AUSTRIAN MASTERPLAN-THERMAL ENERGY STORAGE

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Abstract

Novel, compact thermal energy storage technologies are of key importance to achieve the national long-term renewable energy targets. The aim of this project was to set up the Masterplan-TES-AT that describes the actions and measures needed to obtain the proper R,D&D infrastructure in Austria.

Future heat storage applications and related research challenges have been identified during several steps of activities in the project. Experts identified applications and markets that are of special importance since they would benefit most of technical progress in heat storage applications. These fields of applications as well as the complete lists with research topics classified into several categories are described in the study. With this input a programmed approach for fundamental and applied R&D and industrial development, it is possible to get new and innovative heat storage technologies to the market.

The concept of the `Masterplan-Thermal Energy Storage- Austria´ is tuned to the international R&D plans and activities in order to maximize the effectiveness and to minimize the effort. With the plan, the position of Austria in the international R&D field on Thermal Energy Storage will be enforced.

1. Introduction

The goal of the project Masterplan Austria- Thermal Energy Storage is to point out the necessary and desired research and development activities for efficient thermal storage technologies in order to substantially increase the renewable share of heat in Austria in the future. The Project started in October 2010 and finished last year in December 2011. The main outcomes are two documents, namely PART A: Basic Document and PART B: Strategic Document. Both contain essential information for the future heat storage development. The documents are part of the project report.

The study enables the government and the appending funding organizations to start an effective and targeted stimulation of R&D in the field of thermal energy storage (TES). The actions and recommended measures laid down in the Masterplan helps to achieve the Austrian long-term renewable energy goals. The Masterplan can also be used to motivate and help establish a European Thermal Storage research institute in Austria.

The methods used to construct the Masterplan are desk study for description of the technology and research projects, interviews with stakeholders, technology roadmapping, balanced scorecard analysis, and two workshops (see Fig. 1).

The first step was to describe the state-of-knowledge with input from international and national review publications and all available other sources. The result is the so called PART A: `Basic Document´ which is a comprehensive summary of the actual projects, the research challenges already mastered and results documented. The study represents the result of the first phase of the project and was used as base for the interviews and workshops.

Interviews with international experts were held to make a sketch of the R&D activities in the storage-related technical and non-technical fields. The results were analyzed and integrated to the roadmap and applications (technical parts) and the accompanying measures (non-technical parts).

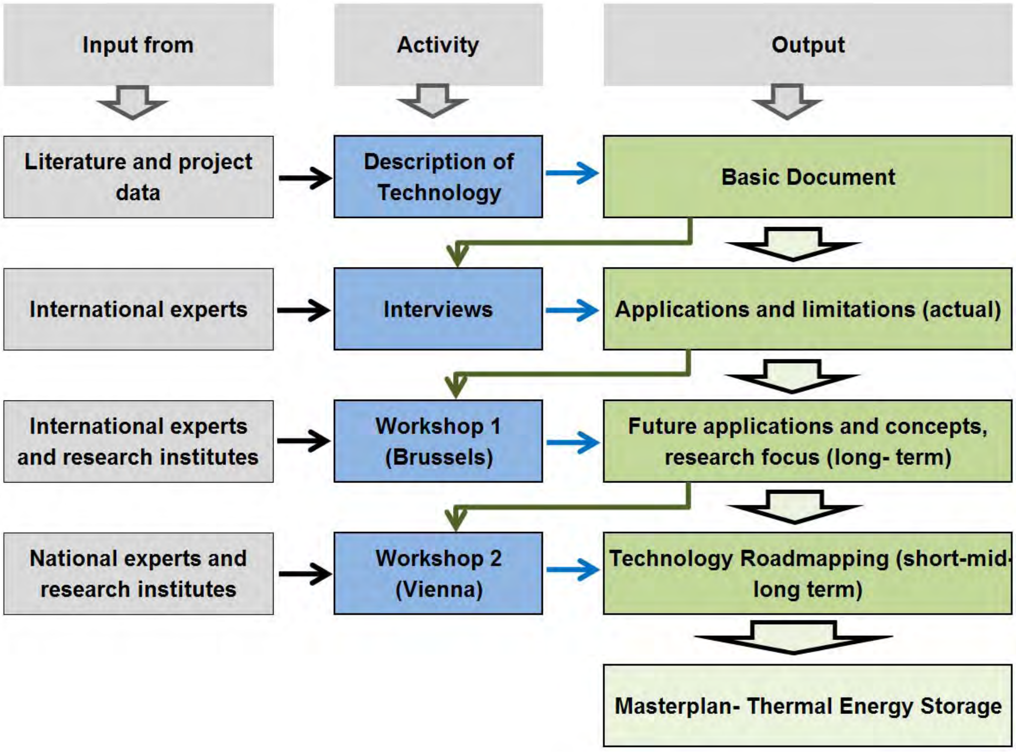

Fig. 1: The activities in the project Masterplan-TES and their input and output

In the next step a workshop was organised in Brussels with a group of international experts. The workshop was aimed at getting a list of future applications for thermal storage technologies and a first list of expertises needed for the R&D on these applications.

