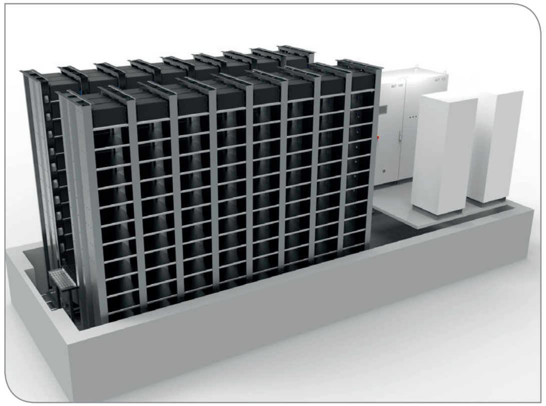
capacity of up to 1.5 MWh and a power output of up to 1.8 MW can be achieved.

The storage system will be built as part of the Helmholtz project "Energy Lab 2.0", which aims to explore the interaction between the components of future energy systems in the field. In this context, different technologies for power generation, energy storage and conversion will be interconnected with consumer loads to form a smart energy system using state-of-the-art information and communication infrastructure.



Interior of the large-scale battery energy storage system (build_up design)

COMPETENCE **E**

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Large-scale battery solutions – load peak compensation or residential storage

COMPETENCE E

Mastering the challenges of the energy transition.

Increasing the share of electricity produced from renewables is one of the core elements of the energy transition. However, power generation from wind turbines and solar photovoltaic (PV) systems is subject to natural intermittency due to weather conditions and the diurnal cycle. In this context energy storage can synchronise demand and load, thus ensuring grid stability. This requires not only suitable storage technologies such as high-performance lithium-ion batteries but also intelligent load management solutions and innovative power electronics. Indeed, if operated correctly such systems are already more profitable than conventional power plants.

Optimised system design based on the operation of prototype storage systems.

As part of the project "Competence E" (PCE) at the Karlsruhe Institute of Technology (KIT), DC- and AC-coupled stationary energy storage systems have been in operation on campus since 2013 (AC system: 32 kWh, 30 kW; DC system: 50 kWh, 250 kW DC/AC, 5 x 30 kW DC/DC), forming part of the 1MW solar storage facility. An additional energy storage system was commissioned in 2015 at the Helmholtz Institute Ulm (AC system: 76 kWh, 60 kW and 31 kWp solar array). These systems provide an ideal testing ground for newly developed hardware as well as for novel algorithms for system control and operation; the experience gathered provides detailed insights into application-specific storage system design, taking both technical and economic aspects into account.

Some of the critically important aspects affecting commercial viability are:

- System design (AC- or DC-coupled),
- Dimensioning (relative sizes of PV array, battery and power electronics),
- System control software,
- Calendar and cycle life of the battery and electronic components.

The fundamental elements of the system control software are its autonomy and self-learning algorithms. In order to increase profitability, the energy storage system must be controlled in such a way that the self-consumption ratio of solar energy is as high as possible, all the while making sure that the battery lifespan is maximised. This means that the electrochemical properties of the battery must be taken into account in the control algorithm design, and that the software must be able to predict both the energy needs of the customer as well as the energy supplied by the solar PV system throughout the day. For lithium-ion batteries, one concrete example of this is that the energy surplus should not be stored immediately at the start of the day, but rather only after midday, since these batteries age faster when their state of charge (SOC) is high. An accurate forecast of supply and demand thus provides the basis for decision-making within the control system.

An intelligent charge and discharge strategy also benefits the grid operator: due to delayed charging, the battery is not completely charged by midday, enabling the system to perform peak-shaving of excess solar production that usually occurs around this time.

In addition, the interaction between hardware and software must be fast and reliable to ensure a high level of security and system availability. The selection and successful integration of hardware components, especially the battery, is thus of utmost importance. Other significant factors that should be taken into account are the cooling system design, auxiliary loads as well as the efficiency of the individual system components.

AC-coupled battery storage system at KIT

Economical design concepts for large-scale energy storage systems with innovative cooling management.

As part of the project "EnergyLab 2.0", a large-scale Li-ion battery energy storage system is being developed and built by PCE. Using mass-produced battery modules from commercial home storage systems as well as an innovative cooling concept, this system combines high energy density with economical design. The thermo-active material of the concrete structure and the use of ground water for battery temperature management (cooling and heating) result in low operating and maintenance costs as well as an extended lifespan of the storage components. Since the container is partially submerged underground it takes up less space,

KIT Large-scale energy storage for a residential areas (build_up design)

which along with its visually pleasing design leads to increased acceptance in residential areas. The pre-cast concrete structure can be rapidly deployed and is robust enough to be able to withstand extreme environmental conditions. Some of its applications include the provision of primary control reserve, day/night compensation or industrial settings. The storage system can be combined with solar or wind power plants as well as different battery technologies, depending on the application. Its highly versatile design allows both the storage capacity and electrical power output to be tailored to the customer's needs without an increase in the project development costs. Depending on the specific model, a storage