Statements on Solar Energy

by the Energy Committee at the Royal Swedish Academy of Sciences

Introduction

Direct sunlight is potentially the most powerful renewable energy source. In less than an hour, the Earth receives the same amount of energy from the sun as is used globally by man during a year. In contrast to most other energy technologies, solar energy is only limited by cost of conversion and intermittency in time. Direct use of sunlight yields up to 100 times more electricity, per land area, than growing biomass for use in power plants. Solar energy at present only amounts to a small fraction of the World's primary energy supply but solar technology markets are developing and growing fast.

These statements have been elaborated by a working group having as members Harry Frank Dick Hedberg, Bengt Kasemo, Sven Kullander, Rickard Lundin, Bengt Nordén and Erik Pihl. A major event was the solar energy symposium held at the Royal Swedish Academy of Sciences on 5th of May 2008. At this meeting presentations were given by Jörg Asmussen, Marika Edoff, Winfried Hoffmann, Florian Holzapfel, Björn Karlsson, Gerhard Knies, Robert Pitz-Paal, Philip Preiss and Bengt Stridh.

Solar Technologies

Utilisation of sunlight can be made with a wide diversity of technologies, varying greatly with the physical principles of energy conversion. The various technologies can deliver energy in different forms: electricity, high or low quality heat, or synthesized fuels such as hydrogen and hydrocarbons. This means that there are several possibilities as to where and how each conversion option is best applied. The main technologies are briefly described below.

Photovoltaics

Photovoltaic (PV) systems use the photo-physical properties of materials to create electricity directly from the photons of sunlight. PV cells, usually quite small, are combined to window-size panels, that typically generate between 60 and 200 W in full sunlight, depending on technology and size. Panels can be assembled to systems that vary in size between simply one and several thousand units. Generation of electricity is instantaneous and silent. The dominating technology, so far, has been cells based on silicon photovoltaics (Si-PV) which make use of similar manufacturing technologies as the electronic industry does. The resource base is enormous since silicon is one of the most common elements in the Earth's crust, but production of Si wafers is today energy and time demanding and has so far been relatively expensive. An alternative to Si cells are so-called thin film (TF) cells. These are made out of much thinner layers than Si-PV and can be produced using less energy and in a shorter time. There are also other interesting PV technologies such as dye-sensitized solar cells (DSSC), carbon-based conducting polymer PV and other alternatives. These are only in a stage of early research and it is unclear if and when they may enter the market of large scale power production.

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Concentrating Solar Power

The concentrating solar power (CSP) technique is based on the principle of using highly (25-3000 times) concentrated sun light. CSP plants require direct sun irradiation (clear blue sky) to operate. The concentrated light can produce heat at high temperatures and drive a thermal cycle (thermal CSP), just as in fossil or nuclear plants, or be aimed at small but efficient photovoltaic cells (Concentrating PV). The thermal CSP is developed along some different techniques: dishes, towers and troughs. Dishes are units with reflecting mirrors concentrating light on to a small volume of a heat transfer medium, for example an expanding gas, which provides heat to drive a small engine. Tower plants consist of a great number of heliostats (mirrors that follow the sun) reflecting light towards a receiver on top of a large tower. Troughs, or the similar linear Fresnel-mirrors, concentrate the light on receiver pipes. In the tower and trough receivers, air, steam, liquid mineral oil or molten salts is heated. Air and steam can be used directly as working medium in a power cycle, while the heat transfer medium only provides heat for a power cycle.

Dish and concentrating PV systems are modular with sizes of about 20-75 kW while towers and trough/linear Fresnel plants generate electricity from a few up to hundred MW. These plants with large central generation have economical benefit from their large sizes and can employ daily energy storage, by keeping a heated medium in large isolated tanks. As thermal storage is more efficient and considerably cheaper than electric storage, this enables a rare opportunity of renewable base-load power.

Solar heating and photovoltaic/thermal hybrids

Solar heating makes use of a collector, a surface with high absorption of light, from which the heat is transferred to a liquid or air system, which in turn is used for heating of indoor air or tapwater. The collector can consist of a metal/plastic panel, or a metal absorber inside an evacuated transparent tube. Hot liquid can be stored from periods of hours in small tanks, up to large scale seasonal storage in bedrock or large tanks. Photovoltaic/thermal (PV/T) hybrids are basically made up by PV cells cooled by liquid or another medium, from which both electricity and heat can be extracted. PV/T systems are often concentrating, by factors of 4-20 times. While solar heating is established technology, PV/T systems are only in early, very small scale commercialisation.

Solar Fuel Synthesis

Solar energy can be converted into chemical energy. One option is the splitting of water to hydrogen and oxygen in a high-temperature-catalysed reaction, using concentrating solar-power (CSP) devices. Another is the electrolysis of water by the use of solar-produced electric energy. Hydrogen can, in principle, also be produced from water by artificial photosynthesis, at room temperatures – using similar processes as organic PV – which is an exciting possibility as it may utilize a closed system without moving parts or by passing via electric energy. However, artificial photosynthesis is still in its infancy of research and will probably require design of some sophisticated and novel supra-molecular reaction systems.

