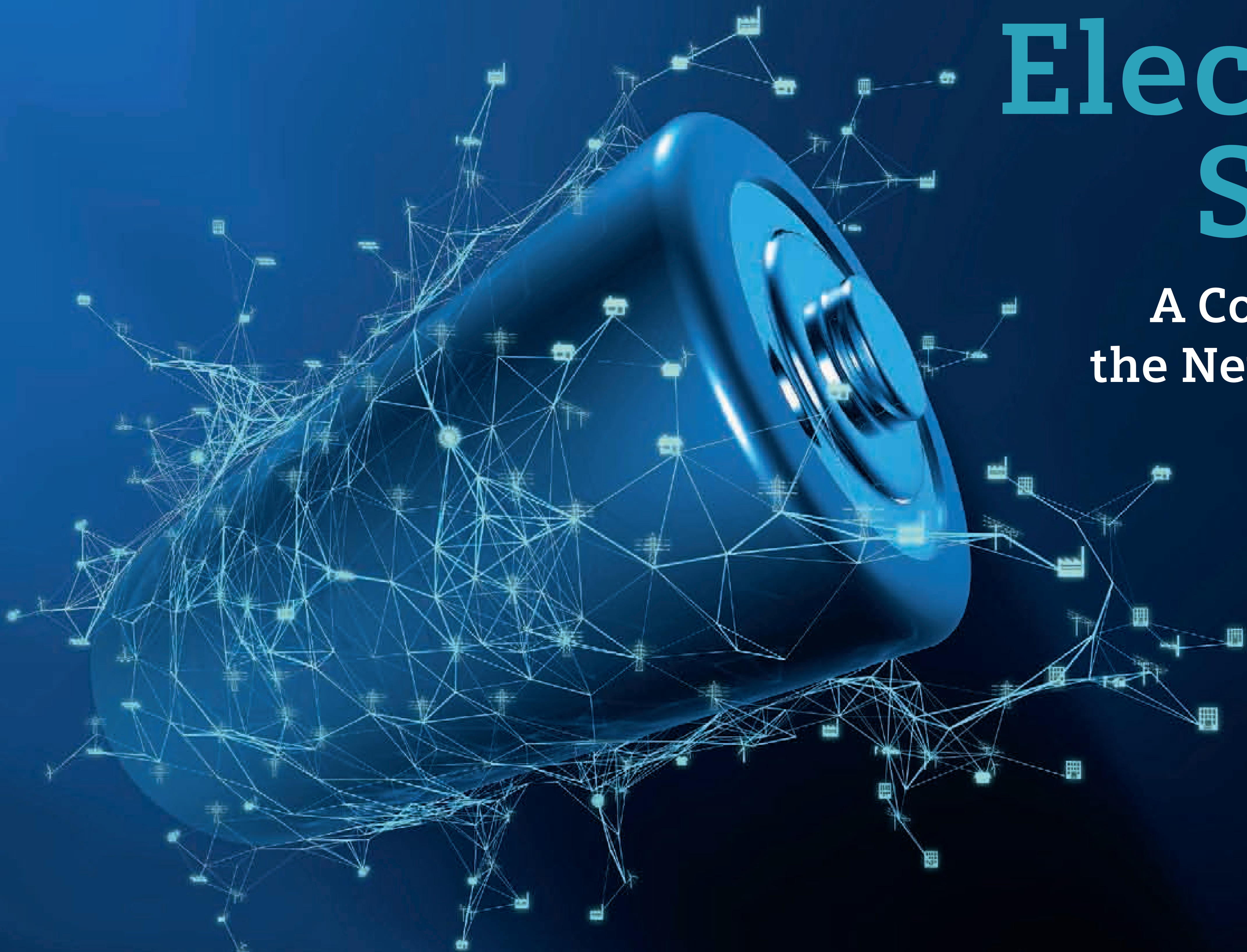


Electricity Storage:

A Cornerstone for the New World of Energy

As the share of renewables grows, storing electricity is crucial for balancing generation and loads. Decision makers must analyze the economic and technical merits of storage options. *Living Energy* takes stock of the range of current and future options.

Text: Ulrich Hottelet   Illustration: Jochen Stuhrmann

Flexibility is a hallmark of the new world of energy. Renewable energies like solar and wind play an increasing role, making this emerging decentralized energy system more environmentally friendly and contributing significantly to fighting climate change. However, they also raise new challenges. Since sunshine and wind cannot be precisely predicted, the supply of electricity from these sources fluctuates dramatically. A balance may be achieved by energy storage, which decouples the moment of power generation from consumption. Moreover, energy storage provides greater stability in transmission and distribution grids, and greater security for the energy system as a whole.

