# International Energy Agency

**Technology Collaboration Programme: Energy Conservation through Energy Storage**

TES for Energy Management and $CO_2$ Mitigation

## Annex 30

**Thermal Energy Storage for**
**Cost-Effective Energy Management and $CO_2$Mitigation**

Final Report

Reporting period: July 2015 – June 2018

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# 1. Introduction

Reduction of $CO_2$ emissions and increases in energy efficiency are two important aspects of the ongoing energy transition in Europe and the rest of the world. In particular, two energy targets set by the European Union are relevant in the discussion of thermal energy storage (TES): a 40% reduction in $CO_2$ emissions compared to 1990 levels by 2030 and a 27% increase in energy efficiency by 2020 [1]. In addition, the EU has committed itself to a 27% share of renewable energy consumption in the energy system. Increased uptake of TES technologies will play a major role in achieving these goals.

Thermal energy storage is critical to reducing the energy end-use consumption in power plants, industrial sectors and buildings for heating and cooling. In terms of end-use sectors, global statistics show that around 50% of final energy consumption is accounted for by the heating sector and in highly-industrialized countries such as Germany, nearly half of this value is industrial process heat [2]. This represents a large potential for TES technology to improve process efficiency, enable waste heat usage and reduce industrial energy consumption.

As an enabling technology for sector coupling, TES systems can also facilitate the efficient management of electricity. The increasing share of variable renewables in the transition to a clean, secure and efficient energy system generally represents a future challenge. TES technologies will play a critical role in this transition by increasing the flexibility of the energy system through coupling of the heat and power sectors.

Despite this potential, TES technologies are only being utilized in limited applications so far and remain relatively underutilized, especially on an industrial level. This is largely due to diversity of relevant processes and thermal energy storage technologies – there are numerous different applications for each TES technology and often multiple technologies could be chosen for the same process. Improving the ease of integration of TES technologies into processes is a critical step to increasing TES contribution to the energy targets. In this context, Annex 30 has developed a methodology that systematically evaluates thermal energy storage systems being integrated into a processes and assesses how such systems will benefit the specific application. This methodological work begins by introducing a set of process analysis guidelines that consider a wide variety of relevant aspects when integrating a TES system into a process. This is followed by definitions on technical parameters and the system boundary for thermal energy storage. Finally, a method has been proposed for evaluating the benefit of an integrated TES system from different stakeholder perspectives.

This report comprises an overview of the structure, participants and completed work of Annex 30 with respect to the subtasks. In addition, it presents a list of the activities and a detailed account of each reporting period. A full accounting of the methodologies and results of Annex 30 can be found in the public report "*Applications of Thermal Energy Storage in the Energy Transition: Benchmarks and Developments*". This publication details the methodologies developed over the three years, introduces benchmarks that characterize certain application fields, investigates technologies developed by the participants of Annex 30, and presents an analysis on the four examined application fields: district heating, non-residential buildings, industrial processes, power plants and vehicles.

## 2. Annex 30 framework

### *2.1 Objectives of Annex 30*

The general objective of Annex 30 is to advance the implementation of thermal energy storage technologies in order to:

- Reduce $CO_2$ emissions and
- Improve cost-effective thermal energy management (i.e. increase energy efficiency).

These overarching targets can be supported by the integration of thermal energy storage systems to:

- Improve overall energy efficiency of the processes,
- Increase process flexibility,
- Increase utilization of renewable energy technologies (including solar thermal technologies as well as fluctuating power generation by PV and wind), and
- Boost energy system flexibility through peak shaving and demand response.

Advancement of the process integration of thermal energy storage systems will make significant contributions to all of these fields. Crucial to the improved integration of TES systems is a better procedure for discussing the systems. A first objective of Annex 30 was therefore to define guidelines for process analysis and specify technical and economic parameters of thermal energy storage on a system level. Subsequently, determination of key performance indicators (KPI) was an important step in the performance evaluation of a TES system. Annex 30's ultimate goal was to evaluate thermal energy storage systems integrated into a given application. The methodology was applied to various case studies originating from development and demonstration projects where TES systems are applied. Thus, in a long-term perspective examples of integration of thermal energy storage systems can be discussed with stakeholders ranging from industry as process owner and turnkey or component supplier to national, European and other decision makers.

