Contributors to this Annual Report 2017:
Antje Seitz, Andreas Hauer, Christian Doetsch, Manfred Reuß, and Teun Bokhoven

International Energy Agency
Technology Collaboration Programme
Energy Storage through Energy Conservation

www.iea-eces.org

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The international focus on accelerating the energy transition from fossil fuels to a renewables-based energy system increases the need for more flexibility. This is needed to match the variable production of renewable energies (like wind and solar) with variable and changing demand profiles. This requires flexibility between time of use and production as well as interaction between sectors (sector coupling). In each case energy storage in any form is required to provide affordable solutions. Whether that be storage solutions at a large scale (such as pumped hydro storage or the conversion of surplus electricity into hydrogen) or more decentralised thermal or electrical energy storage solutions in the build environment, industry and mobility sector; all will be needed. With a growing interest in energy storage technology and an identified need to deploy more energy storage, a better assessment of the “value” of energy storage, like the “value” of flexibility is required.

The ambition of ECES TCP is to contribute to this development by coordinating and stimulating the international collaboration on research and development toward new and innovative energy storage concepts.

The IEA Future Building Forum held in Singapore identified the need to find solutions to manage the increasing energy loads for cooling in hot and humid climate zones. Energy storage can contribute substantially towards this fast-growing global cooling issue. Energy storage was also identified as one of the key technology areas in Mission Innovation (MI – a global initiative of 23 countries and the European Commission partnering to reinvigorate and accelerate clean energy innovation with the objective of making clean energy more widely affordable). The MI-challenge #7: Affordable Heating and Cooling identified energy storage, together with heat pump technologies, as the highest priority areas. This was explicitly recognised in the MI #7-workshop held in Abu Dhabi in November 2017. The ECES TCP initiative to develop a joint research project with HPT TCP (Heat Pumps) was well received and will most likely materialise in 2018.

The work in the various Annexes is on schedule. Annex 27 “Quality Management in Design, Construction and Operation of Borehole TES Systems” is well underway. The use of the underground for energy storage (normally in combination with heat pump systems) is reaching a new stage of commercialisation. However, quality issues tend to limit growth. In Annex 27 these issues are addressed. The Annex has a very strong industry involvement and contributes to work on pre-normative standards. The focus is on pre-standardisation work to accelerate the use of borehole storage.

Annex 28 “Distributed Energy Storage for Integration of Renewables” will be concluded in 2018. Work in this Annex contributes to a far better understanding of the role of decentralised storage as part of the need for more flexibility in the energy system to balance fluctuation caused by renewable energies. The Annex attracts participation from other TCPs at their annual Paris cross-cutting workshops.

Annex 29 “Material Research and Development for Improved TES Systems” was completed in 2016 and approved, while the research work now continues in Annex 33. This Annex is a joint activity with TCP SHC (Solar Heating and Cooling).

Annex 30 “TES for Cost-effective Energy Management and CO₂ Mitigation through Energy Storage” is expected to conclude in 2018. This Annex is exploring storage options for higher temperatures and industrial applications, and CO₂ mitigation. It has established a methodology in general to evaluate TES
systems and has collected distinct case studies. The next step will be to make the analysis of application cases more systematic and detailed. A new Annex proposal for this topic is expected in 2018. It is important to highlight that this Annex focuses on industrial applications and that there is a strong industry participation and interest in this work.

Annex 31 “Integration of Energy Storage with NZEB: Optimization and Automation” has provided us with a wide range of results, in particular for decentralised storage option as part of a more flexible energy grid. The results have been presented at a workshop on November 15th 2017 in Montreal, Canada. The Annex will be concluded and reported in 2018.

The preparation work for a new Annex (32) on Modelling was delayed due to illness of the operating agent. The Annex will start in 2018.

Annex 33 “Material and Component Development for Thermal Energy Storage” is a joint Annex/Task with TCP SHC (Task 58) and is a further continuation of work aimed at more compact thermal storage systems. Innovative thermal energy storage technologies such as phase-change materials or thermochemical storage systems can contribute to the integration of renewable energies (e.g. by demand-side integration) or to increasing energy efficiency (e.g. by industrial waste heat utilisation). For such systems, the question of appropriate novel storage materials is crucial. While Annex 29, focuses on the development and the characterisation of new materials and their integration into the storage system, this Annex extends this work and will provide more in-depth knowledge on materials to enhance more compact storage volumes.

Preparation of the 14th International Conference on Energy Storage – EnersSTOCK2018 (April 2018) in Adana, Turkey, is proceeding to schedule. By the end of 2017 close to 250 abstracts had been received from over 30 countries.

In 2017 the importance of energy storage gained in momentum. It has been a pleasure and source of inspiration to work with all the (alternate) delegates on our Executive Committee, our Operating Agents and the IEA desk officer, John Dulac.

