SERI/TP-234-1681
UC Category: 62

Thermochemical Energy Storage and Transport

R. Gerald Nix

August 1982

To be presented at the Physical and Chemical Storage Annual Contractors' Review Meeting
Washington, D.C.
23-27 August 1982

Prepared Under Task No. 1296.00
WPA No. 12-348

Solar Energy Research Institute
A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401

Prepared for the
U.S. Department of Energy
Contract No. EG-77-C-01-4042

THERMOCHEMICAL ENERGY STORAGE AND TRANSPORT

R. Gerald Nix
Solar Energy Research Institute
1617 Cole Boulevard, Golden, CO 80401

ABSTRACT

This paper describes feasibility studies performed by SERI of thermochemical energy storage and transport (TEST). Cases studied include a large central receiver heat utility and a small industrial process heat application with distributed parabolic dish solar collectors. TEST does not appear to be generally cost-effective; however, there are special cases of cost-effectiveness. The overall recommendation is that research on thermochemical processes should emphasize the manufacture of renewable fuels using solar energy and the search for more cost-effective TEST systems.

INTRODUCTION

This paper describes feasibility studies of thermochemical energy storage and transport (TEST). TEST involves the capture of thermal energy as near-ambient-temperature, chemical bond energy through use of a reversible chemical reaction. The chemicals are not consumed, merely acting as energy carriers in this cyclic process. The primary motivation for studying TEST is the potential for efficient long-term energy storage and efficient long-distance energy transport because both are possible at near-ambient temperatures. This study is to determine the technical and economic feasibility of TEST and make recommendations for future thermochemical energy research. This paper describes the results of studies for a large-scale heat utility (Case A) and a small-scale industrial process heat application (Case B).

CASE A: LARGE-SCALE HEAT UTILITY

System Definition. A large-scale heat utility (Fig. 1) was studied. From the single central receiver heat source, 10 equally sized heat users each receive 26.2 MW_t (89.5 x 10^6 Btu/h) as 4.14 MPa (600 psig), 400°C (750°F) superheated steam. The energy transport and storage system is thermally decoupled from the solar energy collection system through use of a working fluid system which contains an independent diurnal storage system. The source and users are connected by pipelines, and the users are grouped together in an industrial park. Each user is sold the product steam since the utility owns all equipment. The analysis is structured so that the storage capacity and the transport distance can be varied.

The objective met by TEST can also be met through use of sensible thermal energy storage and transport. Therefore, for comparison, a molten draw salt system (60% $NaNO_3$, 40% KNO_3) was studied with storage provided by multiple insulated tanks as proposed by Martin-Marietta (1). Another standard for comparison is steam generated by fossil-fuel-fired boilers at a central site and transported to the individual users.

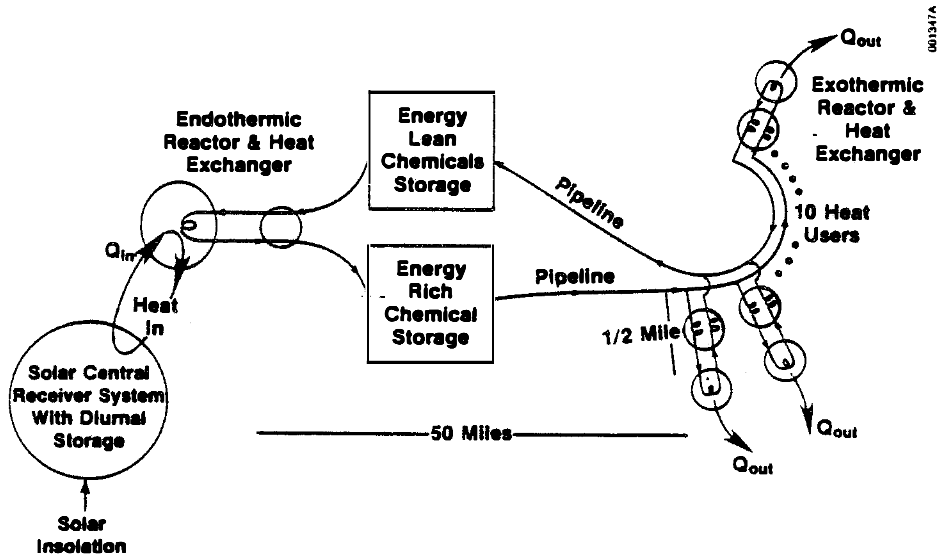

Figure 1. Heat Utility Model

Economic Model. The economic model described in the EPRI "Technical Assessment Guide" (2) is appropriate for a heat utility. The levelized revenue requirement is the appropriate criterion because alternatives can be compared by single numbers that characterize the cost of each alternative.

