major contributor to our energy supply, some form of storage is necessary. Conversion of solar energy into chemical fuels is an attractive method of solar energy storage. Solar fuels, such as hydrogen, can be used for upgrading fossil fuels, burned to generate heat, further processed into electrical or mechanical work by turbines and generators or internal combustion engines, or used directly to generate electricity in fuel cells and batteries to meet energy demands whenever and wherever required by the customers. The challenge is to produce large amounts of chemical fuels directly from sunlight in robust, cost-effective ways while minimizing the adverse effects on the environment.

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The success of solar thermal power generation-known as 'concentrating solar power' (CSP) – is already moving towards sustainable, large scale fuel production: concentrating solar radiation with reflecting mirrors provides high temperature process heat for driving efficient thermochemical processes. Nevertheless, solar fuels are among the most promising technologies to curb the growing demand for fossil fuels and to mitigate the effects of climate change.

To facilitate the introduction of new solar fuels production processes, the existing know-how from both the fuel production industry and the CSP research institutes should be merged. At a later stage, the emerging solar fuel technologies will be based on processes that are completely independent of any fossil fuel resources. The main vector for this transformation will be the production of hydrogen, a potentially clean alternative to fossil fuels, especially for use in transport. Today, however, more than 90% of hydrogen is produced by using high temperature processes from fossil resources, mainly natural gas. If hydrogen is generated from solar energy, it is a completely clean technology; no hazardous wastes or climate changing byproducts are formed and only sunshine and water are required as inputs to the process.

Ministers from the G8 countries[5], China, India and South Korea, acknowledged this need in their June 2008 meeting (Aomori, Japan) and expressed their desire to have development and deployment of innovative energy technologies.

Global climate change

There is growing concern over the possibility of global climate change resulting from increased anthropogenic greenhouse gas build up in the atmosphere. Although there seems to be growing evidence of a global warming trend, the causal relationship to atmospheric greenhouse gases has not been substantiated at present. Current trends show the potential for a doubling of atmospheric greenhouse gases in the next 30 years. This is largely due to economic growth in developing countries. However, should the link between climate change and atmospheric greenhouse gases prove to be correct, the potential for catastrophic environmental impacts in the future is significant. From a risk assessment standpoint, it is clear that we need to be making significant efforts today to reduce the potential impact of greenhouse gas emissions in the future.

The United Nations Framework Convention on Climate Change (UNFCCC) seeks to stabilize atmospheric greenhouse gas concentrations at levels that would prevent dangerous anthropogenic interference with global climate. This can be achieved only through dramatically increased utilization of the so called backstop technologies, such as renewable energy technologies with low emissions of greenhouse gases.

The Global Environment Facility (GEF) is an organization set up to deal with global environmental issues including climate change. The GEF provides grants and funding to developing countries for projects and programs that protect the global environment and promote sustainable economic growth. The GEF has developed a number of operational programs to help increase utilization of these backstop technologies. These programs focus on:

- Removing barriers to energy efficiency and energy conservation;
- Promoting adoption of renewable energy by removing barriers and reducing implementation costs;
- Reducing the long-term costs of low greenhouse gas emitting energy technologies.

The GEF has identified parabolic trough technology as one of the renewable energy technologies, it supports in its operational programs. Based on the commercial success of the Solar Electric Generating Systems (SEGS), parabolic trough technology is considered the most proven concentrating solar power technology; still, it is not currently cost effective in most power markets.

Concentrating solar power technologies

In Concentrating Solar Power (CSP) technology the incoming radiation is tracked by large mirror fields, which concentrate the energy towards absorbers. They, in turn, receive the concentrated radiation and transfer it thermally to the working medium. The heated fluid operates as in conventional power stations directly (if steam or air is used as medium) or indirectly through a heat exchanging steam generator on the turbine unit which then drives the generator.

To make solar high flux, with high energetic value originating from processes occurring at the sun's surface at black-body-equivalent temperatures of approximately 5800 K usable for technical processes and commercial applications, different concentrating technologies have been developed or are currently under development for various commercial applications.[3] Such solar thermal concentrating systems will undoubtedly provide within the next decade a significant contribution to efficient and economical, renewable and clean energy supply.