Teun Bokhoven
Chairman, ECES TCP
Established in 1974, the International Energy Agency (IEA) carries out a comprehensive programme of energy co-operation for its 29 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 ENERGY TECHNOLOGY NETWORK

The IEA Energy Technology Network (ETN) is comprised of 6000 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 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

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 Energy Conservation through Energy Storage Technology Collaboration Programme (ECES TCP) relates to the EUWP. Within that framework, The ECES 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 first TCP was created in 1975. To date, TCP participants have examined close to 2000 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.
The mission of Energy Conservation and Energy Storage (ECES) 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. ECES TCP is responsible for fulfilling this important task. ECES 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).

To meet the GHG-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 CO₂ 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. However, the electricity sector only accounts for around 25% of the final energy demand. Therefore, considerable changes in the other energy intensive sectors such as heating and transportation are also required.

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 sector as well. This global development – with its individual characteristics in each country – will determine the future relevance 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 storage systems have an intrinsic storage capacity (and with that are able to absorb short-term fluctuations), electrical storage systems are highly dependent on perfect balancing.

Thermal storage (e.g. hot water) is used when the final energy to be stored is heat. 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”) to decentralised island solutions or even in industrial environments (heat integration).
Electrical energy storage (e.g. pumped hydro storage or batteries) have experienced a very dynamic development, especially due to mobile applications such as electro-mobility. Compared to thermal storage systems, electrical 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 storage) are mostly used for long-term or seasonal storage and to guarantee security of energy supply. Virtual storage systems are controllable loads which 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 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 plants (e.g. Poland), hydroelectric power (e.g. Norway), gas-fired power plants (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 which increases value-creation and allows for technological degrees of freedom (e.g. thermal 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 will soon undergo significant changes. The percentage of renewable energy generation will 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. Grid expansion, as well as flexibility mechanisms, will be necessary at the global system level. 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. 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 and sodium-sulphur 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 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 there exists a significant portion of industrial heat demand within the 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.
### CONTRACTING PARTIES AND SPONSORS

<table>
<thead>
<tr>
<th>Name</th>
<th>(Alternate) delegate/Sponsor</th>
<th>Country</th>
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<tr>
<td>Bert Gysen</td>
<td>Delegate</td>
<td>Belgium</td>
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<td>Adan Tuck</td>
<td>Delegate</td>
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<td>Xu Wei</td>
<td>Delegate</td>
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<td>Zhang Shicong</td>
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<td>Paul Frich</td>
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<td>Per Alex Sørenson</td>
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<td>Jussi Mäkelä</td>
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<td>Louise Oriol</td>
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<tr>
<td>Hendrik Wust</td>
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<td>Steffen Linsmayer</td>
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<tr>
<td>Mick McKeever</td>
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<td>Aidan Duffy</td>
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<tr>
<td>Pier Paolo Prosini</td>
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<td>Masaya Okumiya</td>
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<td>Kouichi Ishida</td>
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<td>Yeon Sun-Hwa</td>
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<td>Uros Strith</td>
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<td>Vincent Butala</td>
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<tr>
<td>Luisa F. Cabeza</td>
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<td>Camila Barreneche</td>
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<tr>
<td>Emina Pacic</td>
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<tr>
<td>Carina Alles</td>
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<td>Andreas Eckmanns</td>
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<td>Philip Sharman</td>
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<tr>
<td>Imre Gyuk</td>
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<tr>
<td>Lynn Stiles</td>
<td>Alt. delegate</td>
<td>USA</td>
</tr>
<tr>
<td>Thomas Badenhop</td>
<td>Candidate Sponsor delegate</td>
<td>Germany</td>
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CONFERENCES, WORKSHOPS, AWARDS, PAPERS AND POSTERS

CONFERENCES, WORKSHOPS AND EVENTS

An overview of all the ECES TCP attended conferences, workshops and events in 2017:

- Building Co-ordination Group meeting – 22nd February 2017 – Paris, France
- EUWP meeting – 21st-22nd March 2017 – Paris, France
- ESE 2017 Expo & Conference – 14th-16th March 2017 – Düsseldorf, Germany
- IEA Heat Pump Conference 2017 – 15th-17th May 2017 – Rotterdam, The Netherlands, and joint meeting with the Executive Committee (ExCo) of HPTTCP
- ExCo 83 ECES TCP – 16th-17th May 2017 – Rotterdam, The Netherlands
- Second Universal Meeting of Technology Collaboration Programmes – 9th October 2017 – Paris, France
- Future Buildings Forum think-thank workshop – 3rd November 2017 – Singapore
- Mission Innovation workshop ‘The Comfort and Climate Box’ – 1st-2nd November 2017 – Abu Dhabi, United Arab Emirates
- ExCo 84 ECES TCP - 16th-17th November 2017 – Montreal, Canada

After a successful Stock-conference in Beijing in 2015, preparations started in 2016 for the tri-annual Stock-conference in 2018. The Enerstock Conference will be held in April 2018 at the Çukurova University in Adana, Turkey.

