

**INTERNATIONAL ENERGY AGENCY
(IEA)**

**ENERGY CONSERVATION THROUGH ENERGY STORAGE
(ECES)**

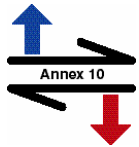
Annex 17

**" Advanced Thermal Energy Storage through Application of Phase
Change Materials and Chemical Reactions -**

Feasibility Studies and Demonstration Projects "

Prepared by

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1. Description of Technical Sector

Energy storage serves at least three different purposes.

- Energy conservation
 - Natural energy sources
 - solar energy
 - utilization of differences in outdoor temperature between night and day
 - Waste energy utilization
- Peak shift
 - Shifting the energy peak from the more expensive daytime to the more cheap nighttime
- Power conservation
 - Running energy conversion machines on full load instead of part load reduces the power demand and increases the efficiency of the machines.

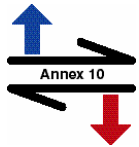
Storage of thermal energy can be performed by sensible heat storage, e.g. heating a material to a high temperature at loading and cooling it down at deloading. Water is a common material for sensible heat storage at temperatures between 5 and 100 °C. The storage density is in the order of 0,01 MWh/m³

Another way of storing thermal energy is the utilization of the latent heat of phase change materials. Usually the heat of melting is utilized. The heat of melting is 80 to 100 times larger than the heat required for heating a material one degree. The energy density of the storage becomes in the order of 0,1 MWh/m³. The use of liquid -vapor phase change further increases the energy density.

The use of chemical reactions for thermal energy storage expands the temperature range for storage and also increases the potential energy density in the storage up to 1MWh/m³.

Chemical reactions for thermal energy storage are however combined with a heat pumping effect. Energy at a low temperature level has to be provided in order to discharge the storage. This energy is for instance used for vaporization of water. At the charging process energy is withdrawn from the process for instance by condensing water. The chemical contrary to phase change materials for thermal energy storage therefor has to be combined with utilization of energy and also requires energy for decharging.

The storage itself could be an underground thermal energy storage (UTES). The storage media is the groundwater (Aquifer Thermal Energy Storage) or the rock or soil itself



(Borehole Thermal Energy Storage, Cavern Thermal Energy Storage). A cavern could be filled with snow or ice utilizing the latent heat of melting of the water.

The storage could alternatively be made in tanks or containers. A phase change material could also be included in materials for construction.

The scope of the work undertaken in this annex includes thermal energy storage by solid-solid, solid-liquid, liquid-vapor and solid-vapor phase transfer, for instance melting/solidification, crystallization/solubilization, vaporization/liquefaction as well as by solid sorption processes and by chemical reactions.

The difficulties in using phase change materials for energy storage are

- (a) finding suitable materials for the required temperature range
- (b) mass and heat transfer limitations
- (c) phase separation, subcooling and other irreversibilities of the system
- (d) system integration

The thermal energy that needs to be stored comes from different sources. Solar energy and district heating are just two possibilities. In these fields collaboration with the implementing agreements "Solar Heating and Cooling" and "District Heating and Cooling" is planned.

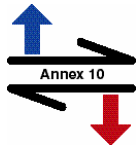
Three main areas of application will be covered in the annex:

1. Heating and cooling of buildings
2. Temperature sensitive materials
3. Waste heat utilization

1.1 Heating and Cooling of Buildings

The energy consumption for heating and cooling of buildings in Germany was about 3180 PJ for the year 1998. This is more than one third of the total energy consumption. The average household in Germany needs more than 75 % of its total energy consumption for space heating. The cooling demand in buildings increased rapidly over the last few years. The reason, beside general climatic and architectural boundary conditions, is an increase in the internal cooling load and higher comfort requirements. These aspects show the huge potential in this field for the implementation of advanced thermal energy storage technologies.

The heating and cooling of buildings can be identified as one of the most promising fields of application for thermal energy storage (TES) by phase change materials (PCM)



and chemical reactions. Depending on the location and the use of the building, heating or cooling is the main application for the storage system. Due to high insulation standards and high internal heat production in many of today's buildings, cooling is necessary even in cold climates. Therefore many buildings in fact need heating **and** cooling. A demonstration project concerning the use of adsorption systems for cold and heat storage by the same system is planned.

