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Hydrogen from Solar Energy

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HYDROGEN FROM SOLAR ENERGY

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ABSTRACT

This paper describes those portions of the Photo/Thermochemical Research Program that possibly apply to the production of hydrogen from sources such as water or hydrogen sulfide. That research centers around understanding high flux solids decomposition reactions and how to best exploit photoreactions so the energy contained in the entire solar spectrum is used.

INTRODUCTION

The Photo/Thermochemical Research Program, sponsored by the Solar Thermal Technology Division of the United States Department of Energy, has the primary goal of defining the potential of solar energy in achieving desirable solar unique or solar beneficial effects that are cost-effective, with emphasis on fuels and chemicals production. Solar unique effects are those energy transformations that can only be achieved by using solar energy. Solar beneficial effects are those energy transformations that can be achieved more cost-effectively or easily by using solar energy rather than other energy forms, such as fossil energy. Hydrogen production is a part of this Program, although it is not the focus. This paper describes the portions of the program relevant to hydrogen production.

The solar resource is characterized by:

Availability of photons of distributed energy levels for direct use (photoreaction applications),

Ability to achieve very high heating rates (solids decomposition reaction applications),

Ability to achieve very high temperatures (thermochemical applications).

The research program addresses the opportunities defined by the above attributes. The high-temperature thermochemical reactions have a rich history of research, whereas the high heating-rate decomposition reactions of solids have been little researched. Photoreactions have also been extensively researched, with much more emphasis on science than on application.

PROGRAM STRUCTURE

The management structure is depicted on Fig.1, which shows that technical management support for research activities is provided by the Solar Energy Research Institute (SERI) and for development and application activities by Sandia National Laboratory-Livermore (SNL-L). This paper emphasizes those activities for which SERI has technical responsibility.

Fig.2 shows some of the relevant activities for which SNL-L has technical responsibility. These activities center around the sulfur-iodine water-splitting cycle developed by GA Technologies. Briefly, GA Technologies has built and is testing a pressurized sulfuric acid decomposition reactor in a laboratory radiant furnace environment. The test will determine if a metallic reactor can be built to successfully operate in a high-temperature, high-flux environment. The other activity is to develop and test a SiC vaporizor for sulfuric acid, with emphasis on developing a viable seal for the tube ends. That work is being performed by Garrett Airesearch.

Fig. 3 shows some of the relevant activities for which SERI has technical responsibility. These activities center on solids decomposition reactions, with research being performed at the University of Hawaii and at the Lawrence Berkeley Laboratory, and on photoreactions, with research being performed at SERI.

RESEARCH TASKS

Goals for the high heating-rate solids decomposition reaction research are:

To understand the chemical and physical phenomena that occur in high heating rate solids decompositions, and

To assess the potential of solids decompositions reactions for practical application in fuels and chemicals cycles.

Potentially practical applications range from calcination of limestone to decomposition of solid sulfates produced in water-splitting cycles. The rationale for the research is that it may be possible to control the reaction pathway by controlling the rate of heat input to the reacting solids. The general approach is to develop a fundamental knowledge of the phenomena, with complementary tasks approaching the problem from different directions.

Mike Antal at the University of Hawaii is investigating the direct radiant heating of inorganic solids from a chemical approach to determine the effect of heating rate on zinc sulfate decomposition with emphasis on understanding the mechanistic and kinetic effects. Experiments are being run with high and low heating rates to determine if low heating-rate data can be extrapolated to describe high heating-rate decompositions. A high heating-rate thermogravimetric analyzer, capable of 4-5 weight readings per second, is being constructed for use in an arc image furnace that can supply light at an intensity up to 10,000 suns. The bulk of the work will be done using that equipment and very high heating rates.

Arlon Hunt, of the Lawrence Berkeley Laboratory is investigating the direct radiant heating of particle suspensions from a physical approach to characterize the effects of very high fluxes and rapid heating rates on the heat transfer and optical phenomena for reacting solids. Progress is being made both experimentally and theoretically. A literature assessment to chose the appropriate reactions and to catalog the appropriate physical properties is well underway. Computer programs to describe the interaction between the flux and the solid particles have been written, debugged and are being revised. A small, high-intensity arc image furnace is operational, and they are currently investigating iron oxide decompositions.