AWARDS, PAPERS AND POSTERS

In preparation for the Enerstock Conference, 228 abstracts where received from 30 different countries. The full paper review started at the end of 2017. Papers could be submitted under four different categories:

- Energy Storage Materials: 93 abstracts
- Energy Storage Applications: 107 abstracts
- Energy Storage Cross-Cutting Aspects: 11 abstracts
- Climate Change: 17 abstracts
COMMUNICATIONACTIONS IN 2017

WEBSITE AND NEWSLETTER

In line with IEA/ EUWP recommendations, ECES TCP adopted a new communication plan. For 2017 the plan focused on the following areas:

- New website
- Newsletter

The new website was built and is now fully operational. Take a look at: https://iea-eces.org. The new website allows annexes to have their own (protected) web-environment. The website is managed by the ECES TCP secretariat.

The new website provides general information and also highlights:

- Completed annex reports
- Agendas for upcoming events
- General ECES TCP publications and strategic plans

The first newsletter for ECES TCP was send out on 20th October 2017 to 79 email-addresses.

PARTICIPATION IN EVENTS, MEETINGS AND NETWORKS

The Chair, vice chairs and individual delegates have contributed to a number of scientific events (workshops, forums, meetings, etc.). ECES TCP was one of the supporting organisations of Energy Storage Europe 2017 - this is a major annual international trade fair and conference that takes place in Germany. Participation at these conferences provides opportunities to attract interest from new countries to ECES TCP. In addition to these conferences, ECES TCP is organising workshops in parallel with ExCo and annex meetings with different focused themes. Industry engagement also features prominently in workshops organised by the annexes. See the annex reports below for further information.

In terms of further international collaboration, ECES TCP has links with a variety of organisations through its delegates and operating agents. ECES TCP maintains contact with the activities of the European Energy Research Alliance (EERA), which is an integral part of EU Horizon 2020, through the Operating Agent of Annex 30. ECES TCP also maintains contact, via the Spanish sponsor member delegate, with the European Technology Platform on Renewable Heating and Cooling. The team responsible for leading Mission Innovation Challenge #7 on Affordable Heating and Cooling (where storage is identified as a high priority theme) is also a recently-established ECES TCP contact.
COMMUNICATION PLAN FOR 2018

In anticipation of the possible establishing of a new energy storage centre, ECES TCP has the following communication plan for 2018:

- Update corporate identity:
  - New logo
  - Colour scheme to complement the colour scheme of the ETN

- Update website:
  - Categorisation of annexes
  - New (alternate) delegate and operating agents page (with contact information and photographs)
  - Additional pages on special projects, such as Mission Innovation

- Update printed material:
  - New brochure
  - New business cards

In addition, all the final reports of closed annexes will be placed on the website (as far as they are available).
FINANCING

All contracting parties and sponsors make an annual financial contribution to the common fund used for ECES TCP administration and communication matters. The following table outlines the budget distribution among participants.

The completed and ongoing annexes in 2017 were all task-shared. The additional effort for the cooperation within the IEA is usually 3 man-months/year. The work of the respective operating agents requires funding of about 3-6 MM/year.

The overall ECES TCP 2017 budget from the common fund was $61,800. Per ultimo, $51,864 was received.

Table: ECES TCP common fund distribution in 2017

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<th>No. of Countries X Common Fund/ Country (USD)</th>
<th>Total Common Fund (USD)</th>
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<td>Germany, Canada, Japan, USA, France, Italy, UK</td>
<td>7 X 4,800</td>
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<td>China, Korea, Sweden, Finland, Norway, Denmark, Switzerland</td>
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<td>Belgium, Slovenia, Turkey, The Netherlands</td>
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<td>University of Lleida (Spain)</td>
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<td>TOTAL (USD)</td>
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ANNEX INFORMATION

GENERAL

Duration: Start 2016 – End 2019
Website: http://www.eces-boresysqm.org

OPERATING AGENT

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ABOUT ANNEX 27

The thermal use of the underground with its different technologies and applications is an important measure to increase energy efficiency. This results in an increasing market for ground source heat pumps and underground thermal energy storage. Borehole heat exchanger play an important role in this context.

Unfortunately, failures in design, construction and operation can in the worst-case result in serious damages to buildings and the environment. Thus, quality management is an important issue in all project phases.

To elaborate reliable measures of quality management within the IEA ECES implementing agreement an international experts group is set up to analyse this technology and failures in the different markets worldwide. This group will work out preventative measures and recommendations for national and international guidelines and standards to avoid problems but also solutions for fixing and remediation.

The results will be transferred to practice by national teams recruited from involved parties like members from related industries, technical associations and regulatory bodies through workshops and publications.
## CONTRACTING PARTIES

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<td>Vlaamse Confederatie Bouw</td>
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<td>IGSHPA – Canada, International Ground Source Heat Pump Association</td>
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<td>KEA - Korea Energy Agency</td>
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<td>The Netherlands</td>
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<td>Sweden</td>
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<td>Iller Bank, Ankara University, Istanbul Technical University</td>
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"Learn from experiences, don't make a mistake twice!"

The thermal use of the underground is an important technology to increase energy efficiency for heating and cooling in domestic and commercial applications. The market for underground thermal energy storage (UTES) for heating and cooling and especially for ground source heat pumps (GSHP) was growing rapidly in the last years. Depending on the local geological situation different technologies are applied. Besides aquifer-based systems like ATES or groundwater heat pumps systems with borehole heat exchangers like BTES or heat pumps with BHE’s are the most popular applications covering a wide range from family homes to large commercial buildings for heating and/or cooling and very large BTES for seasonal storage of heat (e.g. in solar district heating systems, cogeneration, ...). In consequence such growing markets require special effort in quality management to achieve well running systems without harmful effect to the underground environment.