A second workshop with all national stakeholders was organised to get the blueprint for the Masterplan, a technology roadmap. With technology roadmapping, first a list of future applications of thermal energy storage (TES) technologies was used to make an inventory of the technological developments that need to be done. In their turn, these technological developments need research activities, all basic, applied, and demonstration. For every R&D activity, an estimate is made of the time needed, the scientific expertise, and the area of application which benefits most.

International activities

The interest for thermal energy storage on a national and on an international level is steadily increasing. The necessity of thermal energy storage has been put forward in several strategic and technology roadmaps: from the European Solar Thermal Technology Platform ESTTP, the Renewable Heating and Cooling Platform RHC-ETP and from several national platforms, notably from Austria and Germany. This led to a stronger position of thermal energy storage in the different subsidy programs. The EU opened a large call for R&D projects including thermal energy storage in 2011, with a budget of over 12 M€. In this same year, Germany also started a very large R&D call for storage technologies in general, including thermal energy storage with an estimated budget of 30 M€. And there is a continued attention for thermal energy storage in the national energy R&D programs in France and Austria.

This positive increased effort in thermal energy storage on an international level makes coordination of the activities more important, in order to minimize duplication of work and to improve the efficiency of the R&D activities. A majority of the researchers active in the field of compact thermal energy storage are collaborating in the Task4224 of the International Energy Agency's Solar Heating and Cooling program. Through this collaboration, the researchers are better informed about each other's work and have better possibilities for coordination of the activities. Coordination of the work in other fields of thermal energy storage (for large, water-based systems and for district heating) could be done in other IEA programs, like the Energy Conservation through Energy Storage (ECES) program. Another body for the coordination of the activities is within the European Technology Platform for Renewable Heating and Cooling, the RHC-ETP. One focus group in this platform is fully oriented at thermal energy storage and can serve as a platform for coordination.

2. Methodology

The development of the Masterplan strategy was enabled by the use of different tools in order to collect, to analyze, and present information related to thermal storages. During the two expert workshops, the expert interviews and the preparation of the technology survey a lot of ideas, perspectives, possible applications, development challenges and limitations where discussed. This information was collected and summarized to ensure the consideration of the whole bandwidth of the technological potential and all fields of applications for thermal energy storage.

The following paragraphs sketch the methodological background of the tools Balanced Scorecard and Technology Roadmaps and give a short introduction why they are used, and how these tools have been adapted in the master plan.

Balanced Scorecard

"A Balanced Scorecard (BSC) is a management tool that provides senior executives with a comprehensive set of measures to assess how the organization is progressing toward meeting its strategic goals" [1]. This definition indicates its characteristics as a tool that provides on the one hand traditional financial metrics and on the other hand strategic non-financial performance measures. The BSC suggests four different perspectives to look at the organization, develop metrics, collect data and analyze them relative to each of these perspectives. The business vision and the derived strategy are translated into aims and metrics for these four perspectives. All of them should be in balance to reach the organization's strategic aims. It is typically used to implement and control strategies in business organization but with adaptations it is also in use for NPOs and governmental activities. The four perspectives are:

Financial Perspective is always in touch with profitability, revenue, cash flow and other classical key financial figures like return on investment etc.

Customer Perspective concentrates on the influence of the customers, their expectations and the satisfaction of these by the organization's products and services.

Internal Business Process Perspective gives information about the internal key business processes that are a decisive factor to reach customer satisfaction.

Learning and Growth Perspective identifies the infrastructure, knowledge and learning abilities which are necessary to generate an ongoing ability of innovation – product, process and organizational innovation.

The four perspectives could not be seen isolated, on the contrary they are interconnected very closely and have different cause and result relationships to one another. These can be illustrated in a strategy

[1] (Smith M., How to link IT Metrics to Business Value, Garner Research, 2007, p. 166)

map as a cause and result network. A special type of these maps concentrating on technological progress is known as technology roadmaps.

Technology Roadmaps

With the use of technology roadmaps, future developments of technologies may be predicted, analyzed and visualized through systematic gathering and bundling of expertise.

Robert Galvin (1998) at Motorola defined roadmap as, "... an extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of change in the field. Roadmaps can comprise statements of theories and trends, the formulation of models, identification of linkages among and within sciences, identification of discontinuities and knowledge voids, and interpretations and experiments."

The roadmap generation process can be understood as a kind of extrapolation of the present situation. That means that already established technologies and product lines are adjusted into the future and a generation chronology is presented. One tries to estimate the certain point of availability and the demands of a technology as precise as possible.

