Task 42 **Annex 24**

Compact Thermal Energy Storage: Material Development and System Integration

Annex Text
May 2008

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Introduction

Thermal energy storage is an important technology for renewable energy systems and energy efficiency. By improving the effectiveness of thermal storage, the effectiveness of all renewable energy technologies that supply heat can be improved.
Particularly for solar thermal systems, thermal energy storage is essential. To reach high solar fractions, it is necessary to store heat (or cold) efficiently for longer periods of time. Until now, no cost-effective compact storage technologies are available to do this. For high solar fraction systems, hot water stores are expensive and require very large volumes of space. Alternative storage technologies, such as phase change materials (PCMs) and thermochemical materials (TCMs) are available on a laboratory scale. However, more research and development is needed before these technologies can be developed into commercial solutions.
In several IEA Annexes[1], it was concluded that materials are the main bottleneck for finding effective solutions for compact thermal energy storage, and that there is a need for new storage materials with a higher specific energy storage density and lower material cost.
Around the world, several groups are working on either thermal energy storage materials or applications. However, these activities are not sufficiently linked. The current activities are either limited to specific applications, or to specific materials. What is needed, and what can be provided by this task, is a way to bring the ongoing work on materials and applications together.
Until now, two expert meetings were held to help shape this task: a first expert meeting in October 2007 in Zürich, Switzerland, followed by a Task Definition Meeting in April 2008 in Petten, the Netherlands. In addition, a proposal for the Task was presented to both the ECES and SHC ExCos in November and December 2007, respectively. Finally, a separate meeting was held in Düsseldorf, Germany in March 2008 between the two proposed Operating Agents and the Dutch and German ExCo members, to discuss the possibility and desirability of organising the Task as a Joint Task. This document is the result of these five meetings.

1 Description of the technology

Thermal energy storage (TES) is a broad field, covering different storage technologies as well as different applications for storage. It is also a supporting technology, enabling heating and cooling systems to operate more efficiently, reliably, etc. And finally, TES is a multidisciplinary field of research, requiring knowledge of materials science, thermodynamics, reaction dynamics, systems integration, etc. Because of these reasons, TES has been a relatively fragmented field of research. One of the primary achievements of this task will be to bring together experts with all of the different required backgrounds, to work together on the development of thermal energy storage.

[1] *Including IEA SHC Task 32, IEA ECES Annex 10, 17, 18 and 19.*

Thermal energy storage can roughly be categorised in three classes of technology:

- **Sensible heat storage**. Heat is stored by increasing the temperature of a medium. This includes for example hot water boilers, solar combi systems, aquifer storage, ground heat exchangers, but also high-temperature stores using concrete or thermal oils, or close-to-ambient storage in the thermal mass of a building. Sensible heat storage is *not* included in this task.
- **Latent heat storage**. Heat is stored in a phase change, e.g. by melting ice, paraffin or organic salts. Latent heat storage materials typically have a very high phase change enthalpy, making them very effective over a small temperature range. Hence, typical applications of latent heat storage include stabilisation of indoor climate or medical applications. Latent heat storage is included in this task.
- **Chemical heat storage**. Heat is stored in a chemical reaction, resulting in a reversible structural change in the storage material. Of the three storage classes, chemical heat storage has by far the highest potential storage density (estimated up to 10 times higher than water). Because a thermochemical storage has virtually no storage losses, it is very suitable for long-term storage applications such as seasonal storage of solar heat. Chemical heat storage includes ad- and absorption reactions, and is included in this task.

2 Objective and scope

Objective

The overall objective of this task is to develop advanced materials and systems for the compact storage of thermal energy. This can be subdivided into eight specific objectives:

- to identify, design and develop new materials and composites for compact thermal energy storage,
- to develop measuring and testing procedures to characterise new storage materials reliably and reproducibly,
- to improve the performance, stability, and cost-effectiveness of new storage materials,
- to develop multi-scale numerical models, describing and predicting the performance of new materials in thermal storage systems,
- to develop and demonstrate novel compact thermal energy storage systems employing the advanced materials,
- to assess the impact of new materials on the performance of thermal energy storage in the different applications considered, and
- to disseminate the knowledge and experience acquired in this task.

A secondary objective of this task is to create an active and effective research network in which researchers and industry working in the field of thermal energy storage can collaborate.

