



Energy storage

The key to sector coupling

Learn more about how

- The transformation to a carbon-neutral society can succeed
- Batteries and power-to-X processes improve supply reliability
- Suitable connection technology makes energy storage safer and more efficient

Introduction

The message of the International Energy Agency (IEA) is clear: “There can be no energy transformation without powerful storage batteries.” In this conclusion, they are in agreement with researchers all over the world. But what role does energy storage actually play in the transformation to a carbon-neutral society? And what is important to consider when selecting, designing, and operating such systems?

Specialists in development, project management, and implementation will be increasingly faced with the questions that are addressed in this white paper over the coming years. To achieve international climate targets, the IEA study “Innovations in batteries and electricity storage” assumes that at least a global storage capacity of 10,000 gigawatt hours will have to be available for use by 2040. This amount of energy would be around 50 times the capacity currently available.

The IEA study identifies battery systems and power-to-X processes as having the greatest potential to expand this capacity. This white paper also focuses on these two areas. The paper uses them as examples to show what must be taken into consideration in any energy storage solution, whether it is built from scratch or its performance capabilities are being optimized – namely:

How sustainable, safe, reliable, and efficient is the system? And are all areas of potential truly being exhausted? Even those that do not relate directly to battery type and size? They may lie, for instance, in the connection technology, another topic addressed in this white paper. The following pages provide more information on this, and on the role of energy storage solutions as part of the path to a carbon-neutral world.

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1 Sector coupling to achieve the All Electric Society



Climate change and population growth are posing an urgent question for the world: How can global warming caused by greenhouse gases be stopped – particularly at a time when more and more people are striving to attain prosperity and development? Or, to put it another way: How can we permit increasing energy consumption, while still protecting the climate? From a technical standpoint, there is just one answer to both of these questions: the future vision of the All Electric Society.

Technical solutions for a livable world

The All Electric Society describes a world developing in a sustainable way, where affordable electrical energy is available everywhere, at all

times, in sufficient quantities, whether for private needs, business purposes, or to benefit society.

Instead of being produced from fossil fuels such as oil, gas, and coal, of which there is only a limited supply that is partially subject to geopolitical dependencies, this energy is produced in a carbon-neutral manner entirely from renewable sources, from the power of wind, water, and sun. According to researchers at Oregon State University, it will be possible to cover all energy requirements for the entire globe even into the future using today's solar technology, while using less than one percent of the earth's surface to do so.

However, the path to achieving the complete energy transformation and the goal of the All Electric Society will be a long one. It begins with a massive expansion of renewable energy and the technological approach of sector coupling.



In sector coupling, central areas of our work and lives are networked and automated through electrical and data technology. This makes them into smart sectors that save energy and use energy more efficiently in their interactions.

The efficient use of renewable energy

The basis of sector coupling is the comprehensive electrification, networking, and automation of all relevant areas of our lives and economies, ranging from industry to energy, mobility, infrastructure, and buildings. These sectors have been considered and managed primarily independently from one another for many years, but ideally they would be networked to create a self-controlling system. The sectors will become intelligent. They will not only detect their own needs and react automatically, but will do the same for coupled sectors. This results in improved efficiency and energy savings through optimally balancing all energy consumers, producers, and storage systems.

The energy that is generated can be used dynamically, wherever it is currently needed. And if only part of the energy that is generated is currently needed, excess energy can be stored and then used as needed at any later time.

Controllable devices like charging stations for electric vehicles will also help balance out the networks and ensure the efficient use of volatile renewable energy sources. This means that, no matter how strongly the wind blows or the sun shines, generation peaks and peak loads can be smoothed out through sector coupling, ensuring the stability and availability of the power supply without a huge amount of excess capacity. However, without energy storage systems, none of this will be possible. They are the key to sector coupling.



The percentage of renewable energy in overall power generation is growing: In the European Union, this percentage was 38% in 2020, a figure which was above that for fossil fuels for the first time.

2 Energy storage as the guarantee for supply stability



Energy storage systems play a key role on the path to the All Electric Society. After all, the only way to ensure a stable power supply is to compensate for the volatility of renewable energy sources through sufficiently sized and sufficiently reliable storage facilities. Which systems and technologies will be best suited for this purpose depends primarily on the required storage capacity, power, and duration.