### *2.2 Scope of Annex 30*

In terms of technology, Annex 30 covered all three main types of thermal energy storage: sensible heat, latent heat and thermochemical energy storage. Heat, cold and electricity energy sources and sinks were all considered. Annex 30 focused on system integration, particularly on an application-oriented level. The following sectors were investigated:

- District heating and cooling
- Non-residential buildings
- Industrial processes
- Power plants
- Vehicles

## 2.3 Work program and structure

The work program of Annex 30 was split into five separate subtasks as shown in Figure 1. Following the annex approach, subtasks 1-3, shown inside the dotted line, consider the process and the thermal energy storage system separately and focus on determining the process requirements by process analysis (subtask 1) and defining TES system parameters from a technical and economic point of view, respectively (subtasks 2 and 3). Integrating the TES system into the process subtask 4 is dealing with application case studies of TES systems. Subtask 5deals with the development of a methodology for determining key performance indicators to describe the performance of the thermal storage system within the specific application. Finally, selected case studies were evaluated with the complete Annex 30 methodology.

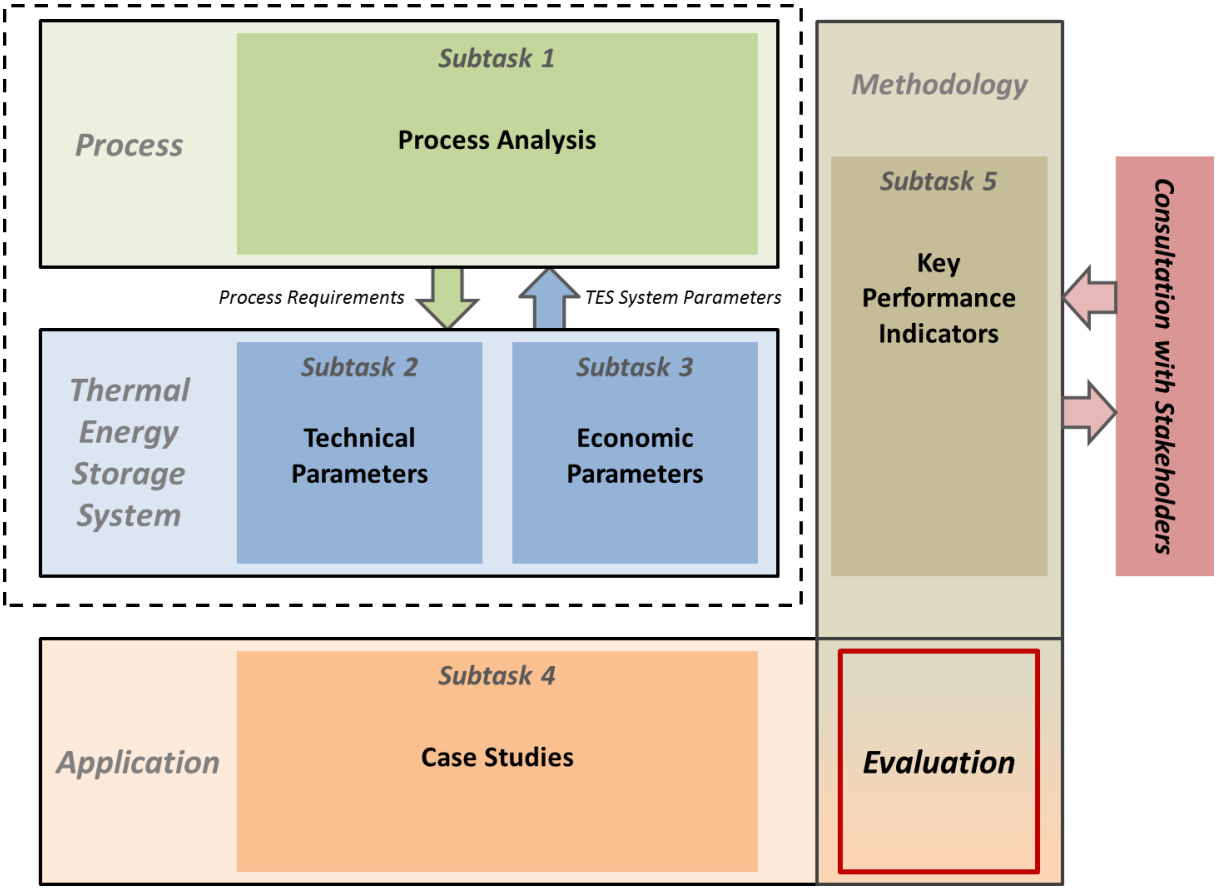


**Figure 1: Annex 30 work program**

## 3. Subtask outcomes

### *3.1 Subtask 1 – Process analysis*

Lead by: Maike Johnson (DLR)

Main outcomes:

- Development of a set of process analysis guidelines that cover both greenfield and retrofit applications. These guidelines are to be used to both serve as guidance to researchers developing TES systems as well as to assist process customers in assessing the necessary information at the different steps of evaluation and design. This document is an official publication of Annex 30 and has been distributed to other annexes in ECES. An abridged version is also published in the Annex 30 public report.
- Through process requirements templates distributed in February 2016, collection of a series of process data covering a range of applications and process types. Data collected included technical data (storage capacity, power, temperatures etc.), non-technical data (process type, space available, infrastructure, economics etc.) and global criteria (environmental aspects, social acceptability etc.).

