CHIMIA 43 (1989) Nr. 7–8 (Juli–August)

Some Basic Reasons for Developing Renewable Energies

Carlos Gómez Camacho*

Carlos Gómez Camacho: Born 1952 in Sevilla. Aeronautical Engineer 1976, Doctor in Aeronautical Engineering 1986, both at the Universidad Politécnica de Madrid. Member of the International Test and Evaluation Team of IEA-SSPS Project in 1981. Lecturer in Thermal Machines and Engines since 1979 at Escuela Técnica Superior de Ingenieros Industriales de Sevilla. Technological adviser in Renewable Energies of Expo'92. His main field of research is solar energy and its application at medium and high temperatures.

Human beings, like any other thermodynamic system that tries to have a continuous evolution, need to interchange energy and matter with their environment. Consequently, they are open systems which fully interact with the biosphere. Until now, effects of human beings on their environment have been absorbed by its autoregulation capacity mainly due to the relatively low values of demography, per capita consumption, and ecological negative impact of waste disposals. Nevertheless, increasing world population with higher requirements of both, raw materials and energy, exhausts the earth's resources and overcomes its recycling capacity. The very serious problems arising from these facts are, or should be, sufficiently well known and will not be commented here again. Instead, such problems will be considered as a hint suggesting a new way of understanding the unavoidable new management of matter and energy that humans require for their welfare, together with an environmental regeneration. – Let us consider the biosphere as a system, rather than human beings as individuals, groups, or as a whole. The biosphere is in fact a thermodynamical closed and non-isolated system. It is closed because matter interchanged with its limits, outer space on one hand and inner parts of the earth on the other, can be clearly neglected, at least under a human time scale; so, its ability to accommodate disposals is limited. It is not isolated because there is an energetic interchange through its limits; most of this interchange is radiative, and solar radiation income is by far the most significant. – The main consequence of the biosphere being a closed, non-isolated system, whose energy input is solar radiation, becomes evident: to maintain the progress of mankind we must recycle the constant amount of matter available, some nowadays as pollutants, with the inexhaustible, plentiful, clean, and highly available energy of solar radiation, avoiding pollution. All of us know that the time period in which to do that is short; a couple of human generations, about 50 years, appears to be the limit. Fortunately, this amount of time is what we foresee is needed to implement new processes that, using the finite amount of matter available, including the pollutants, and driven directly or indirectly by renewable energies, will be able to fulfil reasonable requirements of an increased population, a significant part of which is under acceptable consumption of matter and energy.

1. Objectives

The aim of this contribution is to glance over the problem arising with the thermal use of solar energy to meet the requirements of human beings, justifying its technological viability, and pointing out progress lines towards economic and social viability. To proceed, general features of solar energy should be stated: as positive characteristics inexhaustibility, plentifulness, cleanliness, and cheapness; as negative ones, those related with both space and time distributions. The spatial one is mainly related to geographical latitude; beside this, temporal distribution depends on solar declination, which is mainly a function of the day of the year. Moreover, both distributions are strongly concerned with microclimate. From another point of view, thermodynamic characteristics of radiation are to be considered: easy concentration and high exergy against practical impossibility of storage as it is electromagnetic radiation.

Once these general characteristics, well known by those people dealing with solar energy, are stated, it appears convenient to outline how energy and matter can be obtained through solar radiation. To do that, a double classification is made, based on solar input and aimed output, respectively.

Solar input can be separated in direct or indirect. The first deals with solar radiation as it is, without previous transformation to another kind of energy. The second is related to a conversion to another energy, prior to performance of a final process. This case of indirect use can be subdivided again into two: with or without storage.

Desired output is also double: matter production or energy conversion. In close agreement with thermodynamics, energy conversion can be to heat or work, the latter with multiple forms: mechanic, electric, chemical and so on.

Once these classifications are made, the question arises as to how to match solar energy with its results. Direct conversion to matter can be made through thermochemistry, photo-chemistry or photo-biology; direct conversion into heat is performed photo-thermally, whereas photovoltaic conversion is the best known example of direct conversion into work.