Scope
This task deals with advanced materials for latent and chemical thermal energy storage, and excludes materials related to sensible heat storage. The task deals with these materials on three different scales:

- material scale, focused on the behaviour of materials from the molecular to the 'few particles' scale, including e.g. material synthesis, micro-scale mass transport, and sorption reactions;
- bulk scale, focused on bulk behaviour of materials and the performance of the storage in itself, including e.g. heat, mass, and vapour transport, wall-wall and wall-material interactions, and reactor design;
- system scale, focused on the performance of a storage within a heating or cooling system, including e.g. economical feasibility studies, case studies, and system tests.

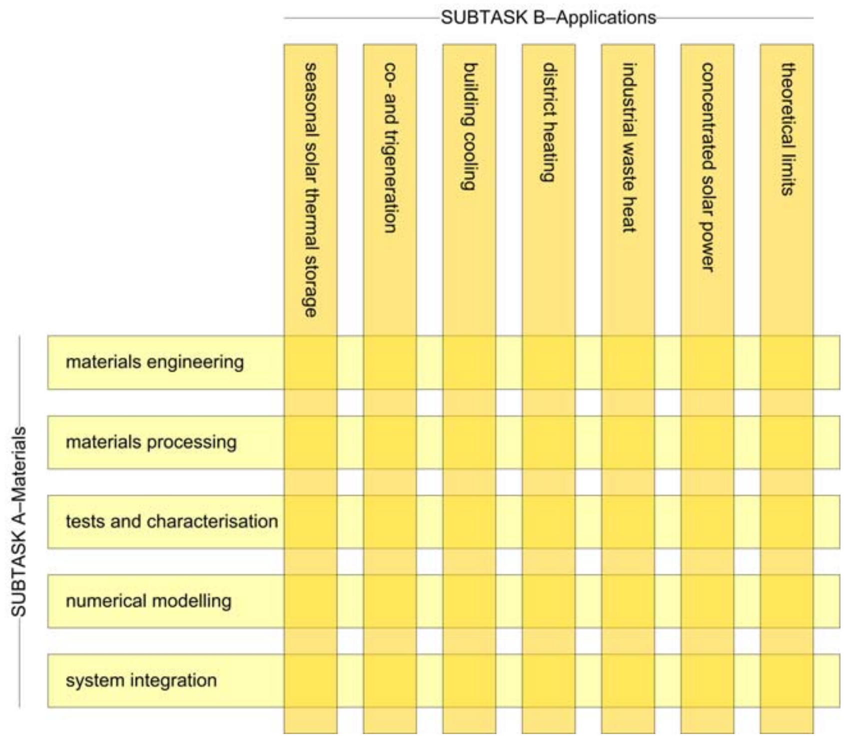
Because seasonal storage of solar heat for solar assisted heating of buildings is the main focus of the SHC IA, this will be one of the primary topics of this task. However, because there are many more relevant applications for TES, and because materials research is not and can not be limited to one application only, this task will focus on multiple application areas.
Applications that will be included from the start of this task are:

- seasonal solar thermal storage,
- cogeneration and trigeneration and heat pumps,
- building cooling,
- district heating,
- industrial waste heat, and
- concentrated solar power.

Temperature control, e.g. for medical applications, will be taken into account as an interesting spin-off. Finally, as a special theoretical 'application', the theoretical limits of advanced storage materials will be investigated as one of the covered applications.
This subdivision will be treated with a certain amount of flexibility. If, during the task's four-year operation, new promising applications are revealed, they can be included in the task's scope at a later point. Vice versa, if the interests in one of the above-mentioned applications fade, it can be decided to drop this particular application as a focus point of the task. The organisation of the task (see section 5) allows for this flexibility.

3 Activities

To achieve the maximum amount of cross-fertilisation between the different backgrounds of the two Implementing Agreements and experts in this Joint Task, the Task is organised in a matrix-like structure (see diagram below). For more information on this structure, see section 5.



One axis represents materials-related activities. It is divided into groups of similar activities:

- materials engineering,
- materials processing,
- tests and characterisation,
- numerical modelling, and
- system integration.

The other axis represents application-related activities, and is grouped into application categories:

- seasonal solar thermal storage,
- cogeneration and trigeneration (also including heat pumps),
- building cooling,
- district heating,
- industrial waste heat,
- concentrated solar power, and
- theoretical limits as a ‘special application’.

Each axis corresponds to a Subtask, and each category corresponds to a Working Group (see also section 5).
The activities in each Working Group are described in more detail below. Because of the similarity between the activities in the various Application Working Groups, these are described under one heading.

