IEA Technology Collaboration Programme

International Energy Agency

Technology Collaboration Programme on Energy Storage

(ES TCP)

Annual Report 2021

Contributors to this Annual Report 2021:

Bijan Adl-Zarrabi, Dan Bauer, Teun Bokhoven, Ayşegül Çetin, Christian Doetsch, Andreas Hauer, Ryozo Ooka, Christoph Rathgeber, Wim van Helden, and Peter Wagener

International Energy Agency, Technology Collaboration Programme

ES TCP – Energy Storage TCP

www.iea-es.org

Content

CHAIRMAN'S REPORT

Following a turbulent 2020, the COVID pandemic in 2021 had again great impact on meetings both for the Tasks as well as the ExCo meetings. We have learned to deal with it, but there is a growing notion that we start losing effectiveness. However, work is progressing, despite the lack of physical meetings and some Task meetings have increased the frequency of the meetings in order to keep up with the planning and to work towards results.

Early in 2021 the CERT has approved the Request for Extension (including a new Strategic Plan, an Overview of achievements and End of Term report). The ExCo has approved the new ES TCP communication plan which will lead to a more pro-active communication strategy. The additional cost of these activities will be covered by an increased contribution to the Common Fund of appr. 20% as of 2022. The implementation of the Modernization process was successfully completed. The (modernized) nomenclature has been implemented and is now incorporated in the ES TCP website. Furthermore, the ExCo has appointed a special internal Working Group on Communications to guide the communication activities.

Tasks activities progressed well. Four new Tasks have been approved by the ExCo and will start work in 2022. This brings the total of eight Task currently in operation. There is a balanced portfolio of Tasks within the scope of the current strategic plan. Several new Tasks initiatives have been presented and will be further developed for approval by the ExCo in 2022.

In 2021 the tri-annual ES TCP scientific conference "Enerstock "was organized by Slovenia and, although online, it was very well attended and a great success.

Strategic priorities, ongoing and new Tasks

The current strategic plan (2021-2026) calls for the following priorities: System Integration (now addressed by Tasks 32, 34, 35, 36, and 37), Electrical Storage (addressed by Tasks 35, 36, and 37), and Thermal Storage (Tasks 34, 35, 36, 37, 38, 39, and 40).

The ExCo approved the following new Tasks in 2021:

- Task 37: Smart Design and Control of Energy Storage Systems
- Task 38: Ground Source de-icing for Infrastructure
- Task 39: Large TES for District heating
- Task 40: Compact Thermal Energy Storage (joint Task with SHC TCP)

The ongoing Tasks are:

- Task 32: Open Sesame – Open-Source Energy Storage Models
- Task 34: Energy Storage with Heat Pumps – Comfort & Climate Box (joint Task with Heat Pump Technologies (HPT) TCP, also connecting to MI)
- Task 35: Flexible sector Coupling by the implementation of Energy Storage
- Task 36: Carnot batteries
- Task 37: Smart Design and Control of Energy Storage Systems
- Task 38: Ground Source de-icing for Infrastructure
- Task 39: Large TES for District heating

The new Task is:

- Task 40: Compact thermal energy storage materials – Materials within components within systems

Policy Priorities

Energy Storage is gaining a lot of interest from policymakers, industries, grid operators, utility companies and academia. There is an expanding awareness that storage is an essential element in system integration, sector coupling, and overall energy system efficiency based on decarbonized resources. This is reflected in an awareness that energy storage represents a growing economic value. It can reduce cost of the energy infrastructure, is an essential element for sector coupling and technically supports the overall trend to electrification in mobility, heating & cooling and in the industry.

Partnerships between other international bodies (like UN, World bank, MI, CEM, IDO, CEN) and affiliated initiatives (like other TCP's) are encouraged by the ExCo, also at Task level.

The main policy messages ES TCP communicates are:

- Energy storage has an economic and technical value as major contributor to CO_2 reduction technologies and the overall energy transition. The ExCo's ambition is to seek better, and convincing exposure and visibility of the impact energy storage will have on the energy system, both the demand and supply side.
- There is a need to establish an analytical regime of metrics for valuing energy storage across energy technologies, end use profiles and jurisdictions.
- Improved communication efforts are needed, such as better visualization, successful demonstration projects and show case applications, simpler language, and communication of results of ES TCP work to speed up the deployment of energy storages.

Communication and Outreach

The ES TCP chair, vice chairs, and delegates contributed to several events and meetings. ES TCP participated in eight workshops and conferences in 2021.

The tri-annual Enerstock conference provided a great opportunity to share scientific results from the Tasks and brought together an inspiring group of scientists and experts. Thanks to the excellent organization of the Slovenian team led by Uroš Stritih and Alenka Ristic.

Furthermore, ES TCP participated in two workshops organized by IESCG and contributed with a keynote speech in the Global Energy Storage Conference in October

Several cases were presented for the IEA initiative *Today in the lab – Tomorrow in energy*. As in 2020 again, some storage cases were selected.

The ES-TCP is closely connected to the MI challenge #7 (affordable heating and cooling). There are bi-monthly co-leaders calls on the various subjects related to this challenge and ES-TCP actively contributes by reporting the progress of Task 34 (CCB) and other storage related subjects. In 2022 a new structure will be discussed.

Membership

In 2021 the ES TCP ExCo could welcome two new participating countries, Israel and Czech Republic, and one new sponsor, University of Seville. Current membership (per December 31st 2021) includes 21 countries and 2 sponsors.

To conclude

2021 was the first year of implementation of our new strategic plan and an enriched communication plan. We are grateful for all the support and commitment from the delegates and our secretariat in strengthening the position of ES TCP in this challenging time of energy transition. With many Tasks in operation and more in the pipeline and a good secretariat, communication team and working group, the ES TCP is well positioned to contribute to the further development and deployment of energy storages. It is a great pleasure to be part of this inspiring network.

Teun Bokhoven

Chair, ES TCP

ES TCP (ENERGY STORAGE TECHNOLOGY COLLABORATION PROGRAMME) CONTRACTING PARTIES AND SPONSORS

Name	(Alternate) Delegate/Sponsor	Country
Contracting Partners		
Christian Fink	Delegate	Austria
Sabine Mitter	Alt. Delegate	Austria
Bert Gysen	Delegate (Vice Chair)	Belgium
Adam Tuck	Delegate	Canada
Xu Wei	Delegate	China
Zhang Shicong	Alt. Delegate	China
Vaclav Novotny	Delegate	Czech Republic
Jan Spale	Alt. Delegate	Czech Republic
Mads Lyngby Petersen	Delegate	Denmark
Per Alex Sørensen	Alt. delegate	Denmark
Jussi Mäkelä	Delegate	Finland
Paul Kaaijk	Delegate	France
Kévyn Johannes	Alt. Delegate	France
Hendrik Wust	Delegate (Vice Chair)	Germany
Stefan Busse-Gerstengarbe	Alt. delegate	Germany
Gideon Friedmann	Delegate	Israel
Yael Harman	Alt. Delegate	Israel
Raffaele Liberatore	Delegate	Italy
Margherita Moreno	Alt. Delegate	Italy
Masaya Okumiya	Delegate	Japan
Takayoshi Shuto	Alt. delegate	Japan
Yeon Sun-Hwa	Delegate	Korea
Hyun-Choon Cho	Alt. delegate	Korea
Rajinder Kumar Bhasin	Delegate	Norway
Uroš Stritih	Delegate	Slovenia
Alenka Ristic	Alt. delegate	Slovenia

Name	(Alternate) Delegate/Sponsor	Country
Contracting Partners		
Emina Pasic	Delegate	Sweden
Paul Westin	Alt. Delegate	Sweden
Andreas Eckmanns	Delegate	Switzerland
Michael Moser	Alt. delegate	Switzerland
Stefan Oberholzer	Alt. delegate	Switzerland
Stan van den Broek	Delegate	The Netherlands
Teun Bokhoven	Alt. delegate (Chair)	The Netherlands
Halime Paksoy	Delegate	Turkey
Yalcin Katmer	Alt. Delegate	Turkey
Georgina Morris	Delegate	UK
Jonathan Radcliffe	Alt. delegate	UK
Eric Hsieh	Delegate	USA
Sponsors		
Andreas Hauer / BVES	Sponsor	Germany
Urban Windelen / BVES	Alt. Sponsor	Germany
Cristina Prieto / University of Seville	Sponsor	Spain
Francisco Javier Pino / University of Seville	Alt. Sponsor	Spain

We would like to welcome Vaclav Novotny and Jan Spale from Czech Technical University as delegate and alt. delegate for the new member country Czech Republic, as well as Gideon Friedmann and Yael Harman as delegate and alt. delegate for the new member country Israel. We also welcome University of Seville with Cristina Prieto and Francisco Javier Pino as as delegate and alt. delegate as a new sponsor to our TCP.

TASK MANAGERS

Prof. Bijan Adl-Zarrabi

Chalmers University of Technology

41296 Gotenburg, Sweden

bijan.adl-zarrabi@chalmers.se

Dr. Dan Bauer

Thermal Process Technology

German Aerospace Centre (DLR e. V.)

Pfaffenwaldring 38-40, 70569 Stuttgart, Germany

Dan.Bauer@dlr.de

Dr. Ayşegül Çetin

Turkish Society of HVAC and Sanitary Engineer-TTMD

Bestekar Cad. Çimen Apt. No:15/2 Kavaklıdere Ankara 06680, Turkey

aysegulcetin32@gmail.com

Prof. Dr.-Ing. Christian Doetsch

Fraunhofer UMSICHT – Fraunhofer Institute for Environmental, Safety and Energy Technology (UMSICHT)

Osterfelder Strasse 3, 46047 Oberhausen, Germany

Christian.doetsch@umsicht.fraunhofer.de

Dr. Andreas Hauer

Bavarian Center for Applied Energy Research, ZAE Bayern

Walther-Meißner-Str. 6, 85748 Garching, Germany

Andreas.hauer@zae-bayern.de

Prof. Dr. Ryozo Ooka

Institute of Industrial Science, University of Tokyo

4-6-1 Komaba Meguro-ku, Tokyo, Japan

ooka@iis.u-tokyo.ac.jp

Dr. Wim van Helden

Division Technology Development, AEE - Institute for Sustainable Technologies

Feldgasse 19, A-8200 Gleisdorf, Austria

w.vanhelden@aee.at

Peter Wagener

BDH b.v.

Stationsplein 128, 3844 kr Harderwijk, The Netherlands

wagener@bdho.nl

CONFERENCES, WORKSHOPS, EVENTS, AND COMMUNICATION

Conferences, Workshops, and Events in 2021

An overview of all the ES TCP attended conferences, workshops, and events in 2021: The ES TCP chair, vice chairs, and delegates contributed to a number of events and meetings.

Date	Event
February 15	Mission Innovation- Innovation Platform meeting and survey
February 22	Reporting to IEA Secr. Annual report (for EUWP and BCG)
February 25	BCG meeting (online) - ES TCP Presentation
March 10	EUWP meeting (online); presentation and input for research focus and outreach
March 11	Workshop (online); Integrated Electricity system Coordination Group (IESCG) on Over-capacity, diversification and storage; ES TCP presentation
March 16 -17	Energy Storage Systems 2021 Online conference
May 12	Input (survey) for TCP universal meeting
June 7-8	ExCo meeting Online
June 9-11	Enerstock 2021 Conference (Ljubljana, hybrid)
June 13-14	Planning + update session MI7
July 20	Interview research on TCP effectiveness (TU-Eindhoven, Kyoto University)
August 16	Interview Energy Storage for Energy World (Articles published October 2021)
September 14	Webinar Digitalization and Decentralization (IESCG-meeting) - ES TCP presentation + preparation of case study Eneco
September 15	EUWP update
September 13-14	NEIS 2021 Conference Presentation ES TCP by vice-chair Hendrik Wust
September 22	World Energy Storage Day: Virtual Global Conference and Expo
September 27 – October 1	SolarPACES 2021 Conference with keynote speech by vice-chair Hendrik Wust and Thomas Bauer of DLR
October 21	EASE Energy Storage Global Conference - key-note in session: energy Storage Innovations
October 25	Input for BCG Joint article
October 26-28	IEA TCP Global conference – Online; contributing to sessions
November 23	Invited talk at the Highlights of Energy Research 2021 Online Conference

November 24-25	ExCo meeting Online
Quarterly	Mission Innovation Update calls on MI#7- project-team

Communication Actions in 2021

Website and Newsletter

The new Task subsites for Tasks 32, 34, 35, 36, 37, 38, 39, and 40 have been integrated to the ES main website and have been filled and updated continuously by the Task Managers, their assistants, and the Secretariat. These sites can be managed by the Task Managers and edited by the Task participants themselves, as well as offering the possibility of exchanging documents.

Four newsletters for ES TCP activities were sent out in 2021. The contact list is gradually growing.

In addition to communication via the IEA ES TCP mailboxes, the contact page of the website has also been maintained.

Handbook

To get a quick overview about the structure und the work done within the ES TCP a handbook was created. It also includes the different ways to become a member of ES TCP as well as the responsibilities and obligations of Task Managers and how to propose a Task.

Participation in Events, Meetings, and Networks

IEA Initiative *Today in the Lab - Tomorrow in Energy?*

The initiative *Today in the Lab – Tomorrow in Energy?* aims to promote the TCP's work to governments, the industry, and the broader public. To this end, it chooses easy to communicate projects from the TCP network which address key energy policy concerns. Two of these projects are coCO2vac (related to Tasks 33 and 40, https://www.iea.org/articles/high-performance-transport-materials-for-thermally-sensitive-vaccines) and giga-TES (related to the Task 39, https://www.iea.org/articles/very-large-thermal-energy-storage-for-renewable-districts).

Communication Plan for 2022

ES TCP plans to further increase its communication and outreach with the following activities. Major effort will be devoted to increasing the interest in, and sharing the results of, the ES TCP work in the Tasks and to anticipate growing interest in deploying energy storage.

- Further developing of the website and integrating an information platform on energy storage based on energy storage technology fact sheets
- Sharing information about statistics on energy storage markets and R&D funding programmes by publishing country reports from ES TCP member countries on the website
- Providing updates related to ongoing and finished Tasks, international events (workshops and conferences), and relevant publications from within the IEA ES TCP and other resources
- Extending the mailing and contact list for the ES TCP newsletter

- Organization and announcement of the Enerstock *Online* Conference (scheduled for beginning of 2023)
- Setting up an Online Seminar series based on running Task activities and current trends in the field of energy storage (recordings to be published via ES TCP's YouTube channel)
- Maintaining and improving the social media strategy (e.g. via Twitter, YouTube, LinkedIn)
- Increase visibility of ES TCP activities and dissemination of Task results with presentations and participation in panel discussions at external events
- Completing and updating the ES TCP standard presentation about energy storage in general and the ES TCP activities

FINANCING

All Contracting Parties and Sponsors make an annual financial contribution to the common fund used for ES TCP general, administration, and communication matters. The following table outlines the budget contributions from participants.

The overall ES TCP 2021 budget from the common fund was $ 63,300. Per ultimo 2021, not all contributions have been received. The corresponding contracting parties are indicated in the table with square brackets.

Contracting Party	No. of Countries X Contribution/Country (USD)	Total (USD)
Canada, [China], Italy, Japan, France, Germany, Norway, [UK], [USA], Switzerland	7 X 4,800	33,600
Austria, Belgium, Czech Republic, Denmark, Finland, Korea Netherlands, Sweden, Israel [1]	(8 X 3,000) + 1,500 [1]	25,500
Slovenia, Turkey	2 X 1,200	2,400
Sponsors: BVES (Germany), University of Seville [1] (Spain)	1,200 + 600 [1]	1,800
TOTAL CONTRIBUTIONS 2021 (USD)		63,300

The ongoing and new Tasks in 2021 were all ‘task-shared’ (not ‘cost-shared’) activities. The additional effort for the co-operation within the IEA is usually 3 person months (PM) per year. The work of the respective Task Managers requires funding of about 3–6 PM/year.

[1] reduced fee because membership started in the current year

ONGOING TASKS

Task 32: Open Sesame
»Open Source Energy Storage Models«

Task Information

General

Duration: Start: February 2020 – End: March 2023

Website: https://iea-es.org/annex-32/

Task Manager

Prof. Dr.-Ing. Christian Doetsch

Fraunhofer Institute UMSICHT

Osterfelder Str. 3, 46047 Oberhausen

christian.doetsch@umsicht.fraunhofer.de

About Task 32 – Open Sesame

The energy system is changing due to variable energy production. This requires new and more storage devices to balance demand and production and additionally to increase flexibility. The aim is to select always the best fitting storage systems with the best fitting operation mode to balance the energy system. The challenge is that there are hardly any, scientific proven, source models for energy storage systems, which are an indispensable prerequisite for operation or structural optimisation and for assessing the value of storage systems. The goal is to develop a standardised and scientifically proven approach and methodology to asses various storage devices for various applications: grid connected and grid operated, island grids/ remote areas, industrial sites and residential areas. The results are generic open source models and data sets. These scientifically proven models should be used to find answers to current storage questions (technical, economical and regulatory). The overall aim of this task is smart energy conservation and to understand and foster the role of energy storages in the energy system by optimising applications and operation modes and by assessing the benefit to the energy system.