Indirect conversion without storage of solar energy into matter covers topics such as solar electrolysis or desalination, whereas simultaneous conversion into heat and work is performed in cogeneration plants or fuel cells. Indirect conversion with storage also deals with previous processes; other cases could be the synthesis of a given substance using raw materials of a solar origin, work and heat from solar fuels, or must use one of the existing solar thermal power plants with intermediate storage.

To preserve solar energy uses from the inconveniences of both space and time distributions, we need practical transportability, and storability of the aimed production: easy transport avoids the problems arising from space distributions; good storage capacities solve these related with time distributions. Heat as well as work are ways to interchange energy, energy transformations and, consequently, to deal with intrinsically complicated transport and storage.

Thus, to produce stable solar fuels and chemicals becomes a priori a very convenient way to use solar energy, fulfilling mankind's needs of matter and energy and compatible with easy transport and storage.

The next paragraphs will deal with acquired experience, actual status, more promising trends, and decisions to be taken in order to get technological, economical, and social viability of solar thermo-chemistry. To be coherent with most of its thermodynamical requirements, only high-temperature processes will be taken into account; so solar devices will be mainly parabolic dishes and, for higher powers, solar towers driven by heliostat fields.

* *Correspondence:* Dr. C. Gómez Camacho
Escuela Técnica Superior de Ingenieros Industriales
Avda. de Reina Mercedes s/n
E–41012 Sevilla
(España)

2. Actual Situation of High-Temperature Solar Technology

In the middle of the 1970's, projection, design, construction, tests, and operation of solar central receiver systems began. Most of these plants were planned to produce electricity. In the early 1980's, six of them were working with nominal powers ranging between 10 MWe and 0.5 MWe. Scientific, technological and international cooperation has been very extensive; therefore, wide and well verified information is available nowadays, allowing well-founded judgements concerning viability of these systems.

Summing-up in a few sentences, the results are as follows:

- Technological viability of thermal solar electricity and process heat, both of them at medium (< 350°C) and high temperatures.
- Working characteristics of purely solar subsystems (parabolic collectors, heliostats, receivers, etc.) are very satisfactory.
- Site selection becomes even more important than thought before results.
- Concentrated solar radiation is about ten times cheaper than electricity produced.

Additional data are meaningful for a better understanding of characteristics of high-temperature solar technology. With respect to matter requirements, 1 g/m^2 of silver suffices for concentrating solar radiation to irradiances of several MW/m^2 during time periods exceeding 20 years. Regarding energy consumption, 1 year is enough to make up the energy used in a heliostat, and 2 or 3 years for the whole plant, even with a direct normal solar exposure as low as 10 MJ/m^2 day. From an economic point of view, relative total cost of solar components is decreasing substantially: heliostat fields represent nowadays $^1/_3$ of global cost, whereas it was $^2/_3$ in the early projects. The experience concerned with not purely solar subsystems («conventional») is clear: they are strongly affected by daily and seasonal cycles, as well as meteorological and operational transients; contrary to the usual procedure, a specific design to match these components with solar requirements is necessary.

3. Actual Circumstances of High-Temperature Solar Technology

Today, at the end of the 1980's, oil is becoming cheaper and the global contribution of renewable energies is far from the expectations raised ten years earlier. Does this mean that renewable energies are economically and socially unfeasible? The answer, after critical analysis is very clear: renewable energies, with special emphasis on high-temperature solar, are firm options for producing raw materials and fuels over medium and long range, even forever.

There are several guidelines for reaching this conclusion:

First, the time needed to develop a technology: as a rule, about 50 years elapse before final implantation; most of this time period is devoted to technical and commercial rounding off.

Second, there are economical conditions: the lowering of costs of high-temperature solar components in this first decade of development is drastic, even if real demand is far from potential. It is sensible to think that costs will reduce when demand increases and mass production techniques are available, competing against traditional technologies. Moreover, conventional procedures are hardly ever charged with decontamination costs, that are very often comparable to, or even exceed, production costs.