The overall objectives of the proposed annex are to avoid mistakes and failures related to the borehole system in design, construction and operation. Information and knowledge collected should serve as a basis for national and international standards. Additionally, the compiled experiences of the international experts group will be a valuable contribution for education of consultants, drillers, installers and operational staff.

This will make BTES technically safer, more cost effective and will strengthen the future usage of this technology. Consequently, the knowledge and confidence of the regulation bodies in this technology should be enforced to avoid ineffective restrictions resulting in increasing costs.

The specific objectives are:

- Collect and compile national standards and guidelines for BTES/BHE for heating and cooling
- Analyse national design procedures and construction methods
- Identify and investigate problems of the design and construction phases
- Work out handbooks and guidelines for design and construction in order to avoid future mistakes
- Investigate operational failures
- Work out preventative guidelines for monitoring, maintenance and rehabilitation measures
- Identify related problems in order to establish further R&D

The scope of this Annex includes quality management issues of borehole heat exchangers for ground source heat pumps and BTES in all project phases ranging from design via construction to operation.
The annex will cover the following topics:

<table>
<thead>
<tr>
<th>Design phase</th>
<th>Construction phase</th>
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<tbody>
<tr>
<td>Energy concept</td>
<td>Site preparation</td>
</tr>
<tr>
<td>Pre-feasibility</td>
<td>Drilling methods</td>
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<tr>
<td>Feasibility</td>
<td>Grouting</td>
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<tr>
<td>Detailed planning</td>
<td>Borehole heat exchangers</td>
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<tr>
<td>Approval procedure</td>
<td>Final test-methods</td>
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<tr>
<td>Call for tenders</td>
<td>Start-up</td>
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<tr>
<td><strong>Operation</strong></td>
<td>Problems, failures, investigation and solution, environmental assessment</td>
</tr>
<tr>
<td>Supervision of operation</td>
<td>Common problems with BHEs and BTES</td>
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<tr>
<td>Maintenance</td>
<td>Problems from poor grouting</td>
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<td></td>
<td>Problems derived from modification of design parameters</td>
</tr>
<tr>
<td></td>
<td>Description of methods how to avoid and how to solve these problems - remediation</td>
</tr>
</tbody>
</table>
Subtasks 4 and 5 are merged together as they correlate significantly. The subtask structure follows the headlines of the Annex topics.

Figure: Organisation matrix of Annex 27
ACTIVITIES AND ACHIEVEMENTS

In 2017 two workshops and experts' meeting were held in Espoo, Finland, hosted by GTK Geological Survey of Finland and in Brussels, Belgium, hosted by Vlaamse Confederatie Bouw. At these meetings 46 scientists and engineers from research institutions as well as from industry and governmental institutions participated giving 19 presentations related to topics of the Annex.

At first each participating country presented the state of the art of BTES and BHE technology which is related to the local geology and hydrogeology. In addition, a brief overview on the market in the different countries was given. While in Sweden and Finland the BHE market is dominated by water-filled boreholes in bedrock which is coming up to surface in most regions, in central European countries with unconsolidated rock boreholes are typically backfilled. These differences are taken into account in the work of Annex 27.

An European standard on borehole heat exchanger was initiated by France. The standard committee CEN TC 451 WG 2 was set-up in 2017 and started working with two meetings of the Working Group 2 (WG 2) committee. As there is significant overlap in the technical subject of IEA ECES Annex 27 and the CEN TC 451 WG 2, collaboration of both expert groups is extremely important. Fortunately, several members of Annex 27 are also involved in the CEN committee.

In Subtask 1 the typical design process from the energy concept via detailed planning to the call for tenders was discussed. Draft text of the chapter on the design phase was prepared by the Swedish members and intensively discussed at the meetings. Subtask 2 covers the construction phase from site preparation via drilling, injection of heat exchanger pipes and borehole grouting to the system start-up. The responsibility for this subtask was taken by Denmark. Construction methods used in the countries are related to the geology but also to the common local drilling technology. The information collected from the countries was compiled to a draft subtask report by the Danish team and discussed in detail at the meetings. The Japanese team evaluated the situation in the operation phase (Subtask 3). However, the feedback shows a quite heterogeneous picture regarding the situation of monitoring guidelines. While Subtask 1 is already very advanced and can be finished in 2018 the other subtasks require further input from the countries. Subtask 4 on problems, failures and solutions and Subtask 5 “environmental assessment” are merged together in Subtask 4 because of the close correlation of the subjects.
ANNEX 28: DISTRIBUTED ENERGY STORAGE FOR THE INTEGRATION OF RENEWABLE ENERGIES - DESIRE

ANNEX INFORMATION

GENERAL
Duration: January 2014 – December 2017
Website: http://www.eces-desire.org

OPERATING AGENT

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ABOUT ANNEX 28

The overall goal of Annex 28 is to foster the role of Distributed Energy Storage (DES) and to better evaluate the potential storage capacities for the integration of renewables at an economical competitive level. For this the following measures are taken:

- Identifying current applications for DES to integrate fluctuating renewable energy sources into energy systems
- Examining DES systems and their properties (including mechanical, electro-chemical, thermal and chemical and biogas approaches)
- Reviewing storage properties requirements depending on the different renewable energy sources (wind, PV, solar thermal, ...)
- Studying possible control and operation strategies for DES and technologies by smart grids
- Quantifying potential of DES systems for the integration of renewable energies based on the current final energy demand
- Developing guidelines for choosing the most suitable DES technology for the current application
- Promoting best practice and success stories examples.