The strengths of battery storage and power-to-X processes

Battery storage systems are the preferred way to store small quantities of energy up to multiple gigawatt hours for a timeframe of just a few seconds to several days. They can deliver energy to the grid quickly and flexibly, whether to provide regular power or for redispatch measures. So-called power-to-X processes are the preferred method for storing large quantities of energy over multiple



The UK government is planning to combine offshore wind farms directly with power-to-X facilities.

weeks and months, for instance to compensate for seasonal fluctuations in renewable power generation. The variable X stands either for heat or for various energy-rich gases, liquids, and chemicals. These synthetically generated fuels are called e-fuels. They can be stored in a manner similar to fossil fuels and transported over long distances, for instance using existing pipelines. E-fuels are used, for instance, in the mobility sector; in heat generation, and in industry, where they are utilized, for instance, to re-convert stored energy with the help of combined heat and power plants or fuel cells. The fuel cells suitable for this purpose generate power by oxidizing a constant feed of hydrogen or methane and have a power capacity designed primarily to cover continuous loads, while battery storage systems can also be used to handle peak loads.

Section 3 of this white paper explains how power-to-X works in detail, as well as providing more information on the benefits of such processes. First, it should be noted that battery storage systems and power-to-X processes even today already offer the technologies that will be needed in the future of the All Electric Society to provide sufficient energy generated through clean and climate-neutral processes everywhere in the world, at any time of the day or night.

Sector coupling: Both ecologically economically expedient

To keep the power grid stable, energy supply and demand must be continuously balanced. If the load is too high, the grid frequency will drop. If the load drops, it will increase. Often, the necessary balancing is not handled very economically. Gas turbine power plants which can be started up quickly are used to handle short-term peak loads. Low loads, in turn, are sometimes handled by the controlled powering down of wind turbine generators. On the one hand, electrical energy is generated with a high percentage of primary energy usage, while on the other the available kinetic energy of the wind is not utilized.

If wind farms are combined with large-scale battery storage systems, load distribution in the grid can be buffered much more efficiently. The wind turbines, which have their own storage systems, can keep turning even when the grid is full. Conversely, power can then be drawn from the storage systems when there is no wind. Solar parks can deliver power even overnight in the same way using storage systems. Power generation and consumption can occur at different times. This is an important prerequisite for the success of the All Electric Society – and for replacing a previously centralized supply system with few generators and many consumers with a decentralized, more efficient system on a step-by-step basis.



Photovoltaics and wind turbine generators are combined with large battery storage systems to create decentralized, hybrid power plants that feed power into the grid from renewable energy on an as-needed basis.