Contracting Parties / Sponsors

Institution	Country
Fraunhofer UMSICHT DLR Steinbeis SOLITES	Germany

Berner Fachhochschule CSEM Paul-Scherer-Institute	Switzerland
KIER	South Korea
EMD International Aalborg University	Denmark
NRC Carleton University University of Calgary	Canada
VITO	Belgium
ISQ	Portugal
CETHIL	France
AEE INTEC	Austria
University of Izmir	Turkey

Overview of Scope:

The overarching aim of task 32 is smart energy conservation and to identify the crucial role of energy storages in the energy system by optimizing applications, structures and operation modes and by assessing the benefit to the energy system.

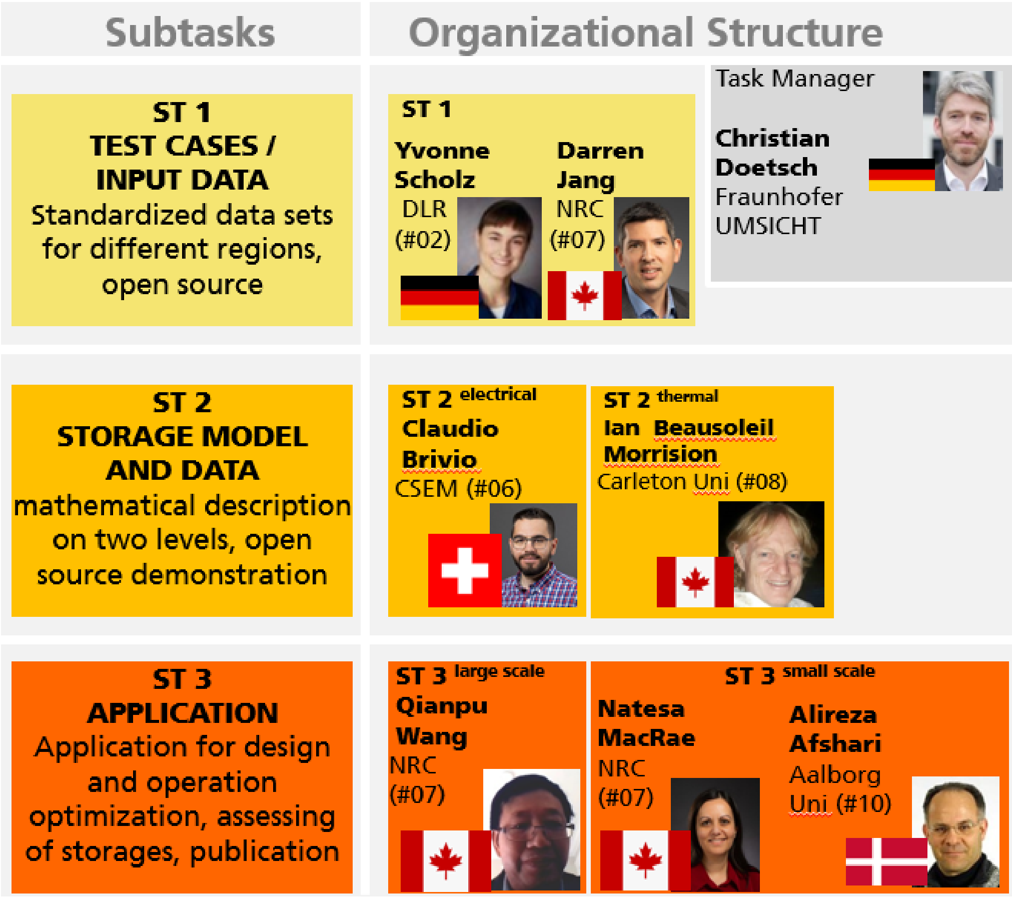
The technological aim of Open Sesame is the development of comprehensive models for relevant energy storage devices and input data sets for simulation. These models must be scientifically proven, open source and implementable.

Using the open source models developed in this project in existing energy system models to find answers to various technical, economical questions.

The scope of task 32 covers the following types of storage devices: Electrical storages (power-to-power), thermal storages (heat-to-heat) and hybrid storages (two different storage devices technically combined and combined operated) – see below.

Subtasks

The work of the Task is split into three different subtasks with some subgroups.



There was a change in ST1, now Yvonne Scholz and Darren Jang are both subtask-leaders.

- Darren Jang will organise the collection of datasets from and for task participants and the processing to derive demonstrator datasets for the models developed in ST2.
- Yvonne Scholz will focus on the preparation of a report and an IEA website about our datasets and their availability.

Activities and Achievements

Subtask 1 – Test cases / input data

In order to provide demonstrator datasets for the storage models that are in development, a Task-internal dataset collection is ongoing. As the NRC is providing its server to compile and process the data, the lead of ST1 is shared with Darren Jang from NRC since October 2021 to enable a more direct interaction with the task participants. In addition to Task32-internal datasets, external datasets can also be used. An overview of existing datasets of load and renewable power or heat generation time series has been developed and is constantly extended within the task.

Subtask 2 – Storage model and data

ST2 electrical: ST2 started with an inventory of the storage technologies currently being worked on and the models that exist for them in the task: CAES, PH, RFB, Li-ion, Na-ion, lead acid. Furthermore, it was discussed and provisionally determined how level 1 and level 2 are to be understood (provisional definitions). For Li-ion two regional clusters emerged - Swiss and Canadian cluster.

A document is currently being drafted to summarize the existing models within Open Sesame and their parameters. Work on this document is ongoing.

ST2 thermal: Scope of ST2 thermal includes sensible heat, PCM, seasonal storage, thermochemical storage, aquifers, pit stores, boreholes and industrial applications. There exists a wide range of models, so first an inventory must be made. Required information is more extensive than usually reported in journal articles. All significant assumptions and modelling simplifications, the property values and source code snippets will be regarded.

One difficulty with thermal storage systems is that they are usually closely integrated into the entire energy system and specially adapted so that the storage system can often not be viewed in isolation.

ST2 thermal has created a template for documenting the models under development by participants. A number of the ST2 thermal participations have completed the template and these have been assembled into an early draft of a compendium of models. The goal is to consistently declare items such as model inputs and outputs, underlying assumptions, validation, etc.

Subtask 3 –Applications

ST3 was divided in three subgroups – large scale vs. small scale additional the small-scale group was divided into one electrical and one thermal part. These subgroups are working together for the definition part of their work.

Within the subtask a draft document to include summaries of ST-3 application models is prepared with a comprehensive list of energy storage applications, by scale and by type (thermal, electrical, or hybrid). In 2021 there was a lot of exchange between the subtasks.

ST-1: Provided a 'template' on the types of data and descriptors that would be helpful for ST-1. These data types were then added to ST-3 requirements document.

ST-2: Worked with ST-2 using the same requirements document template to allow ST-2 to communicate information about their models to ST-3.

Meetings

2021 was the second pandemic year, so every meeting had to be online. In fact, there was no possibility to meet the task members in real life up to now.

Date	# Participants/organisations/countries	Location
23rd February 2021	40/18/10	online
27th April 2021	31/18/10	online
22th June 2021	about 20/16/9	online
6th October 2021	about 20/17/10	online

To strengthen cooperation between ETSAP and Open Sesame, a workshop with 28 participants took place in September 2021. Main focus of this workshop was the networking and socializing aspects. The response to the workshop was very good, the follow-up is under discussion.

Upcoming workshop IEA ETSAP – IEA TCP Energy Storage Task 32
Agenda: Thursday, Sept. 9th, 4:30 pm (UTC+2) - Duration: 2.5 h

	Topic	Who
4:30-4:35	Welcome	Christian
4:35-4:55	First break-out session	Eva
4:55-5:15	Presentation ETSAP/TIMES	George
5:15-5:35	Presentation Open Sesame	Christian & Eva
5:35-6:20	Break-Out Sessions for work A-D (see note)	Astrid
6:20-6:40	Presentation of results from the break out sessions A-D	All
6:40-6:50	Follow-Up	Christian
6:50-7:00	Check-out	Eva

- Break out sessions A & B deal with the Thermal Storage
  - Session A discusses exchanges from ETSAP to Task 32
  - Session B discusses exchanges from Task32 to ETSAP
- Break out session C & D deal with the Electric Storage
  - Session C discusses exchanges from ETSAP to Task32
  - Session D discusses exchanges from Task32 to ETSAP

Outlook

We plan to publish data (and possibly models) before the end of this task most likely via open energy platform (https://openenergy-platform.org/). In addition we plan to publish the documents mentioned above in the subtasks as a "Not yet approved pre-information - from work in progress".

We have started planning to have the first ever live meeting in May or June 2022 - the intended location is Canada.

Task 34: Heat pumps and energy storage (Comfort Climate Box)

Task Information

General

Duration: Start: January 2019 – End: January /February 2022

Website: https://iea-es.org/annex-34/

Task Manager

Peter Wagener

BDH b.v.

Stationsplein 128 3844 kr Harderwijk – The Netherlands

wagener@bdho.nl

About Task 34 – The CCB concept

Integrated systems consisting of heat pumps, storage and controls are in general considered to be an important technological option to accelerate the deployment of renewable energy in the domestic sector. Improving the coordination and integration of heat pump operation and storage, performance of the system can be enhanced in several ways: price, compactness, reliability, efficiency and serviceability etc. Meanwhile, a better smart-grid integration and a larger share of direct renewable energy use becomes feasible.

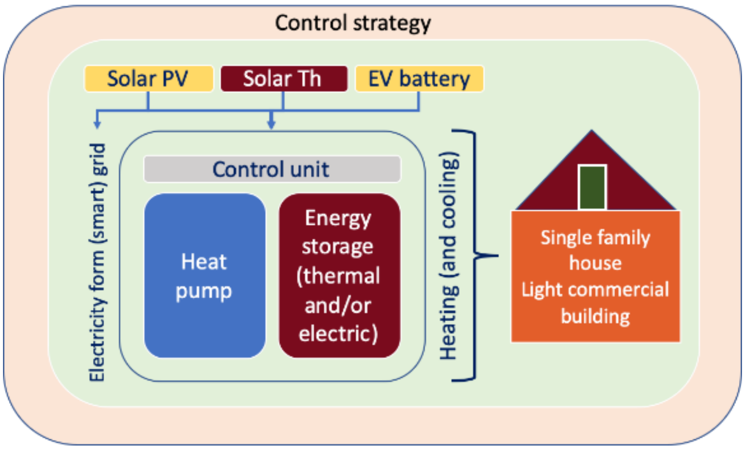
Under the combined direction of the IEA Technology Collaboration Programmes (TCPs) on energy storage (ES) and heat pumps (HPT), Task 34 started in early 2019 and will focus on improving combined systems of heat pumps, storage and controls. Integrated systems consisting of heat pumps and storage are an important technological option to accelerate the use of renewable energy for heating and cooling. By combining heat pumps and storage, several issues may be tackled in one and the same process, such as:

- Balancing and controlling electricity grid loads
- Capturing a large(er) share of renewable (local/regional) energy input
- Optimizing economics, CO2-emissions, fuel use throughout time
- Providing optimal supply security to buildings

Commercial development of this type of solution is progressing very slowly so the combined Task 34 (HPT Annex 55) will accelerate market development of combined heat pump / storage packages (working title “Comfort and Climate Box”, or ‘CCB’). This will be the first Task to integrate the work from the TCPs HPT and ES, building upon the earlier work in the fields of heat pumps and energy storage systems.

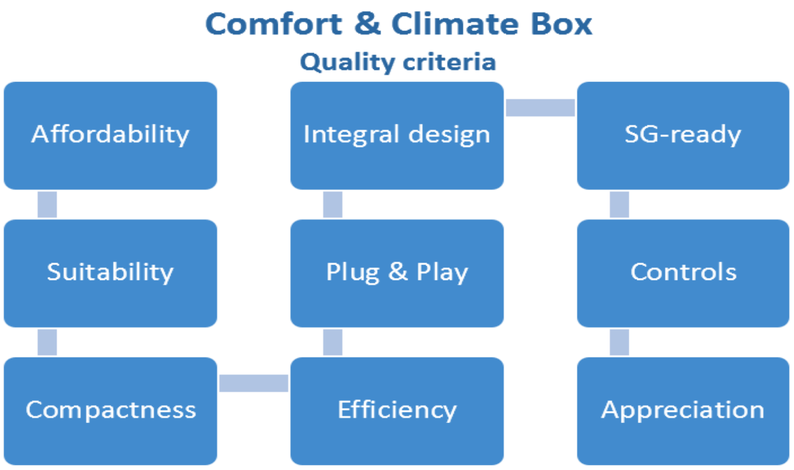
Comfort and Climate Box (CCB)

The central concept in Task 34 is the Comfort and Climate Box, a concept that denotes a combined package, consisting of a heat pump, an energy storage module and controls. This package may form an actual physical unit but can also consist of separate modules that form an integrated 'virtual package', where all components of the CCB should be designed to work together in a modular fashion and should be operated under a dedicated and optimal integrated control strategy.



Quality criteria

There are already several attempts to put CCBs on the market. However, market uptake is still slow and hesitant. We analysed market access and potential success by looking at 9 design criteria that play a role in developing CCBs.



Depending on the local market, available systems may need to improve performance with respect to one or several of these criteria. These criteria form our central reference to describe and measure CCB development and quality. Overview schemes based on scores on these criteria per country give an impression at a glance how CCB developments proceed within the participants' countries.

This Task focusses on improving the integration between the heat pump and storage components. A CCB should not just be a set of components that have been put together. Rather, all components of the CCB should be designed to work together and should be operated under a dedicated and optimized integrated control strategy.

An integrated system consisting of a heat pump and storage component together with an optimized control is called a Comfort & Climate Box, or CCB. The goal of the combined Task to speed up the development of CCBs and to bring CCBs closer to the consumer market.

Through better integrated heat pumps and storage, several issues may be tackled, such as

- Balancing & controlling electricity grid loads
- Capturing a larger share of intermittent renewable (local/regional) input (i.e. solar thermal, solar PV)
- Optimizing economics, CO2-emissions, fuel use throughout time
- Providing optimal supply security to building users
- Providing smaller and more cost-effective renewable heating systems.

Contracting Parties

Institution	Country
Cukurova University	Turkey
Fraunhofer ISE Institute	Germany
RISE, KTH	Sweden
Oakland Research Institute	USA
China Academy of Building Research	China
RVO	The Netherlands
Politecnico di Marche, ENEA	Italy
AIT / University of Graz, University of Innsbruck	Austria
BEIS, University of Ulster	UK
Hochschule München	Germany
National Resources Canada	Canada
University of Ulster	UK - Ireland
VITO	Belgium

Overview of Scope

The general objective of Task 34 is to advance the implementation of thermal energy storage (TES) 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 in order 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)
- Boost energy system flexibility through peak shaving and demand response applications

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 Task 34 is therefore to define a methodology for process analysis and specify technical and economic parameters of TES on a system level. Subsequently, determination of 'key performance indicators' (KPIs) will be an important step in the performance evaluation of a TES system. The ultimate objective of Task 34 is to evaluate TES systems for a given application. The methodology has been applied to various case studies originating from demonstration projects where TES systems are applied in a real environment. Thus, in a long-term perspective real-world example of integration of TES systems can be discussed with stakeholders ranging from industry as process owner and turnkey or component supplier to national, European and other funding agencies as well as national governments.

Subtasks

This goal is translated into the following explicit objectives for each participant:

- Present state of market and system types
- Prototyping & Criteria for CCB 1.0
- Testing and pre-standardisation
- Roadmap/Conditions for successful implementation

These subjects have resulted in seven work packages plus two overarching reports by means of a one-page summary, and an overview summary.

The participants have prepared package reports under guidance of their work package leaders with the following content.

Subtask 1: One page executive summary

According to the IEA report "Net Zero by 2050 – A roadmap for the global energy sector" (2021) one of the defined key milestones, are "no new sales of fossil fuel boilers by 2025" and that "50% of heating demand is met by heat pumps in 2045". To fulfil this the stock of installed heat pumps needs to increase from 180 million units in 2020 to 600 million units in 2030 (almost quadruple) and thereafter a tenfold increase to 1.800 million units in 2050.

One way to increase the amount of heat pumps installed is by integrating the heat pump with thermal storage and intelligent control into a 'comfort and climate box'; a CCB. The goal of this Task is 'to speed up the development of CCB's and to bring CCB's closer to the consumer market. Integration of the three components can satisfy different implementation strategies: affordability, flexibility, compactness and energy efficiency. These four implementation strategies relate to nine quality criteria: Affordability, customer appreciation, compactness, plug and play, energy efficiency, monitoring and control, smart grid performance, market suitability and level of integration.

The market status report investigates the local situation in the participating countries, to see what the local differences and similarities are. Which quality criteria have a priority in the respective countries and how much work is there still to be done on these quality criteria? It is concluded that both the priorities and status of local market differ greatly. This makes sense as the technical boundary conditions in the participating countries also differ heavily. The weather, building size, solar orientation, envelope quality and lifestyle choices, to name a few, are very different between the countries.

An overview of research project and field trials reveals that in research efficiency is still the main focus, where field trials' focus is more divided over the different implementation strategies. The closer one gets to actual implementation of a technology, the more relevant boundary conditions become. In the Netherlands the Stroomversnelling created a special set of boundary conditions that led to the introduction of 'energy modules' by more than ten different companies. Energy modules fit the CCB concept perfectly and show the technical and commercial feasibility of the concept.

Standardization worldwide is focused on stationary performance of individual components; heat pumps and storage vessels. There are no standards to be found for the combination of components or real-life performance. The creation of standards that take these aspects into account will promote the development of integrated solutions with better real-life performance.

