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Thermal Energy Storage
Market-Oriented Background Paper

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THERMAL ENERGY STORAGE

MARKET-ORIENTED BACKGROUND PAPER

1. Introduction

Thermal energy can be stored in a variety of media including bricks, pebbles, water, eutectic salts, hydrates and reversible chemical reactions. The stored energy can be used for many diverse purposes. Within the residential and commercial sectors, it can be used to provide space heating, cooling or domestic hot water; the thermal energy storage (TES) system is charged either with solar power or with off-peak electricity and used to provide services when the energy source is not available or higher priced. In industry, TES can be utilized in batch processes, in cogeneration, for waste heat recovery, and for solar process heat supply. Electric utilities can use TES at their generating plants. Thermal storage can also be used to power a vehicle via a heat engine (e.g. Rankine or Sterling). So the uses for TES are varied, but all involve collecting energy and storing it as thermal energy for use at a later time.

This paper is organized as follows. First, TES technologies and their applications are discussed. Then the markets and commercialization status and potential are explored. Next the ERDA TES program plans are presented. The paper ends with a brief summary.

2. TES Technologies and Applications.

2.1 Residential Sector

TES can help electric utilities with load management problems. If the peak load, which generally occurs during the day, can be reduced and that energy supplied during low-load or off-peak times, then the utilities requirements for new generating equipment will be reduced. Load leveling also saves the utility gas and oil which would otherwise be used in peaking generating equipment. Baseload generation is generally done with coal or nuclear power. However, most of the monetary savings that occur from load leveling are in the capital costs of new generating equipment.

Some utility load leveling can be achieved by the use of TES to provide service hot water, space heat or space cooling to the residential sector (Reference 1). The TES is charged with off-peak electricity and then used as an energy source to provide the services during the peak part of the day. Space heating TES can help a winter-peaking utility, while space cooling TES is useful for a summer-peaking utility. Since the primary monetary savings are from a reduction in required generating capacity, the TES systems must operate during the utilities peak season to be economical. TES water heating can aid both summer and winter peaking utilities.

The same services (hot water, space heat and space cooling) can also be provided by solar power. Since the sun shines only in the daytime and cloudy days can occur, there is a need for energy storage; TES plays an important role in solar-powered systems. Solar systems can also be used to assist a heat pump which can provide useful heat from a lower temperature solar output. Thermal storage is again useful in these systems.

Seasonal storage to provide space heating and/or cooling is another possibility. One such concept is Annual Cycle Energy Storage (ACES) (Reference 2). Which used a heat pump to make ice while providing winter heat; the ice is stored to provide summer cooling. Other possibilities use confined subsurface water (aquifers), earth, ponds or other natural formations for the long term storage of heat produced in the summer or heat removed in the winter.

2.2 Commercial Sector

TES applications in the commercial sector are very similar to those in the residential sector, though the size of the systems is generally larger. TES to aid utility load leveling is applicable, especially to provide service hot water and space cooling. Solar power systems have application in commercial buildings, as does the seasonal storage concept.

2.3 Industrial and Agricultural Sector

In industry, there are several opportunities for thermal storage (Reference 3). Where heat is used in batch processes, TES could achieve some load smoothing. TES can be used with cogeneration to store the process

heat until it is needed. TES can also be used in some instances to recover heat which would otherwise be lost. There are applications for solar energy in industry (Reference 4) such as solar crop drying and solar generated process heat. Only a few crop drying techniques include storage, but storage is essential for many uses of solar-generated process heat.

2.4 Transportation

TES could be used to power a vehicle. Using a Stirling engine running off thermal energy stored in lithium fluoride salt, it is estimated that such a vehicle could have a range of up to 320 miles and could be recharged quickly (Reference 5).

2.5 Electric Utilities

The electric utilities can directly make use of TES to help meet peak demands (Reference 6). An existing boiler can be used to charge the TES during off-peak periods. Then a separate peaking turbine can run off the stored energy. Alternately with a modified turbine, the stored energy can be used to heat the feedwater thus increasing through-flow and power production. The TES is charged by increasing steam extraction during non-peaking hours. Electric utilities can also use TES with a solar-powered boiler in producing electricity in a "power tower" type arrangement (Reference 5). A central receiver collects concentrated solar energy which is used to run a turbine generator. Thermal storage is included in some of the proposed designs.