3 Function and benefits of power-to-X processes

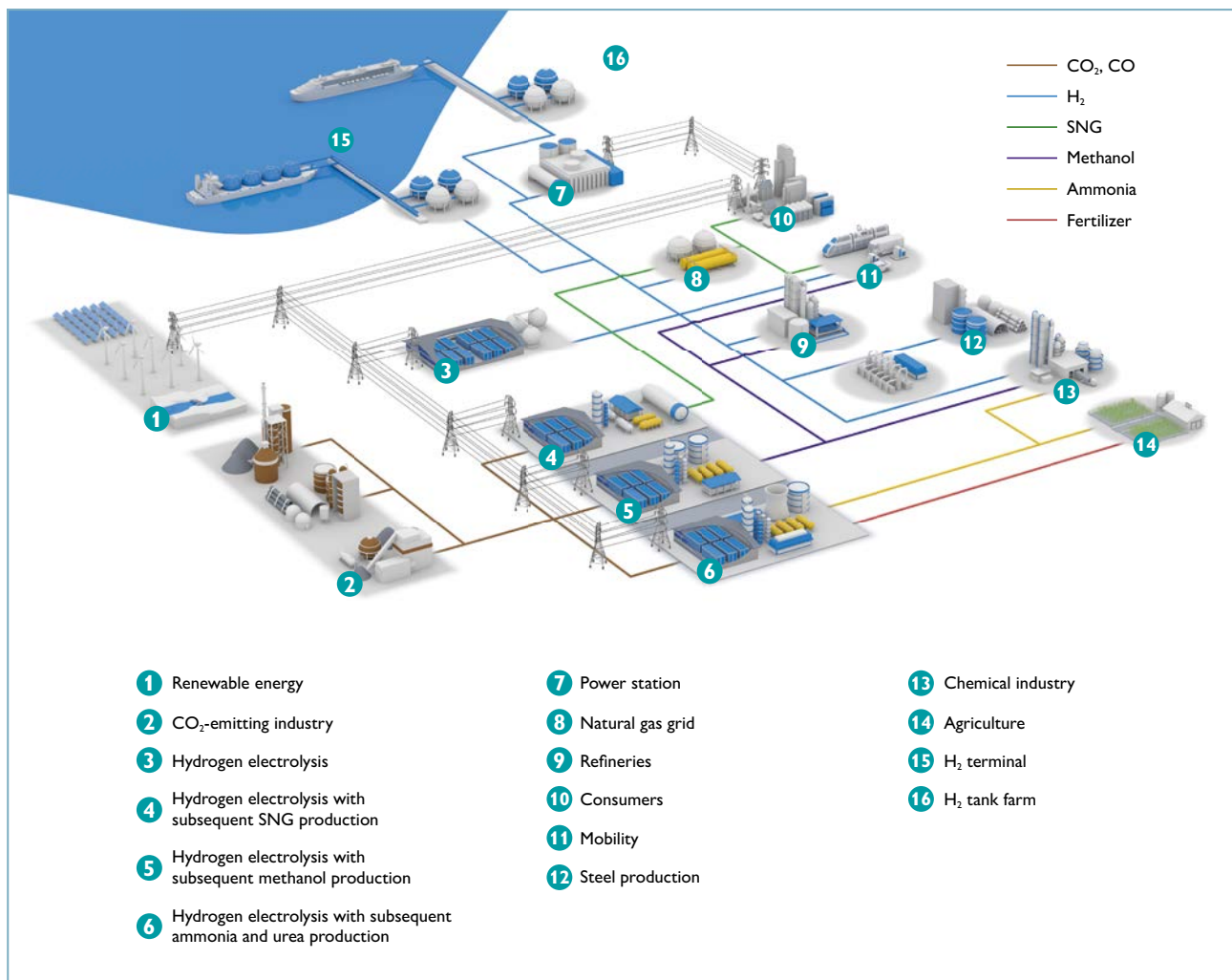


Power-to-X processes are based on generating hydrogen. It can be used directly as an energy source, but also as a raw material for e-fuels, synthetic gases, or chemicals.

Pure hydrogen must be obtained from compounds such as water, natural gas, petroleum, or coal. There are two main ways to do this: thermal conversion and electrolysis. Currently, thermal conversion is the primary method used. In this method, the hydrogen is obtained through a multi-step process using water vapor (steam reforming) or oxygen from fossil-based hydrocarbons. As

established and well-developed the technology behind this method is, it does have one major disadvantage: The use of fossil fuels in thermal conversion always results in emissions of greenhouse gases. Because of this, the hydrogen produced in this way is referred to as “gray”.

Partially for this reason, electrolysis is becoming a more established alternative to produce hydrogen. In electrolysis, pure water is split into hydrogen and hydroxide ions using electricity. The hydroxide ions then break down into water and oxygen. The two gases can then be extracted separately from one another in the electrolyzer. If this power needed



for electrolysis comes from solar and wind power generated in a carbon-neutral manner, then this is referred to as “green” hydrogen.

All power-to-X processes generate hydrogen through electrolysis. The electrolysis itself is also considered a power-to-X process: electricity is converted into another energy source (X) – in this case, pure hydrogen. However, processes that use this hydrogen as the raw material for generating e-fuels, synthetic gases, and chemicals also bear this label.

As explained in the previous section, in addition to hydrogen, fuels created from synthesizing hydrogen with carbon dioxide, such as synthetic natural gas (SNG) or methanol, are particularly relevant energy sources. The carbon dioxide needed for synthesizing these fuels can be generated, for instance, from industrial processes or as direct air capture from the ambient air. However, the more conversion steps are required on the way from power-to-X, from electricity to storage and continued usage product, the more the individual power-to-X processes are affected by energy losses. Because of this, the balance for electrolysis alone is best in this context. This is counteracted, however, by high energy expenditures in some cases to store pure hydrogen, which generally needs to be compressed for storage at high pressure levels of up to 700 bar, or liquefied by cooling it down to -253°C .



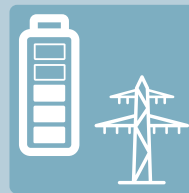
However, there are factors besides the high expenditures for compression or liquefaction that make hydrogen a comparatively expensive energy storage option today. Just like all power-to-X processes, the investment costs for an electrolysis system and the required peripheral systems are factors in the total expense. Nevertheless, it is likely that costs for electrolysis will drop in the future. Most electrolyzers are already produced in series production, but certainly not yet mass production. Therefore, the potential from realizing scaling effects is correspondingly high. At the same time, it should be assumed that technological developments will improve efficiency. This will make power-to-X processes an economical and smart supplement to battery storage systems.