### *3.2 Subtask 2 – Technical Parameters*

Lead by: Luisa F. Cabeza (UdL) and Yukitaka Kato (Tokyo Institute of Technology)

Main outcomes:

- Definition of analysis levels in a thermal energy storage system. This includes the system boundary, a designation that was used throughout the evaluation section from Figure 1. Also defined are the boundaries for modules, components and storage material within a TES system.
- Definition of a series of technical parameters for a thermal energy storage system. This includes the following: system storage capacity ($ESC_{sys}$), nominal power ($P_{nom}$), efficiency ($\varepsilon_{sys}$), auxiliary energy ratio ($Aux_{sys}$), response time ($ReTi_{sys}$), minimum cycle length ($MinCy_{sys}$) and partial load suitability ($PL_{sys}$).

Both documents are official publications of Annex 30 and have been distributed to other annexes in ECES. An abridged version is also published in the Annex 30 public report.

### *3.3 Subtask 3 – Economic Parameters*

Lead by: originally Justin Chiu (KTH Royal Institute of Technology), assumed responsibilities in 2017 by Duncan Gibb (DLR)

Main outcome:

- Application of the bottom-up cost calculation methodology ($SCC_{real}$) from Annex 29 to collected case studies in Annex 30. Expansion to include bottom-up costs based on nominal power as well ($SPC_{real}$).

### 3.4 Subtask 4 – Case Studies

Lead by: Richard Gurtner (ZAE Bayern)

Main outcomes:

- Collection and evaluation of 49 "real-world" cases of TES in application. Validation of technical information for these cases and preliminary analysis within different application fields. Cases have been used in the Evaluation section to test the methodological work of Annex 30.
- Comprehensive collection and validation of cases on district heating and cooling as reported in the Annex 30 public report.

### 3.5 Subtask 5 – Key Performance Indicators

Lead by: Duncan Gibb (DLR) & Antje Seitz (DLR)

Main outcomes:

- Development of an analysis methodology for benefit evaluation of thermal energy storage integrated in an application.
- Methodology takes into account the most important system parameters, external factors and considers a stakeholder perspective to provide an analysis.
- Methodology validated through use in the Evaluation section.

