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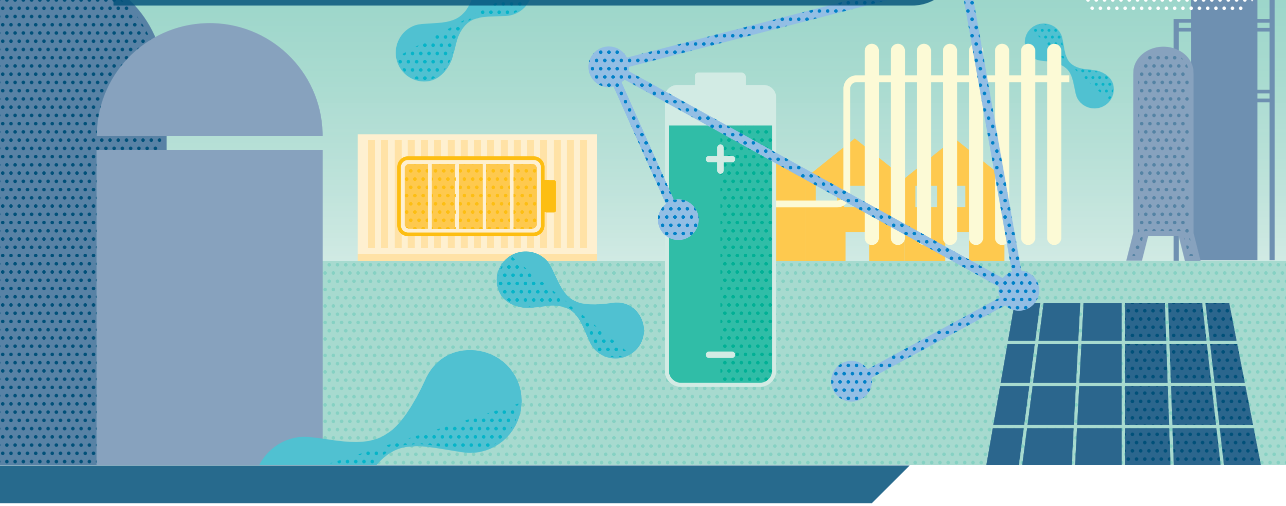
Energy storage – but how?

Ensuring a reliable energy supply with the right storage mix



Achieving a climate-neutral future requires energy storage.

At a glance

- Life as we know it would not be possible without energy. To ensure that energy is available whenever it is needed, energy storage systems are essential.
- With the energy transition, storage becomes even more important, as renewable power is weather dependent and not always generated when it is needed.
- To ensure a reliable supply, we need short-term storage, such as batteries and buffer storage systems, as well as long-term storage to balance seasonal fluctuations.
- Existing underground gas storage facilities are unmatched in terms of storage duration and capacity. They can be converted to store hydrogen but such conversions can take up to ten years.
- A rapid and targeted expansion of storage capacity is essential for creating a stable and resilient energy system.

Security of supply: the foundation of a stable energy system

A key objective of energy policy is security of energy supply. This means ensuring that households, industry and critical infrastructure have access to sufficient energy at all times, regardless of weather conditions, geopolitical crises or market fluctuations. Otherwise, serious consequences could arise, including cold homes, production shutdowns and economic damage.

Storage facilities are essential

To ensure energy security, energy reserves must be available and accessible whenever needed. This is particularly important on cold winter days, when energy demand increases due to heating requirements. Today, energy is stored primarily as natural gas in large underground storage facilities. These facilities help balance fluctuations in consumption and ensure a reliable energy supply even during periods of peak demand.