Standardization is one of the things that can be done to promote the introduction of CCB's. In the roadmap a number of other actions are suggested that can be taken on each of the implementation strategies. Depending on the local situation and relevant quality criteria a different implementation strategy will emerge that requires different actions by the local stakeholders. These actions may promote the adoption of heat pumping technology separately or the CCB as a total concept.

At the start of this Task a CCB was a paper concept. During the execution of the Task the energy module concept with a strong focus on the affordability and compactness quality criteria emerged as a CCB that fits the local demands in the Netherlands. The roadmap gives an overview of actions to be taking depending on the local demands, to promote the development of CCB's and therewith the promotion of heat pumps and thermal storage. We hope to see more CCB developments that solve the local challenges to a more sustainable heat infrastructure.

Subtask 2: Present state of the market and system types

This report gives and overview of the market status regarding CCBs in all participating countries. It is based on the input from the participants and discussion in working group meetings. The main focus is on providing the background on the CCB market, but also to 'rate' markets based on the nine quality criteria and find optimal implementation strategies. Much of the information presented here depends on the personal knowledge and judgements of the contact persons from each Task participating country. As such, the contents of this report should not be taken as official policy statements from the respective countries.

Subtask 3: Field trials results

This report collects details about CCB field trials that have taken place in several of the participating Task countries. The purpose of this collection is to highlight through real implementations in the field the basic functionalities needed in a CCB, problems in installation, and considerations on system size and user interaction. We have projects from Canada, Austria, The Netherlands, UK and Turkey.

Subtask 4: Technical boundary conditions in participating countries

This report presents a comparative overview of the technical boundary conditions for CCBs in the participating countries. As such, it supplements the country reports discussed in Subtask 2 of the Task report series.

Subtask 5: Research projects

This document gives an overview of research projects that have been carried out within the Task framework, supplemented by some earlier findings that relate to the work from this Task. Many of the research projects are still ongoing (as of July 2021). For those projects, preliminary results have been shared. This project overview gives an impression of the breath of work that can be done on the CCB concept. While most of the projects have at least a minor focus on efficiency, affordability, flexibility and compactness are also gaining ground. This will help speed up the development of market-oriented CCB packages that will provide efficient renewable heating and cooling to a broad range of customers.

Subtask 6: Standards

The Comfort Climate Box is defined within the scope of this Task as "an integrated system consisting of a heat pump and a storage together with an optimized control". The ultimate goal of the Task is to speed up the development of CCBs and to bring CCBs closer to the consumer market, focusing on the optimal integration of the CCB components that can reach their best performance when optimized together for specific tasks.

Given that the CCB is an assembly of components/systems with different features, it is here critically evaluated how it is possible to assess the CCB performance taking all the aspects into consideration and it is analysed if existing standards can cover the integration of components in the CCB.

The term standard is generally used to refer to a measurement method or it can have the meaning of (minimum) requirement. In both cases, standards are very important for CCBs because they can help to measure the performance of these complex systems and to compare CCBs from different manufacturers or with different specifications. Rating a CCB on the basis of its efficiency or flexibility is not a trivial issue, but it is a paramount step for transparency towards the final user and/or the external electricity grid. The purpose of this analysis is to identify potential limitations in the present state of affair and discuss possible approaches to overcome them.

In this report, firstly some preliminary notions will be provided on the main characteristics that depict a standard, explaining how they are related to the CCB. Secondly the state of the art on existing standards referred to the different elements of a CCB is presented for the following areas: Europe, Canada, US, China. An overview of the main findings is reported below. On the basis of the existing standards and of the relevant characteristics of a CCB, the gaps in the existing standards are highlighted and suggestions are provided.

Subtask 7: Roadmap/Conditions for successful implementation

According to IEA's recently published report "Net Zero by 2050 – A roadmap for the global energy sector" (2021) one of the defined key milestones, are "no new sales of fossil fuel boilers by 2025" and that "50% of heating demand is met by heat pumps in 2045". To fulfil this the stock of installed heat pumps needs to increase from 180 million units in 2020 to 600 million units in 2030 (almost quadruple) and thereafter a tenfold increase to 1800 million units in 2050.

The efforts made so far to support and stimulate improvement and deployment of heat pumping technologies have resulted in growing markets and more efficient products, but more efforts are needed. There are still many remaining barriers, but also a number of drivers that could be profited upon.

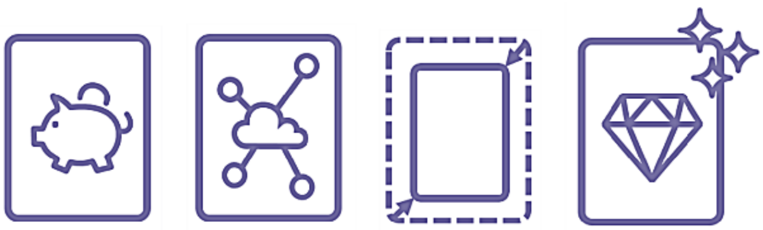
For all regions of the world, it has been concluded that increased electrification of the building, transport and industry sectors is one of the main pathways to reach net zero carbon emissions, which requires a strengthened electricity system with zero net emissions of greenhouse gases.

By combining heat pumping technologies in buildings with energy storages and integrated control, i.e Comfort and Climate Boxes, several issues may be tackled, such as

- Balancing and controlling electricity grid loads;
- Capturing a larger share of renewable (local/regional) input (i.e. solar thermal, solar PV);
- Optimizing economics, CO2-emissions, fuel use throughout time;
- Providing optimal supply security to buildings;
- Providing smaller and cheaper heating systems.

To achieve these policy goals, several different implementation strategies for the CCB concept can be used. Heat pumps and storage units are typically designed to give the best energy efficiency. That means: high COP, and low thermal losses. When looking at those components from a system perspective, the performance goals for a CCB may be extended beyond energy efficiency.

Four 'archetypes' for possible implementation strategies that form the focus and goal of CCB development has been defined by this Task - Affordability; Flexibility; Compactness; Energy efficiency.



Four archetypes for CCB implementations. From left to right: Affordability; Flexibility; Compactness; Energy efficiency.

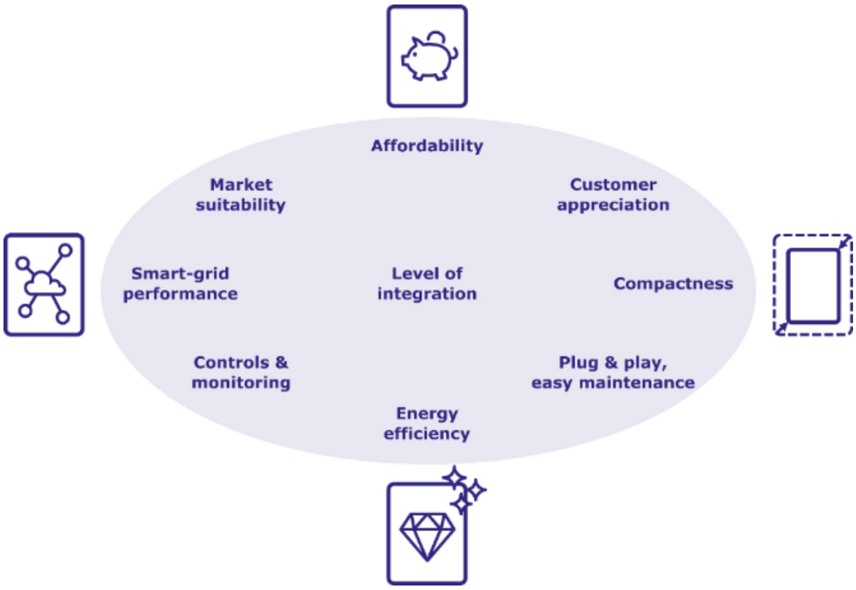
Depending on the local conditions - the market maturity and which are the main drivers and barriers on the market in the actual country region, different implementation strategies are recommended. This is especially important for policy makers, because the four archetypes can help to achieve different policy goals and support different use cases. The next step then is to establish a package of specific policy support measures, tailored to that strategy. The technical solutions are available already; our present task is to establish and develop new heat pump & storage markets.

Activities and Achievements

Heat pumps and storage solutions have been mainly developed as separate entities, focusing on the efficiency of those separate components. However, an integrated system containing HP and storage components, may achieve much better performance. In particular, it may not be optimal to focus on component efficiency. Within the Task group, we have developed an overarching set of implementation criteria for integrated HP/Storage systems (CCBs), together with 9 quality criteria to assess the performance of CCBs.

This framework allows for an unbiased judgement of CCBs in relation to the desired optimization goals. This gives an explicit insight in the multiple ways to put together an 'optimal' CCB.

Different (policy) goals ask for different CCB solutions. See the infographic as below. Four archetypes for CCBs, clockwise from the top: focus on affordability, compactness, energy efficiency, flexibility. Nine associated quality criteria are shown in the middle, where each criterion specifically applies to 1 or 2 design archetypes.



Technical Achievements in the Task

Since this Task its functionality is less hard technological oriented and perhaps more on combining and integrating running and/or existing developments into an integrated solution, hardcore technical achievements were not foreseen in the scope of the Task.

Deviations compared to Work plan and suggested corrective actions

Completion of the project initially aiming for June 2021 has been somewhat extended with permission from HPT and ES. As previously reported completion was originally foreseen for summer/Q3 2020. The final project team meeting with the 11 participants was at the 14th of October 2021 in an online video meeting.

Reports

1st Draft of final report was scheduled for December 2021. Final report for comments to ExCo ES and HPT in February/early March 2022. Final presentation of results of Task 34 in ExCo TCP ES in spring 2022.

Task 35: Flexible Sector Coupling by the Implementation of Energy Storage

Task Information

General

Duration: Start: June 2019 – End: May 2022

Website: https://iea-es.org/annex-35/

Task Manager

Dr. Andreas Hauer

Bavarian Centre for Applied Energy Research, ZAE Bayern

Walther-Meißner-Str. 6, 85748 Garching, Germany

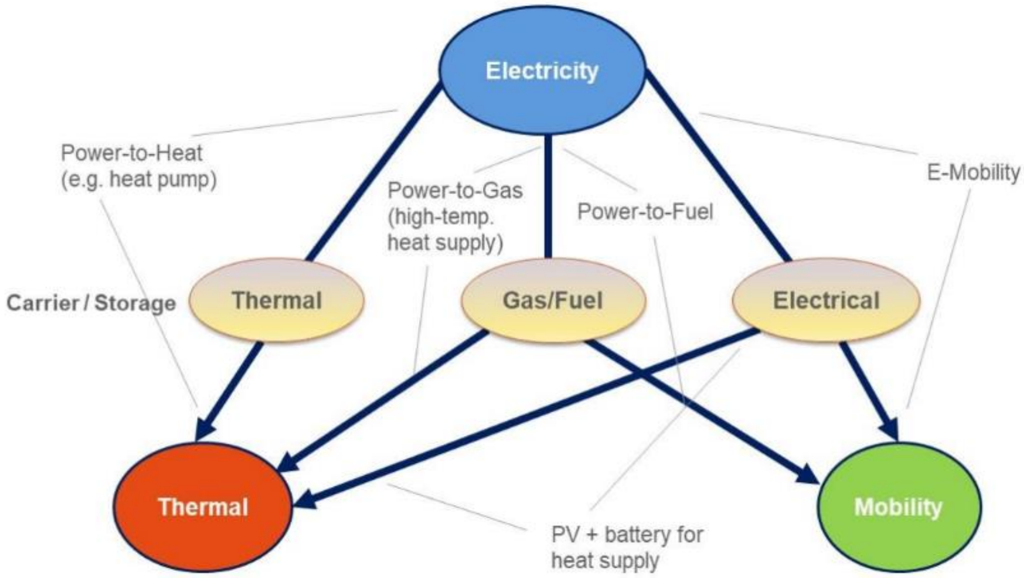
andreas.hauer@zae-bayern.de

About Task 35 – Flexible Sector Coupling by the Implementation of Energy Storage

IEA ES TCP Task 35 deals with the impact of implementing energy storage in sector coupling. The aim of this task is to evaluate the possibilities and the influence of energy storage in the context of Flexible Sector Coupling (FSC) in order to develop policy and research recommendations.

The main input of renewable energy to the future power grid will be renewable electricity by wind and photovoltaics. Reaching higher shares of fluctuating renewables in the power grid may cause a variety of problems. One option to tackle these challenges, by simultaneously further increasing the share of renewable electricity in the overall energy system, is to distribute renewable electricity to other sectors, mainly the heating/cooling and the mobility sector. By leveraging the potential of different energy storage technologies, it is possible to supply a sector with previously stored renewable energy on demand. This approach can help to reduce the stress on the power grid at different levels (high, medium, and low voltage). Possible energy storage technologies include thermal, chemical, and electrical storages.

The developed visualization of the FSC concept is shown in the figure below.



Sectors are seen as demand sectors (electricity = electric demand, thermal = heating & cooling demand, mobility=kinetic demand), that are connected by energy carriers (thermal, gas/fuel, electrical). In that sense, carriers are interpreted as 100 % energy to store and to provide (thermal, electrical, chemical).

According to the FSC definition, five pathways are possible starting from renewable electricity via the three types of energy storage to the two consumption sectors. The pathway renewable electricity–thermal storage–mobility is excluded for technical reasons.

Contracting Parties / Sponsors

Institution	Country
AEE INTEC, AIT, UiBK	Austria
National Resources Canada	Canada
PlanEnergi	Denmark
ZAE Bayern, DLR, Fraunhofer ISE, Kraftblock, Firstsolar	Germany
RSE	Italy
KIER	Korea
Moroccan Solar Energy Agency	Morocco
TNO	Netherlands
KTH, Norrenergi AB	Sweden
HSLU	Switzerland
Cukurova Üniversitesi, SHURA Institute	Turkey
IRENA	UAE
Ulster Univ.	UK

Overview of Scope:

Task 35 deals with the impact of energy storage implementation between the demand sectors when it comes to sector coupling. To provide a manageable workload, it was decided to strictly focus on energy storage only in this Task and to neglect other flexibility options like power-to-X (where chemical products are not used as energy storage) or demand side management.

Task 35 is considering:

- All energy storage technologies
- All applications in the heating and cooling sector (heating and cooling of all kind of buildings, domestic hot water, process heat/cold for industry)
- All applications in the mobility sector (cars, trucks, busses …) and all propulsion technologies (EV, fuel cell, hydrogen …).

Subtasks

The work of Task 35 is divided into four subtasks:

Subtask 1: Flexible Sector Coupling (FSC) Concept Development

The focus of subtask 1 is to develop the main concept of flexible sector coupling (FSC). A whitepaper as a delivery format to document the process of FSC concept development will be set up. Information on regulatory frameworks and identified bottlenecks will be collected. Finally, policy and R&D recommendations will be given based on the input from all subtasks.

Subtask 2: Configuration-related Storage Technology Specifications

The aim of subtask 2 is to collect existing and future sector coupling storage configurations to show the variety of examples existing already today and the technical potential for the future. The configurations will be clustered regarding market applications and the most promising configurations will be identified.

Subtask 3: Local Energy System Design and Operation

Subtask 3 aims to assess the energy storage potential in sector coupling applications on a local system level. The evaluation will consider the heating/cooling, electricity, and mobility sectors. Scenarios for local energy systems with time horizon of 2030 and 2050 will be developed, and techno-economic indicators for the assessment of the results will be defined.

Subtask 4: National-scale Energy System Analyses of FSC Potential

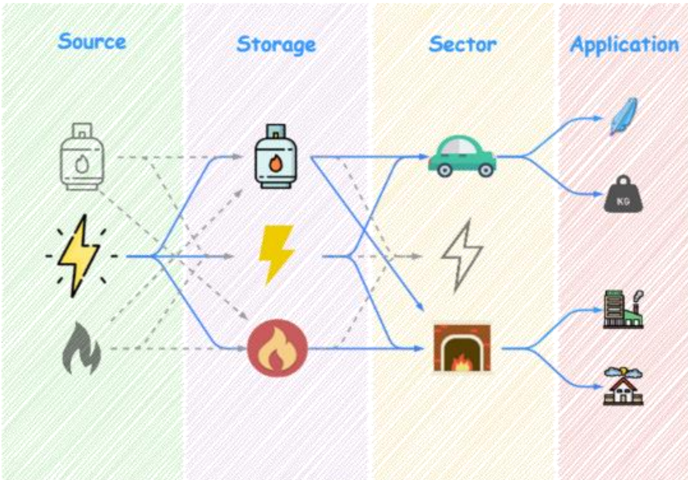
The goal of subtask 4 is to analyze and quantify the potentials of energy storages in sector coupling from a national energy system perspective. The work will elaborate on the analyzed scenarios in subtask 3 by putting them into the context of national energy system level activity and upscaling them to assess their potential in a large-scale application of FSC.

Activities and Achievements

Within the year 2021, the fourth and the fifth expert meetings took place.

The fourth expert meeting was held online on 28–29 April 2021. The meeting was in total attended by 32 participants. The meeting started with a short summary of the contents and goals of this task and the presentation of the latest definition on FSC. Afterwards, each subtask leader presented their recent progress and discussed possible key messages of this task to different stakeholders. Within the meeting, four participants contributed with their presentations on recent project results to the different topics of the subtasks.

As an outcome of subtask 2 work, the following figure shows the definition of sector coupling configuration possibilities.



A configuration consists of the storage technology in the respective application that couples the sectors (sector 1–storage–sector 2). Sector 1 is the electricity sector with renewable energy surpluses, sector 2 is either the thermal or mobility sector as energy consumers. The consumer sector can further be separated by application. The applications (e.g. buildings or industry) are not defined as sectors, but continue to be referred to as the application and part of the category, since the application significantly influences the technologies used. Energy storage is the link between source and demand sectors.

