SOLAR THERMAL POWER APPLICATIONS

Program Area Synopsis:

A comprehensive development of thermal storage technologies has been planned with DOE to match the solar thermal power system requirements and milestones in the FY 80-85 period. The program provides advanced storage subsystems for nearer term solar thermal applications, and establishes a storage technology base for future applications. Early efforts will stress storage for repowering/industrial retrofits, total energy, and small community systems. These applications reflect the current direction of the Thermal Power Systems Branch of the DOE Division of Central Solar Technology. The program will be implemented by DOE-designated lead laboratories with overall program management to be the responsibility of a DOE-designated lead center. SERI's tasks as they relate to supporting research and technology are an integral part of this activity.

SOLAR THERMAL POWER STORAGE APPLICATIONS

LEAD LABORATORY OVERVIEW

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SUMMARY

This overview describes the implementation of the applications elements of the Thermal Energy Storage for Solar Thermal Applications (TESSTA) program. The TESSTA program evolved from a joint plan of the DOE Division of Energy Storage Systems (STOR) and Central Solar Technologies (CST). The program includes the accelerated development of thermal storage technologies matched to solar thermal power system requirements and scheduled milestones. The program concentrates on storage development in the FY80 to 85 time period with emphasis on the more near-term solar thermal power system applications. The basic strategy of the program is both aggressive and flexible. Reflecting the current direction of the Thermal Power Systems (TPS) Branch, CST, storage for repowering/industrial retrofit, total energy, and small community system applications is stressed in the early years.

GENERAL PROGRAM DESCRIPTION

Recognizing thermal energy storage as potentially critical to the successful commercialization of solar thermal power systems, the DOE Divisions of Energy Storage Systems (STOR) and Central Solar Technologiest (CST) have established a comprehensive and aggressive thermal energy storage technology development program in direct support of solar thermal power applications. The program concentrates on storage subsystem development in the FY80 to 85 time period with emphasis on the more near-term solar thermal power system applications.

The overall objective of this storage development program is to develop general solar thermal energy storage technologies that provide:

- Second-generation storage subsystems offering cost/performance improvements over the first-generation storage subsystems currently being developed for solar thermal power applications.
- First-generation storage subsystems for those solar thermal applications that presently have no storage subsystems under development.
- A technology base to support storage subsystem development for future solar thermal power applications.

Implementation of the first two program elements, which are application oriented, is the responsibility of the Field Lead Laboratory, Sandia Laboratories Livermore (SLL), who also directs and coordinates the storage activities of Jet Propulsion Laboratory (JPL) and Sandia Laboratories Albuquerque (SLA). The Field

Lead Laboratory for implementation of the technology base goal is the Solar Energy Research Institute (SERI). Private industry, competitively selected, and universities perform the implementation as operating contractors with SLL, SLA, JPL, and SERI performing only that R&D appropriate to a national laboratory and necessary for management of the program.

APPLICATIONS PROGRAM DESCRIPTION

The applications portion of the program has been divided into seven major elements according to the tasks outlined in Figure 1. The first element represents generic activities required to support program management functions; the remaining six elements are keyed to storage development for specific collector/receiver technologies. Several tasks have been further divided into subtasks which represent specific concepts being pursued. Project applications* for the six major elements have been identified to provide a development focus for the storage technology development. The relation between the elements and the project applications is shown in Figure 2.** A summary description of first and second generation thermal energy storage technologies for each application element is given in Table I.

The TESSTA program has developed cost and performance goals for these solar thermal system applications. Representative goals for both first generation and second generation systems are shown in Table II.

The cost goals, which assume fully developed storage technologies incorporated in large commercial systems, represent the lowest achievable total capital cost consistent with system performance requirements. They were based on the results of studies of commercial solar and conventional power systems that incorporate thermal energy storage.

A general performance goal for a storage subsystem is to maximize the round trip efficiency, that is, maximize system performance when operating from storage. The round trip efficiency combines the recoverable energy and power cycle conversion efficiencies of the storage subsystem. High recoverable energy efficiency, that is, the energy out of storage divided by the energy in, is important in that it minimizes the required collector area. Furthermore, it is the primary criterion when the recovered energy is utilized for industrial process heat. Power conversion cycle efficiency will vary depending on the conditions of the working fluid input to the power conversion subsystem from storage. Ideally, the

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*The repowering/industrial retrofit program may result in two system applications: repowering of an existing electric power generating plant and retrofitting of an existing industrial process heat plant. Storage requirements, which may differ significantly for the two applications, will be further defined pending completion of conceptual design studies in FY80.