Materials engineering

The activities in this Working Group focus on engineering new materials or composites, i.e. changing the properties of existing materials and developing new materials with better performance, lower cost, and improved stability. Eventually, this should lead to the ability to design new materials tailor-made to specification.

This Working Group includes the following activities:

- synthesis of new materials;
- determination of material characteristics such as phase diagrams;
- determination of the relation between material performance and material structure and composition, in order to direct the search for improved materials;
- create material safety data sheets;
- determination of the role and importance of material containers.

Materials processing

The activities in this Working Group focus on the processing of raw materials that is required to make these materials function in a realistic environment. In nearly all cases, storage material can not be used to store heat in its raw form, but e.g. needs to be processed into a slurry, encapsulated, or otherwise processed.

This Working Group includes the following activities:

- finding optimal methods for micro- and macro encapsulation of phase change materials;
- processing of phase-change slurries
- find new combinations of materials

Tests and characterisation

The performance characteristics of novel thermal energy storage materials, like phase-change materials or thermochemical materials, often cannot be determined as straightforward as with sensible heat storage materials. In order to have proper comparison possibilities appropriate testing and characterisation procedures should be developed and assessed. The activities of this Working Group are aimed at developing these new procedures and include:

- comparative testing of materials and their required methods
- long-term stability determination
- (pre-)standardisation of testing methods

Numerical modelling

The activities in this working group are aimed at developing and testing numerical models that help to understand and optimise the material behaviour and the dynamic behaviour of compact thermal energy storage systems and components. Ultimately, these numerical models could help to find ways to optimise the materials in combination with the system components. The activities in this working group can help lay the foundation for such models.

The Working Group includes the following activities:

- molecular dynamics
- multiscale modelling
- thermomechanical modelling
- storage (system) modelling

System integration

The storage system is composed of the storage material and the equipment necessary to charge and discharge the storage material in a controlled and optimal way. This includes heat and mass transfer equipment like heat exchangers and pumps or fans and (chemical) reactors. Methods for the design and optimisation of components and system should be developed, together with appropriate testing methods and procedures to assess the long-term behaviour of a system.
This Working Group includes the following activities:

- improve heat transfer from material to reactor wall or heat exchanger wall
- develop and apply test and validation methods for storages
- system performance assessment
- container and reactor design
- storage system design
- assessment of durability of components

Applications

There are several applications for compact thermal energy storage technologies, each with a different set of boundary conditions for the technology. The activities for every application, however, are similar and are given for all Application Working Groups. The activities are serving the underlying principle of guidance of the materials development within the limitations of the application. The materials development will be directed by the desired system performance. A constant assessment of performance criteria for a given application will be used to determine the chances for a given material/system combination. These criteria can come from economic, environmental, production technology or market considerations.
Activities in the Application Working Groups include:

- storage testing and validation
- performance assessment
- numerical modelling on application system level
- perform case studies
- economical modelling
- feasibility studies
- market potential evaluations

4 Results

The results of the Task are designed for experts and organisations in the materials sector as well as all the applications sectors. For the materials sector, the task results will represent better understanding of existing and new materials for thermal energy storage, new methods and procedures for material and system performance improvement and a good overview of the possible applications for this class of materials. The application sectors will get a better understanding of the possibilities and impossibilities of compact thermal energy storage materials and systems for their application.
The results per Working Group are described below.

Materials engineering

First version of a Materials Database with material properties and relations

Material safety data sheets
Samples of new materials for material testing

Materials processing
Inventory of production technologies
Material prices data sheets

Tests and characterisation
Long-term stability test protocols for several classes of materials

Numerical modelling
Test procedures for model validation
Validated numerical models for all applications

System integration
System testing methods
First version of reactor design method

Applications
List of requirements for each application
Case studies
Technological and economical potential of each application
System numerical model of each application
Study of theoretical upper limits of storage performance
Field test of a least one application
At least one 100% solar fraction laboratory prototype
Life cycle cost analysis