Prime objectives

- Developments of solar energy systems for bulk electricity production and the conservation of fossil energy, consequently preserving the environment in particular with respect to their high potential to contribute to the reduction of the CO_2 emissions.
- To reduce the generating costs of solar power plants, and thus contribute to ensure durable and reliable energy services at affordable costs in the medium- to long-term range.
- It will provide industries with a privileged technological position, thus opening industrial growth possibilities not only to the internal market but also to the export market and services.

Principles of solar energy concentration

The conventional method for concentrating solar energy, i.e. collecting solar energy over some large area and delivering it to a smaller one, is by parabolic-shaped mirrors. A parabola focuses rays parallel to its axis into its focal point. However, sun rays are not parallel. To a good approximation they can be assumed to originate at a disk which subtends the angle θ = 0.0093 radian.[6] When a perfectly specular reflective paraboloid of focal length f and rim angle $Ø_{rim}$ is aligned to the sun, reflection of the rays at the focal plane forms a circular image centered at the focal point (shown in Fig.). It has the diameter.

$$d = \frac{f \times \theta}{\cos Ø_{rim}(1+\cos Ø_{rim})}$$

where,

d = Diameter.

θ = Angle subtended by the sun at the earth's surface.

$Ø_{rim}$ = Rim angle of a parabolic concentrator.

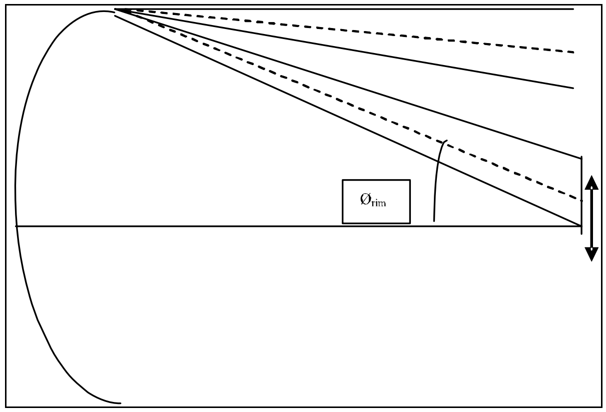


Fig. 1: Concentration of sunlight by a parabolic dish of focal length f and rim angle $Ø_{rim.}$ When the dish is aligned toward the sun, reflection of sun rays at the focal plane forms a circular image centered at the focus of diameterd

On this circle, the radiation flux intensity is maximum and uniform in the paraxial solar image (the "hot spot"). It decreases for diameters larger than f′ X θ as a result of forming elliptical images. The theoretical concentration ratio C at the hot spot is defined as the ratio of the radiation intensity on the hot spot to the normal beam insolation, and is approximately.

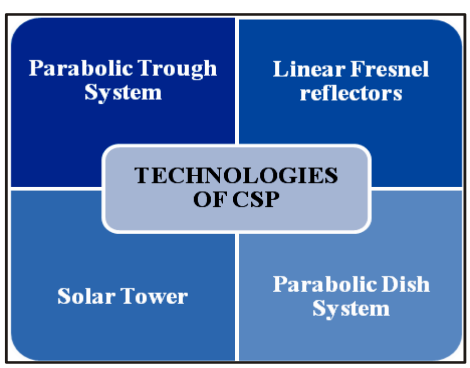
$$\mathbf{C} = \frac{4}{Ø^2} \sin^2 Ø_{rim}$$

Where,

C = Solar flux concentration ratio.

Current technologies of CSP

CSP is used to produce electricity (sometimes called solar thermoelectricity, usually generated through steam). Concentrated-solar technology systems use mirrors or lenses with tracking systems to focus a large area of sunlight onto a small area. The concentrated light is then used as hea1t or as a heat source for a conventional power plant (solar thermoelectricity). The solar concentrators used in CSP systems can often also be used to provide industrial process heating or cooling, such as in solar air-conditioning.



Parabolic trough systems

Parabolic trough system work on the principle of line focus, mobile receiver. Parabolic trough systems consist of parallel rows of mirrors (reflectors) curved in one dimension to focus the sun's rays. The mirror arrays can be more than 100 m long with the curved surface 5 m to 6 m across. Stainless steel pipes (absorber tubes) with a selective coating serve as the heat collectors. The coating is designed to allow pipes to absorb high levels of solar radiation while emitting very little infra-red radiation. The pipes are insulated in an evacuated glass envelope. The reflectors and the absorber tubes move in tandem with the sun as it crosses the sky.