**The solar interface operating conditions and candidate applications are representative cases only. For example, several water/steam collector/receivers at various operating conditions are under consideration for the repowering/industrial retrofit system application.

conditions of the working fluid coming from storage would be identical to the conditions of the working fluid input directly from the solar collection subsystem. In this case, no modifications in operation of the power conversion subsystem are necessary, nor is there any loss in the ability to generate rated load.

APPLICATIONS PROGRAM STATUS

The basic TESSTA program development flow, consists of three phases:

1. Storage concept development - concept feasibility and lab experiments,
2. Storage subsystem development, and
3. System applications including new projects or retrofits.

The status of this development for each of the major program focused elements is described in Figures 3 to 8.

The strategy of the program is both aggressive and flexible. Reflecting the current direction of the Thermal Power Systems (TPS) Branch, CST, storage for repowering/industrial retrofit, total energy, and small community system applications is stressed in the early years. Particular attention is being directed toward identifying and implementing storage development required for industrial process heat applications. A summary of major FY80 activities in each of these application sectors is presented in Figure 9 and described below.

REPOWERING/INDUSTRIAL RETROFIT SYSTEM APPLICATIONS

The major area of emphasis in this application sector is molten salt sensible heat storage. Early studies conducted under the TPS Advanced Central Receiver Program identified molten nitrate salts as attractive storage media candidates. In particular, molten draw salt (60% $NaNO_3$, 40% KNO_3 by wt.) was singled out because of its low cost, high energy density and potential high operating temperature. A recent study under the TPS program has examined low cost containment techniques in order to reduce the storage subsystem cost even further. This study identified a low cost liner concept which may be applicable to liquid metal as well as molten salt storage.

During FY80 the TESSTA program will initiate storage subsystem development for nitrate salt sensible heat storage. This includes the design, construction, testing, and evaluation of a molten salt subscale research experiment of sufficient scale to insure successful operation of the full-size subsystem. A major objective of this development is to advance state-of-the-art in high temperature containment. Salt material studies are also underway at SLL and contracted work is planned to establish the long-term stability and corrosion behavior of molten nitrate salts at elevated temperatures.

A second area of emphasis for this application is second generation storage development for saturated steam and superheated steam receivers. Studies will be initiated in FY80 for latent heat storage concept development for process heat applications and sensible and/or latent heat storage concept development for Barstow retrofit and repowering applications. Subsystem research experiment design, fabrication, testing, and evaluation will follow in later years.

TOTAL ENERGY SYSTEM APPLICATIONS

Activities in this application sector provide support for and advanced alternatives to storage subsystems under development for midtemperature solar thermal applications, such as irrigation and Shenandoah. First generation storage subsystem support includes analyses and testing of organic fluid single and dual media storage systems at the Midtemperature Solar Thermal Test Facility. Studies to be performed in FY80 include control strategies for a multitank storage subsystem, thermocline performance of single media systems for buffer or diurnal operation, feasibility of a moving piston, and design and fabrication of a dual media system for installation and testing during FY81.

The development of a second generation latent heat storage subsystem for a Shenandoah midtemperature solar thermal application is also planned in FY80. Studies include storage media screening, engineering analyses, conceptual design, and cost estimates. Subsystem research experiment design, fabrication, and testing will follow in later years.

SMALL COMMUNITY SYSTEM APPLICATIONS

The major emphasis of this application sector is the development of a dish mounted latent heat storage subsystem for three small community system applications. Power conversion cycles under consideration include Rankine, Brayton, and Stirling. Development activities include storage requirements definition, conceptual design, media stability and compatibility tests, thermal performance analyses, cost estimates, and a SRE. During FY80 storage requirements definition, concept development and SRE design studies will be initiated for each of the above power conversion cycles.