Direct storage of large quantities of electric energy over longer periods of time is difficult from an economic point of view. Usually, for that purpose, it is more convenient to convert energy into a different, low-cost form of energy and to reconvert it when needed. But due to the losses associated with multiple conversion of one energy form to another, the sum of all losses can be substantial.

Broad Range of Use Cases

Electricity storage may be applied in industrial plants, craft businesses, private homes, and electric and hybrid-powered vehicles. Power storage systems serve two basic purposes: First, they ensure continuous power quality. Even fluctuations of voltage and frequency within a fraction of a second may cause damage to industrial plants. Good power quality depends on compliance with grid codes, e.g., in terms of voltage, frequencies, reactive power, and short-circuit currents. Second, energy storage systems capable of storing energy from hours to weeks are assisting in the reduction of energy system or energy supply costs, e.g., where self-sufficiency or peak shaving are major drivers.

Identifying profitable business cases is key to energy storage. This is based on investment and operating costs, the latter depending on the technical efficiency as well as maintenance and replacement costs. "If a storage form has high efficiency, it also carries high investment costs. But the efficiency only plays a role when electricity is not free, as in times of excess supply," explains Andreas Gutsch. He heads the "Competence E" multidisciplinary project on electric storage and mobility at the Karlsruhe Institute of Technology. "For the German electricity system, storage is not a pressing issue yet, but it will definitely become more important after 2020 as the share of renewables increases further," says Rainer Saliger, Principal Key Expert Energy Storage at Siemens. Any breakthrough will depend on the development of electricity and storage prices. "In the case of Germany, the regulatory framework must make storage more attractive. This refers to the EEG (the law on renewable energies) and the related fees, where regulations have to be modified to remove current roadblocks for storage," says Werner Tillmetz, Head of the Institute for Electrochemical Energy Storage and Conversion at ZSW (Centre for Solar Energy and Hydrogen Research) in Ulm.

> *"We believe that batteries will play an important role in small trade and in areas not connected to the grid."*
>
> Andreas Gutsch, Head of "Competence E" project at Karlsruhe Institute of Technology

High Market Potential on Islands, in Asia, and in the USA

Economic feasibility varies significantly between different regions of the world. "Siemens regards islands as an important market," says Saliger. "Their electricity rates are high, because they use diesel generators. Moreover, some islands already have a high share of solar and wind energy." Experts have identified markets in Indonesia, Hawaii, Puerto Rico, and on the French and Greek islands. In Latin America, Chile is seen as the market with the greatest potential: Its mine operators need stable networks. Another driving force is legislation. US legislators have created remuneration schemes to foster speedy and accurate responses to system imbalances, which also favors storage. California in particular has mandated its three suppliers to install 1.3 gigawatts of storage capacity by 2020. State regulations or initiatives make China, Japan, and South Korea additional attractive storage markets. In continental Europe, Germany and Italy are the most promising markets due to their high electricity rates. Moreover, certain laws of the market are generally applicable: If consumers are empowered to respond to price volatility on wholesale markets, e.g., via the deployment of smart meters, this also fosters the use of storage.

Storage systems in commercial use today can be broadly categorized as mechanical, electrical, chemical, electrochemical, and thermal. There are technologies suitable for large-scale or bulk storage, and others more suited for smaller-scale applications. Siemens is working to develop solutions for many different storage technologies and systems.

Batteries: Great Perspectives and Very Flexible in Usage

Experts see batteries and especially lithium-ion batteries as having the greatest potential among the storage technologies. "They have high dynamics. They can be activated within seconds and are capable of storing electricity for several hours. And their cyclability (charge/discharge capability) is being continuously improved," explains Saliger. Another advantage is scalability. This makes them suitable for private households as well as for industrial plants and for grid applications. "We believe that batteries will play an important role in small trade and in areas not connected to the grid," says Gutsch. They can also help to implement backup power supply. Big battery blocks of up to 10 megawatts can stabilize the grid. Their technical efficiency is high and can reach up to 90 percent.