2.6 TES Materials

Just as there are many applications of thermal energy, there are many materials which can be used to store the heat. Thermal energy can be stored as sensible heat in bricks, pebbles, water (both pressurized and unpressurized), oil, or as latent heat in ice, eutectic salts, salt hydrates, paraffin or lithium fluoride. Thermochemical systems are high density methods for storing energy in reversible chemical reactions. Since they store energy in chemical bonds they may be well-suited to seasonal storage applications where insulation losses impose a penalty on thermal storage systems. Table 1 is a matrix showing which of these TES materials appear to be most useful in each TES application.

TABLE 1
STORAGE MATERIAL APPLICABILITY MATRIX

APPLICATIONS	Bricks	Pebbles	Water	Ice	Eutectic Salts	Salt Hydrates	Paraffin	Oil	LiF	Thermo- Chemical
<u>Residential and Commercial</u>										
Off-peak TES										X
Hot water			X							X
Space heat	X	X	X	X	X					X
Space cool		X								
Solar TES		X	X	X	X	X	X			X
Seasonal Storage		X	X	X						X
<u>Industry</u>										
Batch process										
Load smoothing			X			X	X	X		X
Cogeneration			X			X	X	X		X
Waste heat recovery			X							X
Solar crop drying		X	X							
Solar process heat		X	X			X		X		X
<u>Transportation</u>										
Heat vehicles									X	
<u>Electric Utility</u>										
TES for generation			X					X		X
Solar power with TES		X			X	X		X		X

2.7 Comparison of TES with Other Storage Methods

Since there are many other ways to store energy, these must be compared with TES for each application. For electric load leveling, there are other storage methods which the utilities can use. The most economic of these (Reference 7) are pumped hydro, compressed air, and advanced batteries. These storage systems compete not only with TES at the utility, but also with TES on the customer side of the meter. Customer TES shows some economic advantages (Reference 7), but utility-side storage tends to be less expensive for the utility to control. Batteries can be installed easily and the advanced batteries may be economic for very short term storage discharge. Compressed air storage and pumped hydro can be stored most economically in present geological formations, such as underground caverns or abandoned mines. Thus, appropriate geographies are required for the implementation of compressed air or pumped hydro storage. Batteries can be retrofitted into existing facilities economically.

There are no competing storage systems for storing solar energy, except when solar power is used to generate electricity. In that case, the electricity could be stored instead of the heat.

In industry, TES competes with other forms of energy conservation, such as switching from batch processing to continuous processing.

Heat storage for vehicle applications competes with electric vehicles powered by batteries. Preliminary analysis (Reference 5) suggests that heat vehicles may have greater range, and faster and cheaper recharge than electric vehicles. Also recharge of a heat vehicle could be accomplished with a variety of energy sources, although only high grade heat can be used.

3. TES Markets and Commercialization Potential

3.1 Residential Sector

Currently, there is some limited use of storage water heaters in the residential market. The existing programs consist of a lower electric rate offered when the utility installs a control device on the existing water heater to turn it off for up to four hours a day. Future storage water heaters may be sized larger and the power turned off for a longer period each day. Service should not be degraded.

The potential residential market for TES water heaters is large. Studies (Reference 1) show that the benefits to the utility are greater than the costs. If the proper electricity rates were offered, commercialization would occur. However, the impact would be small since electric water heating typically is less than 5% of the total load on the utility.

TES space heating for residences is currently used widely in Europe. England, Wales and West Germany have the largest installed capacities of thermal storage. The TES units have had a large effect on the daily load profile of utilities in Europe. Figure 1 (from Reference 8) shows the improvement, due to the use of storage heaters, in the daily load curve of two area boards serving England and Wales. Similar improvements occurred in West Germany, where in 1973 the installed TES capacity was 43% of the peak utility system load. Thus, there is no doubt that TES heaters have been very successful in Europe. Commercialization is possible in large parts of the U.S., even though TES space heating is only economical for winter peaking utilities. The availability and relative price of competing fuels will affect the commercialization (Reference 9). In addition, load leveling is not as beneficial to utilities with extensive hydro capacity. However, there is still a large potential market for TES space heaters in the U.S. Figure 2 (from Reference 9) shows the most promising region of the U.S. for TES space heating commercialization based on the combined effects of limited hydro peaking capacity and competing fuel availability. Some utilities, even outside this area, have on-going test programs with storage heaters.