TABLE I

DESCRIPTION OF FIRST AND SECOND GENERATION THERMAL ENERGY STORAGE TECHNOLOGIES

APPLICATION*	SOLAR INTERFACE	STORAGE TECHNOLOGY FIRST GENERATION	SECOND GENERATION
BARSTOW	WATER/STEAM COLLECTOR/RECEIVER	OIL/ROCK THERMOCLINE	SALT, TRICKLE OIL
REPOWERING	MOLTEN SALT COLLECTOR/RECEIVER	MOLTEN SALT WITH EXTERNAL INSULATION	MOLTEN SALT WITH INTERNAL INSULATION
IEA	LIQUID METAL COLLECTOR/RECEIVER	LIQUID METAL WITH EXTERNAL INSULATION	MOLTEN SALT OR LIQUID METAL WITH INTERNAL INSULATION, AIR/ROCK
EPRI/DOE HYBRID	GAS COLLECTOR/RECEIVER	REFRACTORY BRICK WITH WELDED STEEL TANK	REFRACTORY BRICK WITH PCIV
SHENANDOAH	ORGANIC FLUID COLLECTOR/RECEIVER	SILICONE OIL/TACONITE THERMOCLINE	SALT, TRICKLE OIL
SMALL COMMUNITY	LIQUID METAL/ SALT COLLECTOR/ RECEIVER	REFRACTORY WITH WELDED STEEL TANK-GROUND BASED	LATENT HEAT SALT-DISH MOUNTED

*Storage development for these representative applications is emphasizing second generation technology development. First generation technology development will be initiated during FY80 on additional applications, such as industrial retrofit process heat.

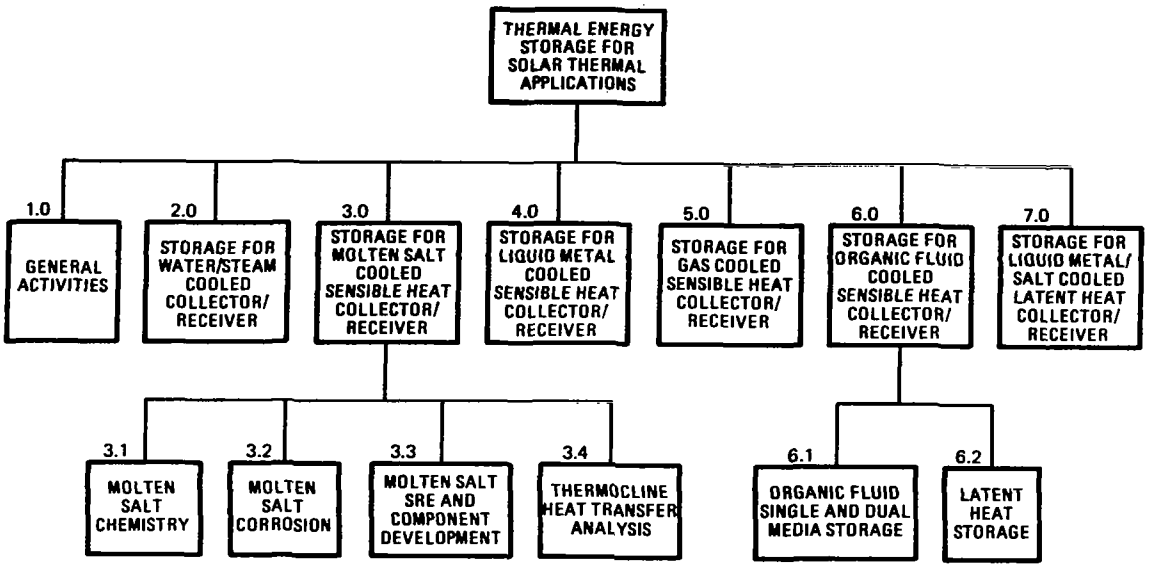
TABLE II

THERMAL ENERGY STORAGE PERFORMANCE AND COST GOAL SUMMARY (FY79 DOLLARS)

APPLICATION*	SOLAR INTERFACE	ROUND TRIP EFFICIENCY FIRST GENERATION (%)	ROUND TRIP EFFICIENCY SECOND GENERATION (%)	CAPITAL COST FIRST GENERATION ($/KWH)	CAPITAL COST SECOND GENERATION ($/KWH)	IMPROVEMENT (%)
BARSTOW	WATER/STEAM COLLECTOR/RECEIVER	70	80	46	35	24
REPOWERING	MOLTEN SALT COLLECTOR/RECEIVER	98	98	28	14	50
IEA	LIQUID METAL COLLECTOR/RECEIVER	98	98	100	43	57
EPRI/DOE HYBRID	GAS COLLECTOR/RECEIVER	80	80	88	61	31
SHENANDOAH	ORGANIC FLUID COLLECTOR/RECEIVER	96	96	51**	25**	51
SMALL COMMUNITY	LIQUID METAL/ SALT COLLECTOR/ RECEIVER	TBD	TBD	TBD	TBD	TBD