The advantage of this tool is its reliable starting basis (that is, the present situation), but both technological discontinuities and leaps cannot be predicted anyhow. As means of visualization, technology roadmaps enable a picture of the interrelationships between individual technologies, of the chronology of their development as well as of their individual diffusion rate.

Technology roadmaps are supporting planning and realization of strategic technology measurements and are able to align technology activities with the general business activities of a single organization as well as one of a whole business or industry.

Adaptation of the roadmapping methodology

For the use of developing and describing a master plan, the general methodology was adapted to the specific needs described above.

First we defined four specific fields of interest consistent with the four application fields of thermal storage as our main structuring principles: mobile applications, buildings, industrial processes and smart grids. We discarded the idea to use product or market development as our guiding principle.

Secondly, in order to reduce complexity, we decided not to combine all the fields of application into one big master roadmap. We expect almost no loss of information as there is only a limited number of substantial linkages between our application fields.

Thirdly, we defined our time line for the master plan. In classical roadmaps there is a huge variety concerning the span of time beginning with just a few years up to fifty or more years. For our purpose we expect 15 years as realistic to make feasible forecasts. We differentiate short, middle and long term developments and define short term up to three years, middle term up to ten years and long term more than 10 years.

Fourthly, we modified the common notation of technologies in roadmaps as bars or rectangles with a specific length indicating the emergence and decline of the technology. With our specific notation we indicate that the intensity of R&D-activities (which we see similar to the diffusion of the technology) will not be constant over the years. We use the width of the bar as indicator for the level of activities and therefore designed a deltoid-shaped symbol (as shown in Fig. 3) instead of the common rectangle. In the rhombus-shape, technologies evolve at a specific point on the timeline, increase their diffusion and penetration rate up to a maximum, and decrease later until they finally disappear at a specific point.

Fifthly we differentiated in our roadmap between "fundamental or basic research", "applied research" and "demonstration activities". We define the first two terms in accordance with the OECD Frascati Manual [2]. "Basic research is experimental or theoretical work undertaken primarily to acquire new

[2] (OECD, Frascati Manual: Proposed Standard Practice for Surveys on Research and Experimental Development, OECD publication, 2002, p. 30)

knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view“. In contrast to basic research we define applied research as „… original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective”. The third term “demonstration activities” is understood as demonstration only directed to the improvement of new processes, systems and services. This is an activity that forms the last link in the R&D chain, just before the market introduction. In contrast to the Frascati definition, which includes also material research and apparatus development, demonstration should approve applicability and reliability of technical concepts as whole.

The results of the application of the described principles to the roadmap of heat storage can be seen in Fig. 3.

Adaptation of the Balanced Scorecard

To use the Balanced Scorecard method for the development of a research-oriented masterplan we adapted the common tool to our specific situation. At the beginning we decided to use the four original perspectives as described above thereby restricting the idea to develop new or other perspectives, either substitutionally or additionally. We found out that even if new perspectives may have fitted better to our intention to find a methodology for controlling the development and diffusion of a masterplan we decided to use the original ones as they are well known and adjustable to our needs.