### 3.6 Evaluation

Lead by: Antje Seitz (DLR) & Duncan Gibb (DLR)

Main outcomes:

- Production of a software-based survey with which the definitions and methodologies created in Annex 30 can be applied to a diverse series of case studies originating from the Annex 30 participants.
- Survey content covered and responses received being consolidated into fact sheet format:
    - Process analysis
    - Technical parameters
    - System boundary
    - Economic parameters
    - Key performance indicators
- Analysis of these responses to form main conclusions of Annex 30 in an application-specific evaluations.
- Ultimately, fact sheets and evaluations presented in the Annex 30 public report.

# 4. Meetings and participants

## *4.1 Workshops and conferences*

Annex 30 workshops

| Meeting type | Dates | Location | Participants |
|---|---|---|---|
| Pre-definition meeting | 25 Aug. 2014 | Stuttgart, Germany | 7 |
| 2nd Pre-definition meeting | 18 May 2015 | Beijing, China | 8 |
| Workshop 1 and Kick-Off | 29-30 Oct. 2015 | Stockholm, Sweden | 23 |
| Workshop 2 | 2-4 May 2016 | Frankfurt, Germany | 24 |
| Workshop 3 | 17-19 Oct. 2016 | Tokyo, Japan | 21 |
| Workshop 4 | 24-26 Apr. 2017 | Lleida, Spain | 24 |
| Workshop 5 | 17-19 Oct. 2017 | Pau, France | 22 |
| Workshop 6 | 1-2 Mar. 2018 | Frankfurt, Germany | 12 |
| Final Meeting | 18-19 June 2018 | Cologne, Germany | 25 |

National TES conferences hosted by Annex 30

| Conference title | Date | Location | Participants |
|---|---|---|---|
| Thermal Energy Storage: Perspectives and Applications in an Industrial Environment | 3 May 2016 | Frankfurt, Germany | 52 |
| Conference on Thermal Energy Storage in Japan | 18 Oct. 2016 | Tokyo, Japan | 38 |
| TES International: Networking and Research Activities in TES | 26 Apr. 2017 | Lleida, Spain | 45 |
| Focus on Thermal Energy Storage Activities In France | 19 Oct. 2017 | Pau, France | 37 |

## 4.2 Overview of participant institutions and countries

A list of participant institutions and the total number of workshops attended is shown in the table below. If multiple members from one institution attended, only one is counted.

| Institution | Country | Workshops |
|---|---|---|
| Austrian Institute of Technology (AIT) | Austria | 2 |
| EnergyVille (KU Leuven & VITO) | Belgium | 1 |
| École de technologie supérieure | Canada | 1 |
| Pioneer Energy | China | 1 |
| Shanghai Jiao Tong University | China | 1 |
| Danish Technological Institute (DTI) | Denmark | 5 |
| Technical University of Denmark (DTU) | Denmark | 5 |
| French Alternative Energies and Atomic Energy Commission (CEA) | France | 6 |
| Université Pau & Pays Adour (UPPA) | France | 5 |
| German Aerospace Center (DLR) | Germany | 8 |
| Fraunhofer ISE | Germany | 1 |
| Fraunhofer Umsicht | Germany | 1 |
| Leuphana University | Germany | 1 |
| Technical University of Chemnitz | Germany | 8 |
| Technical University of Munich | Germany | 3 |
| Bavarian Center for Applied Energy Research (ZAE Bayern) | Germany | 8 |
| Italian National Research Center CNR-ITAE | Italy | 7 |
| Hokkaido University | Japan | 3 |
| Tokyo Institute of Technology | Japan | 5 |
| Energy Research Centre of the Netherlands, part of TNO | Netherlands | 4 |
| SINTEF | Norway | 1 |
| CICenergigune | Spain | 1 |
| University of Lleida (UdL) | Spain | 7 |
| University of the Basque Country UPV-EHU | Spain | 6 |
| Chalmers University of Technology | Sweden | 7 |
| KTH Royal Institute of Technology | Sweden | 5 |
| Svenkst Geoenergicentrum | Sweden | 1 |
| HEIG-VD | Switzerland | 4 |
| Çukurova University | Turkey | 5 |
| Sunamp | U.K. | 1 |