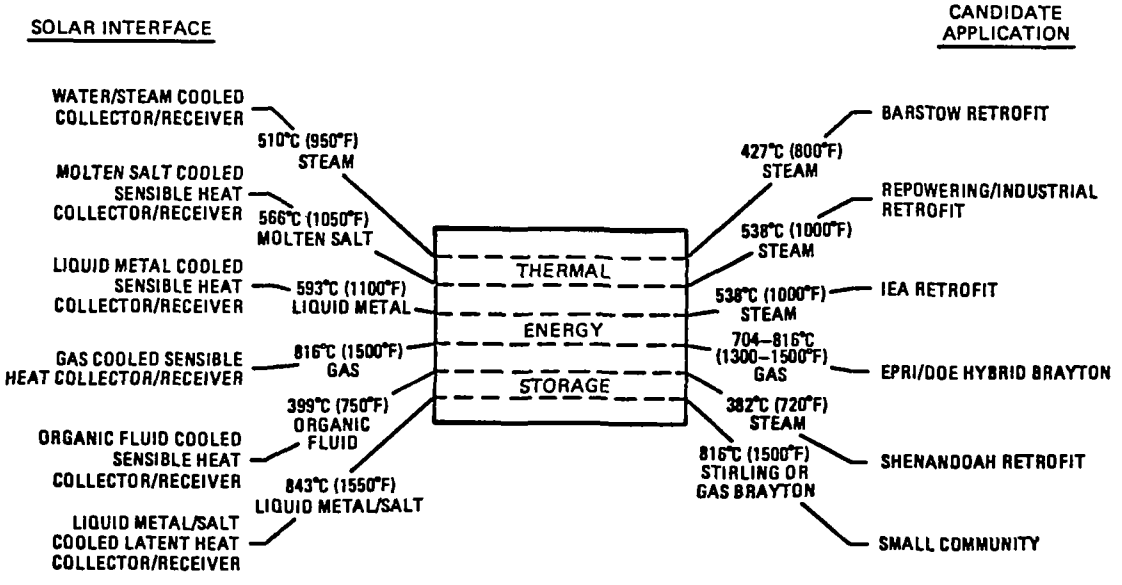
* Applications shown are all electrical power generating systems except for the total energy Shenandoah system. Performance and cost goals will be established for process heat applications pending completion of conceptual design studies in FY80.

**based on KWH_t; costs for other applications are based on KWH_e



TASK OUTLINE

FIGURE 1



FOCUSED ELEMENTS

FIGURE 2

STORAGE FOR WATER/STEAM COOLED COLLECTOR/RECEIVER

STORAGE TECHNOLOGY STATUS*	PLANNED DEVELOPMENT
● BARSTOW SRE COMPLETE ● McDONNELL DOUGLAS EXTENDED LIFE STORAGE FLUID TESTS COMPLETE ● MARTIN MARIETTA STORAGE FLUID MAINTENANCE TESTS COMPLETE	● LONG TERM - Develop Storage Subsystem for Saturated Steam Receiver for Process Heat - Develop Second Generation Storage Subsystem for Repowering or Barstow Retrofit ● FY80 - Initiate Storage Concept Development for above applications

*This work was funded under the TPS Program

FIGURE 3

STORAGE FOR MOLTEN SALT COOLED SENSIBLE HEAT COLLECTOR/RECEIVER

STORAGE TECHNOLOGY STATUS*	PLANNED DEVELOPMENT
● CONCEPTUAL DESIGNS OF MOLTEN DRAW SALT STORAGE COMPLETE ● LABORATORY EXPERIMENTS OF LOW COST CONTAINMENT TECHNIQUES COMPLETE ● COMPARISON OF THERMOCLINE VS. HOT/COLD TANK DESIGNS COMPLETE ● PRELIMINARY STORAGE AND CONTAINMENT MATERIAL SCREENING TESTS COMPLETE	●LONG TERM - Develop Second Generation Storage Subsystem using Internal Insulation for Repowering ●FY80 - Complete Internal Insulation Storage Concept Development - Initiate SRE - Perform Salt Chemistry/ Corrosion Studies

* This work was funded under the TPS Program.