There are no commercially available TES space cooling units. These units would probably make ice; they would not involve new technology, though detailed designs and testing are needed. Phase change materials or reversible chemical reactions are also possible storage media and they would require R&D. As there are many summer peaking U.S. utilities and essentially all air conditioning is done electrically, there is a large potential market in the residential sector for TES space cooling. Estimates of the cost, shown for four utility areas in Table 2 (from Reference 10), indicate that these units will be more expensive than TES space heaters or water heaters but the utility savings can easily be greater than the cost (Reference 1). Necessary utility rate structures or load management contracts could help commercialize these units.

Annual-average Daily Load Curve

Winter-average Weekday Load Curve

Figure 1. Improvement in Load Curves of Two Area Boards in England and Wales.

Figure 2. Most Promising Region of U.S. for TES Space Heating.

TABLE 2. CUSTOMER INCREMENTAL COST FOR INSTALLED STORAGE

SERVICE AREA	CUSTOMER INCREMENTAL COST FOR INSTALLED STORAGE SYSTEMS (\$)								
	4 HOURS STORAGE USE			8 HOURS STORAGE USE			16 HOURS STORAGE USE		
	H ₂ O	HEAT (CENTRAL)	COOL	H ₂ O	HEAT (CENTRAL)	COOL	H ₂ O	HEAT (CENTRAL)	COOL
C	111	276	788	140	791	1093	256	1820	2090
D	105	NA	924	114	NA	1382	214	NA	2597
A	111	279	NA	140	799	NA	256	1839	NA
B	111	311	NA	140	887	NA	256	2039	NA

Note on Service Areas:

A - Strongly Winter Peaking (1.44)

B - Mildly Winter Peaking (1.13)

C - Mildly Summer Peaking (.75)

D - Strongly Summer Peaking (.585)

NA = Not Analyzed

Figures in parentheses are ratios of winter peak to summer peak.

Solar power can also be used to heat and cool houses and to provide domestic hot water. There are many commercial companies which build and sell solar space heaters and solar water heaters. Currently, there are conflicting opinions on the economics of these systems (References 20 and 21, for example) but tax incentives, such as the proposed legislation in President Carter's energy plan, could make the systems cost effective. Solar air conditioning is more expensive and commercialization will probably not occur unless there are some major improvements in the technology which improve the economics of solar cooling. The potential market for solar systems could be very large. They can replace the more expensive fuels, such as electricity, in the near term and other fuels, such as oil, in the future if energy costs increase significantly.

The ACES concept (Reference 7) is in a more developmental stage. The cost estimates (References 11 and 12) are quite varied leading to conflicting assessments of the economics. The system may prove to be too expensive. ACES is applicable primarily to new construction and this limits the market considerably. Other forms of seasonal storage are also in development. Some concepts, such as storage in aquifers, are more promising than ACES (Reference 19).

3.2 Commercial Sector

In the commercial sector, some TES service hot water systems are currently being used. If more off-peak rates were offered by the utilities, the market penetration would increase. There is clearly a possibility for economic pay-off.

The market for TES space heaters in commercial buildings is very limited. In regions where the utilities are (or are expected to become) winter-peaking, very few commercial buildings use electric heat (Reference 13).

At the present time the only widespread use of TES cooling in the U.S. is for the flash cooling of milk units in the dairy industry. However, in Japan there are approximately 50,000,000 ft.² of buildings equipped with thermal storage systems as large as 1,300,000 gallons (Reference 11). Only a few commercial buildings with cooling TES have been built here but the potential market is quite large. Cooling requirements are generally large

in commercial buildings and economies of scale are possible (Reference 14). Cool water appears to be the most economical storage medium for large cool storage when the operating costs of ice-making systems are considered. Retrofit on systems operating with cool water should be possible. Most U.S. electric utilities are summer-peaking (Reference 15), so potential markets occur in most of the U.S. Detailed designs, tests of the systems and rate incentives are needed for commercialization to occur.

There are many opportunities for using solar power in commercial buildings. Service hot water for small users such as office buildings or for large users such as laundromats can be preheated by the sun. Some installations have already occurred. Solar space heat is another possibility for commercial buildings and there are several such installations completed. Currently the economics of solar installations is uncertain, but some economies of scale are possible for commercial buildings. Tax incentives can help commercialize the systems.