These are two of more than twenty collected FSC configurations:

1. Distributed Cold Storage District Cooling

KTH, Schweden

TRL	*8-9*
Storage tech.	*Cold storage*
Capacity	*70 MWh*
Power	*10 MW*
Storage Period	*Hours/Days*
Sector	*Cold*
Application	*Building*

Description:
Distributed and centralized cold storages are used for peak cold shaving for the district cooling grid. The aim is to increase the renewable electricity utilization, lowering CO_2 emissions, cost reductions, and increase efficiency. The cold storage is charged during off-peak hours, using cheaper nigh-time electricity to run the chillers to feed the storages. The cold storage is discharged to cover the peak cold need during the day.

1. Electric Bus On-Route Charging

NRCan, Canada

TRL	*7*
Storage tech.	*Li-Ion Battery*
Capacity	*2,5 MWh*
Power	*0,0025 MW*
Storage Period	*Seconds*
Sector	*Mobility*
Application	*Heavy Traffic*

Description:
eCAMION is partnering with the City of Edmonton and the Universities of Alberta and Calgary to demonstrate core technology solutions that are required to electrify Alberta's transit, thus transitioning buses from highly emissive diesel to Alberta's grid electricity. A 1.5 MWh battery storage will be installed at the City of Edmonton's KATG facility for bus-charging.

The project *Distributed Cold Storage District Cooling* is an example of the configuration power (source)–cold storage (storage)–thermal (sector)–cooling (application). The project *Electric Bus On-Route Charging* serves as an example for the configuration power (source)–Li-Ion battery storage (storage)–mobility (sector)–transport (application).

The fifth expert was held as a hybrid meeting (online and on site) on 9-10 November 2021 in Vienna, Austria. The meeting was in total attended by 17 participants. The meeting started with a summary of the contents and goals of this task. Afterwards, each subtask leader presented their subtask and discussed possible key messages of it.

Currently, a possible extension of Task 35 by one year is discussed. Background is the change in the responsible persons for subtasks 2 and 3. Even though the state of the activities was handed over to the successors, the progress slowed down. In addition to that, the modelling work in subtask 4 will supply first results not before March 2022. At the same time a strong Italian participation has established over the last months especially with respect to the modelling activities of subtask 3 and 4. This could lead to promising additional results, which should be included. Furthermore, a stronger stakeholder consultation was proposed in context with the discussion on subtask 1. The ES TCP Executive Committee agreed on a one-year extension of Task 35, provided that budget constraints are taken care of. A decision will be taken at the XC 93 meeting in May 2022.

Task 36: Carnot Batteries

Task Information

General

Duration: Start: January 2020 – End: December 2022

Website: https://iea-es.org/annex-36/

Task Manager

Dr. Dan Bauer

Acting head of department

Thermal Process Technology

German Aerospace Centre (DLR e.V.)

Pfaffenwaldring 38-40, 70569 Stuttgart, Germany

Dan.Bauer@dlr.de

About Task 36

Carnot Batteries have the potential to solve the global storage problem of renewable electricity in a more economic and environmentally friendly way than conventional batteries by storing electricity as thermal energy. Only a few laboratory or plant-scale demonstration facilities exist that provide the energy storage community with scientific data. Task 36 establishes an international platform that brings together experts from industry and academia in a structured way, assesses the state of the art of R&D for Carnot Batteries, deepens the understanding of their possible role in the future energy system and helps to make Carnot Batteries internationally visible through collecting and providing information on the technology.

Contracting Parties / Sponsors

Institution	Country
AEE INTEC	Austria
ENGIE-Laborelec	Belgium
Ghent University	
Liege University	
University Catholique de Louvain*	
Czech Technical University in Prague	Czech Republic
Aalborg University	Denmark
DTU (energy and mechanical engineering)	
PlanEnergi	
University of Southern Denmark	

Seaborg Technologies*	
CEA	France
Bayreuth University	Germany
Carbonclean	
DENA	
DLR e.V.	
Enolcon GmbH	
FAU Erlangen	
Fraunhofer ISE, IFAM, UMSICHT	
Kraftblock	
KIT	
Siemens Gamesa ES GmbH	
Spilling Technologies GmbH	
TU-Berlin	
TU-Chemnitz	
University of applied science Zittau/Görlitz	
University of applied science Amberg-Weiden	
PT Jülich (observer)	
CNR-ITAE	Italy
ENEA	
Politecnico di Torino	
University of Bari	
University of Pisa	
Hokkaido University	Japan
Tokyo Tech	
Energy transition (former ECN part of TNO)	Netherlands
Korean Institute of Energy Research	South Korea
Azelio	Sweden
Climeon	
KTH	
Rise	
MAN ES	Switzerland
Hochschule Luzern	
Gazi University	Turkey

BEIS Durham University Highview Power University of Birmingham University of Hertfordshire	UK
ARPA-E Echogen Google [X] on behalf of Malta Inc Malta Inc NREL	USA
University of Seville	Spain (Sponsor Institution)

New participants *New country member* *New sponsor institution* **Participation in the Task 36 must be informed to the respective delegates*

The company Ecop Technologies GmbH from Austria has expressed interest via email in attending the next 5th Expert Workshop.

Overview of Scope:

Carnot Batteries are an emerging technology for the inexpensive and site-independent storage of electric energy at medium to large scale. Also referred to as "Pumped Thermal Electricity Storage" (PTES) or "Pumped Heat Storage" (PHES), a Carnot Battery transforms electricity into thermal exergy, stores the thermal exergy in inexpensive storage media like water or molten salt and transforms the thermal exergy back to electricity when required.

In this context, the overarching aim of this Task is to ease the transition from a fossil-fuel based to a renewable source-based energy system, through the promotion of novel energy storage systems, assisting their development, deployment, demonstration and their deep understanding.

Therefore, this Task aims to stablish a platform that brings together experts from the industry and academia, to systematically investigate, assess the state-of-the-art of R&D of Carnot Batteries and strengthen the potential role of Carnot Batteries in the future energy systems gaining international attention.

Subtasks

The work and discussions carried out by the experts is divided in five different Subtasks as shown below:

Subtask 0 – Definitions; Lead by CNR-ITAE, Italy

This Subtask addresses the key definitions and classification of Carnot Batteries in order to standardize the Carnot Battery "language" (definition of acronyms etc.). Furthermore, the key performance indicators (KPIs), such as operating conditions, investment and operating costs, among others, are defined and grouped in three categories, namely materials, components and systems. Technical and non-technical aspects are considered for this task. Finally, state of the art determination for thermal energy storage as a component suitable for Carnot Batteries is carried out following a systematic analysis. This will serve as a guidance for determining the missing information and requirements to the deployment of these technologies.

Subtask A – Rankine Batteries; Lead by DTU, Denmark

Subtask A assesses the state of the art of Carnot Batteries based on Rankine cycles (so called Rankine Batteries) on a system level. Also, the identification of system configurations is carried out, identifying the sinks and sources and the storage temperatures of Rankine Batteries. Finally, the modelling and assessment of the systems are performed in order to get a common understanding of efficiency, dynamic behavior, scalability and the basis for economic evaluations. Experimental data from existing systems and know-how will be shared, as long as it is not confidential.

Subtask B – Brayton Batteries; Lead by Durham University, UK

In analogy to Subtask A, Subtask B assesses the state of the art of Carnot Batteries, based on Brayton or Joule cycles (so called Brayton Batteries), focusing on the identification of promising cycle designs, working conditions and working fluids. The experimental data and analysis of existing or planned systems as well as simulation results for promising system concepts are collected and assessed. The boundary conditions for TES are determined and provided as input for Subtask 0. Finally, the R&D demand will be determined.

Subtask C – Other concepts and combinations; Lead by University of Birmingham, UK

Subtask C investigates concepts that are not classified as Rankine nor Brayton Batteries, as well as combinations of different processes, e.g. the Lamm-Honigmann-Process, Liquid Air Energy Storage with thermal energy storage (TES), gas turbine-based technologies with TES and steam generation for enhancing the gas turbine performance, CO_2 based transcritical cycles for conversion with TES and material-based generation such as thermoelectric generators. System and component level-based data for KPI definition will be provided for Subtask 0.

Subtask D – Market analysis, energy system, policy and regulations; Lead by Google [X] on behalf of Malta Inc, USA

Subtask D focuses on promoting commercial acceptance of Carnot Batteries, by identifying market requirements for these technologies, assisting cost modelling and analyzing the Tech-to-Market transition. In addition, it will support policy and regulations as well as (non-scientifically focused) dissemination activities. Through education, lobbying and advertising, it builds support with hearts and minds.

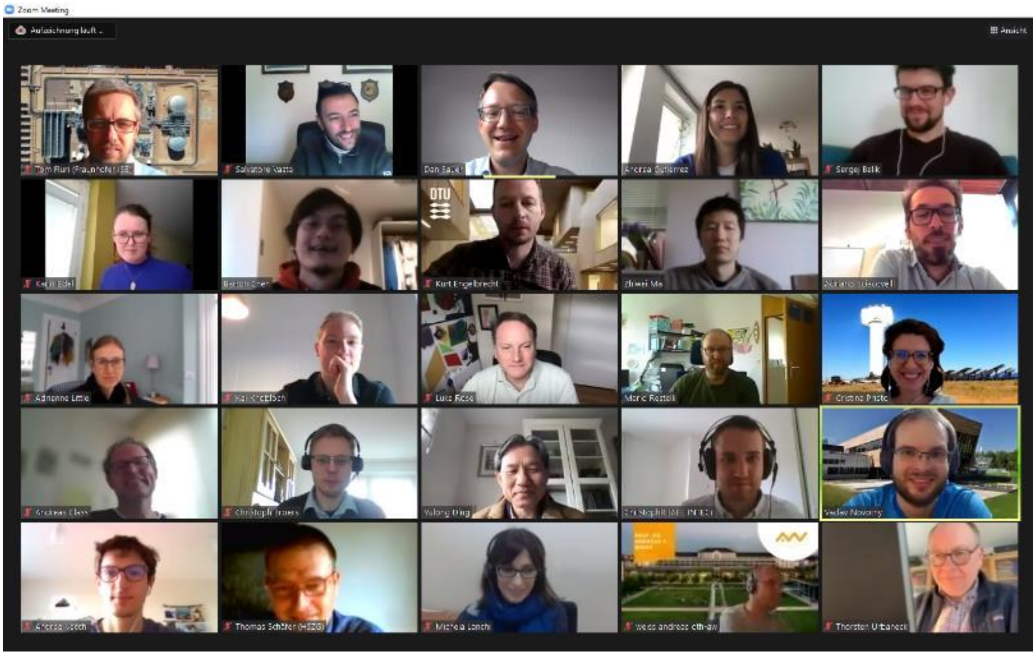
Subtask Leaders

Subtask Leaders	Country
Prof. Kurt Engelbrecht Technical University of Denmark	Denmark
Dr. Salvatore Vasta National Research Council - Advanced Energy Technology Institute (CNR - ITAE)	Italy
Prof. Zhiwei Ma Durham University	UK

Prof. Yulong Ding University of Birmingham	UK
Dr. Adrienne Little Google [X] on behalf of Malta Inc	USA

Activities and Achievements

In 2021 two expert meetings, one industrial workshop and one joint industrial webinar were held. The joint Webinar was organized between the IEA Energy Storage Task 36 and the Supergen Energy Storage Network+ *"Carnot Batteries – Academia meets Industry"* over Zoom. It took place on January 28-29, 2021 and had about 70+ internal and external participants. The recordings of the event can be found here. The first expert meeting of the Task 36 in 2021 – 3th Expert meeting overall - took place on April 15 – 16 as an online event due to the COVID19 pandemic over Zoom. The online event was hosted by the University of Birmingham, UK and coordinated with the support of the German Aerospace Centre (DLR e.V.), the Birmingham Centre for Energy Storage and the Supergen Energy Storage Network+. A total of 93 participants from 19 countries registered for the event.



The second expert meeting in 2021 - 4th overall – and an Industrial Workshop on Carnot Batteries were held as hybrid events at the Technical University of Denmark (DTU) in the Lyngby-Campus, Denmark on September 9 -10. Both events were hosted by the DTU and organized with the support of the German Aerospace Center. A total of 78 participants from 16 countries registered for the events.

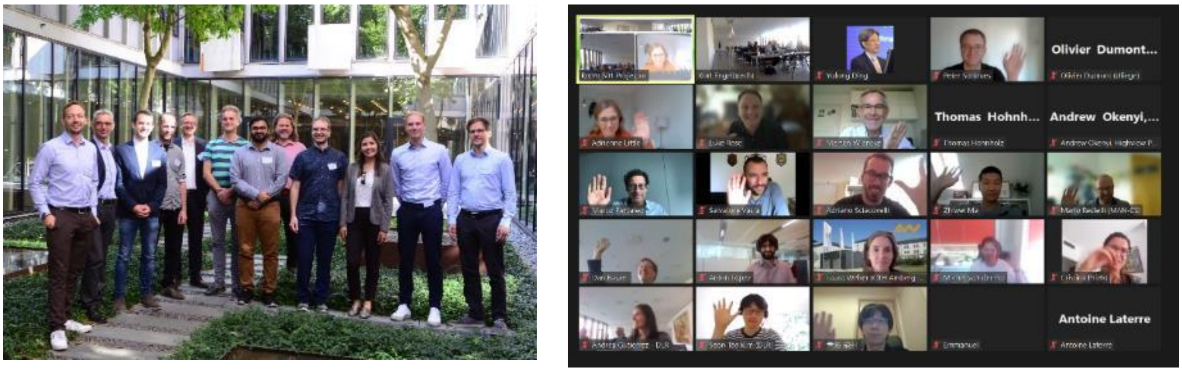


Figure 1 Pictures of the participants at the events. Participants that attended in person to the expert meeting (left) and some of the participants that attended online to the industrial workshop (right).

The communication and work within each of the subtasks took place through regular conference calls and also during the expert meetings. The progress to date is described as follow:

Subtask 0 – Definitions

WIKIPEDIA PAGE

The Wikipedia page on Carnot batteries released in October 2020 has been further edited and translated to seven languages based on the original site in English. The site is now available in English, Chinese, German, Italian, Turkish, French, Japanese and Czech, and it can be accessed here. Since the creation of the item, the views of the Wikipedia page have increased, having a total of about 14,700 views (sites in all languages). The spread of the word during the expert meetings can be identified in the history of views of the Wikipedia site as shown in Figure 2.

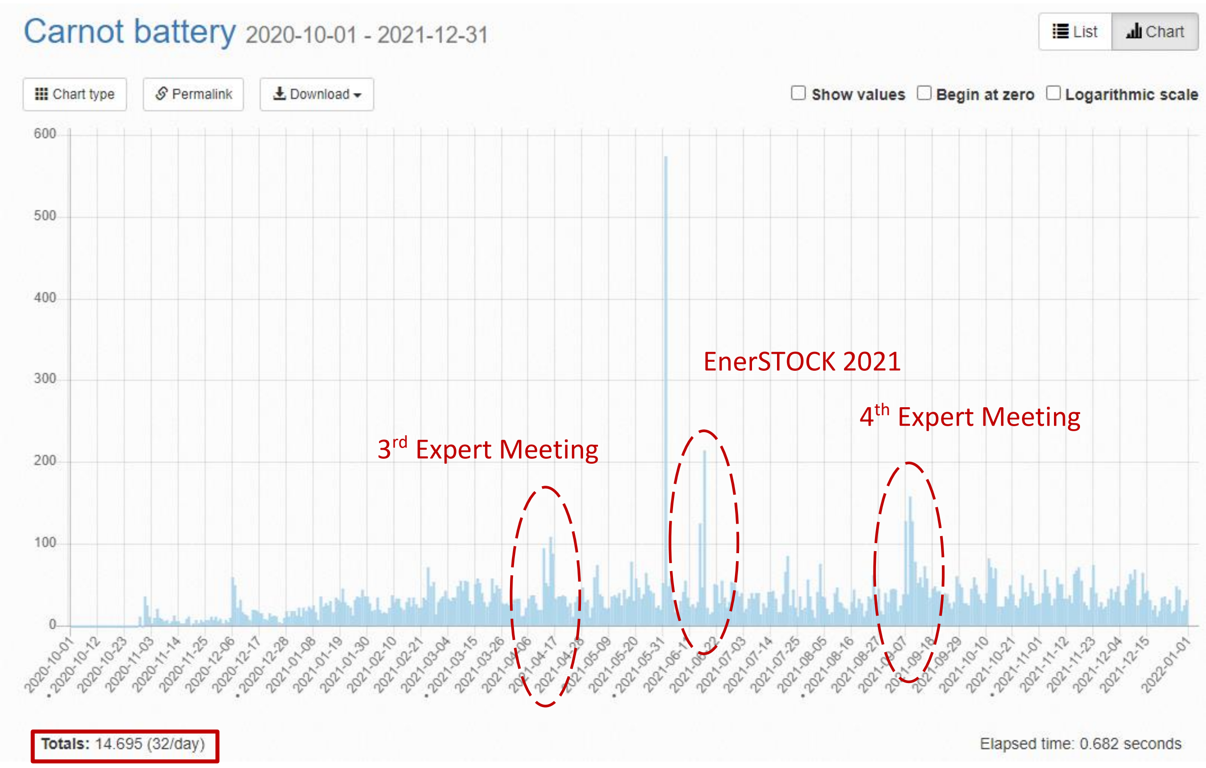


Figure 2 Coefficient of promotion of the Wikipedia Site since October 2020

In order to support the dissemination of the information about the Carnot batteries, the link of the Wikipedia page on Carnot batteries has been published in the official website of the Task 36 (https://www.eces-a36.org/index.php/publications/) and in the Task 36 Sub-page on the TCP Energy Storage website (https://iea-es.org/annex-36/), as shown in Figure 3, respectively.