Workshop attendance from ECES member countries can be found in the table below.

| | Pre-def | WS1 | WS2 | WS3 | WS4 | WS5 | WS6 | FM |
|---|---|---|---|---|---|---|---|---|
| **Belgium** | | | | | | | | |
| **Canada** | | | | | | | | |
| **China** | | | | | | | | |
| **Denmark** | | | | | | | | |
| **France** | | | | | | | | |
| **Germany** | | | | | | | | |
| **Italy** | | | | | | | | |
| **Japan** | | | | | | | | |
| **Netherlands** | | | | | | | | |
| **Norway** | | | | | | | | |
| **Spain** | | | | | | | | |
| **Sweden** | | | | | | | | |
| **Switzerland** | | | | | | | | |
| **Turkey** | | | | | | | | |
| **UK** | | | | | | | | |
| **Austria (observer)** | | | | | | | | |

Overall, Annex 30 saw the active participation of 11 countries. This list includes five countries that were present at one meeting. Austria remained in an observer status, never fully joining the annex.

Of the institutions, 20 can be designated as active participants based on the meetings attended and the content delivered to the subtasks, survey and final report. Overall, 55 individuals were present for at least one Annex 30 workshop during the three years.

## 5. Activities during all reporting periods

The following subsections summarize the activities during each reporting period. Many of this information concerns the work that was conducted during the biannual workshops and the conferences that took place alongside these workshops. More detailed information on the workshops and conferences can be found in the accompanying document in which the minutes of the respective meetings are provided.

### *5.1 July 2015 – December 2015*

After an official start of 1 July 2015, the months that followed were spent recruiting participants for the first workshop, further developing ideas for Annex 30, and preparing for the upcoming three years. Annex 30's first workshop (WS1) took place in Stockholm, Sweden on 29-30 October 2015. 25 members participated in the two-day event. The workshop consisted of two main sessions:

- 18 "Elevator Pitches" were held, in which the participants took 3 minutes to introduce their institutions and research topics in the world of thermal energy storage. The presentation of posters on the participants work enhanced discussions during the coffee breaks that encouraged exchange.
- Subtask 1-4 were elaborated in a "World Café" format, in which four discussion rounds were held on the topics of "Definition of process requirements", "Effective storage density", "Key performance indicators" and "Costing estimation". Work programs for the individual subtasks were developed in these sessions and in the discussion within the large group that followed.

The months following WS1 were spent consolidating the work in the subtasks, executing tasks that were assigned during WS1 and further recruiting members to join Annex 30. This included the attendance of the Solar Heating and Cooling Conference in Istanbul, Turkey on 2-4 December 2015.

### *5.2 January 2016 – June 2016*

Prior to the second workshop in May 2016, a survey was distributed in February 2016 to collect process information on behalf of Subtask 1. This survey was distributed to both research and industrial colleagues and saw the collection of 16 processes with submissions of technical parameters (heat transfer fluid used, storage capacity, power, etc.), non-technical parameters (type of process, infrastructure, safety, etc.) and global parameters (environmental, economics, legal, etc.). The information collected through this survey was used to plan the following workshop and conference.

A conference entitled "Thermal Energy Storage: Perspective and Applications in an Industrial Environment" was held on 2-4 May 2016 alongside the 2nd Annex 30 workshop (WS2) in Frankfurt, Germany. 49 people attended the conference on 3 May that was organized in collaboration with the working group on "Thermal Energy Storage" of ProcessNet being hosted by the German Society for Chemical Engineering and Biotechnology (DECHEMA). The conference brought research and industry together to discuss the most important emerging topics from Annex 30. Seven presentations were held in the Plenum over the course of the

day, the majority of which came from industrial participants. The two keynote speeches covered the two main differing perspectives regarding TES from research and industrial points of view. The research side was presented by Halime Paksoy of Çukurova University in Turkey (the former chair of ECES) who drew attention to the main challenges currently facing researchers in TES. The industrial view was delivered by Günter Schneider from the company Enolcon, a manufacturer of turnkey thermal storage systems.