Seasonal storage is being explored for commercial buildings as well as residential buildings. The costs are uncertain and may be too high for commercialization to occur. If costs are low enough, the ACES concept is useful for buildings in which the annual heating and cooling loads are approximately equal. For commercial buildings, such regions occur farther north than for residential buildings.

3.3 Industrial and Agricultural Sector

In the industrial sector, TES technologies have not been developed yet, though many potential applications have been identified (Reference 3). In the iron and steel industry there is potential for recovering the waste heat from hot coke and using it for process steam. More detailed engineering and economic analysis is needed to verify the cost and performance before commercialization can occur. TES systems could be utilized to make batch paper digestors more energy efficient, though this would have to be compared against use of continuous paper digestors. Cogeneration with TES is also possible in the paper making industry. Several TES concepts are possible in the primary aluminum industry (Reference 16), but the industry is working on more fundamental changes in the productive systems, making evaluation of TES

systems applicability difficult. Undoubtedly, there are other specialized TES applications in industry, but the potential energy savings are small.

There are some possible applications of solar power to industry and agriculture. Solar crop drying is being researched and may prove economic. Whether or not to include storage is currently undecided -- most proposed designs do not include storage. The use of solar process heat for car washing, textile drying, laundry services, food drying, concrete block curing, textile drying, and lumber drying is also under investigation (Reference 4). These methods compete with other conservation and heat recovery technologies. More research and economic analysis are needed before commercialization can occur.

For all TES uses in industry, significant increases in the cost of conventional fuels, time-of-day rates and higher demand charges can all help commercialize the TES technologies. Tax benefits can also help.

3.4 Transportation

Research on vehicles powered by a heat engine running off TES is in the early stages. Cost and performance of such vehicles must be determined before the market potential can be assessed. Increased cost of gasoline and tax advantages could aid commercialization, but only after much additional engineering design and testing. Such vehicles (small in size) are predicted to have a range up to 320 miles (Reference 5) and thus, they could be used for all conventional automobile trips. Thus, heat vehicles have the potential to replace most families' second car, as well as small delivery vehicles.

3.5 Electric Utilities

Thermal energy storage for electric utilities may be the most economic utility-side storage for utilities without suitable geography for pumped hydro or compressed air storage. A system based on heat stored in oil or pressurized water is projected to be commercially available by 1985. There is considerable need for load leveling in the utilities, so commercialization will depend, to a large extent, on comparison with other means of storage. Customer-side-of-the-meter storage may prove to be more economic especially when distribution costs are considered. Of course, utility-side storage is easier for the utility to control and does not require revised rate structures.

No tax advantages should be necessary to speed commercialization though a demonstration project could interest the utilities.

Solar thermal power can be used to generate electricity. Thermal storage will probably be included in such systems (Reference 5). However, instead of thermal storage, the energy could be stored as pumped hydro (Reference 5). Current estimates indicate that solar generated electricity will not be economically competitive with existing technologies.

4. ERDA TES Project Plans

Table 3 is a compilation of ERDA TES projects obtained from References 18 and 19. For each project the table shows the market area applications as defined in Section 3.

Project responsibility in related areas of the energy program is assigned to the national laboratories. The divisions of responsibility in the thermal storage program are:

Oak Ridge National Laboratory - low temperature TES

NASA Lewis - high temperature TES

Sandia Lab at Livermore - thermochemical energy storage and transportation R&D

5. Summary

Table 4 summarizes the current market and technology status and the market potential of the various TES systems. The only TES systems ready for immediate commercialization are storage water heating and space heating charged with off-peak electricity. All that is needed for commercialization to occur is the introduction of appropriate split electricity rates or load management contracts. In the near-term, solar water heating and space heating, electric utility TES and TES space cooling with off-peak electricity may prove economic. Technology for these systems is available now or will be soon. The most promising of these is TES space cooling for commercial buildings where the economies of scale may make the systems very attractive. Again, electric rate structures must be altered for commercialization to occur. Increasing energy costs and tax incentives will help commercialize solar systems. The systems also must be proven reliable and performance accurately predicted for general market acceptance to occur.

More research must be done on seasonal storage, industrial uses of TES, "heat battery" powered vehicles and solar thermal power for electrical generation to determine their commercial potential. Of these, current estimates for heat vehicles are the most promising, although a prototype has not yet been built and the concept must await development of the Sterling engine. If industrial and agriculture use of TES are shown to be economic, there should be no problems with commercialization as this sector is very cost conscious and tends to have available capital. Solar thermal power for electrical generation does not look economical currently, but needs further study as an inexhaustible energy source.

