Workshop on the economics of energy storage

On 19 March 2024, the workshop **"Economics of Energy Storage" took place** at the Ars Electronica Center in Linz as part of the "Heat Highway" and the "IEA Energy Storage Task 41" projects, organized and moderated by Simon Moser and Stefan Puschnigg from the *Energieinstitut an der Johannes Kepler Universität Linz (EI-JKU)*. The project partners of the Austrian participation in the IEA Energy Storage Task 41 from *AEE INTEC*, *University of Applied Sciences Upper Austria* and *Wirtschaftsagentur Burgenland Forschungs- und Innovations GmbH* provided significant support in the organization of the workshop and the acquisition of speakers.

Around 50 people attended part in the event, including representatives from research, industry and public institutions. The workshop comprised 14 lectures on thermal, electrical, and chemical storage technologies, which were presented by experts from research institutions and technology providers. The agenda of the event can be found here.

Energy storage is a key element in the technical and economic balancing of fluctuations in generation and demand, particularly in an energy system that is increasingly based on renewable energy. The aim of the workshop was to bring together Austrian players in the field of energy storage to discuss the various aspects of energy storage. Topics included technological innovations, cost efficiency, business models and the requirements for the economic establishment of energy storage solutions. This report provides a compact summary of each presentation, divided into five defined thematic focus areas: Large thermal energy storages for district heating, electricity storage, high-temperature thermal energy storage, thermal energy storage for space heating, and hydrogen as energy storage for electricity and heat grids.

The workshop was opened by Simon Moser and Stefan Puschnigg with the presentation **"Aspects of the economic efficiency of energy storage - today and in a climate-neutral energy system"** (Link). The Heat Highway and IEA ES Task 41 projects were presented as an introduction. The Heat Highway project focuses on the development of a supra-regional district heating network in Styria and Upper Austria, each over 100 km long, whereby three subsections are being concretized and reproducibility in four follower regions is being ensured. With regard to thermal energy storage, the "Heat Highway" project focuses on the integration of seasonal large-scale thermal energy storage facilities, with which the waste heat available in summer can be made available in winter. Inexpensive land and geographically favourable locations are used to achieve a double optimization of the transmission network and storage. IEA ES Task 41 is investigating the economic viability of energy storage solutions. It aims to quantify the benefits and value of energy storage, collect methods to assess economic viability, define KPIs and identify economically interesting configurations. Both projects emphasize the need to quantify the benefits of energy storage and to turn them into viable business models.

Focus area 1: Large thermal energy storages for district heating

The presentation **"Large thermal energy storage in urban district heating - developments in Austria and Europe"** (Link) was held by Carina Seidnitzer-Gallien (AEE INTEC) and dealt with the progress and market developments of large thermal storages in urban district heating networks. The focus was on the use of large thermal storage technologies that contribute to the improvement of peak load management and the storage of excess heat. Important projects and developments in Austria include storage facilities with high capacities, such as the 50,000 m³ storage facility in Theiß and the 34,500 m³ storage facility in Linz. New initiatives in Europe, such as the Horizon Europe-funded TREASURE project, aim to accelerate the market introduction of pit thermal energy storages (PTES) and promote the integration of renewable energies. Demonstrators in countries such as Germany, France, Poland, Austria, and Serbia play a key role in the decarbonization and flexibilization of district heating networks. The initiatives and projects emphasize the importance of robust, safe, and cost-effective thermal energy storages to achieve sustainable and competitive energy supply systems.

Hubert Pauli presented the **"Experiences from the operation of a district heating storage facility"** (Link) and highlighted the operating experiences and efficiency increases achieved by Linz AG with its hot water heat storage facility. The storage facility enables the conversion of condensation and residual heat from electricity generation into district heating, which leads to significant efficiency increases and optimized efficiency. Other benefits include improved pressure maintenance, savings on peak boiler use and increased fuel utilization. The storage tank has a volume of 34,492 m³ and can reach a maximum storage temperature of 97 °C. The challenges lie in the deployment strategy, which depends on the time of year, and the need to integrate the rest of the plant portfolio. Linz AG is investigating future options such as decentralized storage and seasonal storage with higher temperatures in order to further increase capacity and efficiency.