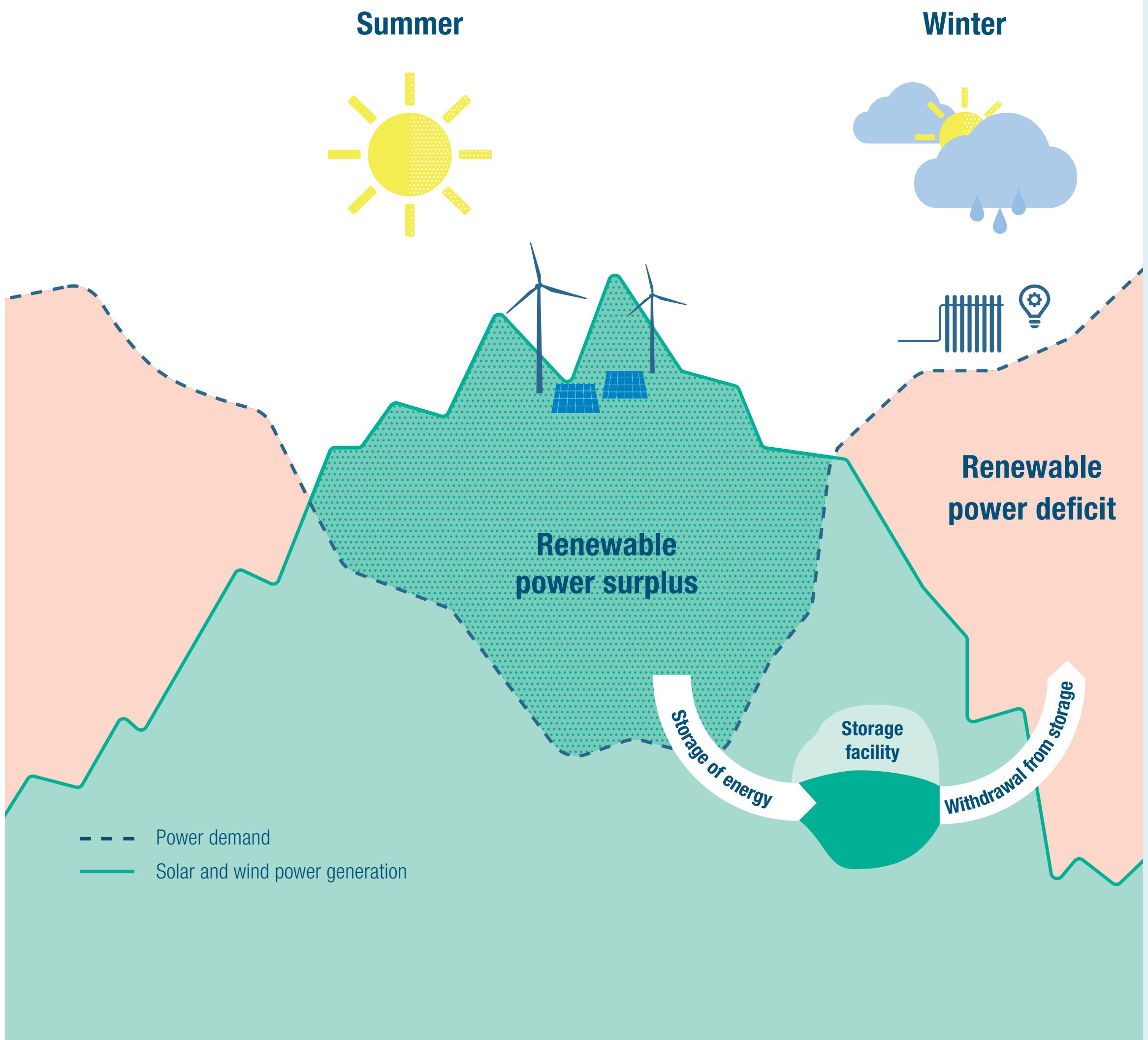
In 2024, about 9 TWh of renewable power were lost through curtailment – that's equivalent to Germany's electricity consumption for an entire week.

The energy transition is changing storage requirements

As renewable energy generation expands, energy storage becomes increasingly important. This is because green electricity is available when the sun is shining or the wind is blowing, but not necessarily when it is needed – for example, on a cold, overcast and windless winter day.

In addition, wind turbines and photovoltaic systems are currently often curtailed. This means, they are temporarily disconnected from the grid when they generate more electricity than the system can accommodate. While this helps maintain grid stability, it also means that large amounts of renewable energy are lost. Storage systems can help capture and preserve this energy.

Energy storage facilities are essential for providing flexibility and ensuring a stable, resilient energy system.



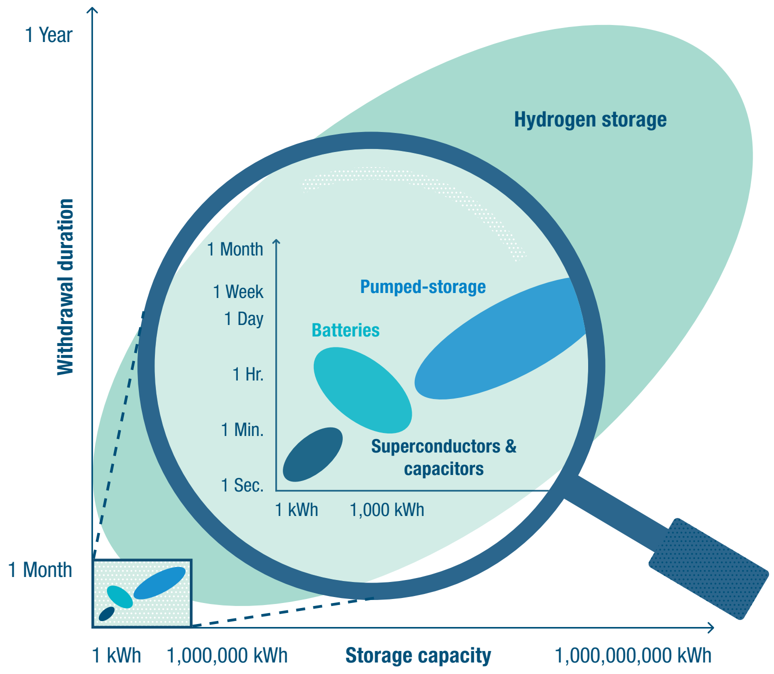
How can electricity be stored?

