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A Solar Regenerative Thermoelectrochemical Converter (RTEC)

Executive Summary of Final Subcontract Report

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El Segundo, California

National Renewable Energy Laboratory
A Division of Midwest Research Institute
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On September 16, 1991 the Solar Energy Institute was designated a national laboratory, and its name was changed to the National Renewable Energy Laboratory.

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Executive Summary

This is the executive summary of Hughes Aircraft Company's final report on research contract ZX-8-07057-1 from the Solar Energy Research Institute (SERI), Golden, Colorado. The full report, which contains a detailed description of the two-year effort by both SERI and Hughes, is currently subject to a government secrecy order which precludes public release of the information. Copies of the full report will be made available for general release whenever that order is lifted.

The contract covered Phase III of a program to investigate a regenerative thermoelectrochemical converter (RTEC) for converting solar thermal energy into electricity. The work at Hughes was performed in conjunction with a complementary effort at SERI.

Several methods have been proposed for the collection of solar thermal energy, but few viable options exist for the conversion and storage of that energy. The choice is particularly limited for small, dispersed systems such as those using parabolic dish collectors. The more established energy conversion methods tend to be inefficient or unreliable on the small scale, while newer methods require a bottoming cycle to achieve adequate efficiencies.

The RTEC operates with high, scale-independent efficiencies and has a built-in capacity for energy storage. For the first time, therefore, efficient, cost-effective conversion and storage of energy are within reach for the whole range of solar thermal energy systems, regardless of scale.

The RTEC converts heat to electricity in a two-stage cycle that couples a high-temperature chemical process with a low-temperature electrochemical process. It comprises two major subsystems: an electrochemical converter and a thermal regenerator. The regenerator is further divided into a stripper and a condenser. The converter and the condenser subsystems were developed at Hughes. SERI took primary responsibility for the high-temperature stripper unit, in which solar heat input is converted to chemical energy.

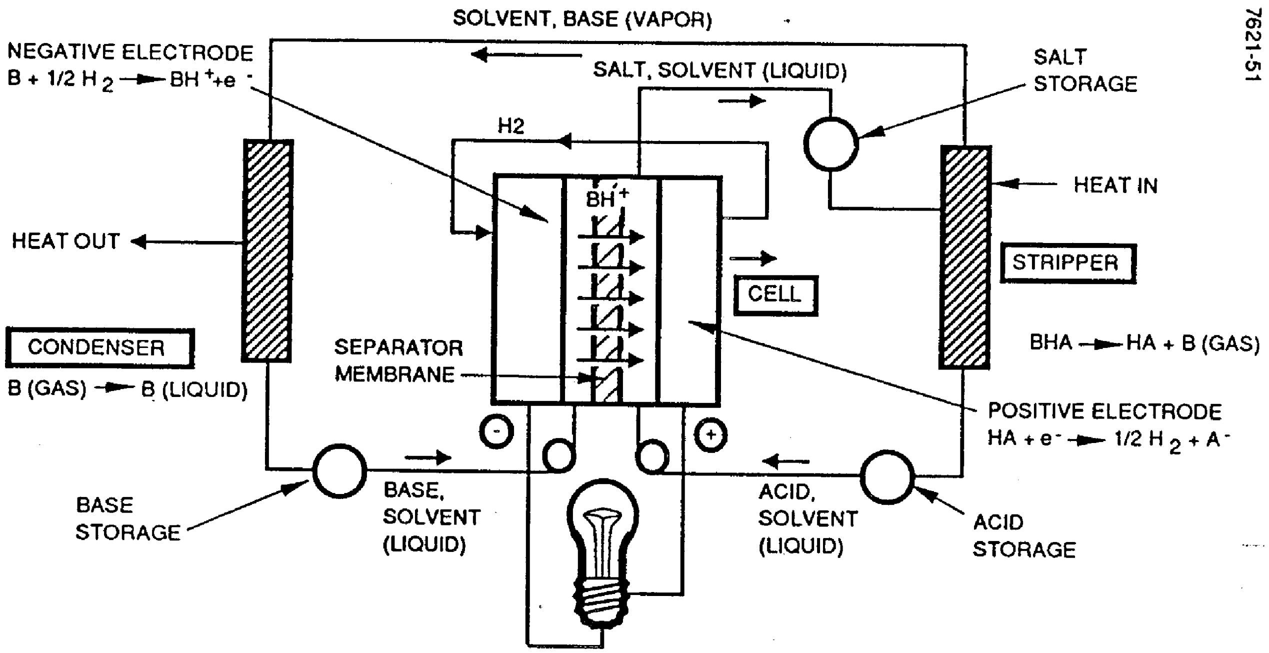

Figure 1. Closed-loop RTEC system uses heat to separate acid and base chemicals, which then recombine to produce electric power.

In the RTEC system (Figure 1), a salt is chemically converted at high temperature to an acid and a base. These chemicals are cooled and fed into an electrochemical cell consisting of two hydrogen electrodes separated by an ion-selective membrane. Hydrogen is evolved at the acid electrode and consumed at the base electrode, yielding electric power and a salt. The salt is returned to the regenerator, completing the cycle. When required, the two halves of the system can be uncoupled and the chemicals held in storage.

The program was divided into several tasks in which electrochemical and thermal subsystems were first developed separately and then integrated into a closed loop. Electrochemical cell research focused on several different types of membranes and electrodes and on their interaction with the working fluids. Open-circuit voltages of 500 to 600 mV were found with typical working fluid compositions. At peak power, current densities of >200 mA/cm^2 were attained, far exceeding the program goal of 50 mA/cm^2 . A corresponding power density of 50 mW/cm^2 was measured. The electrodes were found to be free of activation polarization, indicating that catalysis of the electrochemical reactions is relatively simple.

Scaled-up studies of the electrochemical cell showed that the electrode area and number of cells can be increased without loss of performance. A two-cell bipolar stack with 6-by-6-in. electrodes was constructed. This stack produced 16 watts, exceeding the program goal of 10 watts.

Condenser research showed that the chemistry of the alkaline part of the system is ideal for the RTEC. The kinetics of the condensation/absorption process were found to be rapid, and a scaled-up condenser was constructed.

Regeneration studies established that thermal dissociation of the salt (produced in the electrochemical cell) in the stripper occurs rapidly and with yields of up to 41%. The acid products of the regenerator can be adjusted in composition to match the requirements of the cell. Suitable corrosion-resistant construction materials were identified. However, maintaining high-temperature seals proved to be difficult.

Closed-loop testing proved that the products of the cell match the products of the regeneration process, demonstrating that long-term closed-loop operation is possible. A net conversion efficiency of heat to electricity of 11.76% was measured for the closed-loop system.

An analysis of engineering and cost factors showed that the system is competitive with alternative technologies. Key to improving system efficiency beyond the existing levels is the development of a cell membrane with reduced solvent transport rates. This change will allow efficiencies of 30%–40%. Limited tests indicate that reduced solvent transport can be accomplished, but with the added benefit of using low-cost materials. Furthermore, the relatively simple catalysis of the hydrogen electrode reaction suggests that low-cost catalysts can be used. Based on these projected improvements, costs for the RTEC system (exclusive of the solar concentrator) can be as low as $43 per kilowatt, with a power density of 309 watts per pound.

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