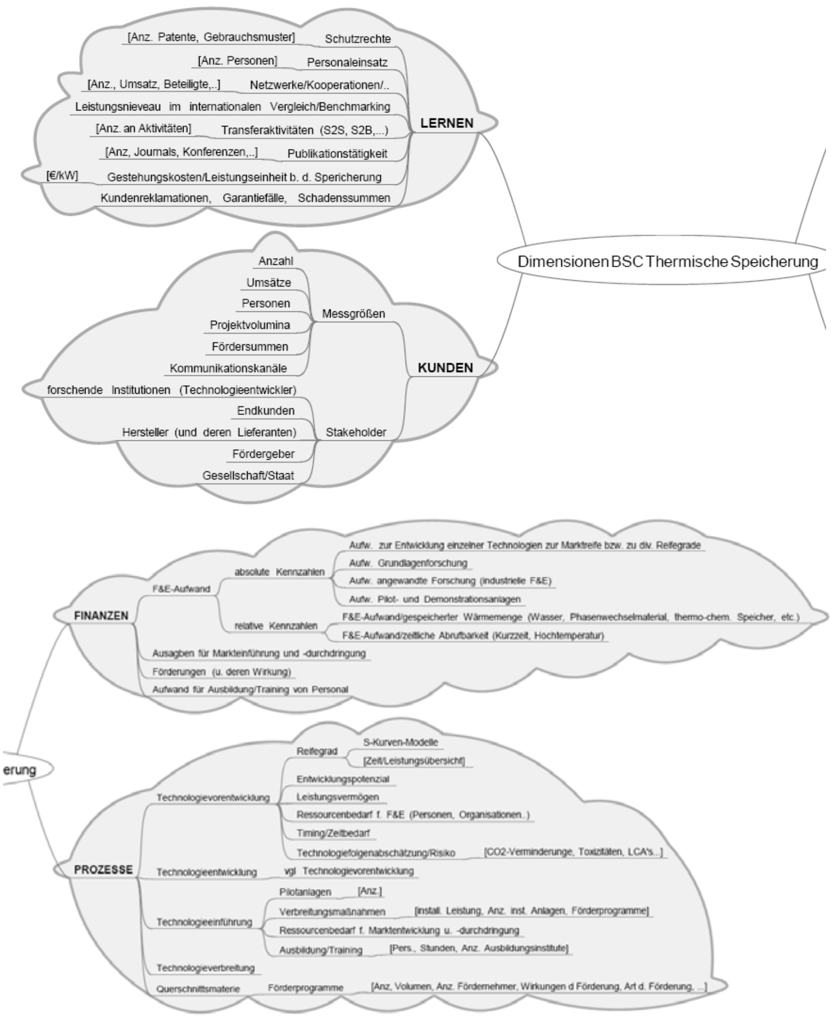

Fig. 2: Examples of indicators for the balanced scorecard “heat storage”

In a next step we developed and discussed possible key indicators for each of the four dimensions and described it in a mindmap. The list of possible key indicators can be seen in Fig. 2.

As a next step we reduced the number of key indicators to a manageable number. We thereby paid attention to neglect none of the dimensions, to find quantitative indicators and to find representative indicators for describing, steering and controlling the field of heat storage research. In the end we had to be convinced that experts are able to fill in the correct numbers.

In an expert workshop we finally discussed the key indicators listed in Table 1 with the participants and evaluated the proposed indicators. We got the feedback that generally all financial metrics are difficult to estimate, especially in a middle and long-term view. Therefore we eliminated the indicator "net heat production cost". In the learning and growth perspective we removed the indicators "number of networks and cooperations" and "number of relevant meetings and events per year".

Financial perspective	- Expenditures for R&D per year - Allocation of the financial resources to basic research, applied research and demonstration projects	[€/year] or [man-year] [%]
Customer perspective	- Number of manufacturers of heat storage devices - Number of sold aggregates per year	[number] [number]
Internal business process perspective	- Number of installed pilot plants	[number]
Learning and growth perspective	- Number of persons working in the specific field of research - Number of cooperative research activities and cooperative research projects	[number] [number]

Table 1: Indicators for Balanced Scorecard

3. Results

Actual situation of heat storage development

In the case of thermal energy storage the different storage technologies appear at very different stages of development. Sensible heat storage is a very established and developed technology, with a huge variety of applications from small to very large storage applications. The temperature is limited due to the nature of the storage medium (mostly water). Storage periods are mostly in the range from hours to days. Nevertheless the storage technology can be developed further to higher temperatures, and longer storage periods.

Heat storage with PCM has already occupied some application fields like construction materials, textiles, room air conditioning, etc., but further progress will open wide new fields of application. Storage materials based on salt hydrates or sugar-alcohol could increase the stored energy density for example if technological problems can be overcome in the future.

Sorption storage and Thermo-chemical storage are at the very beginning of their development and potential and applications cannot exactly be foreseen at the moment. This situation is reflected by the different positions of the deltoid shapes in Fig. 3: the shapes representing activities for Sensible storage are located somehow left (related to the shorter timeframes) while those for Sorption- and Thermo-chemical storage are located on the right side (related to the longer timeframes). Activities for PCM storage unfold in between.

Technology roadmap

The roadmap should provide an overview of potential technology pathways in the future and therefore create options for action in a specific corporate field of action. Since the roadmap generation process is a kind of extrapolation of the present situation the variety of development challenges should fit to structural aspects already existing somehow.

For a better distinction between significant phases during scientific and technical development three periods have been defined: basic-, apllied research and demonstration (see also chapter Methodology). From basic research to applied research and further to demonstration the risk (and therefore public funding) is typically decreasing while contribution of industry is rising. The periods don't show a particular length but total duration is in the range between 10-15 years and the phases will overlap over several years.

The overview of research activities for heat storage is shown in Fig. 3. The deltoid shapes indicate the typical evolution of basic research, applied research, and demonstration activities on specified technical areas: the left apex indicates the beginning of significant activities (e.g. beginning of corporate research), the middle part of the shape is related to the period with extended documentation of scientific or technical progress (e.g. publications, conference sessions), while the right half of the shape marks the period when a new phase of research evolves (applied research after basic research, demonstration after applied research). The activities for product development and market deployment which follow after demonstration is not drawn in Fig. 3, since these are not subject to public funding in general.