Unfortunately, Wien Energie was unable to give the intended presentation on the ScaleUp project. However, as AEE INTEC is a project partner, Carina Seidnitzer-Gallien presented the basic idea. The aim is to build the first urban underground large-scale thermal energy storage facility in Vienna.

Focus area 2: Electricity storage

In the presentation **"Seasonal energy storage for the Burgenland region"** (link), Markus Schindler (Forschung Burgenland) discussed the integration and economic viability of redox flow batteries for storing renewable energy. Redox flow batteries are characterized by their lack of self-discharge, long service life, scalability, and low fire risk, but have disadvantages such as high weight, complex design, and high costs. A case study investigated the integration of such a battery into a 32 MW wind farm and a 32 MW photovoltaic farm in order to compensate for fluctuations in the residual load. The scenarios show that large storage systems (up to 1600 MWh) are necessary to avoid the positive residual load, which results in high investment costs. However, the implementation of a large battery storage system for seasonal storage is still not economically viable due to the high costs. Smaller batteries at individual generation plants could achieve more positive economic results.

Andreas Buchner, Head of Product Management Energy & Infrastructure at Neoom, described in his presentation **"Storing energy efficiently: Applications and economic efficiency of modern battery storage systems"** (link) the comprehensive product portfolio and the wide range of possible applications for modern battery storage systems. The portfolio includes scalable storage solutions such as the BLOKK (120 kW to >10 MW, 199 kWh to >10 MWh), the grid-replaceable BLOKK LIGHT NEA (30 kW to 120 kW, 61.6 kWh to 398 kWh) and smaller storage systems such as the KJUUBE (8.6 kWh to 44.7 kWh) and the STAAK (6.7 kWh to 22.4 kWh). The storage systems are used in self-consumption optimization, peak shaving, grid decoupling, off-grid operation, and flexibility marketing. The efficiency of the battery storage systems varies depending on the application, with typical round-trip efficiencies (RTE) between 60% and 95%. To optimize operating points and profitability, Neoom relies on self-learning models that perform a large number of simulations per day and location, based on location parameters, weather forecasts and consumption forecasts. These technologies enable efficient and flexible use of battery storage systems to meet the specific requirements of different applications.

Nikolaus Rab (Verbund) gave a comprehensive overview of the importance and economic challenges of pumped storage power plants (PSPPs) in Austria in his presentation **"Profitability of pumped storage power plants in Austria - a market review"** (link). Flexible hydropower plays a central role in the provision of peak energy and balancing power. PSPPs make it possible to pump up water when electricity prices are low and use it to generate electricity when prices are high, which is particularly important in an increasingly volatile energy market. However, the economic viability of PSPPs is influenced by several factors. System utilization charges, which are levied for both electricity procurement and feed-in, are a major component of variable operating costs. Since 2024, the tariffs for the feed-in of pumped storage electricity have been charged independently of the grid level and grid area, which means that the advantage of lower losses when feeding into the transmission grid no longer applies. Additional costs are also incurred through guarantees of origin for pumped storage power due to rolling losses. The revenue of a PSPPs depends heavily on the price difference between peak and off-peak times, which is represented by the so-called pump spread. Despite the economic challenges, PSPPs are important investments for a future renewable energy system in which there will be a high demand for flexibility. New projects such as "Reißeck II plus" (45 MW, commissioning in fall 2024) and "Limberg III" (480 MW, commissioning in 2025) underline the ongoing importance of this technology for the energy transition in Austria.

Gabriele Schallegger (CMBlu Energy AG) discussed in her presentation **"CMBlue Energy – Energy storage inspired by nature"** (link) the innovative technology of the organic solid-state battery (Organic SolidFlow Battery). These batteries use organic polymers for energy storage and offer several advantages: high energy density, scalability, and environmentally friendly production. The technology enables flexible adjustment of storage capacity and performance through modular designs, ranging from individual modules and strings to entire storage blocks. This feature makes the organic solid-state batteries particularly suitable for various applications, from small decentralized systems to large industrial storage systems. The presentation emphasized the importance of this technology for future energy storage, as it offers both economic and environmental benefits.