The goals for photoreaction research are:

> To understand the effect of light intensity, along with catalysts, on photoreactions such as water-splitting.
>
> To understand how to effectively use the entire solar spectrum since only a small portion of the solar photons are sufficiently energetic to initiate photoreactions such as water-splitting.

David Johnson of SERI is investigating the feasibility of quantum-thermal hybrids to determine how to use the solar spectrum in a hybrid system with emphasis on determining the potential attractiveness of the hybrid relative to either a pure thermal or quantum process. Fig. 4 illustrates one possible hybrid. Thermodynamic efficiency curves have been calculated for both coupled and decoupled hybrids, spectral splitting techniques have been reviewed and assessed, and an economic appraisal of a water-splitting hybrid is underway.

Art Nozik of SERI is performing photoreaction research to experimentally assess the effect of light intensity (up to 100 suns) and the effect of temperature (up to 100 C) on the photoelectrochemical splitting of water and hydrogen sulfide using various photocatalysts and substrates, e.g., Ru on CdS. It is of interest to determine if the undesirable photoelectrode oxidation reaction can be stabilized when the desired major reaction is enhanced by increasing light intensity. A photoreaction apparatus has been built and is operational and early results indicate some success with hydrogen sulfide splitting, and difficulty with water-splitting.

The investigations of D. Peterson, University of San Diego, and J. Biddle, California State Polytechnic University in Pomona; are also of interest (1,2). Their review of solar fuel-producing quantum conversion processes concluded that a reasonably sized photochemical water-splitting plant would need an overall process efficiency well in excess of 10% to produce hydrogen at a reasonable cost. That efficiency is significantly greater than the actual efficiencies of photochemical processes at the current state of development. Their investigations were sponsored by this program in Fiscal Year 1983.

OTHER RELATED RESEARCH

The Solar Thermal Technology Division also sponsors relevant research in other programs. Southwest Research Institute, through the Innovative Concepts Research Program, is investigating the production of ammonia from moist air which is passed over a porous catalyst being irradiated by solar energy. Since ammonia can be catalytically dissociated to hydrogen and nitrogen, the cycle can be considered a water splitting cycle. An experimental investigation is ongoing, but early results indicate that efficiency of the ammonia synthesis reaction is low.

SUMMARY

Research in the Photo/Thermochemical Research Program relates to and supports hydrogen production, although it is not the current focus of the program. In the long-term hydrogen will be one of the most important of the solar fuels and chemicals.

REFERENCES

1. Peterson, D.B., Biddle, J.R., and Fujita, T., Review of Solar Fuel-Producing Quantum Conversion Processes, DOE/JPL-1060-71, JPL Publication 84-32, May 1984.

2. Biddle, J.R., Peterson, D.B., and Fujita, T., Solar Photochemical Process Engineering for Production of Fuels and Chemicals, DOE/JPL-1060-72, JPL Publication 84-31, May 1984.