The first session focused on the first subtask of Annex 30, "Process Analysis", in which the requirements for processes were discussed at length. Participants worked on low-, medium-, and high-temperature processes. The goal of the session was primarily to collect critical process parameters that are necessary to design a TES system or to evaluate whether the integration of such a system makes sense from a technical point of view. The following conclusions were reached:

- Emphasis on importance of time-dependent data (difficult to obtain)
- Black Box Logic: In- and Outlet process conditions available, nothing else
- Industrial associations should provide more generic process data

The afternoon session focused on the 2nd, 3rd and 4th subtasks, in which the relevant fields of application were covered: district heating, industrial processes, power plants and vehicles. This session concentrated on the decisive issues of Annex 30 in order to reconcile the differing perspectives from research and industry. In the end, several conclusions were reached:

- Key performance indicators depend highly on application
- Both top-down and bottom-up methods are necessary for economic calculations
- Stakeholder perspective is highly relevant for the application

Closing the conference was a plenum discussion that focused on market models and raised interesting issues for researchers on how to better develop storages for commercialization.

23 members participated in the closed Annex 30 sessions that took place on 2 and 4 May 2016. In these workshop sessions, the annex goals, subtask progress and general annex direction were all discussed and further developed.

### *5.3 July 2016 – December 2016*

The third workshop of Annex 30 took place on 17 – 19 October 2016 in Tokyo, Japan. 25 members of the Annex 30 group participated in the closed workshop sessions on 17 and 19 October. An open conference was held on 18 October with 14 additional Japanese colleagues.

During the open conference, Japanese participants from both industry and research took part in discussions on national efforts in thermal energy storage in Japan. The conference began with seven presentations from Annex 30 members that introduced and discussed current research. In the afternoon, two colleagues from Nagoya University and Hokkaido University presented their research on thermochemical and latent heat energy storage. These presentations were followed by two colleagues from the Japanese industry (Sanki

Engineering Co. Ltd. and Japan Facility Solutions, Inc.), who presented their commercial products for thermal energy storage. The day was concluded by a discussion on the challenges and opportunities for thermal energy storage in Europe and in Japan.

The expert workshop on 17 October began with presentations from the Operating Agent Antje Seitz, during which the current status of the Annex was discussed. This was followed by update presentations from the leaders of Subtask 1 Maike Johnson, Subtask 2 Jaume Gasia representing Luisa F. Cabeza and Subtask 3 Justin Chiu. These presentations similarly introduced the status and way forward of the respective subtasks. Update presentations for Subtasks 4 and 5 were held on the final workshop day on 19 October.

The expert workshops gave the Annex 30 group the chance to introduce and discuss their current research covering the whole range of applications. Discussions on the characterization of various thermal energy storage technologies, their process integration and benefit for different applications were an important starting point for the further development of the Annex 30 methodology within the various subtasks.

### *5.4 January 2017 – June 2017*

The fourth Workshop of Annex 30 was held on 24-26 April 2017 in Lleida, Spain. 22 members took part in the expert workshop sessions on 24-25 April. 15 additional members of the Spanish TES research community joined for an open conference on 26 April. This conference, entitled "*TES International: Networking and Research Activities*", brought members of the Spanish TES research community, Annex 30, and the European Energy Research Alliance (EERA) Joint Program on Energy Storage with its Subprogramme on Thermal Energy Storage, together to discuss the international and European networking of institutes. The conference began with four lectures that covered: Annex 30 activities, TES activities in Spain, TES activities in EERA and the INPATH-TES EU project which oversaw the establishment of an online doctoral programme for thermal energy storage. These were followed by presentations from participants from eight Spanish universities and research institutions from Germany (DLR), the Netherlands (ECN-TNO) and Japan (Tokyo Institute of Technology). Current research and projects in TES were the focus of these presentations.