Calculations were based on a 30-yr life from 1990 to 2020, with tax credits, a 0.65 capacity factor for energy transmission without long-duration storage, and a 0.90 capacity factor for systems with long-duration storage. The fuel prices listed in Ref. 3 are used.

Process Definition. The reactions appearing most promising for near-term application and chosen for the feasibility study are

$$\text{heat} + CH_4 + H_2O = CO + 3H_2,$$

$$\text{heat} + CH_4 + CO_2 = 2CO + 2H_2,$$

$$\text{heat} + Ca(OH)_2 = CaO + H_2O,$$

$$\text{heat} + 2NH_3 = N_2 + 3H_2, \text{ and}$$

$$\text{heat} + 2SO_3 = 2SO_2 + O_2.$$

Results. The SO_3 system does not appear to be feasible for this application.

Figures 2 and 3 present some of the results. Details are listed in a report by Nix and Bergeron (3). A recent report by Sandia (4) indicates a base solar energy of $6.63/GJ ($7/MBtu) is possible.

Conclusions. The major conclusions for a large-scale heat utility are as follows:

- The draw salt system has the greatest economic potential for 100-350 h storage capacity.

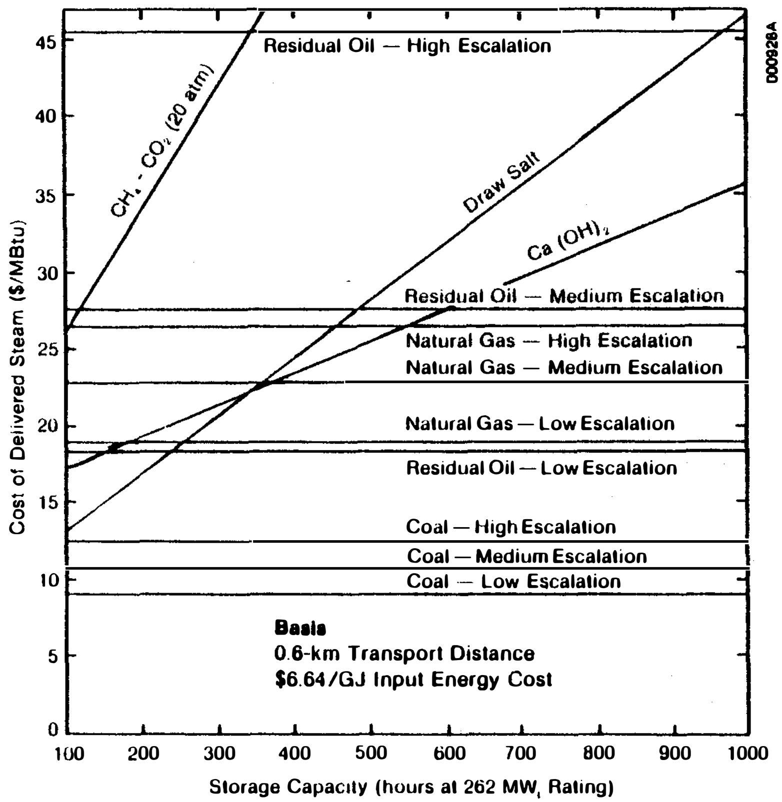

Figure 2. Effect of Storage Capacity on Delivered Energy Cost

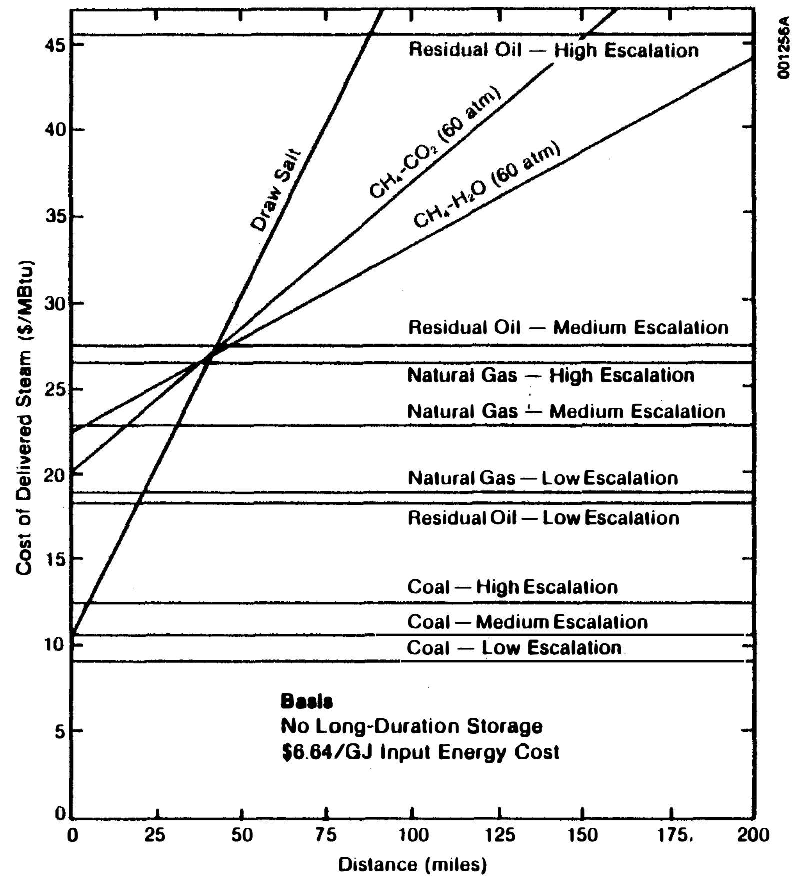

Figure 3. Effect of Transport Distance on Delivered Energy Cost

- The $Ca(OH)_2$ energy storage system has the most economic potential for >350 h of storage capacity.
- Central receiver thermal systems with $Ca(OH)_2$ long-duration storage subsystems can compete with oil or natural gas-fired boilers.
- The CO_2-CH_4 long-duration energy storage system does not appear cost-effective.
- No central receiver thermal system with the long-duration storage subsystems studied is competitive with coal-fired boilers.
