

Thermal Energy Storage Program  
Diurnal and Industrial -

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THERMAL ENERGY STORAGE PROGRAM  
- DIURNAL AND INDUSTRIAL -

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Abstract

The U.S. Department of Energy (DOE) is charged with supporting development of technologies that improve the energy and environmental posture of the country in terms of increased energy efficiency and implementation of fuel switching strategies that emphasize greater reliance on indigenous energy resources. As an enabling technique for utilization of renewable energy resources and for improvement of utility load factors, thermal energy storage (TES) can play a vital role. Development of TES technologies by DOE for diurnal and industrial applications is continuing; current efforts are directed towards initiation of technology transfer activities in major application areas. This paper presents an overview of activities in the Diurnal and Industrial TES Subprograms and describes near term paths to the transfer of technology in specific application areas.

Introduction

Thermal energy storage covers a wide range of technologies that allow an energy supply to be coupled to a heating or cooling demand. In many cases, neither is the demand for heating or cooling constant (e.g building space conditioning, or an industrial drying operation), nor is the energy supply constant. In such cases of "temporal mismatch", TES acts as a buffer storing energy when the supply exceeds the demand and supplementing the energy supply when the demand is higher. In this way, TES effectively couples the energy supply with demand.

Thermal energy storage is applied generally for reasons of capacity expansion, equipment downsizing, electric load management, waste heat utilization or solar energy use.

Equipment Downsizing. In many applications, the demand for heating or cooling may vary greatly with time. Without TES, the energy source must be of such a size so as to meet the peak demand requirement. Through use of TES, this peak demand can be met with a smaller energy supply system. Perhaps the most mentioned application of equipment downsizing is found in the dairy industry where fresh milk must be chilled quickly to avoid spoilage. Without TES, a large chiller is needed to meet this peak cooling demand. However with a cool storage system (ice) available, a small chiller builds ice over a long period that can be quickly melted to meet the requisite cooling demand. This approach has also been used in buildings with short-term cooling loads such as churches or cinemas. The benefit in either case is a savings in the capital cost of the cooling system.

Capacity Expansion. By lengthening the time over which a TES system is charged and shortening the time over which thermal energy is discharged, the effective capacity (power) of an existing system is increased. An example is an expansion to an existing building in which the additional heating or cooling load may be provided by the existing boiler or chiller running during periods of

low demand to charge a TES system. During high demand periods, energy from storage supplements the baseline heating or cooling system to meet the load.

Electric Load Management. Thermal energy storage provides the ability to tailor, intentionally, the use of an energy supply to meet a given thermal load. One of the most interesting and useful applications of this TES capability may be found in electric power generation where excess baseload capacity is available at times that do not coincide with the demand for thermal energy. With storage, this baseload capacity can be exploited for heating and cooling during peak periods, reducing the need for peak electrical power generation. The result of electric load management of this type is an improvement in the capacity factor and overall efficiency of the electric utility through a reduction in peak electrical demand.

Waste Heat Utilization. In many industries, heat is generated as a by-product of a manufacturing process and exhausted into the atmosphere. Often in that same industry, heat is required in a process that does not coincide with the availability of waste heat. Thus there is an opportunity for TES to be used - capturing heat that would normally be wasted for later reintroduction into the second process. The result is an overall reduction in the energy requirements of the industry.

Use of Renewable Energy. Examples of this application include utilization of solar energy available during the daytime for nighttime heating, or, on a longer term, the use of "winter chill" from the ambient environment for cooling in summer.

#### DOE TES Program

Every material whether solid, liquid or gas changes its thermodynamic state with heat addition or removal, thus every material can be considered as having a thermal storage capability. Yet relatively few materials can be expected to meet cost, performance, safety, physical and/or chemical constraints required for implementation as a working TES medium in specific applications. In addition, there are significant technical issues concerned with TES media containment, effective heat exchange between TES media and working fluid(s) and cost-effective means for incorporation of TES systems into these applications. The issues of greatest significance are to a large extent a function of the intended application. To maximize the return on TES R&D, the DOE TES Program is structured along three applications: diurnal, industrial and seasonal. Technical cognizance over the diurnal and industrial subprograms is performed by the Oak Ridge National Laboratory. The method for performing research in both programs is primarily through subcontracts supplemented by complementary in-house R&D.

#### Diurnal TES Subprogram

The application targets for the Diurnal TES Subprogram are the development of TES for passive solar applications and for off-peak building heating and cooling systems. Projects have been classified into the following technical areas:

1. Heat Transfer Enhancement
2. System/Component Studies
3. Mathematical Modeling
4. System Development
5. Media Development (i.e., materials)

These major technical areas along with projects planned or currently underway in each of these areas are shown in Figure 1.

### Heat Transfer Enhancement

Heat transfer is a critical issue in all TES applications because it limits the rate at which thermal energy can be provided to or withdrawn from a source and delivered to an end use. In latent heat storage applications, fouling due to solids freezing on a heat exchanger surface during a charging cycle (as in the case of cool storage) or discharging cycle (as in the case of heat storage) is frequently the limiting heat transfer mechanism. Conventional methods to accommodate this problem are provisions for large heat exchange surfaces or systems that mechanically or thermally clean the heat exchange surface. Either technique results in increased costs.

In ice storage systems wherein ice is formed on an evaporator for later building cooling, work will continue to address the heat transfer issue. Project 111 initiated in FY 1988 and continuing through FY 1989, consists of an examination of methods whereby the evaporator surface may be made "self-cleaning", i.e., the ice that is formed floats or falls away from the surface thereby continuously refreshing the surface. A second project in the heat transfer enhancement area to develop a system for ice release is under consideration.