All parabolic trough plants currently in commercial operation rely on synthetic oil as the fluid that transfers heat (the heat transfer fluid) from collector pipes to heat exchangers, where water is preheated, evaporated and then superheated. The superheated steam runs a turbine, which drives a generator to produce electricity. After being cooled and condensed, the water returns to the heat exchangers. Parabolic troughs are the most mature of the CSP technologies and form the bulk of current commercial plants. Most existing plants, however, have little or no thermal storage and rely on combustible fuel as a backup to firm capacity.

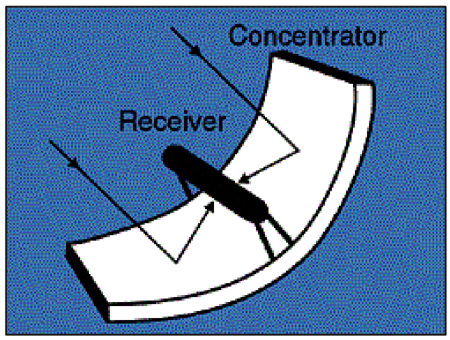


Fig. 2: Schematic representation of parabolic trough system

Linear fresnel reflectors

Linear Fresnel reflector works on the principle of line focus, fixed receiver**.** Linear Fresnel reflectors (LFRs) approximate the parabolic shape of trough systems but by using long rows of flat or slightly curved mirrors to reflect the sun's rays onto a downward-facing linear, fixed receiver. A more recent design, known as compact linear Fresnel reflectors (CLFRs), uses two parallel receivers for each row of mirrors and thus needs less land than parabolic troughs to produce a given output.

The main advantage of LFR systems is that their simple design of flexibly bent mirrors and fixed receivers requires lower investment costs and facilitates direct steam generation (DSG), thereby eliminating the need for – and cost of – heat transfer fluids and heat exchangers. LFR plants are, however, less efficient than troughs in converting solar energy to electricity and it is more difficult to incorporate storage capacity into their design.

Solar tower

Solar tower also named as Central receiver systems, works on the principle of point focus, fixed receiver. It uses heliostats to track the sun by two axes mechanisms following the azimuth and elevation angles with the purpose to reflect the sunlight from many heliostats oriented around a tower and concentrate it towards a central receiver situated atop the tower. This technology has the advantage of transferring solar energy very efficiently by optical means and of delivering highly concentrated sunlight to one central receiver unit, serving as energy input to the power conversion system.

In spite of the elegant design concept and in spite of the future prospects. In spite of the elegant design concept and in spite of the future prospects of high concentration and high efficiencies, the central receiver technology needs still more research and development efforts and demonstration of up-scaled plant operation to come up to commercial use. Its main attraction consists in the prospect of high process temperatures generated by highly concentrated solar radiation to supply energy to the topping cycle of any power conversion system and to feed effective energy storage systems able to cover the demand of modern power conversion systems.

The solar thermal output of central receiver systems can be converted to electric energy in highly efficient Rankine-cycle/steam turbine generators, in Brayton-cycle/gas turbine generators or in combined cycle (gas turbine with bottoming steam turbine) generators. Grid connected tower power plants are applicable up to about 200 MWe solar-only unit capacity.

Fig. 3: Solar Tower

Parabolic dish systems

Parabolic dish works on the principle of point focus, mobile receiver. Dish systems use parabolic reflectors in the shape of a dish to focus the sun's rays onto a dish-mounted receiver at its focal point. In the receiver a heat-transfer medium takes over the solar energy and transfers it to the power conversion system, which may be mounted in one unit together with the receiver (e. g. receiver/Stirling engine generator unit) or at the ground. Due to its ideal optical parabolic configuration and its two axes control for tracking the sun, dish collectors achieve the highest solar flux concentration, and therefore the highest performance of all concentrator types in terms of peak solar concentration and of system efficiency. These collector systems are restricted to unit capacities of some 10 kWe for geometrical and physical reasons.