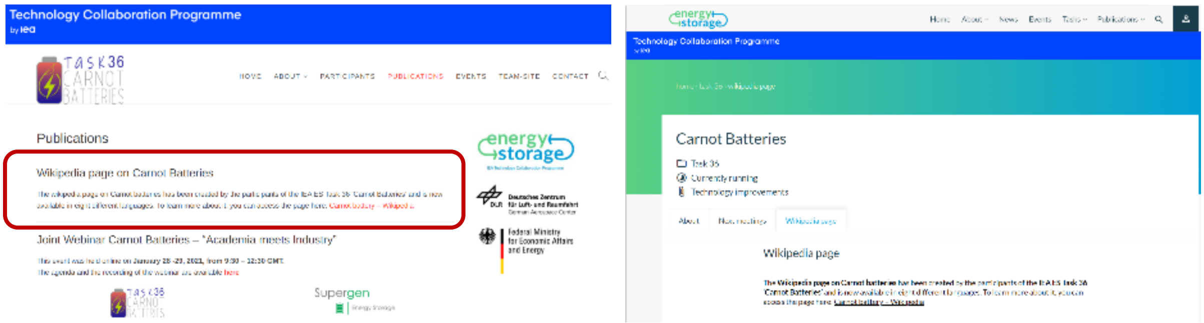


Figure 3 Publication of the information about the Wikipedia page on Carnot Batteries on the official website of the Task 36 (left) and on the sub-page of the Task 36 in the Energy Storage TCP website (right).

The growing interest in this technology was highlighted during the Expert Meeting in September at the DTU, showing that there are more and more publications where the term "Carnot Batteries" is being used either in the title or as keywords. This was compared to the normalized number of publications in Science Direct on CB, LAES, P2H2P, etc. In Figure 4 can be seen that since 2019 the use of the term "Carnot Battery" has clearly increased, and the used of other terms has reduced, such as P2H2P, which, according to the Task 36, corresponds to the base definition of a Carnot battery. It is worth highlighting that in 2019 the pre-definition phase and approval of the Task 36 took place.

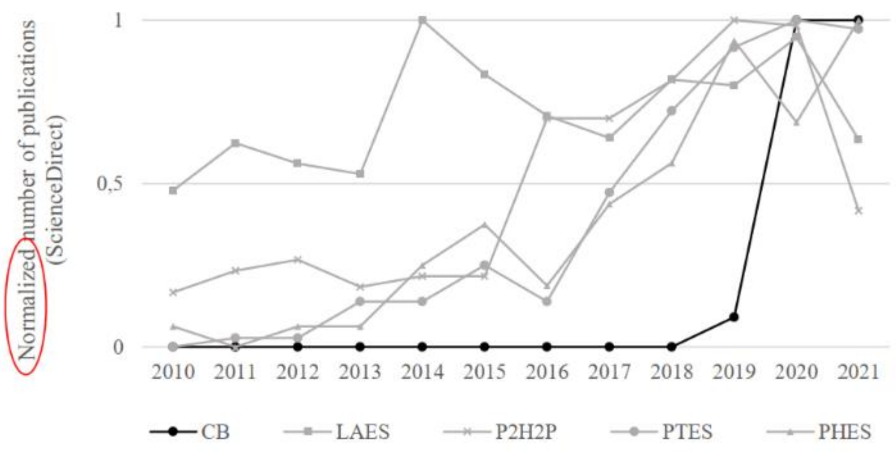


Figure 4 Normalized curves of the number of publications on CB, LAES, P2H2P, PTES and PHES up to date

KEY PERFORMANCE INDICATORS

The identification of the KPI of Carnot Batteries was complete in the expert workshop held in April 15-16 and they are shown as follow:

- System (whole Carnot Battery)
  - Round-Trip Efficiency (adm.)
  - Specific Thermal Efficiency (%/day or %/h -$E_{Disch}/E_{Ch}(t)$- considering also Waste Heat Recovery and Heat/Cold Delivery)

- Required specific area (m^2/kWh)
- Storage time (h – charging /discharging)
- Rest duration (h)
- Operating Temperatures (°C – charging – storage – discharging)
- Capacity range (MWh – GWh or MW_{day} – GW_{day})
- Stand-by losses (kWh/day; kWh/h)
- Discharging Power (electric) (MW, range)
- Charing Power (electric) (MW, range)
- Design Lifetime (Years)
- Ramp rate (MW/min)
- Time from COLD shut down to FULL load (s, min, h)
- Cycles per year (n?)
- Safety and environmental aspect (CO2 footprint)
- Site restrictions ("description", T, RU, dust, water availability, …)
- OPEX (€/year, as a function of TRL)
- Refurbishment Cost (€, at x^{st} years)
- CAPEX (€/MWh charging or discharging, as a function of TRL) + €/MWh_{th} (heating of cooling if available)
- TRL
- Levelized Cost of Storage (€/MWh, depending on cycles and TRL)
- Type of Cooling (Air/Water, T of waste available)

• Components
  - Volume – TES (m3)
  - Thermal Capacity – TES (MWh/m^3)
  - Maximum Charing Power – TES - (MW)
  - Maximum Discharging Power – TES - (MW)
  - Capacity – HPs (MW)
  - Efficiency – Converters, TES – (adm. e.g. COP for HPs)
  - Operational Temperatures (°C, range)
  - Lifetime – TES, converters – (cycles before fail)
  - TRL (1-9)
  - Maintenance costs (€/year; €/cycle)
  - Heat Losses – self discharge - (kJ/h, %/day, kJ/m^2, kW/m^2/year)

• Materials (Storage media, …)
  - Volumetric Energy Density (MWh/m^3)
  - Gravimetric Energy Density (kJ/kg, MJ/ton, MWh/ton)
  - Heat Capacity (kJ/kg K)
  - Thermal conductivity (W/m K)
  - Density (kg/m^3)
  - Operating Temperature (°C or Range)
  - Degradation (%/1000 x cycles)
  - Safety and environmental aspects (see chemical categories. Toxic, flammable, …)
  - Recyclability (➔ CO_2 footprint)

- Availability (GOOD/POOR, natural/synthetized)
- Type (feature: sensible, latent, sorption, Thermochemical
- Latent Heat (LHTES) (kJ/kg)
- Reaction Enthalpy (TCTES) (kJ/kg)
- Operation Pressure (bars)
- Cost (€/kg, €/MWh)

They are now being processed and prepared for the final report of the IEA ES Task 36.

STATE-OF-THE-ART

The technology overview of the components for the Carnot Batteries and Carnot Battery systems developed among the participants of the Task 36, was discussed during the meeting and is being carried out with the help of the Fact-Sheet provided by the participants on their respective components and system. A list of the Fact-sheets available so far is shown in the Table 1.

Table 1 Fact-Sheets on component for Carnot batteries and systems available to date

Nr	Country	Type	Name	Institution	Contact person
1	Denmark	Component	Rock bed TES test concept	DTU	Kurt Engelbrecht
2	Denmark	Component	Rock bed TES Pilot plat	DTU	Kurt Engelbrecht
3	Germany	System	Enolcon OPTES Battery	Enolcon	Jonas Haecker
4	Germany	Component	STORASOL HT TES	Enolcon	Jonas Haecker
5	Germany	System	HiTES	Fraunhofer UMSICHT	Lars Komogowski
6	Germany	System	HiTES-Steam	Fraunhofer UMSICHT	Lars Komogowski
7	Germany	Component	THERESA	HSZG	Thomas Schäfer
8	Germany	System	TMS - Battery	HSZG – Spilling Technologies	Thomas Schäfer
9	Germany	System	CHESTER	EU Project (DLR)	Thilo Weller
10	Switzerland	System	MAN CO_2 ETES System	MAN ES	Emmanuel Jacquemoud
11	UK	System	Isentropic	Durham University	Prof. Tony Roskilly
12	Belgium	System	RENEWBAT	Uliège	Olivier Dumont
13	Italy	System	WOWSUN	ENEA	Russo
14	UK	Component	Sensible TES	New Castle University	Yulong Ding (UoB)
15	UK	System	LAES	HighviewPower	Yulong Ding (UoB)

16	Germany	System	ETES	Siemens Gamesa	Michael von der Heyde
17	Denmark	System	CO2 CB with water storage	DTU - Mec	DTU Mec

Based on these Fact Sheet a white paper on State-of-the-Art of Carnot batteries will be coordinated by DLR – Stuttgart.

Subtask A – Rankine Batteries

Subtask A proposed to assess the state of the art of Carnot Batteries based on Rankine cycles (so called Rankine Batteries) on a system level. Also, the identification of system configurations is intended to be carried out, identifying the sinks and sources and the storage temperatures of Rankine Batteries. Finally, the modelling and assessment of the systems will be performed in order to get a common understanding of efficiency, dynamic behavior, scalability and the basis for economic evaluations. Experimental data from existing systems and know-how will be shared within the working group, as long as it is not confidential.

Subtask B – Brayton Batteries

In analogy to Subtask A, Subtask B proposed to assess the state of the art of Carnot Batteries, based on Brayton or Joule cycles (so called Brayton Batteries), focusing on the identification of promising cycle designs, working conditions and working fluids. The experimental data and analysis of existing or planned systems as well as simulation results for promising system concepts has been gathered since then and still has to be assessed. The boundary conditions for TES are determined and provided as input for Subtask 0.

Subtask C – Other concepts and combinations

During the first expert meeting in 2021 the Subtask C proposed to investigate concepts that are not classified as Rankine nor Brayton Batteries, as well as combinations of different processes, e.g. the Lamm-Honigmann-Process, Liquid Air Energy Storage with TES, GT based technologies with TES and steam generation for enhancing the GT performance, CO2 based transcritical cycles for conversion with TES and material-based generation such as thermoelectric generators. Some of the concepts-information has been delivered in the form of Fac-sheets and will be further assessed.

Joint work among Subtask A, B, C

Subtask A, B and C share common issues and that is why on the 4th Expert meeting in Denmark joint discussions addressing these common issues were held and the progress made is reported accordingly.

R&D DEMAND OF CARNOT BATTERIES, ROADMAP AND RECOMMENDATIONS

In order to developed this point, it was determined during the Expert Workshop that a Survey on R&D Roadmap and recommendations should be prepared and distributed among the participants. These tasks were carried out directly after the expert workshop. Recommendations and comments on what aspects of these technologies have to be further developed have been collected among the participants in the form of a survey. About 14 institutions have submitted their contributions in the second half of 2021. This information has been summarized and grouped in four themes. 13 Pages of material were obtained at the end of this process. The first page of the summary is shown in Figure

5. The information will be further processed for the final report and for distribution among the participants of the Task 36.

DLR

Federal Ministry for Economic Affairs and Energy

energy storage

TASK36 CARNOT BATTERIES

Version 16/09/2021

Carnot Batteries R&D and Roadmap survey

Based on the discussions that have taken place in the IEA ES Task 36, and the observed challenges and the current state of the Carnot Battery-systems and components, which technological and non-technological progress needs to be made to bring this technology closer to market?

Recommendations and Comments on:	How, to your opinion, can this be addressed by a R&D project?	Institution	Author
System level:			
1. Propose a system based on liquid metal heat transfer	Take a reference system and develop different alternative systems in a consortium, use expertise from CSP community from liquid-metal based receivers	KIT	Joachim Fuchs, Klarissa Niedermeier
2. KPIs are defined. But which CB have which key end users? Power market services are location-specific and thermal system integration potentials are unclear.	• Collection of (country-specific) services from CB in power and heat markets (bring in DSOs/TSOs?) • Quantitative and qualitative identification of technical potential for thermal integration – typical sites for available waste heat and/or needed process heat • Find possible demonstration sites for pilot plants • (Power Plant Atlas)	Technical University of Denmark (DTU)	Kurt Engelbrecht, Yousif Muhammad, Kai Knobloch
3. Often only thermodynamic designs have been proposed. Realistic performance estimation needed in order to provide operators with reliable data. Are identified services reasonable? Business case?	Modelling needed (ideally for specific use cases): • Part load calculations • Dynamic simulations • Experimental validation • Laboratory-scale demonstration projects	Technical University of Denmark (DTU)	Kurt Engelbrecht, Yousif Muhammad, Kai Knobloch
4. Overall concept/cycles: I think that the general concepts and technology combinations for the 3 steps of a Carnot Battery (P2T, TES, T2P) are clear / are already developed, but further cycle optimization is possible by	This is mainly theoretical and simulative work. Thinking about measures for cycle optimization and then carrying out simulations to see if this improves the cycle efficiency (or other parameters, but cycle efficiency certainly being the most important one).	University of Stuttgart, Institute for Building Energetics, Thermotechnology and Energy Storage	Sven Stark

Technology Collaboration Programme by iea

Figure 5 First page of the comments and recommendation gathered through the survey on Carnot batteries R&D

STUDENTS EXCHANGE

Within the Task 36 an important resource for researchers and graduate students is the exchange possibilities between institutions working on Carnot battery-related topics.

To help promote collaboration among them, a student exchange list has been created, so that institutions can publish their availability to receive researchers and students for research stays and publish the search for institutions for this purpose, which is especially interesting for graduate students. Figure 6 shows the number of institutions that are already taking part in this activity.

OFFERING EXCHANGE POSITION						
Institute	Level	Possible topics	Time	Duration	Contact	Funding
DTU Department of Energy Conversion and Storage	Master and PhD	Rock bed heat storage, CB system modelling	Any time	Flexible	Kurt Engelbrecht, kuen@dtu.dk	DTU provides office space, a computer, and experimental facilities
DLR - Stuttgart	PhD	TES system and CB system modelling, Experimental work in CHESTER	Flexible	3 - 6 month	Dan Bauer, Dan.Bauer@dlr.de	DLR - Stuttgart provides office space. a computes and access to experimental facilities
CTU in Prague, Faculty of Mechanical Engineering	postdoc	CB system modelling, conversion of CHP plants, thermally integrated systems	start at 2021 or early 2022	1 year	Vaclav Novotny, vaclav.novotny@cvut.cz	CTU provides salary, office, experimental facilities
CTU in Prague, FME / University Centre for Energy Efficient	Master and PhD	CB system modelling, conversion of CHP plants, thermally integrated systems	Any time	Flexible	Vaclav Novotny, vaclav.novotny@cvut.cz	CTU provides office space, experimental facilities
Thermodynamics laboratory - Univeristy of Liège - Belgium	Master, PhD & postodc	Experimentation of a Carnot battery based on a Rankine cycle, part load modelling, life cycle analysis, techno-economic, industrialization	Any time (prototype already functionnal and open source models)	Flexible	olivier.dumont@uliege.be	provides office space, a computer, and experimental facilities
DLR - Cottbus	Master, PhD & postodc	Experimental studies on high temperature heat pumps. Heat pump integration studies for idustrial applications.	Any time	Flexible Master thesis at least 6 months PHDs and Post Docs flexible	panagiotis.stathopoulos@dlr.de	case specific
OTH Amberg-Weiden (UAS)	Master	Turbomachinery design (1D/3D), turbine testing on compressed air test rig	any time i.e. on demand	Flexible Master thesis 6 months	a.weiss@oth-aw.de	OTH provides office space, CFD license, test facility
HSZG Zittau, Germany	Master and PhD	Experimental work on CB system at THERESA test facility, Modelling of CB system	any time	flexible	t.schaefer@hszg.de	HSZG provides office space, a computer, and experimental facilities
Fraunhofer ISE, Freiburg, Germany	Master, PhD & Postdoc	Experimental work and modelling on molten salt storage with filler and PCM slurries	Flexible	Flexible	Tom Fluri, thomas.fluri@ise.fraunhofer.de	Fraunhofer ISE provides office space and experimental facilities
University of Pisa, Department of Energy, Systems, Construction and Territory Engineering	Master, PhD & Postdoc	Performance simulation of Rankine and Brayton Carnot Batteries; High Temperature Heat Pumps; Feasibility and economic analyses;	Flexible	Flexible	umberto.desideri@unipi.it	Unipi-DESTeC provides office space, a computer and software licences
Karlsruhe Institute of Technology, Germany	Master, PhD & Postdoc	Experimental work and modelling of thermocline packed-bed storage; heat transfer modeling	Flexible	Flexible Master thesis 6 months	Klarissa Niedermeier, klarissa.niedermeier@kit.edu	KIT provides office space, computer, experimental facilities on liquid metal heat transfer

LOOKING FOR EXCHANGE POSITION						
Institute	Level	Possible topics	Time	Duration	Contact person	Funding
DTU Department of Energy Conversion and Storage	PhD	System modelling (preferably Dymola), CB pilot plants, degradation studies	09/2021-12/2022	3 - 6 months	Kai Knobloch, kaikn@dtu.dk	DTU provides salary as well as funding for accommodation, travel and a computer
CTU in Prague, Faculty of Mechanical Engineering	PhD	CB pilot plants / lab scale experiments, behaviour of high temperature thermal energy storages (especially packed or fluidized	11/2021-06/2022	1-6 months	Karin Rindt (Edel), Karin.Edel@fs.cvut.cz	CTU provides office equipment (laptop etc.) and scholarship
DLR - Cottbus	Masters, PhD, Post-Doc					
OTH Amberg-Weiden (UAS)	Master					

Figure 6 Exchange opportunities for researchers and graduate students. Institutions offering exchange positions (left). Students looking for exchange position (right).

