Time to Shine

Scrivener Publishing
100 Cummings Center, Suite 41J
Beverly, MA 01915-6106

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Time to Shine

Applications of Solar Energy Technology

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Scrivener

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Co-published by John Wiley & Sons, Inc. Hoboken, New Jersey, and Scrivener Publishing LLC, Salem, Massachusetts.
Published simultaneously in Canada.

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Cover design by Kris Hackerott.

Library of Congress Cataloging-in-Publication Data:

ISBN 978-1-118-01621-3

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

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Summary

Starting from the incoming solar radiation, a subjective overview of the status quo of solar energy use is presented, including the relevant energy transformation processes, solar materials, components, performance and durability requirements. Selected historical, available, and not yet available products are shown, as well as recent and historica examples of solar technology, in particular architecture.

Technical and general development aspects are discussed, including test and monitoring methods, use rate metering, and market introduction experiences.

Outlooks are presented on solar energy in a crowded world, evolving grids, and energy planning aspects.

Reflections in a concentrating solar cooker (Photo: Chris Butters).

About this Book

This book presents an original view of solar energy technology, as well as tools for the understanding of energy-related decisions taken by present and future stakeholders. Particular attention is paid to background phenomena that are not easily found in traditional textbooks. To avoid reader somnolence (falling asleep), questions, smart and naïve, are asked by a sometimes annoying character called the ***"alert reader"*** who shares them with a twinkle in the eye. *Information concerning the alert reader is set in **fat italics**.*

This book can be used as a source of technical information, it can also be read like a coffee table book, by looking at the pictures, reading the figure captions, and skipping over the technical parts. Where no reference is shown, the source is work – published or unpublished – by Synopsis (see http://www.synopsis.org/index1024/eng/indexeng.html, 1997–2006).

Terminology

The term solar thermal energy (sometimes also labeled direct use of solar energy) denotes:

- The transformation and use of the thermal energy of the sun's incoming rays, by any means of heat transfer (e.g., transmission, reflection, absorption, emission, conduction, convection, phase change, heat storage...)
- The use for any application, be it thermal or electric.

It can be somewhat confusing to find the generation of electricity by thermal techniques (such as thermodynamic cycles in power plants) listed under solar thermal energy, whereas the term solar electricity denotes only PV electricity generation. However, this terminology, as they say, avoids fastidious cross-referencing, and is therefore adopted here.

*Also, the **alert reader** (you will meet her or him quite regularly in the following pages) might notice that isolated parts of text are set in **fat italics**, indicating that the corresponding text is a personal opinion and should be taken, as my father said (and the Romans before him), "cum grano salis," with a grain of salt.*

Introduction: Solar Energy

Sudden events, like the BP Deep Water Horizon disaster and the uncontrollable effects of the mega-catastrophe in Japan, and long-term developments, like the steadily growing awareness of the climate issue and of the finite nature of fossil energy sources, as well as doubts about the place left by the phasing out of nuclear electricity have created a regain of interest in renewable energies, in particular solar thermal energy and PV (photovoltaic) electricity.

In the past, public interest in the energy issue was fueled as much by political, ethical, and environmental arguments as by technical and economic drivers, and renewable energy was often perceived as a field of believers, with little credibility amongst professionals. Since then, new players have entered the arena: clients and, in many countries, legislators voted serious incentives, from tax rebate to plain subsidy, in favor of renewable energies. Although the pendulum might swing back, there is an enormous privately-driven mobilization of capital, know-how, and outright audacity, resulting in a multiplication of new solar products arriving on the shelves and in the catalogues. This mobilization has taken many observers by surprise. Two examples follow:

- As always, when big issues and important technological decisions are at stake, cost ceases to be the dominating yardstick and killer of all but the cheapest solutions: no one has ever seriously tried to compare television to radio in terms of efficiency. When TV became available, everybody who could afford it just bought a TV set.

- In Germany, it was found that private households invest more in their own renewable energy equipment than in utilities, for total investment. This has led to momentary electricity glut situations, where nuclear and coal-fired power plants were not needed, but, *waste for wastes' sake*, had to be kept operating while fossil electricity was "sold" at negative rates.

The battle of the energies is far from over, but (as cynics would say), it is being fought with astonishing fairness, considering what is at stake: the control of the driving force of the economy. However, so far, the democratic process (or the fear of electoral *déroute)* seems to hold.

Hot democratic decision processes need cool information, just as the necessary changes in the energy sector need all of the available brainpower and intellectual honesty to succeed. It is the opinion of the authors that these changes are possible, but that not all of them will come for free, while others might not materialize at all. Some will: the *terms à la mode* are "low-hanging fruit" and "picking the raisins from the cake," which refer to the phasing out of obviously wasteful and unnecessary practices. Few people are going to miss these, or even notice their disappearance (again, some will).