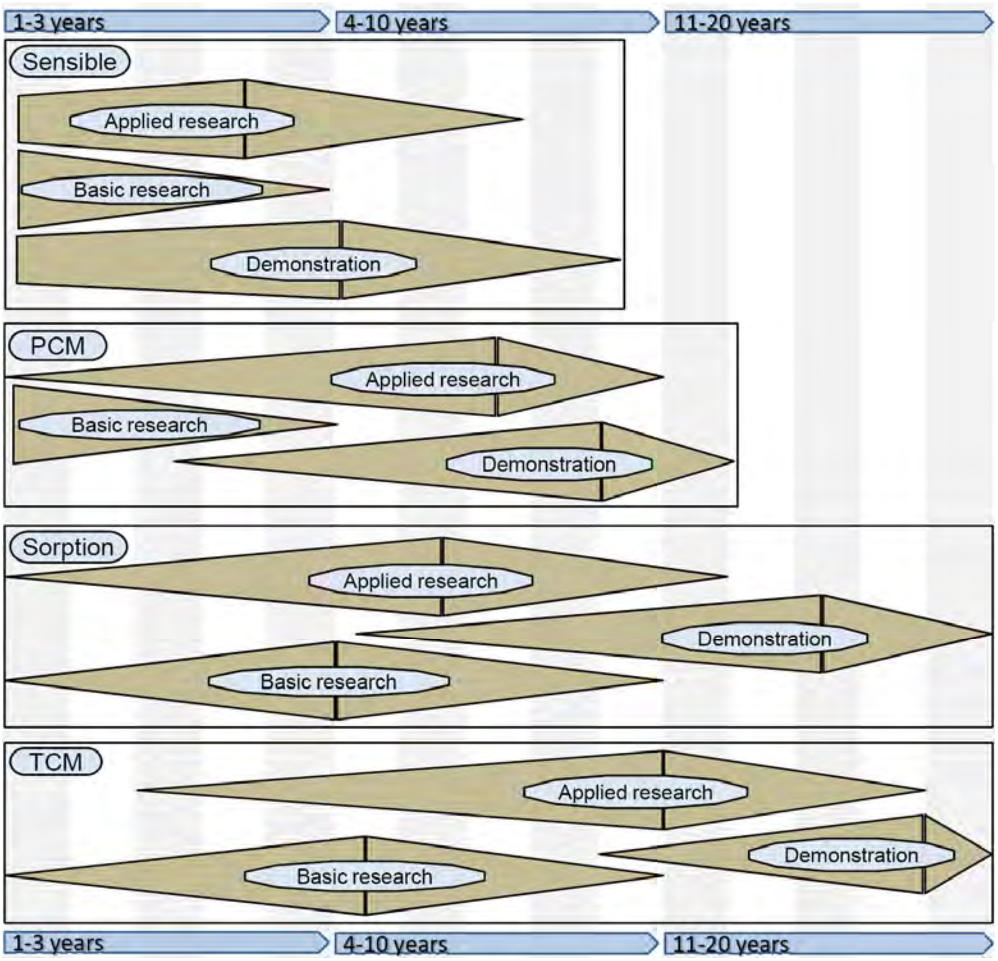

Fig. 3: *The timeline, starting in 2012, of basic research, applied research, and demonstration activities, for the four heat storage technologies. The intensity of the activities is represented by the width of the bars.*

Based on this principal structure the future research topics have been classified. The topics are suggestions of experts and workshop participants concerning future perspectives and challenges in connection with storage development. This information was classified and separated into categories. The categories where developed similar to the scheme presented in Fig. 3: whether or not a research field is essential for each storage technology and if the topic is linked to basic or applied research or is a demonstration activity.

In summary, several lists give a comprehensive overview over the actual and further research topics. They are classified into the following categories:

Storage technology (sensible, PCM, sorption, thermo-chemical)

State of development (fundamental or applied research, demonstration)

Area of Competence (material, components and concepts, system integration and controls)

Area of application (building application, processes heat, smart grids, mobile appl.).

These lists are part of the project report submitted to the initiator of the study and the funding organization.

Use of the lists as inventory and overview on research can be made within research calls: if a call for research projects is made, one or more of the listed categories should provide adequate targets-descriptions for research development. Every category fits into one of the fields in Fig. 3, which means that an overview on the timeline is included also.

4. Fields of applications

During the expert workshops much effort has been spent on the collection of potential future application in the near (1-3 years), medium (4-6 years), and far (11-20 years) time frame. This chapter describes the compilation of different applications which are indicated as most interesting by experts. The application fields are spread over a variety of branches from building heating, process heat generation, energy supply over grids to mobile applications. Some of the proposed applications are advancements of existing concepts while others are completely new in the sense of not possible presently due to technological or economical reasons.