MODELLING AND SIMULATION

In 2021 discussions led by DTU on the modelling and simulation fact-sheets took place. A list of the submitted models and some details regarding to them are shown in Table 2.

Table 2 List of available fact-sheets on modelling and simulation delivered by the Task 36 participants

Institution	Model Level	Model Scale	Details of the software	Task 36 Partnership	Contact person
University of Liege	Heat Pump+ORC	1D	Matlab®	yes	Olivier Dumont
Siemens Gamesa	System Level	1D Finite volume approach	Modelica - Dymola	yes	Michael von der Heyde
Aalborg University	System Level	-	EnergyPLAN programmed in DelphiPascal	yes	Jakob Zinck Thellufsen
UC Louvain	Component and system level	Scaling	Python	yes	Antonio Laterre

Subtask D – Market analysis, energy system, policy and regulations

As mentioned in the description of Subtask D, the activities and progress made by this subtask is focused on analysis and promoting the commercial acceptance of Carnot Batteries by identifying market requirements for these technologies, assisting cost modelling and analyzing the Tech-to-Market transition. To analyze the methods to support the policy and regulations for these technologies as well as (non-scientifically focused) dissemination activities, are an important focus of this subtask. Through education, lobbying and advertising, subtask D aims to build support with hearts and minds. To achieve this, during 2021 Subtask continued to develop a report. In the last two expert meetings the following issues were actively discussed among the participants:

CHALLENGE FACED AND CARNOT BATTERIES ADVANCE SOLUTIONS

Malta Inc is in charge of this section and the main aspects that are reported here are related to the climate crisis and what a just transition would consist of. Furthermore, other aspects that are discussed in this section are the solutions that Carnot Batteries could mean for the climate if these technologies are used for industrial process heat generation, supporting EV development and for using renewable energies 24/7.

MARKETS

Kraftblock and ENGIE/Laborelec are leading this section, where input from the Subtask 0 will be used to analyze the KPI's and the role they play in the way of Carnot Batteries to the market. Also, the use case and services of Carnot batteries as well as business models are being analyzed and will be reported in these sections.

POLICY MAKERS

Highview and Siemens Gamesa are leading this section. Existing energy storage solutions are being analyzed. Based on it, a favorable regulatory framework for these technologies is defined. Echogen and Malta Inc will also contribute to this section, especially in the R&D and commercialization sections.

Task 37: Smart Design and Control of Energy Storage Systems

Task Information

General

Duration: Start: June 2020 – End: May 2023

Website: https://iea-es.org/annex-37/

Task Manager

Prof. Dr. Ryozo Ooka

Institute of Industrial Science, University of Tokyo

4-6-1 Komaba Meguro-ku, Tokyo, Japan

ooka@iis.u-tokyo.ac.jp

About Task 37 – Smart Design and Control of Energy Storage Systems

In this Task, we investigate the present situation of smart design and control strategy of energy storage systems for both demand side and supply side. The research results will be organized as design materials and operational guidelines. Specifically, artificial intelligence that has developed significantly in recent years can be expected to make a significant contribution to the smart design and control systems. This task also covers the availability of artificial intelligence.

Contracting Parties/Sponsors

Institutions	Country
BBA: Industrial Consulting Engineering Firm	Canada
Concordia University	
Institut de recherche d´Hydro-Québec	
McGill University	
Oullet Canada Inc.	
Ryerson University	
Southeast Jiaotong University	China
Zhejiang University	
Aalborg University	Denmark
DTU	
INSA Lyon	France
Lyon University	

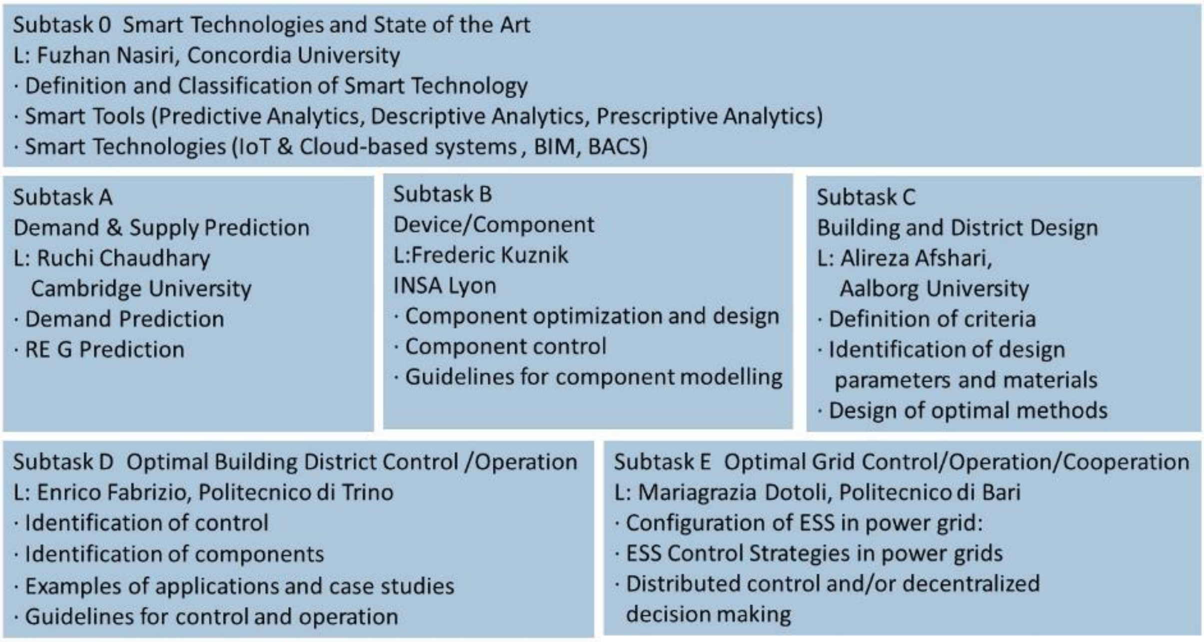
University Savoie Mont Blanc	
Ulm University of Applied Sciences	Germany
Politecnico di Bari Politecnico di Torino	Italy
DAIDAN Co. LTD Nagoya University Tokyo City University Takenaka Cooperation Tokyo Electric Power Company Tokyo Institute of Technology University of Tokyo	Japan
IRESEN	Morocco
Oslo Metropolitan University	Norway
University of Ljubljana	Slovenia
KTH	Sweden
Cukurova University HVAC360 TTMD	Turkey
Alan Turing Institute The University of Nottingham University of Cambridge	UK
Oklahoma University	US

Overview of Scope:

The general objective of this Task is to address the design/integration, control, and optimization of energy storage systems within buildings, districts, power grids, and/or local utilities. The focus will be on the development of design methods, optimization, and advanced control strategies for effectively predicting, evaluating, and improving the performance of Buildings and districts when energy storage is available. The Task shall deal with the fundamental of smart technology and its application to energy storage systems in buildings, districts, and grids.

Subtasks

The work of the Task is split into 6 subtasks.



Activities and Achievements

Sixth expert meeting was held online on 27 May 2021 with 35 participants and seventh expert meeting was held online on 22 October 2021 with 32 participants. Achievements of each subtask were reported and the overall schedule was adjusted.

Report from Subtask 0: Smart tools and tech state of art by Fuzhan Nasiri

Three summer school workshops are under planning, May to July.

Organizing a special issue entitled “Smart Tools and Technologies for Integration, Operation, and Control of Energy Storage Systems” in Journal of Sustainable Cities. The deadline is Nov 1, 2021. Topics are

- analysis of energy storage system
- applications of IoT and cloud base system
- application of BIM and BMS

Preparing a state-of-the-art review paper is an idea. Potential authors are welcome.

Three workshops were (By Navid Shirzadi) regarding

1. Deep learning concepts,
2. Deep neural network for energy systems related to time series analysis
3. Why is Deep neural network used for renewable generation and energy load?

Report from Subtask A: Demand & Supply Prediction by Ruchi Choudhary

The first meeting was called on 25 Feb 2021. Will have 1 meeting every three months. 2 presentations in every meeting, 1 talk from invited external experts.

The UK national meeting was held on 16 March 2021.

The focus of the first year is “Methods”.

1. MPC in the context of energy storage (Univ. Concordia)
2. Change point detection (Univ. of Tokyo)
3. AI-based demand prediction (Tokyo Institute of Technology)
4. Physics-enhanced machine learning (Univ. of Cambridge).

The focus of the second year will be “Applications”.

Report from Subtask B: Component by Frederic Kuznik

Task B focuses on “Components” mainly battery. Most contributors work on heat storage systems. The objective of Subtask B is to analyze the numerical models developed at the component scale for optimization, design, and control of the energy storage systems integrated into buildings and districts.

Structure of Subtask B:

- B1: Data collection
  - Established a system for data collection and created a database.
  - Now Task B is developing a web-based questionnaire for Task 37 participants.
  - Physical Phenomena: electro-chemical, sensible heat, latent heat, sorption heat, thermo-chemical…
  - Purpose: application for building and district
- B2: Component Optimization and Design of heat storage systems.
  - Strategies by using white-box, grey-box modelings. Analyzing existing methodologies.
- B3: Component control
  - Opposite to optimization and design, control of energy storage systems like MPC requires fast models. For insurance,
- B4 Provision of Guidelines for component modeling.

Report from Subtask C: Establishment of Smart Design by Alireza Afshari

Structure of Subtask C:

- C1: Definition of criteria for evaluation of multi-source systems
- C2: Identification of design parameters and materials for a number of energy storage technologies,
- C3: Design of optimal methods for integration of various components
- C4: Provision of operational guidelines for optimal energy storage solution

Materials regarding design criteria from Canada, Denmark, France, Germany, Japan, and Italy are collected. Still waiting for the materials from other countries. Samira is waiting for the response from the participants.

Report from Subtask D by Enrico Fabrizio

Structure of Subtask D

- D1: Identification of control

- D2: Identification of components
- D3: Definition of objective functions and constraints
- D4: Example of application and case studies
- D5: Guideline for energy storage control and operation

In the short term (coming 6 months) we will prepare the first draft of the review paper on control by September 2021. Review the outcomes from Annex 31, and the expertise and experiences of annex participants.

Also planning some new international activities with related researchers.

Tentative outline of review paper:

1. Intro, literature review
2. Control methods
3. Control systems
4. Relation between methods and systems (matrix)
5. Discussion and perspectives
6. Conclusion

Report from Subtask E: Optimal Grid Control/Operation/Cooperation by Raffaele Carli and Mariagrazia Dotoli

The main objective of this task is to represent all system components and propose optima control and op methods in power grid systems.

Structure of Subtask E:

- E1: Roles of energy storage systems (ESSs) in power grids, contributed by Carli and Dotoli
- E3: Control for electrical grids/smart grids/microgrids with ESS, contributed by Dotoli
- E4: Control frameworks for ESS operation in sectoral coupling (transport, heat and electricity)
- E5: Guideline for grid energy storage control and operation, contributed by Carali

Task 38: Ground Source De-Icing and Snow Melting Systems for Infrastructure

Task Information

General

Duration: Start: July 2021 – End: July 2024

Website: https://iea-eces.org/annex-38/

Task Managers


Bijan Adl-Zarrabi [1], Ayşegül Çetin [2]

[1] Chalmers University of Technology (Sweden)
[2] Turkish Society of HVAC and Sanitary Engineer-TTMD, Turkey)

[1] Chalmers University of Technology, 41296 Gotenburg, Sweden
[2] Bestekar Cad. Çimen Apt. No:15/2 Kavaklıdere Ankara 06680, Turkey

aysegulcetin32@gmail.com

About Task 38 – Ground Source De-Icıng and Snow Melting Systems for Infrastructure

Thermal de-icing and snow melting methods to control winter conditions on surfaces of transport infrastructure offer several advantages compared to conventional techniques. These include the automated control of safe surface conditions, avoidance of chemicals and their environmental impact and prolongation of the life of the infrastructure. Hydronic systems can take advantage of collection of solar energy mainly during summertime and seasonal storage of thermal energy by geothermal heat exchange. Making use of these renewable resources and energy storage enables savings in primary energy.

The Task started in June 2021 and the kick-off meeting was organized in October 2021. The long delay between the date of initiation of the Task and the kick-off depend on the financing issues from different countries and different summer holidays in of involved countries in the Task.

Contracting Parties / Sponsors

Institution	Country
University Antwerpen	Belgium
University of Leeds	England*
Chalmers University of Technology, The Swedish Geoenergy Center	Sweden

Turkish Society of HVAC and Sanitary Engineer-TTMD	Turkey

* Simon Rees was the Subtask 2 leader under 2021. In the beginning of 2022, he informed that due to his health condition, he cannot participate in the activities of the Task 38.

Overview of Scope:

Thermal de-icing and snow melting approaches to control of winter conditions on infrastructure surfaces offer a number of advantages compared to conventional techniques. These include the automated control of safe surface conditions, avoidance of chemicals and their environmental impact and prolongation of the life of the infrastructure. Hydronic systems can take advantage of collection of solar energy in summer conditions and seasonal storage of thermal energy by geothermal heat exchange. Making use of these renewable resources and energy storage enables savings in primary energy. Normally snow melting and de-icing systems are conventionally heated using electricity in combination with electrical resistance heaters is the most common form of energy. Others have been operated by a hydraulic circuit that is heated with either gas, oil, or district heating. Shallow geothermal energy, as a classic storage technology, offers great potential for the substitution of conventional energy and can also contribute to relieving the power grids in winter, as snow melting and de-icing systems can't simply be switched off, since they are always used in critical sections of infrastructure. In some cases, the cooling of pavements during summer will decrease the wear on the surface as well as on tires.

The overall goal of this Task is to contribute to the replacement of electrical resistance heater systems and expanding utilization of direct geothermal heating systems or ground source heat pumps in de-icing and snow melting of infrastructure. To achieve the goal of this Task the existing knowledge of the experts working in this area will be summarized and further developed by the planned research activities in the subtasks. According to that, a potential study is to be carried out in each of the participating countries, in which the market volume of as many relevant applications as possible is to be determined. In addition, an overview of the state of the art of these systems for different applications in various climate will be worked out.

Subtasks

In order to achieve the objectives of Task 38, four main subtasks have been determined as Market potential and State of Art, Modelling, Development of system components and Planning-Construction-monitoring. The scopes of each subtitle are given in detail below.

Subtask 1: Market potential and State-of-the-Art

- Market potential for all marketable applications
- State-of-the art of conventional de-icing and snow melting systems
- State-of-the art of geothermal de-icing and snow melting systems
- Economic evaluation
- Overview and discussion of environmental and social aspects.

Subtask 2: Modelling of Geothermal Energy Storage and De-icing Systems Models for de-icing and snow melting load and energy assessment

- Design for effective de-icing, snow melting and solar collection
- Energy storage and heat source modelling

- Integrated system simulation and control

Subtask 3: Development of system components for selected applications

- Thermal design of the heating surfaces
- Mechanical requirements of the surface heating system when required
- Materials for geothermal heating systems
- Adapted drilling methods

Subtask 4: Planning, construction and monitoring

- Mapping of demonstration plants
- Recommendation on design, construction, operation and maintenance
- Recommendation on market and Technology development

Activities and Achievements

One meeting has been held so far, the work done and to be done within the scope of each subtask was discussed. The improvements achieved for each subtask are given in detail below.

Subtask 1: Lead by Sweden (Signhild Gehlin). The activities of WP 1 were started January 2021. The work plan was defined. The objectives of WP1 are determined as follows.

- Historical review
- Overview of the worldwide market potential and state of the art
- Investigate the need for further development of the technology and potential for expansion of the geothermal de-icing market
- Investigate how these systems contribute to energy conversation and transportation.

Subtask 2: Modelling of Geothermal Energy Storage and De-icing Systems, lead by England (Simon Rees). In advance the leadership can be changed. The needed models and their integration were defined. Modelling geothermal energy storage and de-icing systems requires an initial assessment. For different tasks there are various necessities as follows:

- Determining initial assessment of loads and energy demands
- Designing the surface/rail heat exchange system and solar collection components
- Designing the geothermal energy components and heat sources
- Annual assessment and evaluation of control strategies

Subtask 3: Development of system components for selected applications, Lead by Wim Van Den Bergh (Belgium). The broad content of WP 3 was discussed and confirmed in the work package leaders meeting. The initial headings for WP 3 will include: Thermal design of the heating surfaces Mechanical requirements of the surface heating system when required Materials for geothermal heating systems adapted drilling methods. It was confirmed by work package leaders that a close collaboration is important between different work packages since they are interconnected in many aspects.

Subtask 4: Planning, construction and monitoring, Lead by Bjan Al Zarabi (Sweden). The activities in the WP are started. However, this work package needs information form WP 1-3. Thus, full activation of the WP expected to be in beginning of 2022. However, the activities and time plane were suggested.

Task 39: Large Thermal Energy Storages for District Heating

Task Information

General

Duration: Start: October 2020 – End: September 2023

Website: https://iea-es.org/annex-39/

Task Manager

Dr. Wim van Helden

AEE INTEC

Feldgasse 19, 8220 Gleisdorf, Austria

w.vanhelden@aee.at

About Task 39 – Large Thermal Energy Storages for District Heating

Motivation

Large thermal energy storages (LTES) offer more flexibility in DH Systems (also adding operational flexibility to power plants and industrial processes), they enable a higher share of renewables and waste heat, they can provide peak shaving functionality for electricity grids through Power-to-Heat (P2H) thus enabling sector coupling of the power and heating sector.