However, once these easy fruit are eaten, we might run out of soft targets, i.e., once the cheapest measures are taken, more difficult targets will have to be attacked, and priorities will have to be set. In fact, and fortunately, this process is well underway. It would not be wise to limit our action to overdue, and highly lucrative, energy efficiency measures, which could encourage consumers to react to price reductions with higher consumption. The term *à la mode* here is "rebound effect." If this effect is real (some experts doubt this), we might come to regret the low-hanging fruit.

This brings us to the question of priority. What should have higher priority:

- Renewable energies, even expensive?
- Cheap energy savings, even without renewable energies?
- Savings plus renewables?

Most people would spontaneously opt for the third alternative, and we suggest that they are right.

Let us be more incisive: what should be the highest priority option? Energy savings or renewable energy? And: what can energy savings do? By themselves, energy savings cannot deliver any energy service, but they can stretch the time axis, and make fossil fuels last longer. Not bad at all, but not enough: we must make fossil fuels last until we have put into place a durable renewable energy system, capable of sustaining itself, BEFORE FOSSIL FUELS RUN OUT. By then, the energy system must be 100% renewable. This is an ambitious target against which we will be measured. The situation can be described as a fuel lantern running on empty in a dark cave. If we fail to find a replacement in time, we will be in the dark, no matter how hard we save: while we can replace energy carriers by other energy carriers, to, say, run an appliance (a lantern or a cellphone), we cannot save 100% AND run the appliance.

Finally, in order to succeed, solar – like other renewable energy technologies – needs to fit into the bigger picture in ways that are efficient, economical, and socially positive. This includes the overall energy system as well as specific economic and even cultural frameworks.

Chris BUTTERS, May 2011

Time to Shine: Applications of Solar Energy Technology
by Michael Grupp

1

The Incoming Solar Radiation

On top of the earth's atmosphere, at the average distance between the earth and the sun, the mean energy density of the sun's radiation ("irradiance"), referred to a surface of 1 m^2, normal to the incoming radiation, is 1.367 kW/m^2. This value is called the solar constant, although it is not particularly constant; it changes with the sun's activity ("sun spots," see Figure 1). This change is so slight, in the order of 0.1%, that it needed satellite spectrometric data to find it. A more substantial change, in the order of 3%, is caused by the geometric changes of the reference, the deviation of the earth's orbit from the ideal circular form.

However, the influence of these variations is minimal compared to the 20 to 40% reduction in irradiance during the passage through the earth's atmosphere, due to the mixture of gases called air, suspended matter (as free radicals, aerosols, and aviation contrails), plus the complicated interaction between these elements, shifting concentration, their stability over time, the presence of different greenhouse

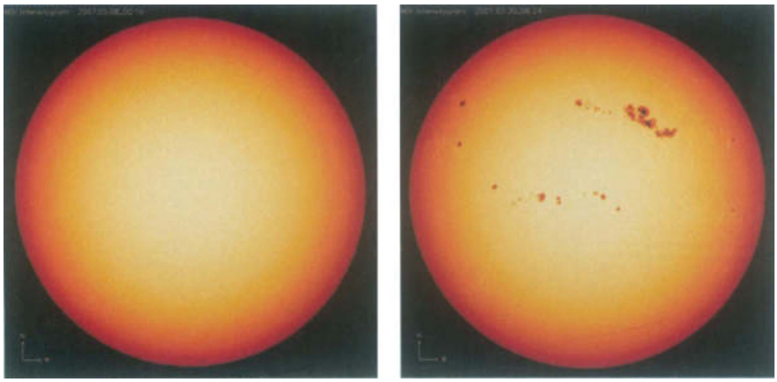

Figure 1 The sun in a calm sun spot period (left) and in an active period (right). (http://lasp.colorado.edu/sorce/newsother/SORCEwebsite_News_Solar_Cycle.pdf).

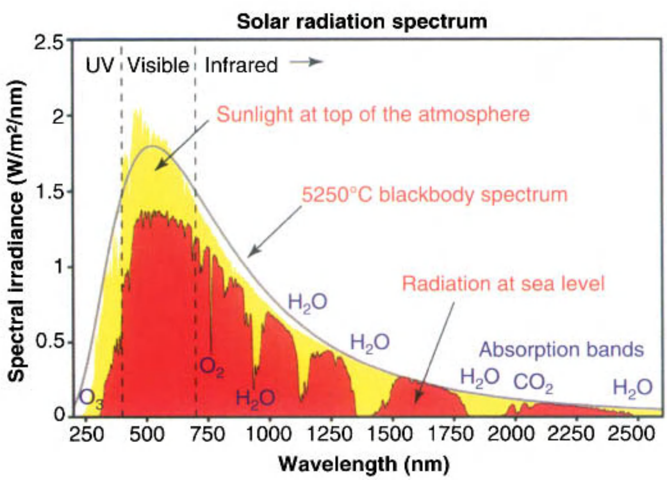

Figure 2 Irradiance spectrum on different levels in the atmosphere (Source Wikipedia).

gases, and solar UV light (photo-smog), all of this whipped by wind and jet stream, sifted through different pressures, temperatures, the effects of human activity and, finally, the eruption of the odd volcano. Figure 2 shows the spectral irradiance (the wavelength distribution of the irradiance). The red spectrum is received at sea level by burned tourists or is available for solar energy applications in two fractions:

- Diffuse radiation having been scattered, but not absorbed on its way. This part is not adapted to concentration, but can be used for low-temperature applications.
- Direct incoming radiation having maintained its original direction on its way through the atmosphere. This part can be used for all applications, concentrating or not.