CONTRACTING PARTIES AND SPONSORS

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OVERVIEW OF SCOPE

A rapidly growing contribution by renewable energies to the overall energy production can be expected worldwide. Most renewables, like wind, PV or solar-thermal, are fluctuating resources. With increasing integration of renewable energies, energy storage /energy balancing capacities are needed. So far, the focus in the public discussion is on large-scale, central and most cost-effective energy storage technologies, mainly pumped-hydro storage. The potential and contribution of small- and medium-sized DES technologies to balance fluctuation caused by local renewable energies is mostly unexplored. This Annex aims to answer the question of what the contribution of DES on the integration of renewable energies in future energy systems can be.

DES can be classified by their purpose of operation and their degree of grid connection:

Storage solutions with no connection to the distribution grids are referred to as "Island" solutions. This might be a PV system with battery in self-contained remote buildings. The category "electricity grid connected, but locally optimised" represents storage solutions that are connected to distribution grids, but instead of providing grid services they are optimised for the local application, like a PV/battery-system with grid connection optimised for the buildings self-consumption. The third category "Electricity grid operated" refers to system configurations delivering grid services like grid balancing by control power.

TOPICS AND PHASES

The Annex work is structured in Subtasks. The structure is shown in the figure on the right. In Subtask 1 storage solutions in ongoing R&D projects (TRL 3-6) as well as actual examples of DES demonstration or pilot installations (TRL 6-9) shall be presented and classified, while Subtask 2 shall focus on techno-economic analysis of these systems. Based on this inventory from both subtasks, Subtask 3 has to identify the general potential of DES solutions (TRL 3-9) in different countries. Subtask 4 is focused on the necessary control requirements for the operation of DES solutions, especially when operated in order to provide flexibility measures for the grid.

The overall goal of Annex 28 is to foster the role of DES and to better evaluate the potential storage capacities for the integration of renewables at an economic competitive level. To reach this goal, DES technologies and their properties were examined, storage properties requirements depending on the different renewable energy sources were reviewed and possible control and operation strategies for DES and technologies by smart grids were studied. Finally, the potential of DES systems for the integration of renewable energies based on the actual final energy demand was quantified and guidelines for choosing the most suitable DES technology for the actual application were discussed. Best practice and success stories examples were identified.
The scope of this Annex includes all energy storage technologies suitable on the consumer side.

**ACTIVITIES AND ACHIEVEMENTS**

In 2017 two workshops and experts meeting were held in Copenhagen, Denmark, and Bad Toelz, Germany. At these meetings over 40 scientists participated and gave over 20 presentations on their ongoing R&D activities.

The main question on how much DES can contribute to the integration of renewable energies in future energy systems is approached within Annex 28 from different sides:

- **Bottom-up Approach:**
  
  Subtask 1 and 2 start from actual DES technologies and applications – put together in "configurations" – and document the technological and economic state-of-the-art.

- **Top-down Approach:**
  
  Subtask 3 derives general trends and dependencies for different DES technologies from the modelling of national scenarios.

In Subtask 4 the state-of-the-art of smart grids in connection with DES was explored.

The picture below shows two pages of the final report, which will be published by mid-2018. It shows best practice examples of the different DES technologies in grey boxes. On the upper right page one of many "configurations" is shown. These configurations illustrate the energy source, the storage technology, the final consumer and how the DES is connected to the grid.

Within Subtask 4 a collection of the state-of-the-art in smart grid solutions in connection with DES was compiled. Based on this collection, nine DES-relevant projects could be identified. Germany presented an approach identifying the actors and possibly divergent interests in DES-related smart grid
applications. A visualisation methodology was introduced showing the necessary information and energy flows in a smart grid. The benefits from a systemic, economic and energetic point of view as a result of the intelligent operation of the storages were derived and highlighted.
ANNEX INFORMATION

GENERAL

Duration: July 2015 – June 2018
Website: http://www.eces-a30.org

OPERATING AGENT

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ABOUT ANNEX 30

The general objective of Annex 30 is to advance the implementation of thermal energy storage (TES) technologies in order to reduce CO₂ 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 utilisation 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 Annex 30 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’ (KPI) will be an important step in the performance evaluation of a TES system. Annex 30’s ultimate objective 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 examples 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.