The market for large thermal energy storages is growing, with new plants built and planned in Denmark and Germany, mostly pit thermal energy storages (PTES) with volumes in the range of 400,000 to 500,000 m³ (in Denmark). In order to facilitate and accelerate the market uptake of these large storages, better materials and knowledge is needed to improve the service lifetime of the storages, better tools are needed for designing, planning and integrating the storages and more knowledge of the potential and integration possibilities of the storages is needed for decision makers.

Aim and objectives of this Task

The Task aims at determining the aspects that are important in planning, designing, decision-making and realising LTES for the integration into district heating systems and industrial processes, given the boundary conditions for different locations and different system configurations.

The key objectives of the Task are:

- Definition of a number of representative application scenarios, the connected boundary conditions and key performance indicators
- Improve LTES materials and materials performance measurement methods
- Prepare guidelines for obtaining proper water qualities
- Compare the performance and accuracy of simulation models for LTES
- Derive validation tests for LTES simulation models

- Generate information packages for decision makers and actively disseminate the information

Contracting Parties / Sponsors

Institution	Country
AEE INTEC, UIBK, AIT, JKU, SOLID	Austria
PlanEnergi, DTU, Ramboll	Denmark
Chalmers University, Absolicon	Sweden
SOLITES, siz energie+, TH Ulm, Solmax, AGFW	Germany
NRCan	Canada
newHeat, CEA	France
CREAR-UniFI	Italy
Ecovat	The Netherlands
Iller Bank.Inc.Com, Gazi University	Turkey
Nottingham Trent University, University of Birmingham	United Kingdom

Overview of Scope:

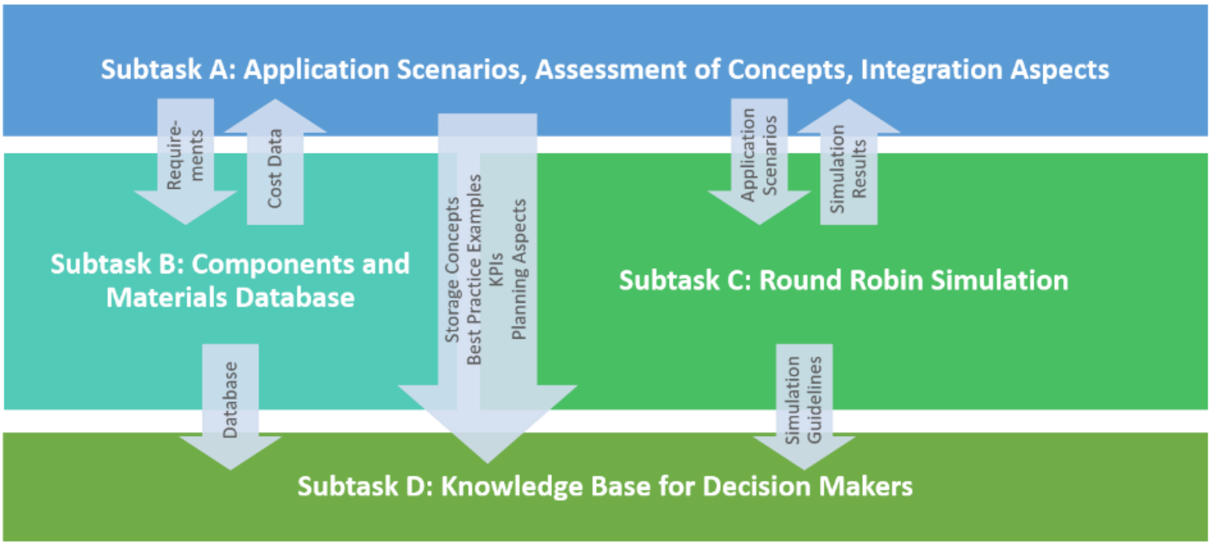
The scope is determined by both technological and non-technological aspects:

- 4 types of storages are considered:
    - Pit Thermal Energy Storages (PTES)
    - Tank Thermal Energy Storage (TTES)
    - Aquifer Thermal Energy Storages (ATES)
    - Borehole Thermal Energy Storages (BTES)
- Water is the storage medium with atmospheric pressure (or slightly overpressure) in PTES and TTES, aquifers in ATES and soil is the storage medium in BTES.
- The (water equivalent) volume of the storages are typically larger than 50,000 m3, while for TTES and slightly over-pressurised storages the volumes can be much smaller.
- The storages are applied in district heating systems or in industries.
- Seasonal storages, daily storages and multifunctional storages will be included.
- Dissemination is targeted to decision makers in policy, municipalities, utilities and DH heating companies.

Subtasks

The Task is organised around 4 Subtasks.

Subtask A works on application scenarios, the definition of key performance indicators (KPI), the assessment of storage concepts in the scenarios and the detailing of integration aspects. Subtask B aims at composing a database of suitable materials that can be used for LTES. Subtask C is dedicated to a round robin of the numerical simulation of LTES with real validation data sets. Subtask D has the goal to develop and distribute information packages for decision makers.



Schematic representation of the Task breakdown into Subtasks and the information flow between the Subtasks

Subtask A: Application Scenarios, Assessment of Concepts, Integration Aspects

This Subtask aims to define application scenarios, storage concepts for these scenarios and key performance indicators for the storages in the different applications. The activities are subdivided into three groups:

1. Application scenarios and boundary conditions

On basis of a list of potential main uses of the storages, a number of reference application scenarios will be sketched and the boundary conditions for the LTES in these applications defined. A subset of the application scenarios will be used in the Subtask C for the round robin. These applications need to have real operation data sets for validation purposes.

2. Definition of storage concepts for application scenarios

Storage concepts will be defined that fit into at least one application scenario.

3. Definition of key performance indicators for feasibility determination

A techno-economic feasibility will be performed on the storage concepts for the different application scenarios. As much as possible existing work on this will be used, working first on a rough, less detailed level, pointing at the best concepts - and then performing more detailed calculations in Subtask C. In order to make a proper ranking, key performance indicators will be defined and used, of which the levelized cost of storage (LCOS) is the most important.

Outcome:

- Boundary conditions generated from chosen application scenarios

- Definition of storage concepts for the application scenarios
- Definition of key performance indicators
- Recommendations on LTES applicability

Subtask B: Components and Materials Database

The goal of this Subtask is to define common test procedures for hygrothermal and mechanical tests for liner materials, to define the water quality and the ways to arrive at this and to create a database for LTES materials that go beyond the standard values. The activities are grouped as follows:

1. Hygrothermal and mechanical tests

The liner and insulation and protection materials mainly in PTES have to perform at higher temperatures and moisture levels than specified in the present standards. Thus, a combined hygrothermal test procedure/method is needed in order to fulfil the conditions. Furthermore, the mechanical behavior of the materials should be determined at operational conditions. Finally, testing of the weldings of the liner is another critical point which should be investigated for finding new/existing measurement methods.

2. Water condition and corrosion protection

Water condition, water quality and corrosion protection are some of the most important parameters concerning the lifetime of LTES. Guidelines, recommendations and procedures are needed for obtaining a proper water quality. Parameters of interest are pH, organic components, calcium content, salts and oxygen. In addition, guidelines/recommendations for corrosion protection are needed.

3. Materials database for LTES

Especially for use in non-standard conditions, as is the case in higher temperature LTES, there is a lack of information on materials that comply to these conditions. Information on these materials will be gathered in a dedicated, open accessible database.

Outcome:

- Proposal for novel hygrothermal and mechanical test methods
- Guidelines for proper water quality and procedures for obtaining this water quality
- Guidelines/recommendations for corrosion protection
- Material database for LTES

Subtask C: Round robin simulation

The aim of Subtask C is to validate and compare numerical simulation models through round robins. Models for the storage will be considered for PTES, TTES, BTES and ATES.

Other system components like heat pumps etc. are not considered. The work focuses on accuracy, applicability and usefulness of the simulation models for LTES. The activities are subdivided in the following parts:

1. Inventory and work plan

An inventory of available data sets and possible system configurations for the simulations are made (together with Subtask A). To focus the work on the LTES models, the LTES is regarded with data interfaces such that no connected energy systems have to be modelled. Monitoring data of the operation of existing LTES is assessed to be the best.

2. Simulation round robin 1

A first round robin will be performed, probably with simpler data sets for the interfaces. Then, the outcomes will be assessed and the criteria for the second round adapted.

3. Simulation round robin 2

The second round will be performed with monitoring data with the aim to evaluate the different LTES models. The outcomes will be assessed and the results described. Conclusions and recommendations for simulation of LTES in DH will be given.

Outcome:

- List/ Overview of existing simulation models of LTES
- Description of round robin tasks
- Report on outcomes and experiences of round robin simulation
- Recommendations for simulation of LTES

Subtask D: Knowledge base for decision makers

The aim and scope of Subtask D is to broaden the knowledge and increase the awareness of LTES and to inform relevant decision makers and stakeholders about the benefits and possible obstacles. This should be achieved by development and distribution of information leaflets and other electronic information and by hosting workshops to further increase the awareness internationally. The activities are subdivided in the following parts:

1. Determination of information need

Engaging groups of decision makers (utilities/energy companies, municipalities, etc.) and determination of the proper level of information.

2. Gathering and assessment of information for decision makers
    a. KPIs
    b. State-of-the-art, market potential and best practice examples
    c. Environmental, non-technical and planning aspects
    d. Financial aspects
3. Compilation and distribution of information material
    - Drafting the information leaflets and online materials
    - Cross-check of information with target groups, e.g. at workshops
    - Distribution of information materials at workshops, conferences, etc.

Outcome:

- Information material A): Technical matters; targeting utilities and energy companies
- Information material B): Targeting financial decision makers
- Information material C): Targeting authorities (municipalities, energy agencies, politicians and other non-technical decision makers)
- Conference papers and presentations
- Workshops for decision makers
  - Technical and non-technical topics

Activities and Achievements

Subtask A: Application Scenarios, Assessment of Concepts, Integration Aspects

Currently, the following items are being processed in Subtask A:

- The definition of what is a seasonal storage and what conditions it needs to fulfil to enter into the scope of work of this task is currently being refined.
- A list of existing installations is currently available and quite complete.
- A consolidated list of KPIs is also available for PTES technology, coming from different national projects. This will be used as a template for KPIs for other storage types. Examples for KPIs are:
  System level: CO2 savings, Primary energy savings;
  Storage level: loading cycles, storage efficiency, thermal losses

As the lead for Subtask A was taken up in September, the work on this will be on full level in the coming period.

Subtask B: Components and Materials Database

A core group of experts that will contribute to the Subtask has been formed.

Tables with the material properties for BTES and PTES were drafted. Different tables and definitions/descriptions of hygrothermal and mechanical tests will be made for PTES and BTES materials.

Another identified topic, taken up by a number of experts, is the water condition and corrosion protection. Already identified external expertise will be contacted to have complete input on this.

A materials Database for LTES will be set up and will be hosted by the University of Birmingham, as part of an already existing database: https://supergenstorage.org/; https://ukesto.supergenstorage.org

Subtask C: Round robin simulation

In Subtask C there are 33 participants from 21 institutions and 10 countries. In the past period an inventory of LTES simulation models (C.1) used by participating partners was created, see Figure 7. Based on this Round Robin Simulations are planned for the following LTES concepts:

- ATES
- BTES

- PTES
- TTES

Target application areas for the models are mainly system simulations and TES design optimisation.

Project phase / main purpose Storage type	Pre-design system	Pre-design TES	System simulation	TES design optimization
PTES (truncated cone or pyramid)	**Pre-Design-Tool** (Excel) (SOLID)	**Pre-Design-Tool** (Excel) (PlanEnergi)	**TRNSYS** Types 1300/1301 (cone, Solites, PlanEnergi), Types 1301/1535 (cone, TESS) Type 1322 (pyramid, PlanEnergi), Types 342 (used/adapted for cones, DTU) Type 343 (IcePit, DTU, SIZ, THU); UGSTS (DTU + CAS IEE) **Modelica** (CEA, SIZ, AEE INTEC); MoSDH library (TUDa) **MATLAB Simulink** (UIBK)	**COMSOL** (UIBK), **FLUENT** (DTU), **OpenFOAM** (SIZ)
TTES (cylinder)	**energyPRO** (PlanEnergi)		**TRNSYS** Types 342 (buried, SIZ, PlanEnergi), Types 534/708 (AEE), Types 1300/1302 (Solites), Types 1534/1302 (TESS), Type 340 (above ground, THU); 'CST' + '2Zones' (TU-Chemnitz); **Modelica** (CEA, AEE INTEC, UIBK, AIT, SIZ); MoSDH library (TUDa) **MATLAB Simulink** (UIBK); LTES with flooding ceiling (TU-Chemnitz)	**COMSOL** (UIBK), **FLUENT** (DTU), **OpenFOAM** (SIZ)
TTES (cuboid)			**TRNSYS** Types 1531/957 (TESS), Types 1531/1267 (TESS)	
ATES			**TRNSYS** Type 345 (TRNAST, Solites)	**FEFLOW** (AIT) **MODFLOW** (NRCAN)
BTES		**EED**	**TRNSYS** Types 557 (DST, PlanEnergi, THU, TESS), Type 346 (SBM, THU) Type 1373 (TESS, NRCAN), Type 370 (TESS) **Modelica** MoSDH library (TUDa)	**COMSOL** **FEFLOW** (TUDa, AIT) **FLUENT** (NTU)
Others (e.g. hybrid)			***TRNSYS*** *Types 341 (buried TTES + BTES)*	***COMSOL*** *(UIBK)* ***FEFLOW*** *(AIT)*

Figure 7: Inventory for LTES simulation models

For the collection of additional basic information on the considered simulation models, a template form for a model fact sheet was created. This will be filled out in the following period by the involved partners for the considered models to complement the overview table presented in Figure 7.

In addition, preparatory work for the Round Robin Simulations (C.2) was done in terms of definition work on the general test procedure. This comprises e.g.:

- LTES concepts to be considered in the Round Robin
- Definition of main focus and two-stage approach for test cases
- Pre-definition of assessment criteria

Ongoing work takes place on the detailed definition of the different test cases for the four LTES concepts to be considered.

The schedule for the work in Subtask C is as follows:

	IEA ECES Annex 39											
Quarter	4/2020	1/2021	2/2021	3/2021	4/2021	1/2022	2/2022	3/2022	4/2022	1/2023	2/2023	3/2023
WP C												
Inventory of simulation models	■	■			■	■						
Inventory of data for applications			■	■			■					
Definition of test cases					■							
Round robin simulations - stage 1						■	■					
Round robin simulations - stage 2								■	■			
Validation procedure									■	■		
Reporting					■					■	■	

Subtask D: Knowledge base for decision makers

The following activities have been carried out:

A questionnaire has been prepared to evaluate the kind of information decision makers are interested in. It was tested by a small number of experts, in order to have it consistent and to have a targeted completion time of about 5 minutes. The questionnaire has been made available in several languages and will help constitute a database of decision makers interested in LTES. It was distributed in January 2022 and the responses will be processed before the next Experts Meeting, April 2022. Once a part of the database, the idea is to start a dialogue with decision makers, through the newsletter and some workshops, in order to adapt to their needs and promote LTES efficiently.

A first newsletter is under preparation and will be distributed in spring 2022 in several languages. It will introduce the task objectives and the progress made so far, and will be accompanied with the translated version of several LTES-related articles extracted from AEE-Intec's journal.

Task 40: Compact Thermal Energy Storage; Materials within Components within Systems

Task Information

General

Duration: July 2021 – June 2024

Website: https://iea-es.org/annex-40/

Task Manager

Dr. Andreas Hauer

Bavarian Centre for Applied Energy Research, ZAE Bayern

Walther-Meißner-Str. 6, 85748 Garching, Germany

andreas.hauer@zae-bayern.de

About Task 40 – Compact Thermal Energy Storage; Materials within Components within Systems

Task 40 deals with an application-oriented development of innovative and compact thermal energy storage (CTES) materials: Phase Change Materials (PCM) and Thermochemical Materials (TCM). PCM and TCM will be studied, improved, characterized, and tested in components. The main components for CTES technologies are heat exchangers and reactors, which are also studied and further improved in Task 40.

The objectives are to have a better understanding of the factors influencing the storage density and the performance degradation of CTES materials, to be able to characterize these materials in a reliable and reproducible manner, to have methods to effectively determine the state of charge of a CTES unit, and to have better knowledge on how to design optimized heat exchangers and reactors.