The implementation of a new technical concept in market-ready consumer products is a very complex process, dependent on a huge variety of boundary effects. Therefore, the time of development of the proposed applications are not always known and therefore not mentioned in this description.

The following list should be used to address certain groups of researchers and developers via different funding programs. The relatively rough distinction into four groups of applications (building, processes, grids, mobility) does not fit to the huge variety of the offered funding programs but progress in research in one field will support progress in other fields anyway. Nevertheless all main fields of research activities for thermal storages are considered.

Building application	Short description
Enhancement of solar combi-systems with improved water storage	Solar thermal systems for space heating and domestic hot water have not yet reached the mass market. In such solar combi-systems the state of the art storage system is water storage, which can still be optimized concerning the heat losses, temperature stratification and costs, in order to increase the attractiveness of such systems on the market.
Compact short-term storage with high energy density	Short time storages reduce the start-/stop-losses of heat preparation systems, assure a hydraulic decoupling of the heat preparation from the heat sinks and reduce the emissions of boilers because of a reduction of start-/stop-cycles of the burner. Since space in buildings is expensive and sometimes rare, an increase of compactness would improve performance and customer acceptance significantly. However, storage tanks are often not installed because of the costs and the space requirement. This results in a requirement for the development of compact, cost-effective short time storage systems with a high storage density.
Long term storage of heat to reach high solar fractions	In order to reach high solar fractions or even 100 % solar supply of buildings large amounts of heat have to be stored for a long period of time (seasonal storage). Using water as storage medium for seasonal storage very large water volumes are necessary. The development of new storage technologies with a significantly larger storage capacity and strongly reduced heat losses is necessary.

PCM storage for active and passive cooling of buildings	Using thermal storage systems for active cooling often allows a reduction in chiller size, as the peak demand can be buffered by the storage tank. If there is a large difference between the peak and off-peak electricity price, operation costs can be saved by replacing the chiller operation by the storage on peak demand. The storage of heat at a low temperature level for the purpose of space cooling is one of the most promising applications for phase change materials, as large amounts of heat can be stored at a small temperature change in comparison to sensible storage.
Storage as source for heat pumps	An increasing number of system manufacturers are providing combined systems of solar thermal and heat pumps for space heating and domestic hot water. The use of a thermal storage, which is charged by solar collectors, as a heat source for the heat pump can increase the efficiency of such systems. Due to the relatively small temperature change the use of phase change materials offers a significantly higher storage capacity compared to sensible storage.

Table 2: List of the most interesting heat storage applications for buildings

Industrial process heat application	Short description
Tapping the full potential of existing storage technologies	Regardless of new technological approaches or new fields of application, there are numerous possible applications for thermal storages in industrial processes, based on technologies available today. These applications should be treated with highest priority. The challenges in these fields comprise optimization of the overall system, improved integration of the storage into existing energy supply concepts and heat exchanger networks, improved heat storage management, and optimal economic performance. Example applications include, for instance, activating thermal mass of industry buildings (e.g. floors of production facilities) or making use of processes with system-integrated thermal storages (e.g. electroplating, where the electroplating baths themselves could act as a thermal storage).
Helping to get promising new applications accepted	Several industrial sectors have a particular potential for employing or integrating thermal storages in the respective energy supply systems. Some sectors to be highlighted include: food industry, foundries, electroplating and galvanizing plants, paint and coating shops as well as agricultural enterprises. In general, all industrial processes which have the characteristic of a high cycle number have high potential for employing thermal storages as first customer.
Integration of solar energy and heat storage into industrial processes	A more intense integration of solar thermal energy into suited industrial processes is important in order to accelerate the development towards a renewable energy supply. Long-term and seasonal heat storage play an important role in this context. This is the case, for instance, in campaign-based operation in food industry. The integration of heat storages in industrial processes should be enhanced particularly in those sectors where solar thermal covers a high fraction of the energy demand.
Allied thermal management of plants and settlements	At present, synergetic effects for heat supply between industrial enterprises and nearby settlements are not used to a sufficient extent. New perspectives are opening up when it comes to storing or transporting industrial waste heat, and thus supply the heat to nearby consumers. Interesting applications in this area include using the waste heat of continuously operating sectors such as computer centers, bakeries, food industry (cooling) or foundry industry.
New perspectives	The variety of technological requirements in different industrial processes opens up new perspectives for employing innovative heat storage technologies. This comprises the application of latent heat storages (phase change materials) and sorptive heat storages, especially in processes where the process medium is air and where process cooling is also required. Just as much, heat storage at temperature levels >100°C in sensible short-term storages (approx. 1 week) is an interesting new field of application. New applications and perspectives also consist in increased application of cold storages or by employing thermal energy storages in combination with power plants: The new opportunity lies in the improved load balancing between energy supply and consumption; the resulting relief could increase the usage of renewable energy sources for the supply of electric energy.