Program Management Structure

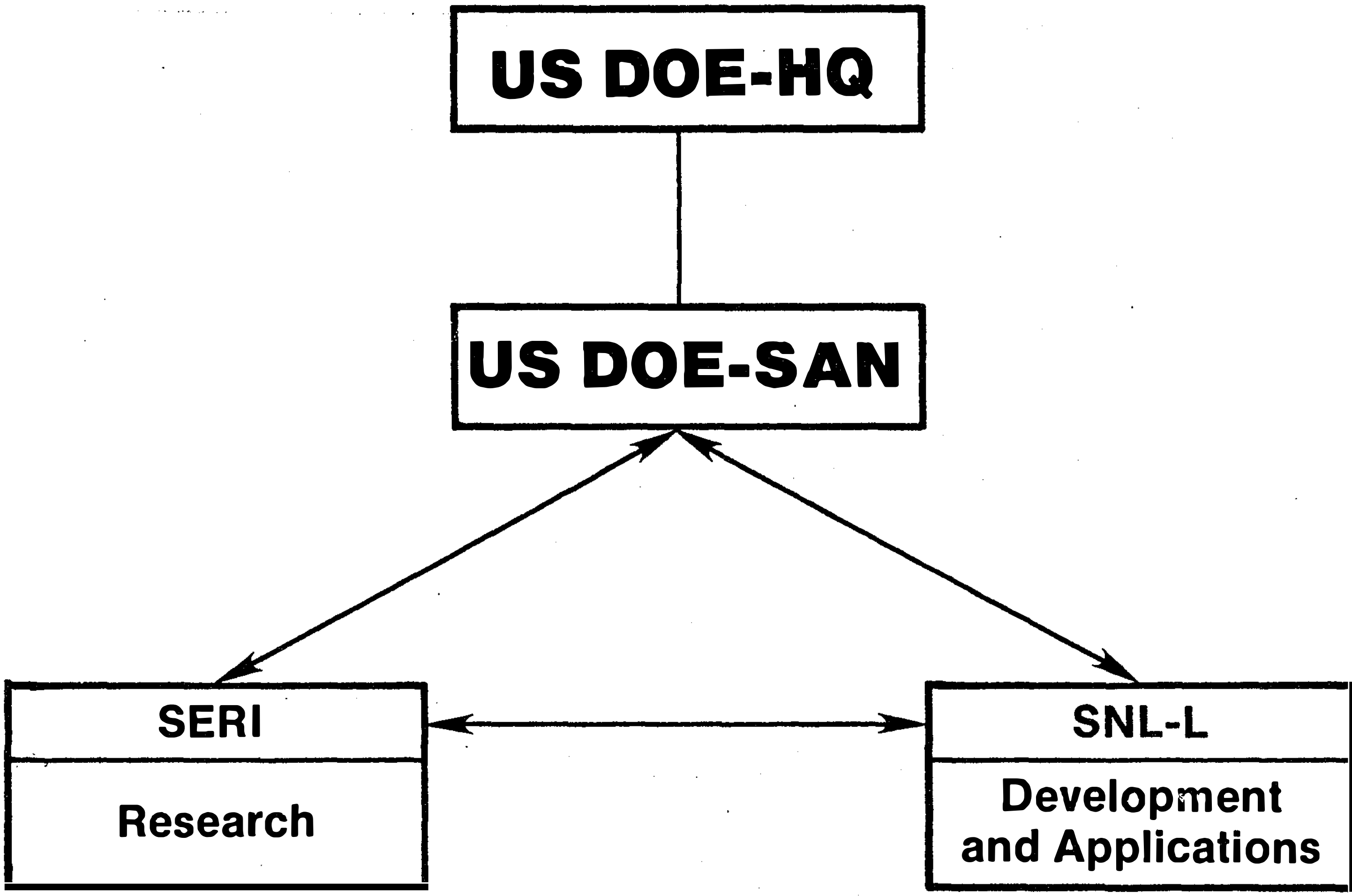

Figure 1

SNL-L Activities

Photo/Thermochemical Research

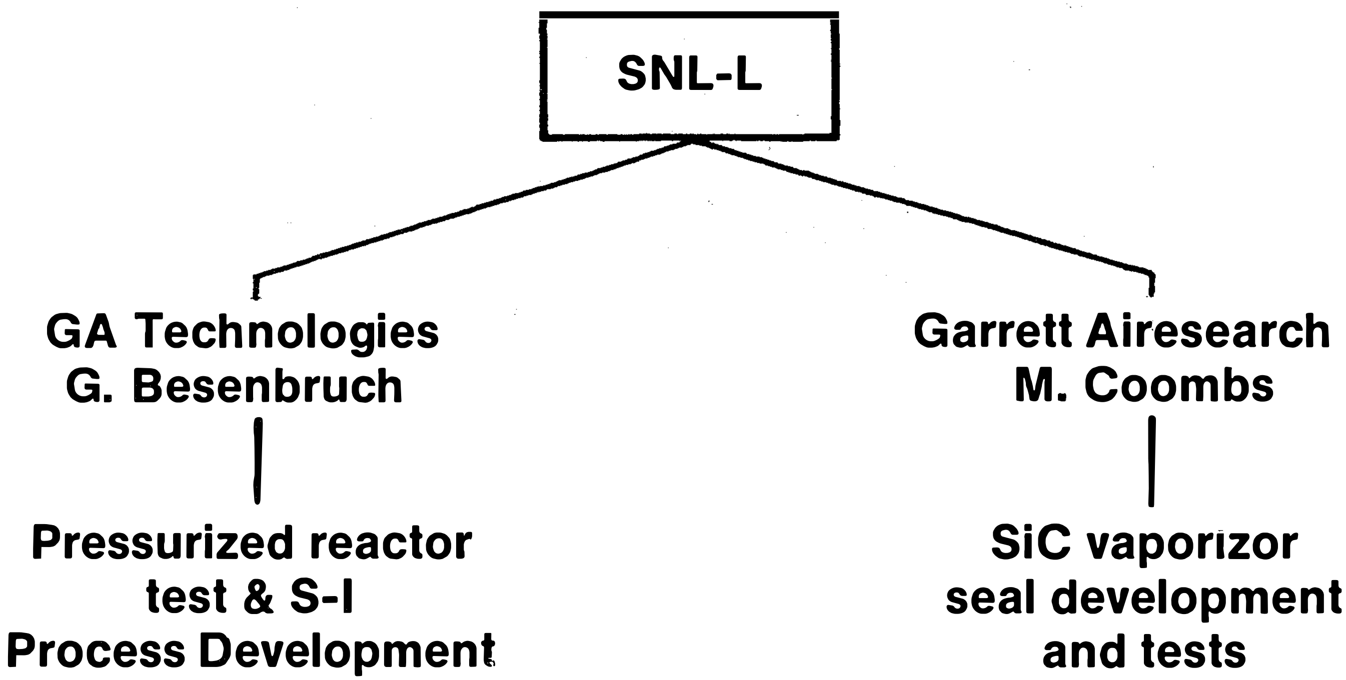

Figure 2