The expert workshop began with an update presentation from the Operating Agent and status reports from the subtask leaders. Following the Subtask 1 presentation from Maike Johnson, the participants worked in different groups to apply the process analysis guidelines to various applications of thermal energy storage and to give feedback to the guidelines themselves. In the course of this session, critical issues were recognized and future improvements were discussed, as can be found in detail in the minutes. Next, colleagues from the University of Lleida and Tokyo Institute of Technology presented their work in Subtask 2 on definitions of technical parameters. This was an opportunity for the participants to give detailed feedback to the definitions and a lively discussion ensued. The topic of the system boundary was touched on as well, which provided helpful feedback to Subtask 2. This resulted in the decision not to take the module level into account, as can be seen in the final results of the system boundary definition.

The second day of the workshop saw the presentation and discussion of the collected case studies, as led by Richard Gurtner Subtask 4 Leader. These cases consist of real-world,

installed examples of thermal energy storage in applications. In particular it was discussed how the cases could be compared and evaluated.

Ultimately, the participants agreed to evaluate different cases from their research work with a survey applying the Annex 30 methodologies, i.e. a series of analyses including the process analysis guidelines, technical parameters, system boundary, economic parameters and key performance indicators. It was decided to distribute this survey over the summer to collect submissions for all discussed cases in the Annex 30 group. Finally, the key performance indicator methodology was again presented and discussed, with substantial, helpful feedback given to the logic and structure of the methodology that was critical in its further development.

### *5.5 July 2017 – December 2017*

Following the fourth workshop, the aforementioned survey on the Annex 30 methodologies was produced by DLR and distributed in the summer of 2017. 18 members of Annex 30 responded to the survey by delivering their responses prior to the fifth workshop. During this time, an extensive analysis was performed on these responses and the results were presented at the fifth expert workshop.

This workshop and French conference took place on 17-19 October at the University of Pau et Pays d'Adour in Pau, France. 21 participants took part in the expert workshop on 17-18 October and a total of 51 participants including the French research and industry on thermal energy storage were at the conference on 19 October.

The main focus of the expert workshop was the presentation of the survey results from the past summer. On the first day, the analysis highlights were first presented by Duncan Gibb and followed by a discussion. Further feedback was provided to the Subtask 1 Process Analysis Guidelines, with the ultimate suggestion that the guidelines be expanded to include the "Greenfield" perspective along with the already-present "Retrofit" perspective. This was confirmed by the group and agreed to be completed prior to the next intermediate workshop. Richard Gurtner also presented the status of Subtask 4 and the collected cases.

The second day of the workshop focused on the system boundary of a TES, technical parameters and key performance indicators. This discussion was informed by the Annex 30 survey results, in that the responses were used to evaluate the definitions previously applied. These definitions were then further discussed and adjusted based on their accordance with the group's understanding. Critically, the final definition of the system boundary was agreed upon and confirmed for final production as an Annex 30 result. The current technical parameter definitions were further discussed and compared with the responses from the survey. New definitions from Subtask 2 were also presented and feedback was provided to further refine them. Despite the absence of the Subtask 2 Leaders in this meeting, the group was able to provide extensive commentary on the system boundary and technical parameter definitions so that work could continue as planned following the meeting and the definitions could be finalized on time in agreement with the subtask leaders. This information can be found on pg. 27 of the accompanying document under "Subtask 2 Memo following Pau". The final presentation was an overview of the KPI results as collected through the survey.