4 Structure and use of battery storage systems



The gains in efficiency generated by battery storage systems through temporal decoupling of renewable energy generation and usage are frequently utilized as an economic advantage, particularly in private and industrial buildings.

Photovoltaic system on the roof, battery storage in the basement, charging column in front of the door: In many households and industrial companies, sector coupling is already a reality. There, home and industrial storage systems do what utility-scale storage systems do in combination with solar and wind farms across the grid: They provide power on an as-needed basis.

	 Residential storage	 Industrial storage	 Utility-scale storage
Use	Coupled with the photovoltaic system and home charger at home	Use in commercial buildings and factories	Combined with wind and solar parks, as well as integrated into the grid or quick charging infrastructure
Energy technology uses	The most autonomous power supply possible	A stable power supply and capping peak loads	Supporting the grid as a backup solution and efficient buffer
Economic benefits	High own use of solar power reduces electricity costs	Peak shaving reduces expenses for power significantly	Reduces the need to expand the grid and makes lucrative trade possible in energy from renewable sources
Capacity	Storage capacity in segment of 10 kWh	Capacity in the MWh range	Capacities up to the GWh range
Size	Approximately the size of a refrigerator	Can fill entire engineering rooms	As large as a semi container, with storage parks full of such containers

The typical structure of energy storage systems

Energy storage systems are the total of many different components, all of which contribute to the function of the overall system. These include inverters to convert the electricity, monitoring equipment, controllers and storage components, as well as electrical connections for electricity and data transmission, which are used to network all of the components on different levels.

Let's take an electrical energy storage system, for instance, based on galvanic cells: No matter whether they are large-scale or residential storage systems – their structure is generally modular. The basic elements are battery cells, which are switched in parallel and series to form packs for voltage and current increase. If a large number of cells are integrated into a housing, this is called

a storage module. Charging and discharging of the cells is controlled and monitored by module balancing. It keeps the cells or groups of cells at the same charge or discharge level so as to prevent premature aging or prevent individual cells from becoming overloaded or from undergoing deep discharge. In addition to the positive and negative connections for the charge/discharge current, it has a large number of connections to the individual cell groups for this purpose. In addition, all information on the status of the battery module is provided via a digital data interface. Data and power connections are routed from the printed circuit boards of the module balancing to the module housing. Frequently, screw connections are used there for the line connections, while the data interface is usually designed to be pluggable. In addition, there are PCB connections for the sensors in the battery module which monitor the temperature at different locations while measuring voltages and currents.



Structure of a storage system, from the module in the rack to the overall system with its external interfaces to combine directly with power-to-X facilities.



View inside a storage module with battery packs, balancing printed circuit boards, and both internal and external interfaces.

A battery module typically has a voltage between 24 and 96 V. However, often the system voltages are significantly higher: To achieve gains in efficiency for the required output voltage of the storage system while reducing the current and ensuring the same performance, multiple battery modules are integrated into racks and connected in series. Flexible cables with ring cable lugs are used between the screw connections indicated for this purpose. In addition, at least one data cable leads from each module to the next for the data technology coupling.

To be able to connect it to the associated battery modules and the higher-level system, each rack also has a control – called the rack BMS – including power and data connections. To control the charging and discharging processes and communicate with the outside world, the system management also has its own controller. Furthermore, auxiliary units such as climate control equipment, fire sensors, and fire suppression devices are also integrated on the system level.

A large number of different electrical connections also play an important role in this context in how the components of the system interact, as well as for external connection of the storage system. More than just the power flows needs to be taken into consideration. The digital connection to the grid and to the feeding solar system and wind turbine generator, as well as sensors and control signals, like those from the weather station, are what make it possible to use the energy storage system efficiently.

5 Connection technology as a factor for efficiency and safety



Research on new storage systems and storage system developments is a lively field. Almost all of the components in such systems are tested regularly to develop optimizations: the cell chemistry of the batteries, as well as the semiconductors. This white paper focuses on the electrical connection technology used in the storage systems. After all, reliable, low-loss connections generate significant added safety and efficiency.