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SERI Activities

Photo/Thermochemical Research

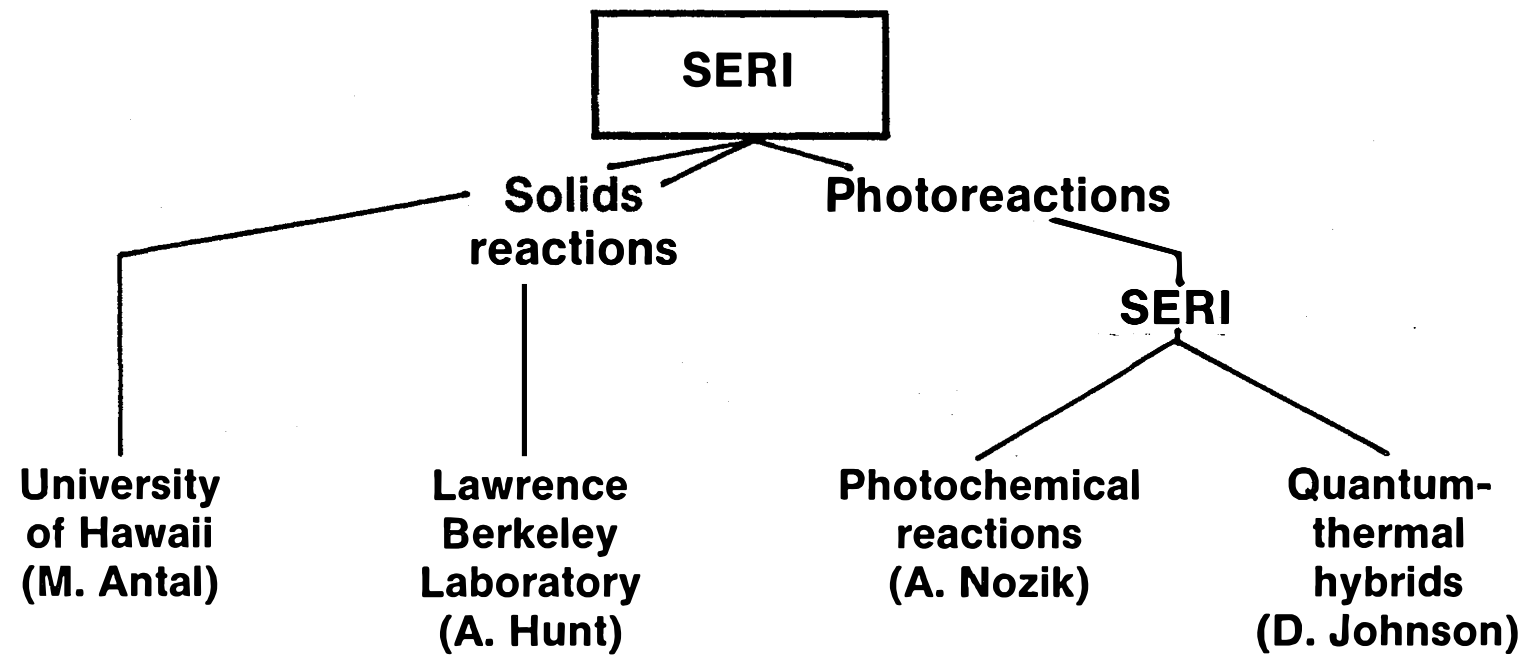

Figure 3

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A Decoupled Quantum-Thermal Hybrid