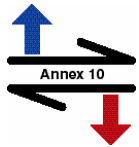
PCM's and chemical reactions can be used for heating and cooling in active or passive systems. Active systems are defined by an actively supported charging or discharging process, for example, by ventilated air or a pumped heat transfer fluid. They are coupled to the building's heating or air conditioning system. The demonstration of active PCM storage with enhanced heat transfer mechanisms is planned. Passive storage systems (only PCM's) are an integral part of the building. They can level out temperature changes in the building by raising the thermal mass of the building. PCM's can be integrated into building materials. Demonstration projects for the implementation of these materials in old and new buildings will be carried out. The integration of PCM's in greenhouses in hot climates for the purpose of temperature control will be investigated as an additional application.

1.2 HANDLING OF TEMPERATURE SENSITIVE PRODUCTS

A tremendous amount of money is lost each year due to the damage of temperature sensitive products and materials when exposed to operating temperature extremes outside of their design specifications. The area of interest includes for example, keeping products within certain temperature limits during transport and protecting electronic equipment from overheating.

Both these application areas have seen a limited use of phase change materials (PCM's) in combination with improved insulation techniques to achieve improved protection. The potential advantages that can be achieved by utilizing the benefits of PCM's in numerous temperature sensitive applications is however, largely unknown. The objective of any demonstration projects in this area will be to optimize the bounds of application and to promote the suitability of incorporating PCM's.

In the medical field there is a large demand to be able to transport for example, blood, vaccines, medication and transplant organs within very specific temperature ranges, no matter what the environmental conditions. A demonstration project in this area will highlight the effect on temperature control when incorporating PCM's in the transport containers.



Another area of interest is the transportation of fresh foods and flowers. The temperatures to which they are subjected during transport tremendously affect the shelf life of these products. The water content of fresh foodstuffs should not freeze nor should they be exposed to higher than normal refrigerator temperatures. Today, either costly refrigerated transport equipment or the use of dry ice is common. The disadvantages of today using dry ice are well documented. A demonstration project will show how a passive system incorporating PCM's is a viable and economically advantageous alternative.

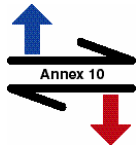
Most electronic equipment is susceptible to permanent damage when exposed to high temperatures. A demonstration project will show how potential overheating can be limited by incorporating PCM's within the system. Of special interest will be the problem of regeneration of the PCM back to its solid state so that it is available in cycles as a heat sink during normal operation.

These demonstration projects will focus on economic viability and the advantages of incorporating PCM's over the alternatives of concentrating on expensive dynamic equipment such as air conditioning and refrigeration equipment or the limited improvement gained by improved insulation. This area of application is also realisable in a relatively short space of time, and as such will demonstrate the use of PCM's for applications in the building and waste heat management industries. The spin off should be increased understanding of the technical and financial benefits of incorporating PCM's and therefore a faster track to commercialization.

1.3 Waste heat utilisation

Industrial processes often encompass a wide range of temperatures and different heat and cold fluxes in any one particular production site. If supply and demand exist simultaneously, heat exchangers can be used very efficiently. In many cases however supply and demand vary in time and quantity. Instead of using energy efficiently, electricity is often used to generate heat and cold on the spot, just where and when it is needed. This is convenient, but inefficient in economical and ecological terms. Heat and cold stores can fill this gap and match supply and demand with respect to availability in time and power.

A wide range of methods for heat storage with different properties is available. Latent heat storage by a solid / liquid phase change, for example, can be used to store heat or cold in a narrow temperature range but with a large storage density. If appropriate heat transfer mechanisms are applied, latent heat storage can also be used to supply large heat or cold fluxes, while equipment to generate the heat or cold is minimised in size,



while operating continuously. The functional principle of latent heat storage has already been demonstrated in several fields. Waste heat utilisation however, has mostly remained on the technological level of hot water heat stores, with all their inherent limitations. Due to the existence of commercial storage materials with phase change temperatures from -33°C to $+120^{\circ}\text{C}$ the potential of latent heat storage however, is large, especially for waste heat utilisation. This temperature range can even be extended to higher temperatures if chemical reactions are included.

Several demonstration projects for waste heat utilisation are planned. In co-generation systems for example, heat is produced in parallel with electricity, but can often not be used at the same rate. Presently, hot water heat stores are used to store the heat, but are not suitable as the temperature of the waste heat is very close to the boiling point of water. Another option are drying processes, where heat has to be supplied for a long time, but might be available as waste heat in a short time process. Further, all batch processes such as in chem. engineering and food processing are potential applications for heat stores. Suitable ones have yet to be identified.