Jürgen Loipersböck (Wirtschaftsagentur Burgenland Forschungs- und Innovations GmbH) highlighted the economic benefits of integrating battery storage in an agricultural business in his presentation **"Energy cost savings through battery storage integration in a practical example"** (link). The farm has an annual energy consumption of 90 MWh and uses a PV system with 30 kWp and a battery storage system of 50 kVA/100 kWh. Without battery storage, the PV system achieves a self-consumption rate of 76% and a 12-month peak consumption of 40 kW, which enables an overall cost reduction of 17%. With the battery storage system, the self-consumption rate increases to 99.9% and the peak consumption drops to 25 kW, reducing the total costs by 21%. The average cost of electricity consumption is €0.25/kWh (as of November 2023), while the feed-in tariff is €0.12464/kWh (as of Q4/2023). The levelized cost of energy (LCOE) for the PV system is €0.03 to €0.11/kWh and for the battery storage system €0.0524 to €0.1972/kWh. The grid fees include a grid usage fee of €60.36/kW/a and €0.026/kWh as well as a grid loss fee of €0.00112/kWh. The integration of battery storage systems leads to significant cost savings through the optimization of self-consumption and the reduction of peak loads, which significantly improves the profitability and efficiency of operation.

Focus area 3: High-temperature thermal energy storage

Lukas Kasper (TU Vienna) dealt with innovative technologies for thermal energy storage in his presentation **"Hybrid PCM and steam storage for saturated steam storage and fixed bed generators for high temperature applications"** (Link). The hybrid PCM/steam storage combines sensible and latent heat storage to increase the storage capacity by up to 40% without complex process integration. A lab-scale prototype showed an increase in storage capacity of approx. 30% with a charging and discharging time of 8 and 12 hours, respectively. The economic viability of these storage systems depends on the reduction of module costs, which must be reduced by more than 90%. In addition, fixed-bed generators for high-temperature applications were presented, which are efficient, robust, and cost-effective. These systems have enormous potential for heat recovery in the iron and steel industry, where only around 45% of waste heat is currently utilized. Ongoing research is aimed at minimizing dust deposition in the storage beds and increasing exergy efficiency.

Herbert Piereder, Consultant at LUMENION GmbH, discussed the advantages and applications of high-temperature storage for the provision of CO_2 -free process heat in his presentation **"Power-to-Heat – high-temperature storage"** (Link). The storage technology enables the sector coupling of electricity and heat, reduces investments and costs in the grid, and reduces grid bottlenecks and shutdowns of renewable energies. With a storage capacity of 20 MWh_{th}, a maximum charging capacity of 7 MW_{el} and a discharging capacity of 2 MW_{th}, the systems are particularly suitable for industrial applications. Various scenarios show that the combination of PV and wind energy enables the highest avoidance of emissions (~15,000 tCO_2 e/a) and covers around 60% of heating requirements. Other scenarios using only PV or PV in combination with gas or e-boilers also offer benefits, but with lower emission avoidance and demand coverage. The high-temperature storage units offer up to 95% efficiency, high output temperatures of up to 350°C, fast charging and discharging times and easy maintenance and operation. They are an immediately available solution for replacing gas and contribute to local value creation.

Focus area 4: Thermal energy storage for space heating

In his presentation **"Economic analysis of mobile thermal energy storage systems as a supplement to district heating"** (link), which is based on the results of the Heat Highway project, Alois Resch (University of Applied Sciences Upper Austria) examined the economic viability of mobile thermal energy storage systems (M-TES) as a supplement to district heating networks. M-TES are a potential solution for connecting remote heat consumers or suppliers where the construction of district heating pipelines is not economically viable. An earlier study showed that at a cost of €73 per MWh, M-TES was not competitive with district heating at €36 per MWh. Current studies consider different storage materials such as thermochemical materials (TCM), phase change materials (PCM) and sensible storage materials. The results show that M-TES with TCM or PCM can be economical under certain conditions (7 km distance, 1092 MWh/a), with zeolite 13X being the most cost-effective solution at €89.5 per MWh. Operational costs, especially for personnel and transportation, are the main cost drivers. Electric traction vehicles currently offer few cost advantages over diesel vehicles, but could be improved by autonomous vehicles. Overall, M-TES can be a useful supplement to district heating, but only for distances of less than 10 km and with suitable storage materials.