FIGURE 4

STORAGE FOR LIQUID METAL COOLED SENSIBLE HEAT COLLECTOR/RECEIVER

STORAGE TECHNOLOGY STATUS*	PLANNED DEVELOPMENT
● CONCEPTUAL DESIGN OF LIQUID SODIUM STORAGE FOR CENTRAL RECEIVERS COMPLETE ● NO ADDITIONAL DEVELOPMENT WORK REQUIRED FOR FIRST GENERATION SYSTEM	● LONG TERM - Develop Second Generation Storage Subsystem for Central Receiver Repowering or IEA Retrofit Applications ● FY80 - Complete Low Level Planning Activities - Complete Laboratory Air/Rock Thermal Cycling Tests

*This work was funded under the TPS Program.

FIGURE 5

STORAGE FOR GAS COOLED SENSIBLE HEAT COLLECTOR/RECEIVER

STORAGE TECHNOLOGY STATUS*	PLANNED DEVELOPMENT
● CONCEPTUAL DESIGN OF REFRACTORY BRICK STORAGE FOR CENTRAL RECEIVERS COMPLETE ● DESIGN AND FABRICATION OF A GROUND BASED REFRACTORY STORAGE TEST MODULE FOR A POINT FOCUSING DISH ONGOING	● LONG TERM - Develop Second Generation Storage Systems using PCIV containment or Latent Heat Media for EPRI/DOE Hybrid Brayton Retrofit - Develop Latent Heat Storage for Point Focusing Dishes ● FY80 - Complete Tests of Refractory Storage Test Module - Initiate Latent Heat Storage Concept Development for Point Focusing Dishes

* This work was funded under the TPS Program.

FIGURE 6

STORAGE FOR ORGANIC FLUID COOLED SENSIBLE
HEAT COLLECTOR/RECEIVER

STORAGE TECHNOLOGY STATUS*	PLANNED DEVELOPMENT
● CONCEPTUAL DESIGN & LABORATORY TESTS OF TRICKLE OIL STORAGE FOR SHENANDOAH COMPLETE ● SHENANDOAH WILL INCLUDE FLEXIBILITY FOR TRICKLE OR DUAL MODE MODE TESTING - THEREFORE NO TRICKLE OIL SRE IS CURRENTLY PLANNED ● SINGLE MEDIA THERMOCLINE TANK DESIGN AND FABRICATION FOR MTTF TESTS COMPLETE ● SINGLE MEDIA THERMOCLINE SYSTEM FOR IRRIGATION APPLICATIONS OPERATIONAL	● LONG TERM - Provide support for First Generation Storage Subsystems for Midtemperature Applications - Develop Second Generation Storage Subsystem for Midtemperature Applications ● FY80 - Complete Single Media Thermocline Tests - Complete Dual Media Thermocline Tank Design - Initiate Second Generation Storage Concept Development

* This work was funded under the TPS Program.

FIGURE 7

STORAGE FOR LIQUID METAL/SALT COOLED LATENT
HEAT COLLECTOR/RECEIVER

STORAGE TECHNOLOGY STATUS*	PLANNED DEVELOPMENT
● HEAT PIPE/MOLTEN SALT TEST MODULE DESIGN AND FABRICATION COMPLETE	● LONG TERM - Develop Storage Subsystems for Small Community System Applications using Rankine, Brayton and Stirling Power Conversion Cycles ● FY80 - Initiate dish Mounted Latent Heat Storage Requirements Definition and Concept Development - Initiate High Temperature Latent Heat Materials Studies - Initiate SRE Design

*This work was funded under the TPS Program.

FIGURE 8

SUMMARY - FY80 FOCUSED DEVELOPMENT

- REPOWERING/INDUSTRIAL RETROFIT SYSTEM APPLICATIONS
  - Molten Salt Sensible Heat Storage
  - Second Generation Storage Concept Development for Water/Steam Receivers
- TOTAL ENERGY SYSTEM APPLICATIONS
  - Organic Fluid Thermocline Testing
  - Second Generation Storage Concept Development for Organic Fluid Receivers
- SMALL COMMUNITY SYSTEM APPLICATIONS
  - Dish Mounted Latent Heat Storage Concept Development for Point Focusing Dish Collectors

FIGURE 9