5 Management

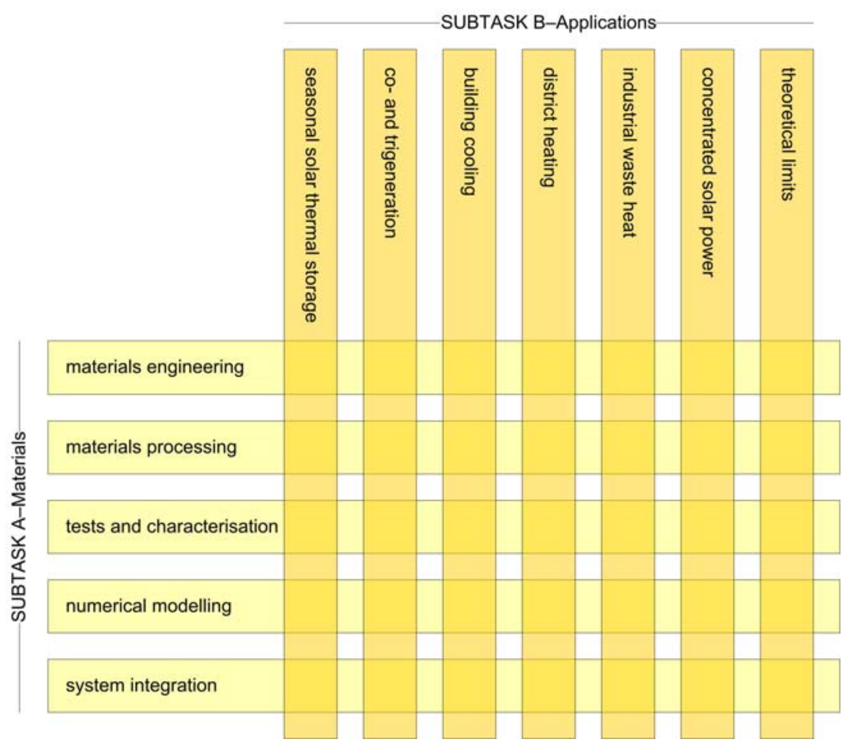
Joint undertaking
The Executive Committees of the SHC and ECES Implementing Agreements both underline the importance of a united approach of the international research and development of advanced materials for compact thermal energy storage. Results can only be achieved effectively if the problems are tackled in both the technology as well as the applications directions. These directions also reflect the primary interests of the two initiating Implementing Agreements. The shared interest in the Joint Task is reflected by the decision to have two Operating Agents with equal responsibility.
A number of applications are also of interest for other IEA Implementing Agreements. A maximum level of co-operation will be sought with these Agreements in order to maximise the basis for the work in this Task. Relevant IA's are:

- SolarPACES (Concentrating Solar Power)
- District Heating and Cooling DHC
- Heat Pumping Technologies HPP
- Energy Conservation in Community and Building Systems ECBCS
- Industrial Energy-related Technologies and Systems IETS
- Renewable Energy Technology Deployment RETD

Although there is a fully shared responsibility of the two Operating Agents, there will be a division of responsibilities over the task in practice. This division will be coupled to the structure of the task. One of the shared responsibilities of the Operating Agents is taking care that in all publications and public addresses, the joint activity is clear (e.g. IEA webpage, SHC webpage, ECES webpage, joint task webpage).
The task is fully joint. There will be one Task Work Plan, one line of expert meetings and one line of reports, submitted to both Implementing Agreements Executive Committees. The submission and presentation of the reports to the Executive Committees and the discussions will be done by the respective Operating Agents.

Steering Committee
A steering committee will be formed, consisting of two ECES and two SHC ExCo members. The ExCo members of the initiating countries will be members of the Steering Committee (NL for SHC and DE for ECES), complemented by two ExCo members from other countries.
Amongst other tasks, the Steering Committee will process draft documents and reports, in order to assist the Operating Agents in their decisions and to mediate in case of conflicting opinions.
The task deals with materials research and development on a medium to long term time scale. A large part of the work will consist of PhD work that will only produce its first results after two or three years. A good incorporation of this work is only possible if the Task has a duration of at least four years. The work project plan should cover the first three years; the last year is predominantly for dissemination.

Task structure
The task is organised in a matrix-like structure (see diagram below).



This type of organisation has several advantages:

- it maximises the interaction between experts with different backgrounds, i.e. materials researchers and application experts;
- it maximises knowledge exchange between groups working on adjacent topics;
- it shows the relevance of the task for other application areas, making it more interesting for materials researchers as well as industry to participate;
- it provides a practical way do share the interest and responsibilities of the SHC and ECES Implementing Agreements in this task.

The task is divided into two subtasks:

- Subtask A: Materials, and
- Subtask B: Applications.