Key Points

1. A viable option for the future

Solar energy is one of the most important alternatives for providing future sustainable energy. The resource base is virtually unlimited and many solar technologies are today mature or maturing. Before the end of this century, not unlikely within half a century, solar technologies can be dominating in powering human societies. Most solar technologies generate electricity as the primary energy, which can be converted to other energy forms – light, propulsion etc – with low losses. This means that an energy system with a growing solar-energy share could meet a strong increase in global demand of useful energy more efficiently than fossil fuels where the primary energy conversion often is more than twice the final energy consumption.

2. Cost issues and trends

Solar energy has so far not been able to compete economically with cheap fossil energy. However, the price gap closes, as fossil fuels become scarce and costly to extract, while solar technologies are continually developed. Present and near term cost of electricity (COE) is estimated based on currently operating systems; for photovoltaics approximately 200-500 €/MWh, varying greatly with location and technology. Present costs for concentrating solar power has been estimated to 180-300 €/MWh which is about 50% higher than earlier estimates, the price increase being blamed on raised material costs and limited competition on some key components. By comparison, the COE for new fossil energy and nuclear power is presently (at least) 20-50 €/MWh. The cost for solar heating is in the range 50-150 €/MWh (European conditions).

Solar energy technologies have great potentials for fast cost reduction. The cost of concentrating solar power should be reduced considerably within two decades, becoming comparable to that of fossil-fuel power, especially if costs of CO_2 emissions and other external effects are regarded. It can be done by upscaling and further research and development – to a great extent by employing the experience with conventional power systems.

PV manufacturing resembles that of electronics in many ways and, as it seems, also regarding its cost trends. Electronics have had exponentially decreasing costs per bit versus time and produced units, and PV seems to follow the same pattern regarding the cost per watt. If the trend continues, PV will offer very cheap power production within a few decades – provided that the costs of installations can be reduced as well. Concentrating PV uses cheap reflectors or lenses, reducing the amounts of costly sensor material and in theory it should offer lower costs, but this remains to be proven in large-scale production.

3. Challenges of realisation

The intrinsic intermittency is perhaps the greatest challenge for future solar technologies. The problem is most prominent in areas with distinct seasons, such as Scandinavia, where the biggest energy (heating and lighting) demands appear in the absence of sunshine. As long as solar energy contributes to only a very small portion of an energy system, the variations can be balanced, but above some 10 % of the total power, the intermittency becomes a problem. It increases in energy systems with large contributions from wind energy and other intermittent sources. Batteries, pumped water reservoirs, compressed air etc are possible storage options. Unfortunately, most of these are expensive or too inefficient for practical use. Today, traditional hydropower is superior for a quick response to fluctuating electricity demands, but the current possibilities of further expansion of hydropower capacity are limited in many countries. In this context, CSP technologies offer a unique possibility. Integrated thermal storage (tanks with molten salt other concepts) can enable up to 24 hours of continuous operation. It can be done at low or zero extra costs, as a storage system enables downscaling of power cycle for a given collector field. In addition, some CSP power systems can be fitted with simple backup burners for fossil or biomass fuels.

Other obstacles for employment of large-scale solar technologies are short-term production bottle-necks for Si-PV purified silicon, CSP turbines and absorber tubes, short and long term limitations of rare indium for CIGS cells, and other material or construction constraints. Robustness is another issue. Solar power must be established cheaply and resource efficient, but still be able to withstand outdoor conditions – such as sandstorms in deserts – for several decades, with little additional maintenance.

4. Uneven geographical distribution

Viability and costs of solar energy technologies are not universal, but heavily dependent on geographic location. The annual solar irradiation is up to three times higher at low latitudes than in, for example, Northern Europe (1000 $kWh/m^2/y$). The large variations mean that costs of solar heat, power and produced fuels will vary widely depending on location. Furthermore, promising technologies such as CSP will only be feasible in areas with very high solar irradiation, basically in or close to deserts. It is evident that long-range electricity transmission capacity greatly facilitates any solar energy scheme. High voltage direct current (HVDC) with a combination of cables and DC overhead lines have been proposed, as these can transfer electricity up to 3000-4000 km at relatively low losses and costs. A great majority of the Earth's population live within 2500 km of suitable solar (CSP) sites. Solar-derived fuels such as hydrogen could become another option for distribution of energy, but is not likely in the near future.

5. Massive growth expected

PV technologies have shown an impressive exponential growth of approximately 40% annually during the last decade. Globally, the cumulative installed solar power increased from 6.8 GW in 2006 to 9.2 GW (10 TWh/y) in 2007 of which 52 % is installed in Europe. The trend of rapid increase in global market volume is expected to continue, but is limited by the annual production capacity which currently amounts to 4 GW. PV installations worldwide are estimated to reach 1 000 GW (1 400 TWh/y) by 2030, with Thin Film systems increasing their market share from the current roughly 10% of total PV market.

CSP technologies have developed slowly since the early 1990s but now seem to have entered a strong developmental stage. Today, CSP contributes only just above 400 MW to the global power supply, but new large plants providing altogether 9000 MW are either under construction or at a planning stage. Dish Stirling systems constitute an extreme growth market in relative figures, with only a few demonstration units yet in operation but tens of thousands contracted, adding up to hundreds of MW.