Third, in close relation to the last statement is public opinion concerning pollution, mainly in developed countries (bigger consumers of raw materials and energy). Ecological disasters such as Chernobyl, acid rain, or desertification, as well as increasing cancer mortality – closely related to industrial wastes – move social groups towards clean, non-polluting processes, even though they involve more expensive and limited production. In this respect, it is evident that renewable energies in general, and high-temperature solar ones in particular, do not have such problems.

Fourth, renewable technologies are feasible: compared to present or future technologies, they have an easier design, construction, operation, and maintenance, so that they can be exported to developing countries or installed in low technology isolated communities.

Fifth, renewable technologies are soft and peaceful ones; features that, together with feasibility, make them very convenient for promoting their use in developing countries.

And, last but not least, sixth: Regions with higher solar exposure, whose latitudes are roughly tropical ones, are also regions with lower economic and social development, as well as being more conflicting internationally; renewable energy technologies, with the leadership of high-temperature solar processes, favour efficiently North-South cooperation, because they produce stable, transportable, and storable raw materials and fuels needed by the two hemispheres, avoid environmental deterioration, and increase technical, commercial and political relations.

4. Ways to Promote High-Temperature Solar Technology

Circumstances for medium- and long-range development of high-temperature solar applications to raw materials and fuels are very promising; nevertheless, to reach this objective, continuous and progressive efforts should be performed. To do that, the best way is beginning to learn what experience has taught us, improving successes, and correcting mistakes. In a previous point of this paper, it was stated that the most critical feature in global performances of high-temperature solar systems is the behaviour of conventional parts when fitted to solar devices.

To serve as an example, let us consider the stair-step daily efficiencies diagram of the IEA-SSPS Central Receiver System. Solar components (heliostat fields, receivers), alone or together, exhibit high efficiency with good improvement potentials. Storage presents good behaviour in short time periods (hours, days), that rapidly worsen over a longer range. The power conversion system has the lowest efficiency among all parts of the plant, as can be easily foreseen regarding the Second Law of Thermodynamics applied to a cyclic thermal engine; its efficiency can be improved mainly with higher hot temperature.

A second critical question arises when considering transients, which cannot be avoided in any way in solar devices. Radiation reflected by heliostat mirrors has of course negligible response time. New technology receivers show excellent fitting to transients, the better the higher the concentration ratio; moreover, warming up can be as short as 5 minutes. However, storage and power conversion systems have bad dynamic responses to transients and need long warming-up times before reaching nominal conditions.

To draw the guidelines in respect to the more promising processes driven by high-temperature solar energy requires matching the features already stated with stable, transportable, and storable kinds of matter and energy. It is easy to understand that direct, non-cyclic production of raw materials and fuels, fulfils the whole set of conditions. As a matter of fact, from a solar technology point of view, only heliostat field or parabolic dish and receiver, acting as a reactor, are necessary, the storage function being carried out by the final product itself, and avoiding as a nonsense in this conceptual scheme, the power conversion system, or equivalent. Regarding transient response of the process itself, high kinetics and non-irreversible changes when transients occur are highly desirable. In relation to environmental cleanliness of the process, the general idea is to use pollutants as reactants and get products with low, if any, negative ecological impact. Beside that, products should have the before mentioned characteristics of stability, transportability, and storability.

Even if the panorama is promising, it would be naive to think that, because we are now on the right track, we will continue on this way forever. There are important unsolved questions that need adequate answers: First, few processes that meet all the requirements stated in the above paragraph have been described and even these have not been fully analyzed, mainly from the point of view of solar technology. Second, size, weight, and materials of receiver-reactor apart from high temperatures and

CHIMIA 43 (1989) Nr. 7–8 (Juli–August)

irradiances give raise to problems whose solutions are not immediate. Third, relatively short periods of direct operation with solar radiation can affect the economy of the processes if receiver-reactor costs are high; these working periods can be prolonged with an intermediate storage, so that it must not be forgotten in advance.

5. Foreseeable Chemical Processes driven by High-Temperature Solar Technologies

A short review of processes that have aroused more interest follows. They are more extensively commented in *Solar Energy for High-Temperature Technology and Applications* (1987) and in the context of the present Charmey Workshop proceedings.