### CONTRACTING PARTIES AND OBSERVERS

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The fourth Annex 30 workshop took place from April 24-26 at the University of Lleida in Lleida, Spain. This included a joint conference entitled, “TES International: Networking and Research Activities”. The conference was hosted by the Annex 30 group in partnership with the University of Lleida and invited members of the Spanish TES community, who consisted primarily of research institutions and universities. The first session gave an overview of networking activities in TES. The second session was split into two parts: Materials & Systems, and Applications & Institutions. The complete list of presentations can be found on the agenda and all materials are available on the team-site. During the closed workshop session, the process analysis guidelines underwent a feedback process, technical parameters were presented and discussed, and the KPI methodology was introduced and discussed. Further details can be found in the meeting minutes on the team-site or available by contacting the Annex manager.

![Annex 30 Participants in Lleida in April 2017](image)

The fifth Annex 30 workshop was held from October 17-19 at the University of Pau in Pau, France. Twenty-one members of Annex 30 took part in the closed sessions on the 17th and 18th, while 30 additional colleagues participated in the conference on October 19th. The conference, entitled “Focus on thermal storage activities in France”, began with an introduction from the University of Pau, CEA from France and DLR that presented the conference proceedings. Following that came a presentation from Ademe, the French Agency for the Environment and Energy, and three sessions on activities in research, industrial production of storage systems and industrial application of storage systems. To conclude the conference, the work of Annex 30 was presented and followed by an hour-long discussion on system boundary and key performance indicators.
ACHIEVEMENTS

During the fourth workshop in Lleida, the decision was made to distribute a survey that applies the methodologies and definitions developed in Annex 30 to a series of case studies originating from the participants. The goals of the survey were two-fold: to collect and evaluate data on integrated TES systems and to assess the methodological work of Annex 30. More information on the survey and its results is available on the team-site and in the second Activity Report of 2017, as delivered to the ExCo before ExCo Meeting 84 in Montreal.

The survey was assembled by DLR and consisted of four sections that encompass the Annex 30 methodological work: process analysis, technical parameters, economic parameters and key performance indicators. Each section requested both qualitative and quantitative data from the participants in order to get a comprehensive overview of the submitted case. The final tab requested further general information to round out the survey. Overall 18 cases were submitted by October 2017, covering 14 research institutions and nine participant countries. Analysis of this data was performed at DLR and the most significant results were presented at the fifth expert workshop in Pau. Included were results that provide an insightful look at the types of cases submitted as well as results that have relevance to the further development and finalisation of the Annex 30 work, namely system boundary, technical parameters.

There was also progress in the individual subtasks in 2017. More information on the results referenced below can be found in both the second Activity Report of 2017 and on the team-site. These results will be published in full in the final report of Annex 30.

In Subtask 1, the process analysis guidelines were finalised in November 2017. Given that they were developed with a focus on industrial processes and power plants, specifically on integrating storage units into already-existing processes, it was decided that they will need to be adapted for use in “greenfield” applications, where a storage unit is considered from the beginning. Colleagues from the Technical University of Denmark and Danish Technological Institute have offered to adapt these guidelines for use in “greenfield” applications such as district heating and cooling.
Subtask 2 has been preparing definitions for technical parameters of a TES system as well as the “analysis levels” of thermal energy storage, i.e. determining the boundaries between material, component, module, and system. A definition for the system boundary of a TES was discussed and finalised at the workshop in Pau. Subtask 2 has also created a definition for system storage capacity that will be finalised before the end of the annex. Three new definitions for technical parameters were also presented and discussed at the Pau workshop: power levels (maximum power, average power, nominal power), response time and efficiency. These definitions were evaluated and their finalisation is being targeted as a final result.

For Subtask 3, the survey also collected costing information that provides an overview of the investment cost and material cost ratios of the cases. Furthermore, information on cost models (type used, discount rate, inflation rate, component lifespan) was also collected through the survey.

In Subtask 4, 16 cases have been collected through the expanded questionnaire prepared in the first half of 2017. Many submissions were provided by the colleagues in Japan and covered a range from lab-scale zeolite boiler to a pilot-scale PCM storage using waste heat from a gas engine. The module sensible storage units from Storasol were also presented, as well as another modular system with concrete storage from a company called EnergyNest. Finally, examples from pressurised water tanks were included as well as seasonal storage examples in Denmark. It was decided that ST4 will accept all submissions, but for the final analysis will focus only on TRL 7+ and commercialised systems. Finally, Annex 30 will only be collecting ‘public’ data on these systems that can be shared, so the extent of the data provided is up to the TES system owners.

The key performance indicator methodology from Subtask 5 has also been finalised and formed a significant section in the Annex 30 survey. In total, 17 cases identified three stakeholders in their case and denoted which of the TES parameters or energy system factors were relevant to which stakeholder. Preliminary results that were presented in Pau will be shown in the following section. Significant points of feedback were also proposed during the workshop and will be incorporated into the methodology in the coming months.

The work in Annex 30 will continue with a focus on an expanded analysis of the data submitted through the survey and finalisation of the outstanding subtask assignments. The collection of further submissions will help to strengthen the database and provide more insight into the uses of TES in the main sectors identified by Annex 30. Another focal point will be the finalisation of the technical parameter definitions that were discussed in Pau.