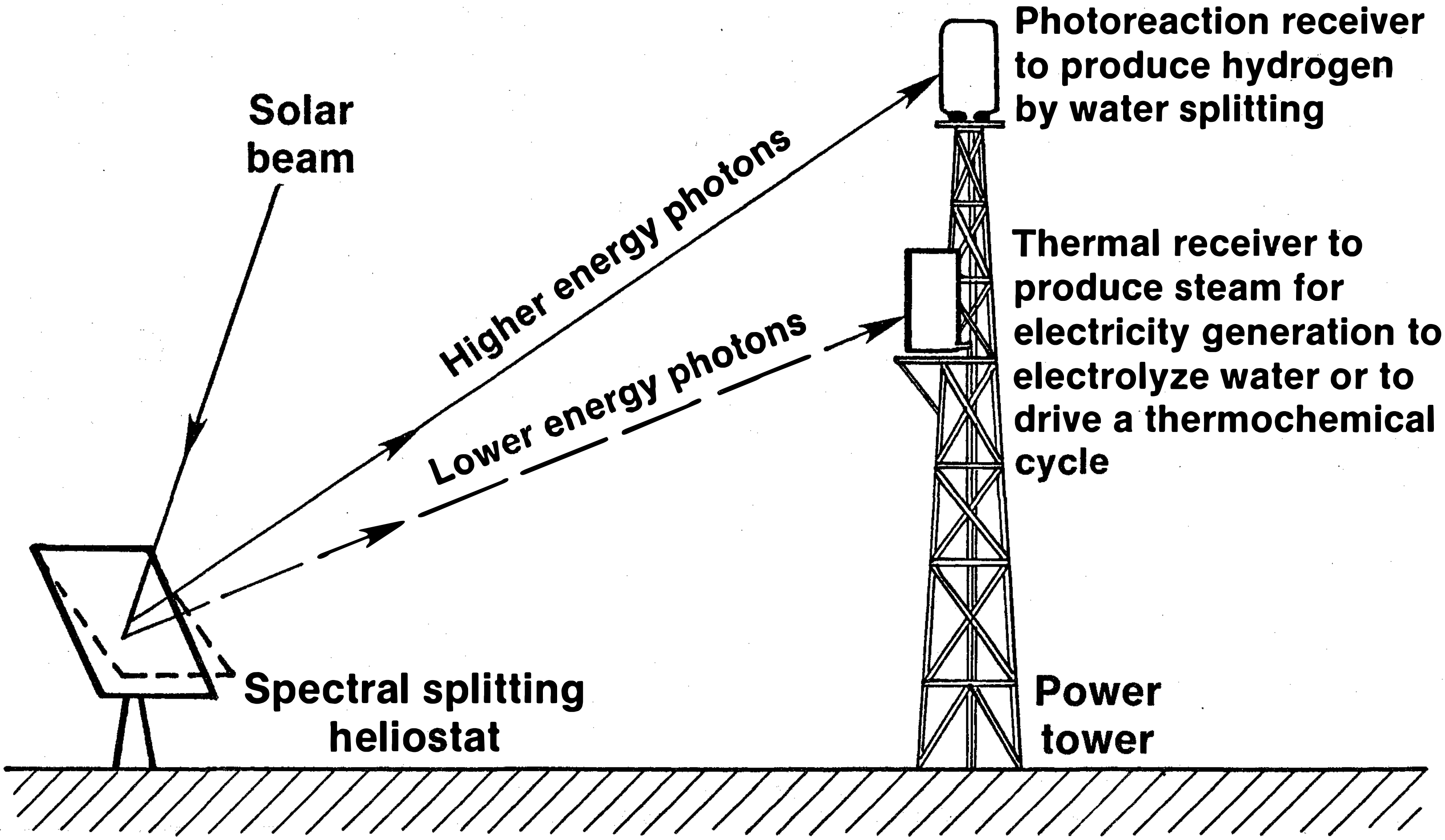

Figure 4