The French conference began on the third day with an introduction from the University of Pau, CEA and DLR. After that, a colleague from Ademe, the French agency for the environment and energy, presented how energy research is funded in France. This was followed by three blocks of lectures concerning activities in research, in the industrial production and design of TES systems and in industrial applications of TES. The conference was concluded by a short introduction on the work of Annex 30 and an hour-long discussion about the Annex 30 approach with the industrial partners, particularly concerning the system boundary and the KPI methodology. During this time, valuable feedback was collected that further informed the Annex 30 work going forward.

To align the focus of the different Annexes within ECES – specifically Annex 30 and Annex 33 – the two operating agents, Antje Seitz and Andreas Hauer participated in each other's expert workshops. From the presentation of the content of work and focus of the two annexes the interface and content alignment could be specified and agreed on. Whereas Annex 33 has the storage material as a starting point and works on its characterization and functionality within the thermal storage as a component, Annex 30 comes from the application side and looks at the thermal energy storage system within the process. The participants of both annexes considered the input from each other annex as beneficial and helpful for the generation of a complete picture starting from the material to thermal energy storage in application.

### *5.6 January 2018 – July 2018*

Two meetings were organized to conclude Annex 30; a sixth workshop took place in Frankfurt and the final meeting was held at the DLR Headquarters in Cologne.

The sixth workshop was on 1-2 March 2018 in the Airport Conference Center in Frankfurt, Germany, during which 12 members of Annex 30 took part. The main focus of this workshop was the confirmation of the expansion of the process analysis guidelines to include the "Greenfield" perspective, the further discussion and finalization of the new technical parameter definitions, and the final reporting of Annex 30.

Lars Reinholdt from the Danish Technology Institute presented the expanded methodology and it was agreed that Maike Johnson (DLR and ST1 Leader) would compile these changes into a single document that considers both Retrofit and Greenfield perspectives. This was followed by a presentation by Richard Gurtner on new case studies and a workshop session in which the system boundary definition was applied to these new case studies in groups. It provided a further opportunity to refine the definition and a few suggestions were made to improve it.

The session on the second day primarily concerned the technical parameter definitions from Annex 30 which were again presented and extensively developed in a workshop format. These definitions were ultimately agreed-upon and the leaders of Subtask 2 committed to summarizing the final version in an official Annex 30 document to be disseminated among the energy storage community.

The final reporting was specified to provide a detailed accounting of the Annex 30 methodologies, an overview of the TES benchmarks and cases in development in several relevant applications and an evaluation within and between applications. It was decided to

publish the Annex 30 results in a public report alongside the ECES final report and a structure and timeline were elaborated for both these final reports. Furthermore, first ideas for a follow-up annex were collected.

Prior to the final meeting, the production of the final report began. The colleagues were encouraged to expand on their survey submissions in Summer 2017 by completing a fact sheet template prepared by DLR that was to be included in the report. In total, 22 original submissions from Annex 30 participants were collected. In the meantime, DLR and ZAE Bayern worked on the production of the report sections for the benchmarks in the application fields of district heating, industrial processes and power plants.

The final meeting of Annex 30 took place on 18-19 June 2018 in Cologne, Germany with the participation of 24 members of Annex 30 and representatives from the German Delegacy. The finalized methodologies for process analysis, system boundary, technical parameters and key performance indicators were all discussed and questions were answered. The main part of the meeting concerned the presentation and evaluation of the benchmarks and submitted development case studies for the final report. The session was divided into four application fields (District heating, non-residential buildings, industrial process and power plants), in which the respective benchmarks and internal cases were presented and discussed. The central statements of these analyses were agreed upon.

On the final day of the meeting, the final report and follow-up annex were further discussed and ideas for the follow-up annex were developed in a workshop session.

The submission of the final reporting of Annex 30 and presentation at ECES XC86 in South Korea will conclude the project.

## Acknowledgements

The management team of Annex 30 would like to express its deepest gratitude to all participants for their contributions over the three years of the project. Whether it was providing feedback to the methodological development, proofreading the report, submitting a case study or simply engaging in lively debate during the workshops, all contributions were extremely valuable to the results in the previous pages.

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