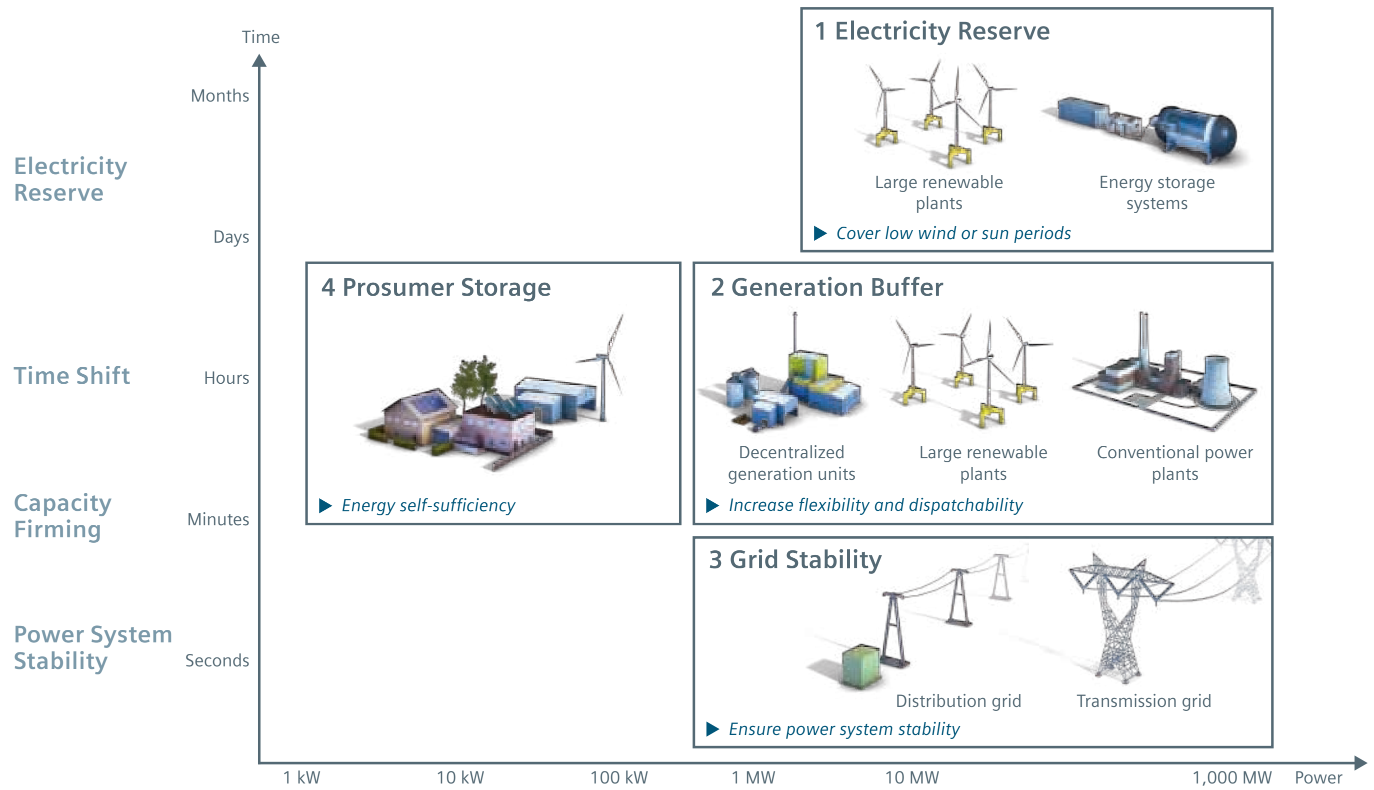
Two trends favor batteries. The first is the rising use of photovoltaics in homes. "The ideal case is for generated energy not to be distributed to the grid, but to be used for covering homeowners' consumption," says Tillmetz. He forecasts an "extreme growth of photovoltaics worldwide" due to the low costs of electricity generation, specifically in southern countries, which may be as low as 5 euro cents per kilowatt-hour. Second, economies of scale will bring down the price of lithium-ion batteries, possibly by 50 percent, since the number of electric cars is expected to grow. Currently, there are over 600,000 electric vehicles worldwide. Their number doubles every year. Lithium-ion batteries are also used in many mobile devices. Less important are other battery types such as lead-acid or sodium-nickel chloride.

Redox-flow (reduction-oxidation) batteries can store electricity for longer periods, from hours to weeks. In contrast to other batteries, they have a separate tank. Performance and energy are scalable. With an output power of up to 100 kilowatts, they are suited for small companies. In Australia, they are usually combined with windmills or solar power systems, facilitating off-grid supply and storage. Their technical efficiency (or "round-trip efficiency") can reach up to 70 percent.

Hydrogen: a Mixed Picture

Storage via hydrogen pathways is the best way to serve long-term storage needs of several weeks or months. This is linked to an attractive alternative use of hydrogen as fuel in transportation. "Temporarily, excess renewable power (e.g., during strong wind phases) can be used for hydrogen production instead of turning down the windmills," Tillmetz ▸

Storage applications can be differentiated by four major use cases



Energy storage serves several purposes: It can stabilize the grid over periods of seconds; it allows prosumers to become self-sufficient and acts as a buffer adding dispatchability to power generation systems for minutes or hours at a time; and it can be used to build up an electricity reserve over days and months.