- Synthesis gas production: future trends of demand go mainly towards fuels, ammonia, methanol, and hydrogen. Actual production is based on catalytic reactions where hydrogen and carbon monoxide act as reactants; methane reforming with steam has a priori excellent conditions to be solar driven.
- Production of light hydrocarbons: methanol, ethene, ethanol or acetylene can be obtained from atmospheric carbon dioxide, so greenhouse effects are decreased. Also, refined products from coal and coal gasification have been cited.
- Hydrogen production by means of electrolysis of high-temperature steam, thermo-chemical reactions like the sulfur-iodine process or water reduction in a multistep reaction using metal oxide systems, or even direct thermal splitting of water.
- Reversible redox processes in metal oxides, like binary transition ones, or spinels or perovskites, to be used as reactants, catalysts, or battery materials.
- Metal hydride systems, mainly as reversible storage of hydrogen.
- High-temperature thermal dissociation, yielding calcium oxide, or alumina.
- Carbo-thermal reduction to obtain silicon carbide or aluminium.
- Calcination of e.g. limestone to produce cement.
- Compound formation, for instance silicon carbide.

6. Technological Developments Required

Most of the processes before mentioned need specific solar components, which must be available prior to their use. These developments can be classified in relation to receivers, direct absorption, and storage.

Receivers can be divided into tubular or volumetric. Tubular receivers have working fluid inside a sort of pipe, whereas volumetric receivers are filled with a porous absorber substance, which communicates heat to the working fluid, usually air, that flows through it. In turn, tubular receivers can be external or cavity ones, in both cases with metallic or ceramic tubes. An important concept that requires further studies is an integrated receiver-reactor, because of its small thermal losses and fast dynamic response; moreover, receiver-reactors can perform at temperatures higher than 850 °C with metal tubes and 1200 °C with ceramic ones. To reach such temperatures and associated irradiances, secondary concentrators are very often necessary; in this way, research and development of these devices will be well worth rewarding.

Direct absorption is very promising because very concentrated radiation strikes directly over reactants or heat transfer media, without interposed walls. Regarding irradiated substances, liquids, solids with catalysts nuclei, or particulate suspensions can be used: as a rule, very small pieces with high surface/volume ratio are convenient. More useful applications are closely related with photo-catalysis, chemical reactions, or heat transfer. Main advantages of direct absorption deal with higher values of irradiance, several MW/m^2, and temperatures, over 2000 °C, with cheaper, lighter receivers as well as lower thermal and mechanical stresses. Further research must be carried out in fields such as particle absorption and scattering of concentrated radiation, mechanics of two moving phases, materials, measurement techniques and devices, and windows transparent to concentrated radiation. An important point is to identify processes matched well enough to direct absorption.

Storage devices must overcome inconveniences that arise with energetic and exergetic losses, and additional equipment to perform charge and discharge operation. Nevertheless, all of them can be worthwhile because of a better global performance of the system, to match supply to required demand, lessen start up and shut down losses, attenuate transient effects, keep working temperatures, and cover peak-hour demand. Classification of storages can be based on how energy is stored (sensible heat, latent heat, chemical storage ...) or how much time it is stored (transitory regime, hours, days, seasonal, and so on). Progress in this field refers to heat transfer phenomena and operation of high-temperature storage in rock beds, composite materials used with latent heat, and chemical reactions more suitable for storage and transport.

Suggested Readings

M. Becker, A. Skinrood (Ed.): *Proc. IEA-SSPS Experts Meeting on High-Temperature Technology and Applications, Atlanta (1985)*, SSPS Technical Report 1/85.

M. Becker (Ed.): *Proc. Third Int. Workshop on Solar Thermal Receiver Systems, Konstanz (1986)*, Springer-Verlag, Berlin (1986).

W. Grasse, M. Becker, B. Finnstrom: *Solar Energy for High-Temperature Technology and Applications*, DFVLR, Köln (1987).

C. Gómez Camacho: *Aplicaciones no electricas de los sistemas de receptor central; Curso sobre sistemas de receptor central; Plataforma solar de Almeria* (1988).