TABLE 3. ERDA TES PROJECT SUMMARY

		MARKET AREAS											
PROGRAM	PERFORMING ORGANIZATION	UTILITIES Fossil/Nuc. Solar	COMMERCIAL/ RESIDENTIAL								Industrial	Agricultural	Transportation
			Heating	Cooling	Service Hot Water	Solar	Seasonal	Total Energy					
Power Station TES Retrofit	Bechtel Corp.	X											
Phase Change TES for Sandia	Comstock & Wescott, Inc.												
TES Application to Brick/Ceramic Industry	General Electric Co.										X		
Rock Bed Heat Accumulators	University of Minnesota	X	X	X						X			
Molten Salt TES Systems	Inst. of Gas Technology	X	X								X		X
TES Materials Thermophysical Properties	Dynatech R/D Co.	X											
Metal Fluoride TES Materials	Pennwalt Corp.	X	X	X	X	X	X						
Metallic Heat Storage Materials	University of Delaware	X	X										
TES Heat Exchanger for Utilities	Grumman Aerospace Corp.	X											
Solar TES for Heating/Cooling	Atomics International		X	X	X	X	X	X	X				
Ammoniated Salts Thermochemical Systems	Martin-Marietta Aerospace	X	X								X		
The Chemical Heat Pump	Chemical Energy Specialists			X	X	X	X						
Sulfuric Acid-Water CES System	Rocket Research Corp.						X	X					
CES for Solar-Thermal Conversion	Rocket Research Corp.		X										
Solar Augmentation for Power Plants	Franklin Institute Research Labs		X										
Advanced TES for Solar-Brayton	Boeing Engineering & Construction		X										
Heat of Fusion Energy Storage-Boiler Tank	Naval Research Laboratory		X										
Macro Encapsulation of Phase Change Materials	Dow Chemical Co.			X	X	X	X						
Glauber's Salt as a TES Material	University of Delaware			X	X	X	X				X	X	
Long Duration Earth Storage of Solar	George Washington University			X		X	X	X					
Salt Hydrate Heat Storage System	Desert Research Inst.			X		X	X						
Immiscible Fluid-Heat of Fusion Storage	Clemson University			X	X	X	X						
Performance of Solid Sensible Heat TES	Pennsylvania State University			X	X	X	X						
Solar Desiccant Crop Drying Facility	Lockheed-Huntsville											X	
TES in Saturated Aqueous Solutions	Franklin Institute Research Labs			X	X	X	X						
Thermocrete Energy Storage Systems	Suntek Research Associates			X			X						
TES Using Prestressed Cast-Iron Vessels	Graz University of Technology	X											
Safety Aspects of High Temperature Storage	Phillips Laboratory			X									X
Subsurface Waste-Heat Storage	Auburn University						X	X					
Solar Energy Storage Research	Xerox Electro-Optical Systems		X										
Assessment of Energy Storage	Argonne National Labs			X	X	X	X						
Demonstration of TES SAHP Residence	Westinghouse			X	X	X	X						
TES in Building Materials	Brookhaven Labs			X	X								

TABLE 4. TES MARKETS

<u>Market</u>	<u>System</u>	<u>Technology Status</u>	<u>Market Status</u>	<u>Market Potential</u>
Residential	TES Water Heating*	Tech. exists	Limited Use	very large
	TES Space Heat*	Tech. exists	Use in Europe	large
	TES Space Cooling*	In development	None in use	large
	Solar TES Seasonal Storage	Tech. exists In development	Limited use Demos	may be large questionable
Commercial	TES Water Heating*	Tech. exists	Limited use	very large
	TES Space Heat*	Tech. exists	Limited Demo	small
	TES Space Cooling*	Some tech.	Limited use	large
	Solar TES Seasonal Storage	Tech. exists In development	Limited use No use	may be large questionable
Industry and Agriculture	Batch Process Load Smoothing	No tech.	No use	Some
	Cogeneration	No tech.	No use	Some
	Waste Heat Recovery	No tech.	No use	Some
	Solar crop drying	In development	Demos	may be large
	Solar process heat	In development	Demos	may be large
Transportation	Heat vehicle	In early development	No use	may be large
Electric Utilities	TES Generation	In development	No use	many competing systems
	Solar Thermal Generation	In development	Demo planned	may be large

* With off-peak electricity

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