The dish technology is applicable to off-the-grid power generation[1], i. e. at remote places or at island situations. Dish systems may optionally be arranged in large dish arrays in order to accumulate the power output from the kWe capacity up to the MWe range. It requires some more continued R&D activities and demonstration before start of market introduction. The power conversion subsystem of dish systems is mainly based on the Stirling engine generator system, but also on the water/steam powered turbine or piston engine generator system or on the gas turbine generator system. Peak-load by solar-only operation or by solar/fossil "hybrid" operation with solar shares may range from 50 to 100 % on an annual average.[4]

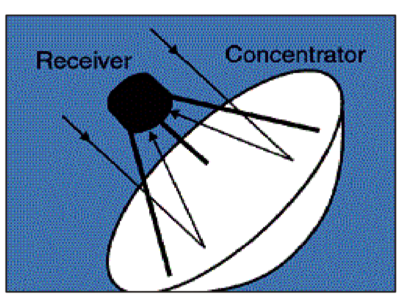


Fig. 4: Schematic representation of parabolic dish system

Intermittent solar energy-need for storage

The growth in worldwide usage of solar energy will be constrained until reliable and low-cost technologies for storing solar energy become readily available. A viable solar energy conversion scheme must result in a 10–50 fold decrease in the cost-to-efficiency ratio for the production of stored fuels and must be stable and robust for a 20–30 year period.

Why solar fuels ?[1]

Conversion of solar energy into chemical fuels is an attractive method of solar energy storage. Solar fuels, such as hydrogen, can be used for upgrading fossil fuels, burned to generate heat, further processed into electrical or mechanical work by turbines and generators or internal combustion engines, or used directly to generate electricity in fuel cells and batteries to meet energy demands whenever and wherever required by the customers. The challenge is to produce large amounts of chemical fuels directly from sunlight in robust, cost-effective ways to deal with growing energy demands while minimizing the adverse effects on the economy and environment. Sustainable, large scale fuel production relies on the success of solar thermal power generation (CSP) : concentrating the incident solar radiation with reflecting mirrors provides high temperature process heat for driving efficient thermochemical processes in compact centralized plants. Although the technical feasibility of various technologies has been demonstrated in the past, commercialization of these processes had been hindered-predominantly due to economical reasons. Nevertheless, solar fuels are among the most promising technologies to curb the growing demand for fossil fuels-associated with soaring prices for diminishing fossil fuel resources – and to mitigate the effects of climate change. Their rapid implementation will create new markets for developing countries and increase the energy security, due to greater independence in fuel production and a larger number of countries supplying solar fuels.

It is recommended that commercial implementation steadily evolves, starting from the current state-of-the-art fossil fuel production technologies. To facilitate the introduction of new solar fuels production processes, the existing knowhow from both the fuel production industry and the CSP research institutes should be merged. At a later stage, the emerging solar fuel technologies will be based on processes that are completely independent of any fossil fuel resources.

Why solar hydrogen ?

Many believe that over the next several decades, there will be a shift away from today's fossil fuel economy toward a much cleaner hydrogen future.[2] The enormous problems accompanied with a fossil fuel economy and the significant environmental advantages of the Hydrogen Economy are strong drivers toward clean hydrogen (H_2) production, supply and utilization, as manifested in a number of political initiatives.

Although H_2 is widely accepted as the energy carrier of the future, it must still fulfil the requirements of a sustainable energy economy, i.e. it must be produced from unlimited energy sources, without GHG emission, at an affordable price. Today, more than 90% of the H_2 is produced from fossil resources, mainly natural gas (NG). Half of the annual production of more than 100 million tons is used for producing fertilizers and about 45% for petro-chemical processes. The latter application alone will drastically rise in the next years because an increasing amount of H_2 is needed for refining heavy oils.

These demands can potentially be fulfilled by high temperature processes, which are able to provide large amounts of H_2 in centralized plants. Many think that H_2 produced using solar energy will provide the long-term solution for solar energy storage. In fact, if H_2 is generated from solar energy, it is a completely clean technology; no hazardous wastes or climate changing byproducts are formed and only sunshine and water are required. A lot of research is currently being undertaken around the world, because solar H_2 seems to have the highest technical and economical potential for successful market introduction. However, since other technologies for energy storage are available – such as carbon dioxide (CO_2) or metal oxides – the pros and cons of all of those alternatives should be carefully evaluated.

Solar fuels production

The conversion of solar energy into solar fuels opens up numerous possibilities. There are basically three routes that can be used alone or in combination for producing storable and transportable fuels from solar energy:

Electrochemical: Solar electricity made from photovoltaic or concentrating solar thermal systems followed by an electrolytic process.

Photochemical/Photobiological: Direct use of solar photon energy for photochemical and photo-biological processes.

Thermochemical: Solar heat at high temperatures followed by an endothermic thermochemical process.