### System/Component Studies

The objective of the first project (Project 204) is to study potential oil-water-refrigerant separation techniques and systems that facilitate use of conventional centrifugal compressor technology with a direct contact ice system. Development of such systems to the point of effecting adequate separation of moisture carryover from refrigerant exiting the evaporator and of separating lubricants from the refrigerant at the compressor discharge would facilitate retrofit applications of ice storage by eliminating the need for compressor replacement. This laboratory study is examining the potential of one thermo-mechanical technique as a means for separating components at temperatures near saturation.

A major project in the Diurnal Subprogram is the development of a wallboard material containing a phase change material (PCM). For reasons of high heat of fusion, little supercooling and low vapor pressure, the PCMs being studied for incorporation into wallboard are organic compounds. As such, they are typically flammable, with smoke evolution perhaps of even greater concern. Project 202 addressing fire/smoke safety issues in the PCM wallboard development program is to be started in FY 1989. This project will initiate a safety testing program on the PCM wallboard in accordance with accepted standards.

The objective of the third project under System/Component Studies is development of temperature-adjusted organic solid-state PCMs. Through the use of dopants to strain the crystal lattice, PCM alloys that undergo solid-solid phase transitions can be tailored for particular temperature applications (e.g., passive solar) with only proportionate decreases in transition enthalpy.

### Mathematical Modeling

Guidance in current research efforts to incorporate PCMs into building materials such as wallboard is being provided through development of a mathematical model of PCMs dispersed throughout a sensible heat matrix. This effort, contained in Project 208, consists of a computer model of

discrete PCM particles of arbitrary size that have been distributed either randomly or in an ordered fashion throughout a support matrix. The model will be validated experimentally and used later to quantify benefits of the PCM wallboard. Incorporation of this model as a subroutine in a larger building simulation code is under consideration.

### System Development

Work will continue on two cool storage concepts for electrical load management. Development of a chill storage system based on ammoniated complexes for food processing and other low-temperature applications (Project 131) will be continued with industry cost-sharing. As a second project (Project 132), an advanced direct-contact ice storage system for building cooling will be developed in a size suited for later field testing. The system design is such that oil and water carryover problems that have paralyzed early efforts to exploit the direct contact approach have been resolved through use of a unique compressor technology.

### Media Development

Due to their ability to store and release energy over small temperature ranges, PCMs are attractive as thermal storage media for space heating/cooling. Project 142 is a major initiative with a near term objective of developing a gypsum wallboard material containing a PCM. The advantage of this concept is that a significant amount of "thermal mass" can be provided to stud wall construction by using the PCM wallboard. The benefit to the occupant is increased thermal comfort and efficiency improvements in building space conditioning through greater utilization of passive solar energy. Due to higher thermodynamic efficiencies, smaller size and the ability to store and deliver heat over a small temperature interval, PCMs are attractive as thermal storage media for building heating and cooling and industrial applications, as well. Thus, development of TES media where one or more components undergo a phase transition is a central element of the program. The first of five projects, incorporation of PCMs into building materials is directed toward comfort and efficiency improvements in building space conditioning. By imbuing paraffinic materials into either the interstices of gypsum or first into pellets of crosslinked high density polyethylene which are then cast into gypsum during wallboard manufacture, an effective PCM system for use in passive solar heating and cooling is possible. A determination of any tendency for PCM redistribution in gypsum wallboard that is thermally cycled is the principal FY 1989 objective of this project. A supporting project (Project 210) is the construction and use of a facility for preparing samples of wallboard that are imbued with the PCM. Full-scale (4 ft x 8 ft) panels of wallboard containing the PCM will be fabricated and tested to determine bulk thermophysical properties above and below the phase-change temperature, and to determine the dynamic response of the panel to a surface thermal flux or temperature profile.

### Industrial TES Subprogram

The scope of the Industrial Subprogram is shown in Figure 2 indicating projects either underway or planned in four of the five program elements.

### Heat Transfer Enhancement

The compactness and high heat transfer effectiveness of packed bed heat exchangers are of interest to the Industrial Subprogram. Direct contact heat exchange is particularly effective in applications of heat transfer between a gas and a liquid. Work initiated in prior years to develop a model of

a model of an air/molten salt heat exchanger is being continued to determine the effects of radiation heat transfer in the packed bed and to verify a heat transfer model under conditions wherein fluid properties are changed.

#### System Component/Studies

An optimization study currently underway is aimed at determining the "best" (highest ROI) high-temperature storage configuration for a two-kiln single dryer periodic brick plant. The study takes into account real-time uses for reject heat for which storage is not required. During FY 1989, this preliminary study will be completed and will be used as a basis for development of a procedure for analysis and TES design studies for a multikiln, multidryer plant.

#### Media Development

Over the past 4 years, a major effort to develop high-temperature TES media for industrial applications has resulted in successful laboratory development of a sintered magnesium oxide (MgO) pellet with porosity suited for containment of a eutectic of carbonate salts. Capillary forces retain the PCM in the MgO interstices so that the pellet remains solid during thermal charging and discharging. During FY 1989, packed bed configurations of this media will undergo initial field testing in a brick plant to examine performance and lifetime issues when the media is used to extract thermal energy from the kiln flue gas (Project 143, 144). A test program will be conducted to measure and evaluate thermochemical and thermophysical properties of the media periodically during the field test.

#### Conclusion

The diurnal and industrial TES subprograms are continuing to show progress not only towards development of technologies but their implementation as well. Of major emphasis is the development of the PCM wallboard which is being supported by several projects. This level of effort is commensurate with the high level of interest shown by manufacturers and the potential market size for the product. In addition, early transfer of the chill storage system to industry through a heavily cost-shared program is anticipated in FY 1990. These projects in addition to the ones further back in the development stage form a strong basis for addressing energy related issues that, through storage, can be successfully resolved.