- Transport of sensible energy by molten draw salt appears more favorable than the CH_4 thermochemical energy transport systems for distances up to 65 to 80 km.
- Beyond 80 km, either CH_4 thermochemical energy transport system is more cost-effective than a molten draw salt system.
- For transport distances greater than 80 km, a solar thermal system with a CH_4 thermochemical energy transport subsystem is competitive only with oil-fired boilers at a high oil price escalation rate.

CASE B: SMALL-SCALE INDUSTRIAL PROCESS HEAT APPLICATION

System Definition. An industrial process heat system with parabolic dish solar collectors (Fig. 4) is to deliver 1 MW_t (3.41×10^6 Btu/h) as 4.14 MPa, 400°C superheated steam. A field of parabolic dishes, each 11 m in diameter, collects the solar energy. The study is not site specific. Both molten draw salt storage and nonstorage situations were considered. The dish field and the steam user are separated by 0.4 km (0.25 mile) with energy transport by either thermochemical reactions or sensible energy. The industrial user owns all of the equipment. Neither the transport distance (0.4 km) nor the amount of storage (0 or 24 h) varies in this study. Fossil fuel backup systems are not included since transport alternatives are compared at equal capacity factors. Standards of comparison are a solar thermal system with molten draw salt transport and storage, or a fossil-fuel-fired boiler to generate steam at the user site.

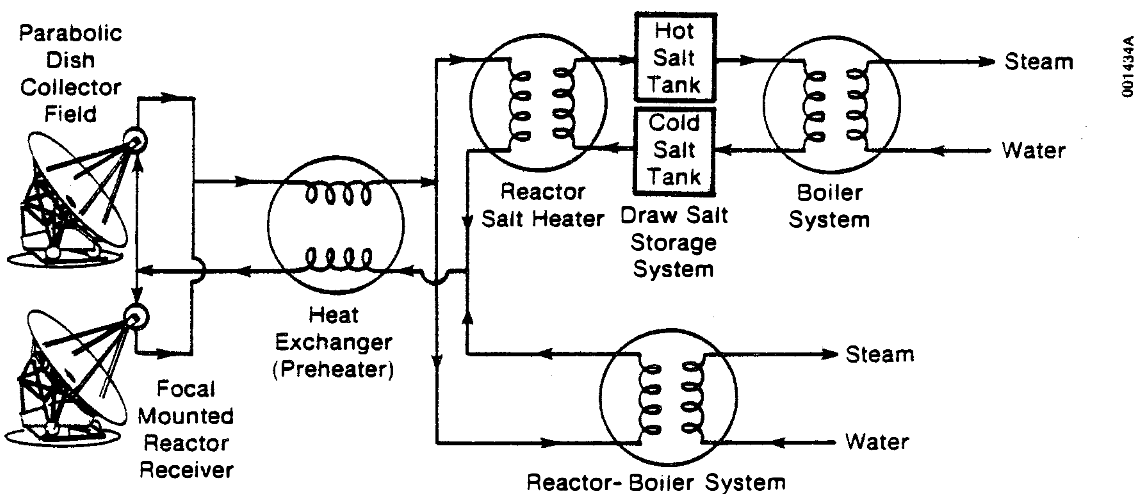

Figure 4. Distributed Dish IPH System: 24-Hour Storage

Economic Model. The economic model and parameters used for Case A are appropriate for Case B. The fixed charge rate is 0.25 and the levelizing factor is 1.886 to reflect the industrial financing situation.