The Operating Agent acting on behalf of the ECES Implementing Agreement will be Subtask A Leader, and the Operating Agent acting on behalf of the SHC Implementing Agreement will be Subtask B Leader.
Each subtask is further subdivided into working groups (see diagram). At the task kick-off meeting, selected task participants will be appointed as Working Group Leaders.
The division in working groups of Subtask B, Applications, can be changed if and when a need for this should arise during the task operation, e.g. because interest in a specific application has strongly increased or decreased.

Obligations and responsibilities of the participants

Each participant shall provide the Operating Agents with detailed reports on the results of the work carried out in each Subtask. In addition, each Participant shall participate in the editing and reviewing of draft reports of the Task and Subtasks.

Obligations and Responsibilities of the Operating Agent

In addition to the obligations of the participants enumerated above, the Operating Agent shall:

- prepare and distribute the results described above;
- at the request of the Executive Committee, organise workshops, seminars, conferences and other meetings;
- prepare the detailed Programme of Work for the Task in consultation with the Working Group Leaders and the Participants and submit the Task Work Plan for approval to the Executive Committees;
- provide semi-annual periodic reports to the Executive Committees on the progress and the results of the work performed under the Task Work Plan;
- provide to the Executive Committees, within six months after completion of all work under the Task, a final report for its approval and transmittal to the Agency;
- in co-ordination with the participants, use its best efforts to avoid duplication with activities of other related programmes 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 with minimum duplication; and
- perform such additional services and actions as may be decided by the Executive Committee, acting by unanimity.

6 Funding

(a) Each country will bear the costs of its own participation in the Task, including necessary travel costs. The cost of organising meetings will be borne by the host country.

(b) Level of effort
The Participants agree on the following funding commitment:
(1) Each Participant (country) will contribute to this Task a minimum of 0.25 person year per year of the Task, i.e. a total minimum of 1 person year;
(2) Participation in the Task requires participation in both Subtasks.
(3) The Operating Agents will contribute with a minimum of 0.5 person year per year to the Task (i.e., a total of 2 person years for their work as Operating Agent).

(c) Participation may partly involve funding already allocated to a national (or international) activity which is substantially in agreement with the scope of work outlined in this Annex. Aside from providing the resources required for performing the work of the Subtasks in which they are participating, all Participants are required to commit the resources necessary for activities which are specifically collaborative in nature and which would not be part of activities funded by national or international sources. Examples include the preparation for and participation in Task meetings, co-ordination with Subtask Participants, contribution to the documentation and dissemination work and Task related R&D work which exceeds the R&D work carried out in the framework of the national (or international) activity.

7 Information and intellectual property

For purposes of this Annex, the following provisions shall apply in addition to the intellectual property provisions contained in Article 7 of the Agreement. In case of conflict, the following provisions shall prevail:

(a) For arising information regarding inventions the following rules shall apply:

(1) Arising information regarding inventions shall be owned in all countries by the inventing Participant. The inventing Participant shall promptly identify and report to the Executive Committee any such information along with an indication whether and in which countries the inventing Participant intends to file patent applications;
(2) Information regarding inventions on which the inventing Participant intends to obtain a patent protection shall not be published or publicly disclosed by the Operating Agent or the other Participants until a patent

has been filed, provided, however, that this restriction on publication or disclosure shall not extend beyond twelve months from the date of reporting of the invention. It shall be the responsibility of the inventing Participants to appropriately mark Task reports which disclose inventions that have not been appropriately protected by filing a patent application.

(b) The inventing Participant shall license proprietary information arising from the Task for non-exclusive use as follows:
(1) To Participants in the Task:
(i) On the most favourable terms and conditions for use by the Participants in their own country; and
(ii) On favourable terms and conditions for the purpose of sub-licensing others for use in their own country.
(2) Subject to sub-paragraph (1) above, to each Participant in the Task for use in all countries, on reasonable terms and conditions; and
(3) To the government of any Agency Member country and nationals designated by it, for use in such country in order to meet its energy needs.

Royalties, if any, under licenses pursuant to this paragraph shall be the property of the inventing Participant.

8 Operating Agents

The German PTJ, Projektträger Jülich, acting through the Bavarian Center of Applied Energy Research (ZAE Bayern), is designated as Operating Agent on behalf of the ECES IA.

The Dutch SenterNovem, acting through the Energy Research Centre of the Netherlands (ECN), is designated as Operating Agent on behalf of the SHC IA.

9 Participants in this Annex

Participants in this task (from the ECES) are:

- Germany
- Sweden
- France
- Finland
- Turkey
- A number of provisional participants