An intermediate workshop will be held in Frankfurt, Germany on March 1-2, 2018 and the final meeting of Annex 30 is in Cologne, Germany on June 13-15, 2018. It was also agreed that Annex 30 will host a 1.5 day "intermediate meeting" in Frankfurt the month of February or March to make final consolidations before the final meeting in June in Cologne. This extra meeting will ensure the objectives set by Annex 30 will be met before the end of the reporting period. A proposed schedule for writing the final report was also presented and discussed at the workshop in Pau.

Annex 30 continues to have a presence online, both for collaborative and informative purposes. A team-site has been established by DLR and acts as a platform for collaboration and the dissemination of work within the annex. Additionally, an external website has been created for the annex and can be found at: www.eces-a30.org.
ANNEX 31: ENERGY STORAGE WITH NET ZERO ENERGY BUILDINGS AND DISTRICTS: OPTIMISATION AND AUTOMATION

ANNEX INFORMATION

GENERAL

Duration: May 2014 – December 2017
Website: -

OPERATING AGENT

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ABOUT ANNEX 31

The general objective of this Annex is to address the integration, control and automation of energy storage with buildings, districts and/or local utilities. The focus is on the development of design methods, optimisation, and control tools related to predicting, operating, and evaluating the performance of energy efficient buildings and districts when energy storage is available.

ACTIVITIES

The second 2017 Annex Expert Meeting was held on November 14-15, 2017 at Concordia University in Canada. This was the last meeting of Annex 31. A one-day workshop was organised where the Annex members presented their work, and some members of Executive Committee attended and provided constructive comments and suggestions.

Task Leaders Reports and Discussion

TASK A (Modelling): Methodologies and tools for the evaluation of combined various energy storage and saving techniques
As part of this task, extensive works on modelling have been carried out at the component level and building level as well as at the community level. The Task leader provided an overview of the achievements. He then presented the format and table of contents of the related sections of the final report. It was discussed and approved.

**TASK B (Optimisation): Methodologies and tools to optimise the total performance (energy, environmental and economical) of whole systems**

The Task Leader presented an overview of the work that has been performed in this task at the component, building and community level. He then gave an overview of the format and contents of the related section of final report. It was discussed and approved.

**TASK C (Control): To develop efficient and advanced control algorithms and/or strategies for the operation of the whole systems, for different climatic conditions and energy markets**

Similarly, the Task Leader gave an overview of the final report on "Operation and Control Strategy". It consists of six chapters. Chapter 1 is introduction. In Chapter 2, traditional control and operation method is described. This chapter is divided into 3 sections, 2-1 component level, 2-2 building and district level and 2-3 predictive control. In Chapter 3, predictive control for thermal energy storage control is discussed. Chapter 4 covers the topic of demand forecasting and calculation condition. Chapter 5 deals with the topic of optimisation control methods (objective function and optimisation algorithms, etc.). The final chapter, Chapter 6, gives some example from the demonstration projects.

**TASK D: Demonstration/Case Studies**

The Task leader summarised the achievements of this task. He reported that a set of 10 basic indicators and related performance indicators was defined within the task in order to ease the classification and the comparison of different energy storage technologies (considering all the possible categories: mechanical, electrical, electrochemical, thermal, and potential).

**ACHIEVEMENTS**

Extensive research was carried out on the development of simplified models both at the component and district levels. There are number of challenges in the design, and operation of energy-efficient district heating systems (DHS); simulation tools are among the essential missing items when such systems are designed and implemented. Over the past few decades, many simulation tools have been developed for predicting the performance of energy efficient buildings such as Energy plus, TRNSYS, eQUEST, etc. These simulation tools are broadly used to investigate the effectiveness of integrating energy storage and renewable energy resources to the building. Nonetheless, only limited research has addressed toward the development of simulation tools associated with the prediction of the energy demand at the district level. Furthermore, detailed building simulation tools (e.g., TRNSYS, EnergyPlus) are utilised for the energy analysis of the district energy networks; while other tools, such as HOMER Pro, utilise the predicted demand profile from other software or measured data in the form of a user-defined profile as an input to the DHS. In both scenarios, existing tools cannot satisfy the current need for a dynamic, reliable and accurate tool that can envisage the demand profile of a large-scale district network in a timely manner. Development of a practical and simplified demand load model for a building stock is a complex task that requires a high-level proficiency, particularly as the demand profile of a building is
varying as a function of time. As a result, simplified methods emerged as popular options for prediction of the demand profile of district networks. As part of this Annex a simplified model was developed to predict the profile of a district system - see Figure 1.

Optimisation of a district energy system is a complex task for several reasons. Firstly, it includes both the spatial aspect associated with location and the temporal aspect associated with consumption, production and price profiles. Second, many combinations can be considered for locations of buildings, size of energy units, and linkage between the possible end user candidates. Third, the consumption profiles vary in a stochastic manner during the day and from day to day, thus requiring much more sophisticated techniques to tackle the multi-period problem. Finally, the temperature level of different buildings may vary from one building to the other and during different periods even for the same building. Extensive works are underway to develop a simplified optimisation tool.