Process Definition. The reactions chosen for thermochemical energy transport are

$$\text{heat} + CH_4 + CO_2 = 2CO + 2H_2 \text{ and}$$
$$\text{heat} + 2SO_3 = 2SO_2 + O_2.$$

Results. The dish IPH solar system can produce steam for $74/GJ using molten salt transport, for $78/GJ using CH_4 thermochemical transport, and for $194/GJ using SO_3 thermochemical transport (no storage). Corresponding costs are $34-$41/GJ for natural gas boilers and $33-$59/GJ for residual oil boilers. Within the error bounds of this study, the draw salt and CH_4 thermochemical transport system costs are equal. When 24 h draw salt storage is included, draw salt transport results in a delivered energy cost of $82/GJ, whereas the CH_4 thermochemical transport system results in $133/GJ, and the SO_3 system costs are even higher. The costs of installed dishes and thermal receivers were taken from Ref. 5. The cost of the thermochemical receivers is the approximate cost of construction materials. Details and additional results are in Ref. 3.

Conclusions. The major conclusions are as follows:

- The CO_2-CH_4 system transports energy at a lower cost than the SO_3 system.
- The CH_4-CO_2 thermochemical system is not cost-effective relative to molten draw salt energy transport, particularly when storage is included.
- Natural gas- or oil-fired boilers will produce energy at a lower cost than the distributed dish system.

GENERAL DISCUSSION OF TEST

For both the large-scale heat utility and the small-scale IPH application, TEST has failed to show economic potential superior to sensible heat transport and storage in molten draw salt.

Why was TEST not particularly cost-effective? The primary reasons are the high investment for chemical reaction systems and the low efficiency of the thermochemical system. These factors are the result of both the choice and process definition for the thermochemical systems. It is difficult to envision any innovations sufficient to change the conclusions of this study.

Are there other thermochemical energy systems that might be cost-effective? Thermochemical energy studies should not yet be terminated. The ultimate application of thermochemical energy is manufacture of a renewable, synthetic fuel. Such renewable fuels are generated from combustion products by the absorption of energy from either solar or nuclear sources. In the hydrogen program, for example, combustion product H_2O is converted back to H_2 fuel. A process that has not been sufficiently evaluated is generation of fuels via the analogous carbon dioxide reactions. Combustion product CO_2 is converted back to CO: heat + $CO_2 \rightarrow CO + 1/2\ O_2$. However, this direct reaction is not favored thermodynamically so it must be coupled with another reaction (e.g., an oxide cycle) to drive it. Once CO is obtained, it can be used to produce H_2. H_2 and CO can be reacted to produce liquid fuels. Thus, a high-energy liquid fuel can be produced using energy from a stationary source such as a central receiver solar system or a nuclear reactor and waste flue gas containing CO_2. Fuel generation via thermochemical reactions should be thoroughly investigated to define the economic potential and research opportunities.

More efficient, less costly TEST systems should be defined and researched. Specific efforts should be to find liquid systems in which the high energy density will result in lower investment and to make use of heat pumping to maximize efficiency and cost-effectiveness.

RECOMMENDATION

The recommendation is that the thermochemical energy portion of the SERI Energy Storage program should emphasize thermochemical fuel generation and the search for more cost-effective TEST systems. The program should be continued through FY 1983, and if justified, through FY 1984 to thoroughly define the potential of thermochemical energy systems.

REFERENCES

1. Martin-Marietta Corporation, "Conceptual Design of Advanced Central Receiver Power System," DOE/ET/20314-1/2, 1978.

2. Electric Power Research Institute, "Technical Assessment Guide," EPRI PS-1201-SR, 1979.

3. R. G. Nix and P. W. Bergeron, "Feasibility of Thermochemical Energy Storage and Transport," SERI/TR-234-1655, in press.

4. K. W. Battleson, "Solar Power Tower Design Article: Solar Thermal Central Receiver Power Systems--A Source of Electric and/or Process Heat," SAND 81-8005, 1981.

5. J. P. Thornton, Kenneth C. Brown, Joseph G. Finegold, James B. Gresham, F. Ann Herlevich, and Thomas A. Kriz, "Final Report: Comparative Ranking of 0.1-10 MW_e Solar Thermal Electric Power Systems," Vol. II: "Supporting Data," SERI/TR-351-461, 1980.