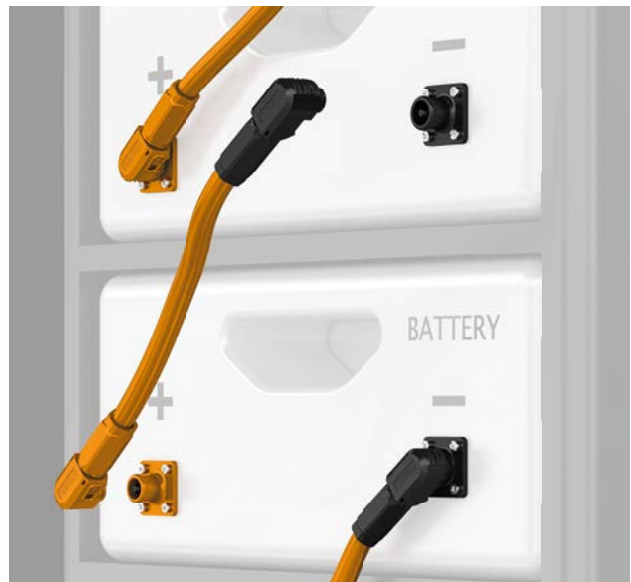
Just as in any electronic system, in energy storage systems the essential factor for avoiding malfunctions and ensuring maximum efficiency is the device design. This starts with dimensioning the connection technology in terms of the amperage and electric strength, and continues with a consideration of environmental requirements. The fact that corrosion can impact electrical connections if they are exposed to moisture regularly or continuously is just one example for improper connection technology design. IP-protected connectors can be helpful in this case.

The use of screw connections like ring cable lugs with threaded bolts and nuts, for instance, is just as problematic. Often, these can cause faults in power connections. Increased contact resistance can be caused by vibrations, or simply because the screws have not been tightened or maintained according to specifications. In the worst case scenario, this will cause a fire, and in every case it will cause significant drops in the efficiency of the storage system.

If we consider the external power connectors of the battery modules, even a correctly designed connection for each module, installed in accordance with specifications, will cause losses through heat of more than 100 kWh over the entire service life.



Screw connections for power transmission harbor the risk of large temperature increases due to increased contact resistance.



Battery-pole connector with reverse polarity protection, electric strength, touch protection, and an interlock are a safe alternative to screw connections.

This increases in direct proportion to the contact resistance. A specific example calculation would be: a module with a 5 kWh capacity, a voltage of 48 V, an average amperage of 50 A and 5,000 charge and discharge cycles loses approx. 100 kWh of energy under the conditions indicated. If the contact resistance is increased three times due to faulty power connections, this does not cause damage, but does cause heat generation, although this is

still not damaging. The energy loss, however, is multiplied at the amount of annual power required for a three-person household, namely to around 3,000 kWh. On the system level, there are even significantly higher losses due to the large number of modules, and therefore even more significant economic damages.



“Blind-mating” connectors for connecting to busbars make it easier to install push-in systems.

The initial investment in high-quality connectors pays off quickly. An alternative to widely used screw connections is a pluggable connection with reverse polarity protection, electric strength, touch protection, and an interlock. In addition, there are contacting systems with entirely new designs on busbars. Both solutions reduce efficiency losses to a minimum, with a maximum level of safety and comfort.

However, all of the other electrical connections in an energy storage system must also be taken into consideration. To facilitate automation, for

instance, replacing the soldered connection for a sensor connection on the printed circuit board of the balancing module with an easy-to-operate spring terminal may be an attractive option. When installing the battery packs, the sensors can be set in the automated process, and the two sensor cables are inserted manually and tool-free when assembling the module. As a result of the improved accessibility, significant time savings – and therefore, cost benefits – can be expected. This also ultimately means more efficiency – as well as fault-free data transmission within the storage system. Here as well, choosing the right connection technology is essential. High-quality components with materials selected for the specific application offer maximum safety, and make it possible to achieve and maintain the efficiency of the overall system.

Conclusion

The design, quality, and correct usage of electrical connection technology in energy storage systems are crucial for the reliability and efficiency of those systems. High-quality connection technology does more than just ensure safety in operation. It also ensures safe, convenient, and time-saving installation and maintenance. A compromise which may initially seem affordable can all too often lead to system failures and high ongoing costs. Therefore, it always pays to hire competent manufacturers and trust in their expertise when designing the electrical connection technology on all levels of an energy storage system. The only way to make the vision of the All Electric Society a reality is through systems and components that offer all-around reliability.

Contact

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