Table 3: List of the most interesting heat storage applications in the field of industrial process heat

Smart grid application	Short description

Infrastructural optimization	One of the biggest challenges for Smart-Grids especially in thermal networks will be the extension of the existing network. The topics are spanning from building new sections, setting up transfer stations for different suppliers to the need of setting up storage stations on strategically important spots in the network. Thus one can ensure thermal energy to be transported through short and efficient links to minimize thermal losses and to enable energy to be stored where it is consumed.
Load management	Besides infrastructure, load management is one of the major tasks in upcoming research. On an IT level one has to develop smart communication between the different participants in a smart-grid. Beyond conventional control strategies they have the ability to reliably decide in terms of optimizing the operation of the overall smart-grid topology. On a hardware level one has to adapt the network infrastructure in the sense of using the grid as storage and providing immediate load compensation through adequate storage systems.
Distributed energy conversion	Wherever it is necessary to optimize the usage of renewable energy carriers, it is suggested to implement decentralized storage systems. Thus it is possible to reduce thermal losses in the grid and prevent the necessity for new supply pipelines.
Cooling of buildings and processes	Cooling demand is a fast growing issue. To ensure an efficient utilization of renewable energy and to optimally operate a load management in a smart grid it is necessary to implement cold storages into the grid infrastructure.
Studies on energy efficiency and changing demands	Recent directives from the EU led to a rapidly decreasing heating demand in the residential sector. Hence domestic hot water preparation will be more important in the smart grid infrastructure in the future. It seems to be efficient to supply thermal energy with different temperature levels or to distribute thermal energy on a low level temperature and raise it only where it is consumed (e.g. with heat pumps).

Table 4: List of the most interesting heat storage applications for future smart grids

Mobile application	Short description
Advanced concepts for thermal management in combustion-engine vehicles	Heat recovery from the cooling and exhaust system of combustion vehicles in principle is able to deliver heat for different purposes. Advanced technologies for engine pre-heating, adsorption cooling, heat storage and other measures for higher efficiency and comfort can make use of this energy source without additional fuel consumption.
Heating of electric-vehicles (EV)	For cabin heating of EV no capable source of waste heat is available compared to conventional vehicles. Nevertheless for save and secure operation during all weather conditions heating, dehumidification, and conditioning of the cabin room is required. The use of the EV battery reduces the driving range dramatically and therefore other solutions like high density heat storage would be favored. Innovative storage technologies (phase change materials and sorption processes) can meet the complex requirements of automotive applications and promise inexpensive and highly beneficial applications.
Utilization of solar heat in vehicles	The use of solar energy as heat source in electric driven vehicles could serve several benefits compared to other technologies. The use of conventional materials, moderate elevated process temperatures, lightweight high density storage, thermal driven cooling and dehumidification, possible integration into existing structures ("solar roof") are some specific advantages. The aim is to realize cabin conditioning and freight cooling in a reliable way by use of renewable resources.
Optimization of heat management and heat storage (2nd Generation)	Irrespective of the driving system, advanced development of the heat management components plays a major role to increase the efficiency and driving-range extension. Advances on the long term are necessary for different parts: • 2nd generation heat storage (double storage density with PCM and TCM) • Innovative heat distribution concepts (seats, belts, roof, etc) • Coatings and insulation of the car body shell • Waste heat recovery and storage of drive chain and cabin • Freight cooling with engine waste heat "Energy-Roof"- integrated body parts modules containing solar thermal, photovoltaic and storage components for managing demands of cabin and cargo compartment
Adsorption process for heating/cooling/dehumidification purpose	During adsorption of water vapor in zeolite materials several processes take place simultaneously: heating of the sorbent, cooling of the adsorbate, and dehumidification of the inlet air. These processes could be utilized for cabin conditioning and cargo compartment cooling in passenger and freight vehicles.

	Development of components and materials as well as process control is required.
Heat transportation in containers	Thermo-chemical processes and PCM storage can be used to store waste heat of industrial processes for transportation and distribution. This concept could supply public buildings and apartment buildings with heat via road transportation. The economic situation depends on the expenses necessary for transportation. Storage gross weight, energy content, heat losses, distances of transportation and also loading time have to be sufficient for this special application. Innovative storage technologies are needed to realize this concept.

Table 5: List of the most interesting heat storage applications for mobile applications

The potential future fields of applications have been divided into four groups also to reflect the fact that different product developments are supported through separate funding programs. In Austria the research is supported via several programs of the FFG (the Austrian Research Promotion Agency) and programs of BMVIT (Federal Ministry of Transport Innovation and Technology) and other organizations. The funding programs like Sustainable Development (with subprograms for building, energy and processes), Neue Energien 2020, A3plus, and many others are addressing different technological fields in a complementary way. They support activities for infrastructural development, networking, thematic research, studies, etc. Each group of applications can easily be assigned to different funding programs as long as they address different branches (mobile application in EV to A3plus or process heat to Factory of the Future for example). Despite this rough distinction into four application groups no further classification was introduced for the applications.