6. Solar energy for security

Solar energy is a pathway to increased energy security, if appropriately applied. Adding solar energy into an existing energy system will decrease the system's dependency on other sources, such as fossil fuels. A network of CSP plants with storage, fuel backup and long range distribution would be rather resistant to local disturbances or shortages of fossil fuels.

7. Filling different purposes

Different solar technologies do not necessarily compete, but complement each other. PV technologies are suitable for small-scale applications (retail market), for off-grid purposes and for making use of available space in urban areas (rooftops, sunshades etc). CSP with storage capacity, on the other hand, is suitable for large-scale applications (bulk utility market) to deliver both base load and balancing power.

The best choice of solar technology will vary with nature of demand. For example will solar heating provide simpler and cheaper technology to meet low-temperature heating demands than what PV can offer. The possibility of large-scale heat storage in bedrock or rock caverns can facilitate use of solar heating in areas where the timing of demand and supply does not coincide, for example in Scandinavia and Canada. As indoor and tap-water heating constitute large shares of the energy demand in such regions, solar-heating schemes with seasonal storage could have a better potential than photovoltaics. However, seasonal storage requires additional investments, implying large-scale systems for cost competitiveness.

8. Environmental performance

All energy conversion affects the environment and solar energy is no exception. Compared to fossil energy it is however relatively benign. "External costs", i.e. the indirect costs of climate change, health risks, environmental pollutions etc, have been estimated to be in the range 20-150 €/MWh for coal power, 10-40 €/MWh for gas power, but less than 10 €/MWh for solar energy. To some extent, solar energy (PV in particular) is connected with environmental problems such as toxic substances, but is more or less free from problems that other renewables face, for example the biomass resource limitations and the landscape change and destruction for wind power and hydropower dams.

The energy pay-back times are for Si photovoltaics 2-7 years and for thin-film technologies 1-3 years - the figures varying greatly with location. This is much shorter than their life times (20-30 years or more), which means that PV technologies will provide energy and avoid CO_2-emissions compared with any fossil-fuel alternative. The conclusion is that solar energy causes some environmental effects that need to be dealt with, but on the whole constitutes a better alternative for the environment than most of today's conventional power plants.

9. R&D, market expansion and support

For many solar technologies, further research and development (R&D) is needed. Solar energy has received only a fraction of the public funds given to energy research and deserves more attention. However, for the short term, up-scaling and better engineering solutions for the manufacturing processes are of highest importance. Some technology has already been developed but even if trends are towards lower costs, solar energy is still not competitive with conventional power systems. Feed-in tariffs (Germany, Spain, Portugal) and other support schemes have been crucial for developing a market and a trend towards larger facilities with better economic performance. These support schemes will most likely still be necessary for a decade or so ahead, if the current positive trends are to continue. A problem is that solar energy requires large initial investments. In developing countries, micro-credit schemes could aid in PV market expansion by facilitating payment of the high initial capital costs.

Concerning CSP there are already mature technologies to deploy. However, they need to be further developed and up-scaled in order to reach cost competitiveness. Just as with the case of PV, economical support schemes will be necessary for further CSP expansion, at least as regards the coming one or two decades. Massive construction of CSP plants in remote desert areas also requires availability of high capacity, long range electricity power lines. To address the future needs of carbon free power in regions some thousand kilometres from solar-rich areas, prospects of very long range distribution power lines should be regarded in infrastructure planning processes already today. In the European case, plans and legal framework for that should be decided at EU level.

10. Conclusions and recommendations

Solar energy technologies are developing rapidly and before the end of the 21st century, probably within the next 50 years, solar energy can become a major global energy provider. The solar resource base by far exceeds that of all other renewable alternatives. So far, a breakthrough has been limited by the high costs involved and the intermittent nature of solar radiation. The latter factor makes it necessary to ensure that back-up energy sources are available.

While global energy prices are rising, the costs for solar energy tend to be decreasing. The cost of Concentrating Solar Power (CSP) technologies is anticipated to become comparable to that of conventional power sources within the next two decades. With integrated heat storage and hybrid technology, CSP has the potential to provide significant amounts of base load power, but will be feasible only in areas with a high input of direct sunlight, i.e. basically in or close to desert areas. In some countries, CSP plants can become a dominant domestic-power supplier, and a provider of electricity for export. The latter would require long range, high capacity, continental power grids, the establishment of which would in all likelihood have positive spin-off effects, such as attracting private and public investments.

In addition, local small-scale solar energy systems, such as photovoltaics and heating panels, will become increasingly important, for example in private and public buildings. It is to be expected that the market for these small-scale systems for direct energy supply will grow rapidly, as they become more readily available.

There are still large needs for basic research and development of solar technologies, but even more important is to have a market pull that can upscale investments and lead to better production solutions. Economic support systems, such as the feed-in tariffs that are used in, e.g. Germany, Spain, and a number of countries, should be maintained and/or enhanced and employed in other countries. Huge infrastructure investments will also be required, including high capacity electricity connections from solar-rich areas to regions with high consumption.

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