Storage is about balancing production and consumption on different time scales

With storage capabilities, entire energy systems can raise the quality of power in the grid and help smooth intermittent generation ("capacity firming"). With the option of time shift in consumption, storage also facilitates energy arbitrage. Over the longer term, it can be used to build up a power reserve for periods of less insolation or wind.

believes. The economic feasibility is difficult to assess. "The electrolyzer is currently the most critical element. The price per kilowatt is between €500 and €1,000. Therefore, cost reduction is the main challenge," says Saliger. In the early phase of a new "hydrogen economy," renewable hydrogen produced by electrolysis will have a much higher value in other areas than for burning in conventional gas power plants. For customers who are not satisfied with the range of battery electric cars, development of hydrogen-powered vehicles with fuel cells is the technology to watch. They reduce CO_2 emissions, help to meet climate protection targets, and reduce fuel costs per kilometer. Due to the existing regulatory obstacles influencing the economics of hydrogen electrolyzers, besides several funded power-to-gas demonstration projects, investors in Germany remain reserved. In Asia, the situation is different. "Politicians there have a clear strategy. For example, the Japanese subsidize the rollout of hydrogen refueling stations as well as fuel cell vehicles," Tillmetz notes. With this clear vision that hydrogen is the important future energy storage medium and energy carrier, much more momentum can be achieved between the involved stakeholders. If there are concerns related to safety, hydrogen could be further processed with CO_2 to a synthetic natural gas (SNG) that is easier to handle and could be conveniently fed into the natural gas grid.

Pump Storage: a Proven Technology Worldwide

Pump storage is the form of grid energy storage with the greatest installed capacity worldwide. The "top dog" among the storage technologies, as Saliger calls it, is an established mechanical storage medium for large plants that typically store power for several hours. At times of low electrical demand and commensurately low prices, excess power generation is used to pump water from a lower into a higher reservoir. When demand rises, water is released back into the lower reservoir through a turbine, generating electricity that is then sold at higher prices.
The round-trip efficiency of pumped-storage hydropower is in the range of 80 percent. However, there is only little technical and economical potential in Central Europe. "You reach certain limits, since power plants linked to hydro dams in the Alps are operating at full capacity. New plants cannot be built due to strong political opposition on the part of residents," says Tillmetz.

Compressed Air Energy: like Giant Air Pumps

Compressed air energy storage works like a giant air pump, using a compressor for pumping. Upon release of the compressed air, a turbine or engine connected to a generator produces electricity and thus recovers part of the charged energy. The disadvantages are rather high losses and associated low efficiency levels of 50–70 percent, depending on the availability of heat recuperation. This storage form is mainly used together with caverns, but smaller above-ground pipe storage systems are also being considered.

Thermal Storage: Lowest-Cost Storage Medium

Thermal storage can take many forms. Low-temperature storage in hot water tanks (up to about 100 degrees Celsius) is state of the art for heating purposes. Nowadays, with increasing volatility, excess electricity may be converted via a heating rod into heat for a district heating system, as a means of adding flexibility to CHP plants. In this power-to-heat concept, the heat is not converted back into electricity: "This is cost-efficient. The technology can store thousands of kilowatt-hours and is available for balancing night and day," says Gutsch. In a modified variant, excess power is converted via a compressor into heat at much higher temperatures of up to 350 degrees Celsius. When storing at these high temperatures, a conversion back to electricity is technically feasible using an engine or a turbine, for example.

Supercapacitors: Performance for Vehicles

Supercapacitors offer ultra-short-term performance storage. They bridge the gap between conventional capacitors and rechargeable batteries. They are mainly used for mobile applications like electric cars, buses, and streetcars, where they recover energy from braking and discharge it for acceleration. In the future, these features may qualify the technology for power storage applications in the grid as well. Their level of efficiency is 90 percent.

Flywheels: Energy by Rotation

Flywheels offer another means of mechanical storage. Similar to supercapacitors, they cannot store large amounts of energy. They work by accelerating a rotor in a vacuum enclosure to a very high speed and maintaining the rotational energy in the system. When energy is extracted, the flywheel's rotational speed is reduced, whereas adding energy to the system correspondingly results in increasing speed. The construction of flywheels is a mature technology, and their round-trip efficiency is 85 percent; however, self-discharge rates are rather high. Moreover, the technology is limited in terms of modularity and scalability.

> *"Due to decentralized supply, the classic top-down process of energy distribution no longer works."*
>
> Werner Tillmetz, Head of the Institute for Electrochemical Energy Storage and Conversion at ZSW

Obviously, all storage forms have their respective pros and cons. Decision makers must carefully ponder them by taking into account the particular use case. "For more than 150 years, the classic top-down process of energy distribution has worked. Power plants simply generated and distributed energy. The energy revolution turned this principle upside down. Due to decentralized supply, this system no longer works. And we are only beginning to understand interdependencies," sums up Tillmetz. ■

Ulrich Hottelet is a freelance business journalist in Berlin. He focuses on IT and energy and has published articles on energy in Focus Online, Cicero Online, VDI-Nachrichten, and the *German Times*.