The difference between the yellow and red spectra is reflected and/or absorbed by the atmosphere. In general, the spectrum marked in red may be available for solar energy applications, provided the sun is shining.

The Availability and Power Density Issue – Fossil vs. Solar Energy

There has been some confusion in the debate on availability and power density, and hence, usefulness, of fossil vs. solar energy. Solar (and particularly solar thermal) energy was often described as a highly diluted, unreliable energy source with limited potential for storage and high-temperature applications, whereas, at present, most experts would agree that:

- Solar energy (and its source, the sun) is a highly reliable, non-depletable energy source… but it is plagued by frequent "meteorological power cuts" (clouds) and limited storage potential; its high and intermediate temperature potential depends on the availability of direct radiation and sufficient concentration ratios; and its potential for low-temperature applications depends on available irradiance and adapted technology, good for tailor-made solutions for specific tasks. It is not particularly diluted: the power of the sun shining on the safety area of a nuclear power plant is in the order of the plant's power, but only during the day... Also, solar energy is prone to heat loss: in order to catch radiant energy, the absorbing element has to be open to incoming radiation, which means also open to potential heat loss, for example, at night.

- The reliability of solar energy can be improved by a number of measures, such as adaptation of supply and demand (e.g., solar air conditioning), storage (heat, dried products), transport (PV super grids), and transformation (synfuels).
- In some respects, fossil energy is the inverse of solar: depletable, but easy to store and uncritical to use at all temperatures. It is practical and versatile, just how much so we realize now that we are running out.

Luckily, many advantages of fossil fuels are also advantages of all fuels (shared by non-fossil fuels); sustainable fuels will remain part of the future energy supply system, as they have been since prehistoric times.

The Need for Tracking

To complicate the solar energy issue further, the sun does not have a constant position in the sky, which is rather good for us (otherwise we would not be here), but bad for solar energy devices. They must be tracked in order to function at optimum efficiency. Also, tracking must be more precise with increasing concentration ratio (and temperature).

The quantitative implications can be found in tables (Solar Energy Pocket Reference, Christopher L. Martin, D. Yogi Goswani, ISES 2005) and websites (www.nasa.org).

To summarize, it can be concluded that the sun's position in the sky is surprisingly different for different places on the globe, and it is standard practice to fool seasoned overseas solar visitors by asking them to indicate due north without a compass.

Of course, this would NEVER happen to our alert reader who, in the meantime, will have realized that the solar vs. fossil issue is getting more complex with every line, and that the voice level is increasing. This is the point where cool information, based on the necessary understanding of details, can help the reader to arrive at his or her own conclusions.

You are welcome.

2

The Basic Solar Energy Heat Transfers

The following first part of this volume presents the technical outlines and functions of heat transfers in solar energy applications.

The angle of description chosen here is to keep track, ad hoc, of the chronological order of heat transfer events facing the incoming light, going through potential or actual transformations, getting:

- Transmitted
- Absorbed
- Used
- And, finally, dissipated.

Put in a more familiar way, we will take a look at the transformations of a light ray, getting caught and used in a solar energy device as heat.

Qualified decisions on the role of solar energy in our future energy system should be based on a shared understanding of the potential and limitations of this technology, which includes the corresponding energy, particularly heat transfers.

Heat Transfer – Experiment and Simulation

Heat transfer can be understood as the metabolism of thermal energy, the exchange of heat between hot and cold. This description can be more or less detailed, in terms of spatial resolution (microscopic, down to the molecular level) to macroscopic; it can treat individual heat transfer modes or

> A more traditional description of individual heat transfer modes (conduction, convection, and radiation) can be found in specialized works, such as *Principles of enhanced heat transfer* (Book) Webb, Ralph L, New York: John Wiley & Sons, Inc, 1994 (*ref* 3). As already mentioned above, a typical heat transfer chain in solar thermal energy involves a number of radiative (optical, infrared (IR)) and other heat transfer mechanisms and their interactions. In general, this transfer chain starts with a light ray being ejected by the sun, partly admitted or rejected by control devices, reflected by internal and/or external reflectors; absorbed (transformed into heat) by absorbers or receivers; re-emitted as infrared radiation, reflectors or concentration devices, transmitted by glazing or other transparent components; re-absorbed, cooled (and partially lost) via conduction, convection and other heat transfer modes, used for (hopefully) useful purposes demanding heat or mechanical power; and, finally, dissipated in the environment, i.e., emitted and most likely to end up in the great sea of infrared (IR) radiation bathing the universe at a "cool" temperature of 3K.