![Figure: Predicted heating demand schedule vs. simulated demand profile of community 1; Last 11 Days of December](image)

**RELEVANT PUBLICATIONS**


ANNEX INFORMATION

GENERAL

Duration: January 2017 – December 2019
Website: https://iea-eces.org/annexes/material-component-development-thermal-energy-storage/

OPERATING AGENT

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ABOUT ANNEX 33

This joint SHC TCP Task 58 / ECES TCP Annex 33 deals with advanced materials for latent and chemical thermal energy storage, Phase Change (PCM) and Thermo Chemical (TCM) materials. The task deals with these materials on three different scales:

- Material properties, focused on their behavior from molecular to bulk scale, including material synthesis, micro-scale mass transport and sorption reactions;
- Material performance within the storage system, focused on the materials behaviour and when they are implemented in the storage itself, including heat, mass, and vapour transport, wall-wall and wall-material interactions and reactor design;
• Storage system implementation, focused on the performance of a storage within a heating or cooling system, including for instance economic feasibility studies, case studies and system tests.

Because seasonal storage of solar heat for solar-assisted heating of buildings is the main focus of the IEA SHC TCP, this will be one of the primary focus areas of this task. However, because there are many more relevant applications for TES, and because materials research is not and cannot be limited to one application only, this task will include multiple application areas.

### CONTRACTING PARTIES

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OVERVIEW OF SCOPE

This Annex deals with advanced materials for latent and chemical thermal energy storage, PCM and TCM materials. It is a joint activity with the SHC TCP. The task deals with these materials on three different scales:

- Material properties, focused on their behavior from molecular to bulk scale, including material synthesis, micro-scale mass transport and sorption reactions;
- Material performance within the storage system, focused on the materials behavior and when they are implemented in the storage itself, including heat, mass and vapor transport, wall-wall and wall-material interactions, and reactor design;
- Storage system implementation, focused on the performance of a storage within a heating or cooling system, including for instance economic feasibility studies, case studies and system tests.

Because seasonal storage of solar heat for solar assisted heating of buildings is the main focus of the SHC TCP, this will be one of the primary focus areas of this task. However, because there are many more relevant applications for TES, and because materials research is not and cannot be limited to one application only, this task will include multiple application areas.

The main outcomes of the preceding Task/Annexes are a well-defined and tested characterisation method for PCM, an increased knowledge of a first set of salt hydrates and of new combinations of sorption – salt hydrate composite materials.

Numerical modelling was further developed to give a first understanding of the mechanisms at molecular scale and on microporous scale. Models of components containing compact thermal storage materials were developed and validated.

A further finding was that the knowledge on proper design of critical components, like reactors and heat exchangers, is still missing.

Therefore, the focus of the new Annex/Task is on the further understanding and development of PCM and TCM materials, on the development of measuring procedures and test methods for validating the performance of PCMs and the development of characterisation procedures and test methods for TCMs and on getting better design approaches for components.
TOPICS AND PHASES

The topics have been divided onto the subtasks:

- **System**
  - **Subtask 1:** “Energy Relevant Applications for an Application-oriented Development of Improved Storage Materials”

- **Material**
  - **Subtask 2:** “Development and Characterization of Improved Materials”
  - **Subtask 3:** “Measuring Procedures and Testing under Application Conditions”

- **System**
  - **Subtask 4:** “Component Design for innovative TES Materials”

Two of the planned subtasks will concentrate on the material itself, its characterisation and the definition of testing procedures. Subtask 1 and 4 deals with the relation between the new material and the storage component and the actual application, respectively.

ACTIVITIES AND ACHIEVEMENTS

In 2017 two workshops and experts meeting were held in Lyon, France, and Dübendorf, Switzerland. At each meeting over 40 scientists participated and gave over 20 presentations on their ongoing R&D activities.

The possible improvement of thermal energy storage performance by innovative material development can only be quantified within an actual application. The application defines the technical and economic operation conditions, like number of storage cycles or required temperature, thermal power and energy as well as the price for any replaced fossil energy source.

At the same time the new storage materials have to be deeply understood in order to identify mechanisms responsible for degradation under certain conditions given by relevant applications or to tailor materials properties to fit the application requirements.

Examples of R&D activities for these two statements will be given below from Subtask 1 and 2:

**SUBTASK 1 “ENERGY RELEVANT APPLICATIONS FOR AN APPLICATION-Oriented DEVELOPMENT OF IMPROVED STORAGE MATERIALS”**

A life-cycle-analysis concerning storage materials was started in Germany two years ago. The University of Stuttgart together with Fraunhofer ISE and the ZAE Bayern presented first results. In this context storage material are quite relevant. Only to compensate the production impact concerning the global warming potential and the primary energy recovery of some storage materials (PCM and TCM) more than 100 storage cycles are necessary (see figure below for PCM n-Octadecane).
A new method to visualise the adsorption of water molecules into adsorbent pellets was presented by EMPA. This innovative approach highlighted the very basic differences between the ad- and desorption – the discharging and charging - process, which is quite relevant for material stability. Below pictures of the different states of ad- and desorption are shown.