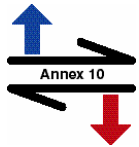
2. Objectives

The objectives of this Task are to overcome technical and market barriers for introduction of long- (seasonal) or short-term phase change and chemical reaction thermal energy storage for energy savings and for reduction of peak demand of energy in buildings, agricultural and industrial applications. Specifically this will be achieved by the demonstration of thermal energy storage with phase change materials or chemical reactions

- in building materials
- for cold and heat storage for comfort purposes
- for long and short term storage in the food sector including the transportation of food and other temperature sensitive goods
- for applications in industrial processes.

3. Means

The Participants shall share the coordinated work necessary to carry out this Task. The objectives shall be achieved by performing case studies and demonstration projects on thermal energy storage with phase change materials or chemical reactions in the building, the agricultural and the industrial sector. The result of the projects should be distributed to the participating member countries in the annex. If possible the projects should be performed jointly between two or more of the participating member countries.



Semi-annual meetings should be held for discussion of the results and for arrangement of workshops.

Observers from non-member countries are encouraged to participate in the workshops and to take part in the information exchange except for what is stated in Article 10.

4. Results

The results of this Task shall be

- periodic documents and interim progress reports on the results achieved under the Program of Work
- recommendations for future case studies shall be given by priority by the Participants.
- final report describing the work carried out under this Task. The final report should restate the scope and objectives of the Annex, its findings and documentation of case studies and demonstration projects

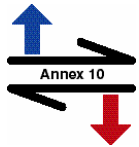
5. Time schedule

This Annex shall commence 1st of July 2001 and remain in force until 30st of June 2004. It may be extended by agreement of two or more Participants, acting in the Executive Committee, and taking into account any recommendations of the Agency's Committee on Energy Research and Technology concerning the term of this Annex. Extensions shall apply only to those Participants who agree to the extension or who notify the IEA Secretariat of their decision to continue to participate.

6. Specific obligations and responsibilities of the Participants

Each Participant shall

- provide the Operating Agent with detailed reports on the results of the work carried out
- collect, assess and report to the Operating Agent data on ongoing projects in the field of thermal energy storage with phase change materials or chemical reactions and on other data relevant for the use of thermal energy storage with phase change materials and chemical reactions
- participate in the editing and review of draft reports on the Task
- be prepared to host experts meetings and arrange work-shops
- participate in case studies or demonstration projects either nationally or in cooperation with other participating member countries

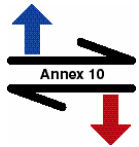


- participate in activities to enroll new members to the annex by spreading information about the annex and act in technology transfer to non-members where appropriate

7. Specific obligations and responsibilities of the operating agent

In addition to the obligations enumerated in Article 6 of this agreement the Operating Agent shall:

- Prepare and distribute the results mentioned in Article 4 above
- At the request of the Executive Committee organize workshops, seminars, conferences and other meetings
- Prepare the detailed program of work for the Task in consultation with the Participants and submit the program of work for approval to the Executive Committee
- Propose and maintain a methodology and a format for the submission of information on data and results from case studies and demonstration projects and other on ongoing projects as described in Article 6
- Provide the semi-annually and other periodic reports to the Executive Committee on the progress and the results of the work performed under the program of work
- Provide to the Executive Committee within six month after completion of all work under the Task a final report for its approval and transmittal to the Agency
- In coordination with the Participants use its best effort to avoid duplication with activities of other related programs and projects implemented by or under the auspices of the Agency or by other competent bodies
- Provide the Participants with the necessary guidelines for the work they carry out assuring minimum duplication effort
- Coordinate the efforts of all Participants and ensure the flow of information in the Task
- Perform such additional services and actions as may be decided by the Executive Committee acting by unanimity



8. Funding

- (a) Semi-annual meetings. The Participants shall host the semi-annual meetings pursuant to Article 3 above in turn. The cost of organizing and hosting meetings shall be borne by the host Participant.
- (b) Publications. The Operating Agent shall meet the cost of publishing the reports and summary assessments described in Article 4 above.
- (c) Individual financial obligations. Each Participant shall bear all the costs it incurs in carrying out the Task activities, including reporting and travel expenses.
- (d) Task-Sharing requirements. Apart from the participation in case studies and the demonstration projects, which are anticipated to be financed outside of the annex, the Operating Agent should devote 6 man-month per year to the work in the annex. The Participants are expected to devote 3 man-month per year to the work in the annex.