Concentrated solar power technology in India

Amid the growing demand for sustainable energy, concentrating solar power (CSP) technologies are on the verge of large scale global deployment. These technologies harness concentrated sunlight to generate electricity. In the coming decade, the CSP market is estimated to be worth over a billion dollars. The Government of India too has identified solar power as an important renewable energy resource and its commitment to develop solar power is reflected in the 'National Action Plan for Climate Change' wherein it has announced the 'National Solar Mission' as one of the eight missions to combat the challenges of climate change.

In the month of February, 2012 India’s finance minister, Dr. Pranab Mukherjee, declared that concentrating solar thermal plants and equipment in India will now be exempt from import duty. CSP installed capacity in India is a mere 8.5 MW as compared to 481.48 MW for PV technology. There is no domestic manufacturing base for CSP equipment in India and there are only a handful of experienced technology providers abroad. In addition, CSP as a technology faces water issues that will require CSP developers come up with creative plant cooling solutions. There is also consternation about the 30% local content requirement.

India proposed to scrap duties on imports of solar-thermal equipment as it seeks to reduce project costs for Reliance Power Ltd. (RPWR) and other developers adding plants.“Solar-thermal projects need encouragement,” Finance Minister Pranab Mukherjee said in his annual budget speech, proposing to spare such ventures from the so-called special countervailing duty.

The exemption would lower costs for the seven companies building a third of India’s planned solar capacity using solar-thermal technology, which concentrates sunlight to boil water, used to power steam turbines. Reliance Power is importing turbines from Areva SA, while the others have ordered units from suppliers including General Electric Co. (GE) and Siemens AG. (SIE)

The developers building India’s solar-thermal capacity, targeted at 470 megawatts by early 2013, are Reliance Power, Lanco Infratech Ltd. (LANCI), Godawari Power & Ispat Ltd., Aurum Renewable Energy

Pvt., KVK Energy & Infrastructure Pvt., Megha Engineering & Infrastructures Ltd, and Abhijeet Group's Corporate Ispat Alloys Ltd.

The key challenges to CSP in India remain, an exemption of import duty on plant and equipment contributes to an overall reduction of CSP project costs. This will invite greater investment in the Indian CSP market.

Adavatages of CSP technology

1. No Fuel
2. Predictable, 24/7 Power
3. No Pollution and Global Warming Effects
4. Using Existing Industrial Base

Bright future for solar fuels

Solar thermal power plants have paved the way for solar fuels production plants. Similar to concentrating solar power (CSP) plants emerging as an alternative for large scale power generation, concentrating solar chemical plants will presumably become the salient option for sustainable renewable fuels production. Solar energy is free, abundant and inexhaustible, but at least two crucial steps are necessary for a successful market introduction of solar fuels. Firstly, the solar chemical production technologies must be further developed and proven to be technically feasible and economical. Secondly, a worldwide consensus on the most promising future energy carriers-both renewable electricity and H_2 – needs to be reached.[1]

The arguments in favor of a future hydrogen economy are excellent, and the political commitment to move in this direction has been manifested in many initiatives. What is urgently needed; now is a clear decision to start the transition from fossil to renewable energies and from gasoline to H_2. We encourage politicians and policy-makers, energy officials and regulators, utility companies, development banks and private investors to firmly support the massive production of solar fuels – primarily H_2 – by taking concrete steps to enable future infrastructure and market development without delay. We have only a short time window of opportunity to tackle and solve the critical problems of greenhouse gas emission and climate change. Solar fuels are part of the solution; they have the capacity to contribute to the energy supply and security and to help satisfy the energy needs of the world without destroying it.

CONCLUSION

An attempt to look into the future is subjective at best, as emphasized above. Nevertheless, some global trends will continue to influence and spur the research on solar energy materials for decades to come. Among these trends are a growing population, which will boost the demand for safe and affordable energy to fulfil its needs and aspirations; a continuing agglomeration of people in mega-cities, which has important effects on human health, as well as on microclimates tending to aggravate the effects of a general global warming; and a progressive depletion of raw materials, which will make it increasingly needed to employ abundant ones.

Point focus systems

- Provide High overall system efficiency
- Reduce the consumption of resources per generated kWh

- Can be installed in hilly areas
- Have a maximal unit size probably smaller than for parabolic trough
- Up-scaling could be realized with a connection of several units to one big power block (like Dish Stirling plants)
- In the future tower technology enables solar driven combined cycles for further efficiency increase
- Cost-efficient storage systems are still not available even for direct steam cycles.

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