5. Accompanying measures

Many storage experts made suggestions for non technical topics relevant for storage development. Even if the experts had different technical background some of the statements appeared repeatedly. The most significant statements are listed and grouped into four topics: research institutions, research funding, public awareness, and customer benefits.

Topic A: Research institutions and networks

- From a strategic point of view a common research agenda has to be shared among the European institutes. Today there are still different institutes doing their research on the same topics with limited resources instead of working on different topics and sharing the results. Moreover it seems that there are too little young academics to cover the recent research topics and far too little to cope with a growing research demand.
- Leadership of a major research institute or a comparable institution is needed, but existing research groups should continue their work.
- Founding of a central, international or supra-national research institution for thermal energy storage with concerted research targets. Main target is the proper coordination of different branches like material development and process technology.
- Over the last 30 years there has been much progress in the field of research on thermal water storages. Unfortunately the knowledge that has been gained could not be transferred into the manufacturing process. Therefore the market still provides low quality products and inefficient components. In some countries that led to a bad product image. In many cases there is a lack of inter-branch knowledge when it comes to integrating thermal storages into different systems.
- Concerning the development of thermal storage technologies there has to be a close cooperation between science/research and the related industry, in order to take into account the requirements of the market.

Topic B: Research funding

- Research on thermal storage has to be better funded. There are too few research institutions and researchers that can work on research on thermal storage for a longer period of time.
- Especially in the field of material research and development, there is a strong requirement for basic research, which is at the moment not covered by funding.
- There are not enough financial resources in the area of sorptive and thermo-chemical research available in the present situation and also insufficient networking and knowledge transfer between the research institutions.
- Incentives for innovative storage technologies during market introduction will be necessary in order to guarantee a reasonable payback time.

Topic C: Public awareness

- Focus the public and political awareness on the importance of renewable energies and the role of energy storage as enabling technology for gaining high solar fractions of heat supply in private households.
- Studies on the potential market and applications for thermal storages to have concrete numbers for the environmental effects and business development are crucially needed. Public institutions like ministries should initiate these studies to evaluate benefit of customers, public, and industry to stimulate awareness of storage technology and to coordinate long-term policies.
- Focus on demonstration projects on innovative applications as they play an important role in public awareness.
- At the present a hostility towards some techniques is noticeable. Renewable energy policy should pave the path via federations and consumer organizations.
- Funding and lobbying of projects with clear benefits for the public. Promoted applications need to have the potential of self-support on the medium time-scale.
- Energy suppliers should recognize the storage agendas as possible market. These companies and others like manufacturing industry should play the leading role in lobbying activities (in 5….10 years), not research institutions.

Topic D: Customer benefits

- Innovative storage systems have to be easy to operate and standardized, storage design has to be easily possible with simple design tools.
- High failure rates can be found on installed storages due to the fact that plumbers do not have the appropriate skills and know-how. Training and certification of installers could overcome this problem and improves the level of quality.
- Standardization and Certification: The existing standards on thermal storages do not provide the available knowledge of storages.

6. Conclusions

- The storage of thermal energy is of key importance to arrive at a very high share of renewable heat in the Austrian energy consumption mix. Especially for solar thermal energy the fraction of renewable heat in households, utilities and industrial processes can only attain high values if existing thermal storage technologies are greatly improved and novel technologies are developed.

- The technologies for storage of thermal energy can be divided into sensible heat storage, latent heat storage, sorption heat storage and Thermo-chemical storage. In this sequence, the first technology has the broadest application and less potential for improvement, while the last has the highest potential but is still in an early research stage. The broad range of technologies, materials and system applications involved implies that the further development can only be done by universities and institutes collaborating on a national and international scale.
- The effective development of new and improved thermal storage technologies needs a well established R&D network, in which there is a programmed collaboration between industry, R&D institutes and universities.
- The potential future fields of applications can be divided into four groups to reflect the fact that different product developments were supported through separate funding programs. Funding programs like Sustainable Development (with subprograms for building, energy and processes), Neue Energien 2020, A3plus, and many others are addressing different technological fields in a complementary way. Each group of applications can easily be assigned to different funding programs as long as they address different branches (mobile application in EV to A3plus or process heat to Factory of the Future for example).
- Future research should be motivated by the applications described in the present study to focus research activities to special fields which were identified by experts as most important.
- Funding programs should address as much experts from relevant different branches as possible. Therefore research topics for the programs can be listed to reach higher recognition by different research institutions. The lists with topics collected inside the project Masterplan have been prepared to reach this attention.

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