9. Operating agent

FORMAS, the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning, acting through the Royal Institute of Technology, Stockholm, Sweden is designated as Operating Agent

10. Information and Intellectual Property

- (a) Executive Committee's Powers.

The publication, distribution, handling, protection and ownership of information and intellectual property arising from this Annex shall be determined by the executive Committee, acting by unanimity, in conformity with this Annex.

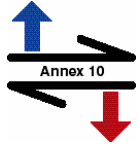
- (b) Right to publish.

Subject only to copyright restriction described in Article 10(i) below, the Participants shall have the right to publish all information arising from this Task, except proprietary information, as defined in Article 10(c) below.

- (c) Proprietary information.

The Participants and the Operating Agent shall take all necessary measures in accordance with this Article, the laws of their respective countries and international law to protect the proprietary information provided to, or arising from this Task. For the purpose of this Annex, proprietary information shall mean information of a confidential nature such as trade secrets and know-how (for example computer programs, design procedures and techniques, chemical composition of materials or working media, manufacturing methods, processes or treatments) which is appropriately marked provided that such information:

- (1) Is not generally known or publicly available from other sources;



(2) Has not previously been made available by its owner(s) to others without obligation concerning its confidentiality;

(3) Is not already in the possession of the recipient Participant(s) without obligation concerning its confidentiality;

It shall be the responsibility of each Participant supplying such proprietary information and of the Operating Agent for developing proprietary information to identify each information as proprietary and to ensure that it is appropriately marked.

(d) Production of Relevant information by Governments.

The Operating Agent should encourage governments of all Agency Participating Countries to make available or identify to the Operating Agent all published or otherwise freely available information known to them that is relevant to the Task.

(e) Production of relevant information by Participants.

Each Participant agrees to provide to the Operating Agent all previously available information and information developed independently of the Task which can assist or is needed by the Operating Agent to carry out its function in this Task, which is freely at the disposal of the Participant and the transmission of which is not subject to any contractual and/or legal limitations under the following conditions:

(1) If no substantial cost is incurred by the Participant in making such information available at no cost to the Task therefor;

(2) If substantial costs must be incurred by the Participant to make such information available at such charges to the Task as shall be agreed between the Operating Agent and the Participant with the approval of the Executive Committee;

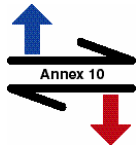
(f) Use of confidential information.

If a Participant has access to confidential information which would be useful to the Operating Agent in carrying out the studies, assessments, analyses or evaluations called for in this Task, such information may be communicated to the Operating Agent but shall not become part of any report or other form of documentation issued as part of this Task, nor shall it be communicated to the Participants except as may be agreed between the Operating Agent and The Participant who supplies such information.

(g) Acquisition of Information for the Task.

Each Participant shall inform the Operating Agent of the existence of information that can be of value to the Task but which is not freely available and each Participant shall endeavor to make such information available to the Task under reasonable conditions in which event the Executive Committee may, acting by unanimity, decide to acquire each information.

(h) Reports on work performed under the Task.



The Operating Agent shall provide reports on all work performed under the Task and the result thereof including studies, assessments, analyses, evaluations and other documentation but excluding proprietary information in accordance with Article 10(c) above.

(i) Copyright.

The Operating Agent, or each Participant for its own result, may take appropriate measures necessary to protect copyrightable material generated under this Task. Copyrights obtained shall be the property of the Operating Agent, for the benefit of the Participants provided, however, that Participants may reproduce and distribute material, but shall not publish it with a view of profit, except as otherwise provided by the Executive Committee.

(j) Authors.

Each Participant shall, without prejudice to any rights of authors under its national laws, take necessary steps to provide the co-operation from its authors required to carry out the provisions of this Article. Each Participant shall assume the responsibility to pay awards or compensation required to be paid to its employees according to the laws of the country.

11. Participants in this Task

Participants in this task are

- Australia (provisionally)
- Germany
- Japan
- the Netherlands (provisionally)
- Spain (provisionally)
- Sweden