Contracting Parties / Sponsors

Institution	Country
AEE INTEC, AIT, TU Vienna, Univ. of Applied Sciences Upper Austria	Austria
CanmetENERGY, Dalhousie University, Univ. of Ottawa	Canada
DTU, Aalborg Univ.	Denmark
INSA-Lyon, CNR, Univ. d'Artois, CEA, Univ. de Nantes	France
DLR, Fraunhofer ISE, ZAE Bayern, TU Munich	Germany
Pluss Advanced Technologies	India

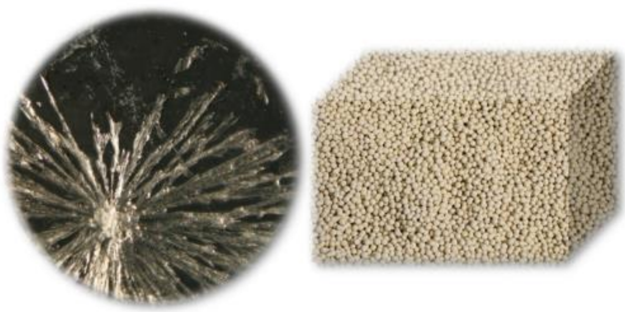
CNR, Univ. of Messina	Italy
Eindhoven Univ. of Technology	Netherlands
SINTEF	Norway
Polytechnic Institute of Setubal, Univ. of Coimbra	Portugal
NIC, Univ. of Ljubljana	Slovenia
CIC energiGUNE, Univ. of Lleida, Univ. Zaragoza, Univ. of Barcelona, CIEMAT, Univ. of the Basque Country	Spain
KTH	Sweden
EMPA, Lucerne Univ. of Applied Sciences and Arts	Switzerland
Birmingham Univ., Swansea Univ., Univ. of Warwick	UK
DoE	USA

Overview of Scope:

Task 40 deals with the development and characterization of compact thermal energy storage (CTES) materials and components.

CTES materials considered in Task 40 are:

- Phase Change Materials (PCM)
- Thermochemical Materials (TCM) including both sorption materials and chemical reactions



Activities will cover CTES material characterization, development, improvement, and testing in components (heat exchangers, reactors).

Subtasks

The Task work is divided in five subtasks.

Subtask A - Material Characterization and Database

Subtask A deals with CTES material characterization. Standardized procedures to measure thermo-physical properties of PCM and TCM will be developed and tested via round robin tests. A material database for high-quality measurements of material properties will be maintained and expanded.

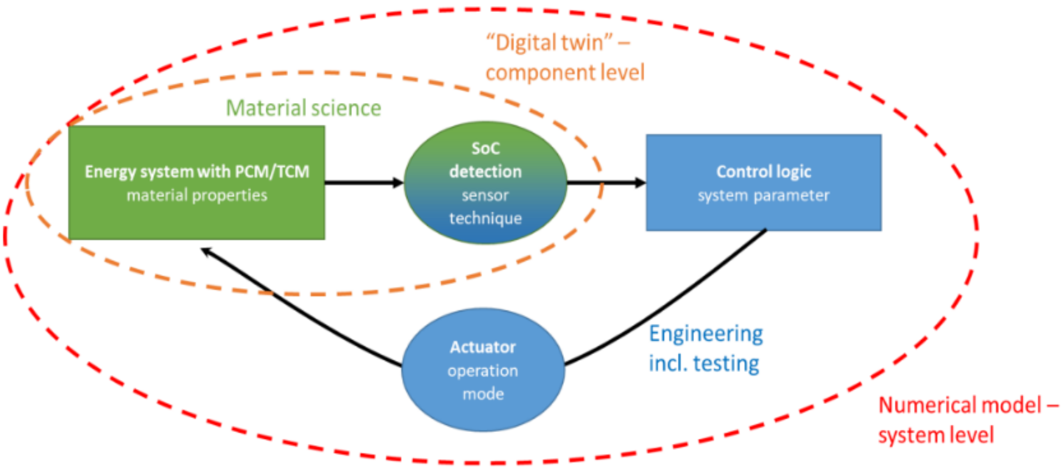
Subtask B - CTES Material Improvement

The objective of subtask B is to identify proper strategies for tuning the properties of CTES materials with the aim to improve their performance in components/storage units. This main goal includes:

- to discover new potential materials for CTES with the targets of low cost, no toxicity, non-flammable, deployment of natural/bio-based materials
- to develop *single component* materials with changed chemistry through modified structure and *multi-component* materials with increased storage capacity and enhanced heat and mass transport properties
- to evaluate the influence of the synthesis and processing methods on the final techno-economic and environmental performances of the materials

Subtask C - State of Charge – SOC Determination

The main objective of subtask C is to develop techniques with which the state of charge (SOC) of a CTES can be determined in a reliable and affordable way. Specific activities of subtask C are to make an inventory of material properties and measurements techniques that can be related to the SOC, to develop methods to link the measured properties to a numerical model of the CTES and use the combination to determine the SOC, as well as to test these in stand-alone storages and possibly in storages integrated in a system.



The topic of SOC determination is thus closely linked to both material science and systemic issues. The extent to which emerging methods of digitalization can be used for SOC determination will be examined in more detail in the course of Task 40.

Subtask D - Stability of PCM and TCM

In subtask D, a better understanding of the working stability of PCM and TCM during their service lifetime and the development of recommendations for an application-oriented investigation of this stability will be addressed. The goal is to arrive at PCM and TCM with a predictable and improved stability.

Subtask E - Effective Component Performance with Innovative Materials

Subtask E focuses on the improvement of material-component interaction for optimal system performance. This is attained by defining performance parameters and standardized characterization procedures, understanding the mechanisms that determine the performance-based interaction between storage material and components (heat exchangers, reactors), and locating/applying methods for improved component and material design.

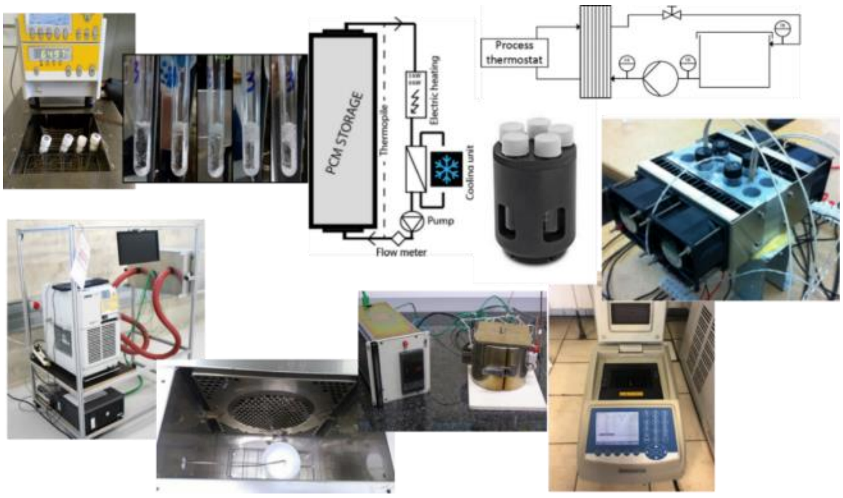
Activities and Achievements

Task 40 has started on 1 July 2021. The Kick-off meeting took place on 27 to 29 October 2021. The meeting was hosted by CIC energiGUNE in Vitoria-Gasteiz, Spain.

It was organized as a hybrid meeting with 24 participants on site and 29 participants online. In the plenary online sessions, the work plan was presented outlining the planned activities and deliverables within the five subtasks.

In order to work systematically towards the targeted deliverables and the final report of Task 40, possible key messages and key questions were already formulated at the kick-off meeting. In the course of the task, these key messages/questions should be backed up by specific case studies and, if applicable, quantified.

Experts within subtask D have continued their collaborative work on CTES material stability. In this context, an open-access paper on experimental devices to investigate the stability of PCM under application conditions was published. Therein, devices for sample treatment and devices to assess the stability after the treatment are introduced and discussed (cf. figure below).



In the case of TCM and TCM composite materials, the following topics were dealt with in connection with stability: calorimetric measurements to investigate the cycling stability upon charging and discharging; structural investigations to assess the stability of composite materials after a certain number of hydration-dehydration cycles; improving the cycling stability of salts by doping with other salts.

Future activities within subtask D are:

- to identify and describe the most important degradation mechanisms for the different material classes associated to the specific working conditions of the storage system
- to establish a common definition for PCM and TCM stability
- to check whether different application-oriented methods to test the stability can be applied to generate reproducible and comparable results
- to find out how degradation can be accelerated in order to faster assess the stability of CTES materials
- to develop recommendations for assessing the stability of PCM and TCM during service lifetime based on simple and short-term experiments

PLANNED TASKS

Economics of Energy Storage – EcoEneSto

This Task Proposal is under development. Its start is planned for July 2022.

Large-scale, medium-duration energy storage

This Task Proposal is under development.

Standardized use of building mass as storage for renewables and grid flexibility

This Task Proposal is under development.

CCB2 – for hot and humid climates

This Task Proposal is under development.

APPENDIX

The International Energy Agency (IEA)

Established in 1974, the International Energy Agency (IEA) carries out a comprehensive programme of energy co-operation for its member-countries and beyond. The IEA examines the full spectrum of energy issues and advocates policies that will enhance energy security, economic development, environmental awareness and engagement worldwide. The IEA is governed by the IEA Governing Board which is supported through several specialised standing groups and committees. For more information on the IEA, see www.iea.org.

IEA Standing Groups and Committes

The IEA Energy Technology Network (ETN) is comprised of 6,000 experts participating in governing bodies and international groups managing technology programmes. The Committee on Energy Research and Technology (CERT), comprised of senior experts from IEA member governments, considers effective energy technology and policies to improve energy security, encourage environmental protection and maintain economic growth. The CERT is supported by four specialised Working Parties:

- Working Party on Energy End-use Technologies (EUWP): technologies and processes to improve efficiency in the buildings, electricity, industry and transport sectors.
- Working Party on Fossil Fuels (WPFF): cleaner use of coal, improvements in gas/oil exploration and carbon capture and storage.
- Fusion Power Coordinating Committee (FPCC): fusion devices, technologies, materials and physics phenomena.
- Working Party on Renewable Energy Technology (REWP): technologies, socio-economic issues and deployment policies.

Each Working Party coordinates the research activities of relevant IEA Technology Collaboration Programmes (TCPs). The CERT directly oversees TCPs of a cross-cutting nature. The ES TCP (Energy Storage TCP) relates to the EUWP. Within that framework, the ES TCP is also part of the Building Coordination Group (BCG). Within the BCG the various building-related TCPs seek opportunities for collaboration (i.e. cross-cutting subjects) and exchange results and developments.

IEA Technology Collaboration Programmes

The IEA TCPs are international groups of experts that enable governments and industries from around the world to lead programmes and projects on a wide range of energy technologies and related issues, from building pilot plants to providing policy guidance in support of energy security, economic growth and environmental protection.

The first TCP was created in 1975. To date, TCP participants have examined close to 2,000 topics. Today, TCP participants represent more than 300 public and private-sector organisations from over 50 countries. TCPs are governed by a flexible and effective framework and are organised through an

Implementing Agreement. TCP activities and programmes are managed and financed by their participants. To learn more about the TCPs, please consult the IEA website (www.iea.org/tcp) which includes short promotional films, “Frequently Asked Questions” and further information on TCP activities.

ES TCP (Energy Storage TCP)

The mission of ES TCP is to facilitate integral research, development, implementation, and integration of energy storage technologies to optimise the energy efficiency of all kinds of energy systems and to enable the increasing use of renewable energy instead of fossil fuels.

Storage technologies are a central component in energy-efficient systems. Since energy storage is a cross-cutting issue, expert knowledge of many disciplines (energy supply and all end-use sectors, as well as energy transmission and distribution) must be taken into account. To use this widespread experience efficiently and gain benefits from the resulting synergies, high-level coordination is needed to develop suitable working plans and research goals. ES TCP is responsible for fulfilling this important task. ES TCP's strategic plan therefore includes research activities (strategies for scientific research and development, dissemination and market deployment), as well as co-ordination activities (aims and administration).

Energy Storage and The Energy Transformation

To meet greenhouse gas emission reduction targets, as well as the 1.5-2 °C aim, a decarbonisation of the global energy system is required (see Climate Summit COP21 in Paris, December 2015). This implies the substitution of fossil energy carriers by low-carbon energy and closed carbon cycles, which means less carbon dioxide (CO_2) from fossil fuel power plants and a higher share of renewable generation. Renewable energy from solar and wind shows a high additional potential for electricity generation. Currently, the electricity sector only accounts for around 25% of the final energy demand. However, as result of the energy transition, considerable changes in the other energy-intensive sectors such as heating and transportation are taking place whereby traditional sources of (fossil) fuels are gradually replaced by renewables and, in particular, a growing contribution of renewable electricity.

By using heat pumps, electric vehicles, or synthetic fuels based on green hydrogen (*power-to-fuels*), renewable electricity will gain more and more importance and will contribute to the decarbonisation of the heating and transportation sectors as well. This global development – with its individual characteristics in each country – will determine the future relevance of energy storage. Today it is also often referred to as *flexible sector coupling*. Energy storage is a key-technology within that process.

Three Shapes of Energy Storage

By enabling the temporary balancing of supply and demand, energy storage has always been an important part of the energy system. Depending on the form of energy which needs to be balanced and the required storage period, different types of energy storage, such as thermal, electrical, material, or virtual storage, can be used. While material and especially thermal energy storage systems have an intrinsic storage capacity (and with that are able to absorb short-term fluctuations), electrical energy storage systems are highly dependent on perfect balancing.

Thermal energy storage (e.g. hot water) is used when the final energy to be stored is heat – or cold. Due to their high efficiency and comparatively low investment cost, such systems can be used in various applications ranging from balancing highly volatile load peaks (*power-to-heat* or *power-to-cold*) to decentralised island solutions or even in industrial environments (heat/cold integration).

Electrical energy storage (e.g. pumped hydro storage or various sorts of batteries) have experienced a very dynamic development, especially due to mobile applications such as electro-mobility. Compared to thermal energy storage systems, electrical energy storage systems are more cost-intensive and less efficient. They store electrical energy which makes them a key technology for grid stabilisation and balancing.

Material storage systems (e.g. gas – or hydrogen – storage) are mostly used for long-term or seasonal storage and to guarantee the security of energy supply. Virtual storage systems are controllable loads that can be switched on or off depending on the actual demand.

Energy Storage in our Energy System

Depending on the specific characteristics of respective national energy systems, the required type and capacity of energy storage varies. Although the electricity flow can be optimised by the interconnection of energy networks and international coupling points, still the national (or rather regional) energy systems are decisive. The differences in status quo as well as in past developments are significant. There are countries with a high share of nuclear power (e.g. France), coal-fired power (e.g. Poland), hydroelectric power (e.g. Norway), gas-fired power (e.g. the Netherlands), or wind and solar power (e.g. Germany).

Even though the development in the energy sector is very heterogeneous, a common trend can be recognised. Overall, wind and solar power show significantly growing capacities whereas the share of fossil energies – especially lignite and hard coal – is declining. The integration of fluctuating forms of energy, combined with a decline in base-load power plants, requires large structural changes in energy transmission and distribution networks. This requires solutions such as the development of energy storage capacities and/or flexibility in demand, or a combination of these two elements.

New Innovations for Energy Storage

As a result, the future role of energy storage will be more complex and more important than today. The value of storage continues to increase. In a growing number of applications energy storage is an indispensable key technology (e.g. electro-mobility, micro grids, decentralised energy systems or integration of renewables) or, rather, a key enabling technology that increases value-creation and allows for technological degrees of freedom (e.g. thermal energy storage for demand side management).

The two major innovation challenges for energy storage are:

- Techno-economic improvement: reduction of investment costs, longer lifetime, higher efficiency, compact design, safety.
- Economic-regulatory hurdles: non-discriminatory market access (*level playing-field*), business cases/market design, regulatory hurdles (e.g. taxation), security of investment in uncertain market development.

Both of these challenges need to be tackled simultaneously because an efficient, low-carbon, sustainable and stable energy system requires the large deployment of renewable (fluctuating) energies, and, with that, a balancing of energy supply and demand by energy storage is crucial.

Background

The energy sector is undergoing significant changes. The percentage of renewable energy generation will continue to increase, mainly through the use of wind, solar, and hydro-power. Variable generation sources such as solar and wind will provide challenges for national grid infrastructures and for matching demand and supply profiles. The amount of fluctuating energy – both on the supply- and demand-side – compels us to control these energy flows and capacities. In combination with the changing profiles in energy demand, the entire energy system requires a new design. Grid expansion, as well as flexibility mechanisms, will be necessary at all levels of the energy system. However, these options are not always the best solutions from an energetic and economic point of view, and they may not be possible for all parts of the world.

Many types of electrical energy storage systems are currently being considered to balance the energy system and to provide solutions to enable flexibility and sector coupling. Pumped hydro storage and various electrochemical energy storage solutions have already been developed. Further R&D activities will improve the efficiency of technologies (e.g. redox flow cells, sodium-sulphur batteries and Carnot batteries), as well as decrease their costs. Even thermal energy storage solutions may prove suitable for balancing the electricity grid (*power-to-heat*). Furthermore, decentralised energy storage is expected to make a significant contribution toward matching local supply and demand.

Energy storage can also contribute to increasing overall energy efficiency in the industrial sector through utilising waste heat. This can be deduced from the fact that industrial heat demand accounts for a significant share of total final energy consumption. There is a wide variety of energy efficiency and energy storage measures applicable to the building stock. Passive measures can reduce the heating and cooling demand of buildings. Cold storage can decrease the total power demand during summer and help to avoid black-outs. Seasonal energy storage can complement energy supplies, especially when used in combination with district heating and cooling systems. In buildings, energy storage bridges the gap between efficiency measures on the one hand and increased use of renewables on the other. Solar and heat pump assisted heating and cooling systems in combination with energy storage provide very promising solutions. Transforming surplus solar or wind energy and storing it in decentralised energy storage solutions, such as batteries or as latent heat, may become very energy efficient and economical solutions.

Energy storage technologies can overcome the temporal mismatch between electricity and thermal energy supply and demand. They are one of the key instruments used to reduce peak loads and enable load management. Electricity, heat or cold, centralised or decentralised, autonomous or grid-connected energy storage solutions are becoming crucial components of the energy systems of the future.