In the presentation **"Power-to-heat and ice storage technology solutions"** (link), Felix Brandstätter (Ecotherm Austria GmbH) discussed the use of surplus electricity through power-to-heat solutions and the application of ice storage technologies. Ecotherm offers electric water heaters with outputs from 25 kW to 30 MW and electric steam generators with capacities from 250 kg/h to 10,000 kg/h. The compact devices cost around €100,000/MW and amortize in around three years. Ice storage solutions enable the storage of cooling energy generated by PV (solar) and load shifting between day and night, thereby cushioning peak loads. One example project is solar ice storage for milk cooling, which comprises a milk cooler (25 kW, 600 l/day), an ice storage unit (1.7 m^3, 110 kWh), a refrigeration machine (4 kW_{el}, 10 kW_{th}) and a PV system (34.4 kWp). This system enables a degree of self-sufficiency of 98% and amortize in around seven years at a cost of €42,000. Ice storage tanks can also be used for heating and cooling by connecting them to the evaporator of a heat pump. These systems offer a high energy potential (70 kWh_{th}/m^3) and can be used for direct cooling and hot water in summer.

Focus area 5: Hydrogen as energy storage for electricity and heat grids

Hans Böhm (Energieinstitut an der JKU Linz) dealt with the economic aspects and future cost developments of hydrogen storage in his presentation **"Hydrogen storage: costs and expected cost development"** (link). The utilization of renewable energies, especially photovoltaics, will lead to seasonal surpluses in the long term, which cannot be fully compensated by short-term storage. Therefore, storable and flexible energy carriers such as hydrogen are necessary to balance peak loads in the electricity and heating market. The storage capacity in European salt caverns and depleted natural gas reservoirs amounts to around 85 PWh and 750 TWh, respectively, although the storage capacity must be expanded due to the lower energy density of hydrogen compared to methane. The demand for hydrogen and power-to-gas capacities will at least triple by 2050, which will lead to a massive reduction in the cost of technologies through economies of scale. Technological learning effects will significantly reduce the costs of electrolysis systems, especially PEMEC and SOEC, with a reduction of over 75% expected. Long-term profitability requires high plant capacities, low-cost renewable electricity production, highly efficient technologies, and the use of synergy effects. CAPEX and electricity costs remain the primary cost drivers, although the dependency of production costs on annual full-load hours is flattening out. Overall, hydrogen is a promising energy source for the future, with considerable potential for cost reductions and efficiency increases.

In the presentation **"Hydrogen storage in practice"** (link), Siegfried Kiss (RAG) explained the practical application and significance of hydrogen storage by RAG. RAG operates 11 modern gas storage facilities with a working gas volume of around 75 TWh and a withdrawal capacity of 33 GW for 90 days, making it the fourth largest storage operator in Europe. These storage facilities play a key role in ensuring security of supply in Europe, particularly in the event of potential energy bottlenecks. The storage capacity of RAG's gas storage facilities, amounting to around 75 TWh, is roughly equivalent to the annual electricity consumption of 14.5 million single-family homes. The storage facilities offer flexibility and help to avoid price peaks. RAG has also been storing hydrogen since 2015 and is a partner in numerous research projects. The UHS Rubensdorf project, which was launched in 2023, produces 2 MW of hydrogen. Other important projects include "Underground Sun Storage 2030" and the recently launched "EUH2STARS" project, which is funded by the EU with 20 million euros. These projects are developing and demonstrating technologies for the purification and storage of hydrogen and CO_2. RAG sees hydrogen storage as an important component of the future energy supply, particularly for covering the increasing demand for electricity in winter.

Conclusion: Workshop on the economics of energy storage

In summary, the workshop "Economics of energy storage" impressively demonstrated that energy storage is a key element for a successful energy transition. With around 50 participants, the event brought together many members of the **Austrian storage community**. The technologies and projects presented illustrated the diversity and innovative strength in this area, while the discussions underlined the **importance of cost-effectiveness and efficiency.** Despite existing challenges, innovative approaches and cross-sector synergies offer **promising solutions for optimizing energy storage**. In the long term, technological advances and economies of scale are crucial to reduce costs and further increase efficiency. Ongoing cooperation between research, industry and political players is essential to fully exploit the benefits of energy storage and successfully shape the energy transition.

Another highlight of the event was the opportunity to view the virtual demonstrator and the newly exhibited prototype of a physical heat highway (supra-regional district heating network) during a guided tour of the Ars Electronica Center with Philipp Gartlehner in the "There Is No Planet B" exhibition. The prototype and the demonstrator were developed in the Heat Highway project.