So far, electric power can be stored directly only for relatively short periods in capacitors or superconducting magnetic coils. To store electricity for longer durations, it must first be converted into another form of energy. Several technologies are available for this purpose.

The most widespread solution are **batteries.** Batteries store energy in electrochemical form and can convert it back into electricity very quickly. This makes them ideal for balancing short-term fluctuations in electricity supply and demand. However, the amount of energy they can store is limited. Although large-scale battery storage facilities are expected to grow significantly in the coming years due to technological advances and falling costs, they require considerable space and their storage capacity remains limited. Germany's largest planned battery storage facility is expected to have a storage capacity of 1.6 GWh. This would be sufficient to supply a city like Berlin for an hour. The facility is planned to occupy around 10 hectares, roughly equivalent to 14 football pitches.

Another established technology is **pumped-storage hydropower.** Excess electricity is used to pump water from a lower reservoir to a higher one. When electricity is needed, the water flows back down, driving a turbine connected to a generator that produces electricity. Germany has around 30 pumped-storage power plants with a combined storage capacity of approximately 24 GWh and a power output of about 10 GW. In theory, they could meet Germany's entire electricity demand for roughly half an hour.

New approaches apply the same principle used in pumped-storage facilities – a height difference and a storage medium that is moved upward when surplus energy is available – to other storage media. One example is **Underground Gravity Energy Storage,** where sand or water is lowered in disused mines to drive generators and generate electricity. In other concepts, weights such as concrete blocks are moved upwards when surplus power is available and lowered to drive generators when power is needed.



Storage capacity of different energy types and technologies

Batteries and pumped-storage systems are both short-term storage solutions. They can absorb and release energy several times per day and contribute to grid stability. However, they cannot store enough energy to accommodate seasonal fluctuations and to ensure energy security.

Thermal storage facilities store power in the form of heat energy and are mainly suited for heating applications.

Long-term storage balances seasonal fluctuations

To balance seasonal fluctuations in energy generation and demand, solutions are needed that can retain energy for weeks or even months. One option is **power-to-gas technology**, which converts surplus renewable electricity into hydrogen. Through the gas grid, hydrogen is injected into underground storage facilities. Following withdrawal, hydrogen can either be used directly or converted back into electricity in power plants. In this way, power-to-gas plays a crucial role in sector coupling.

Cavern storage facilities

29 facilities in Germany

155 TWh

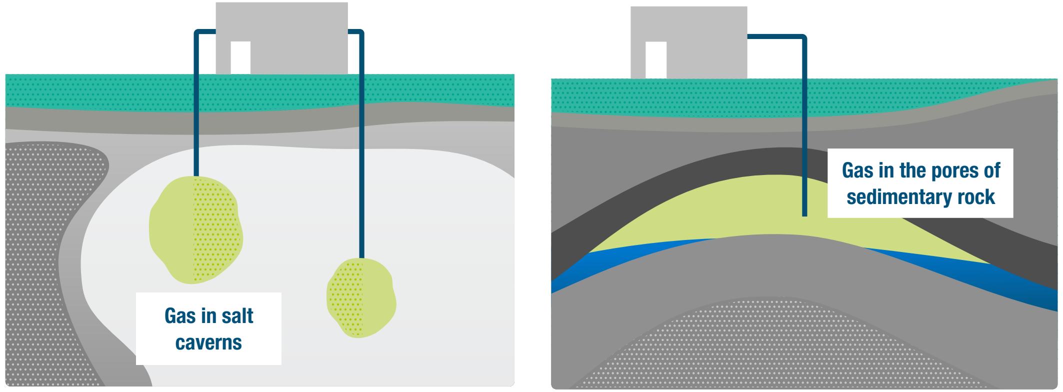
62 % of current capacity

Porous storage facilities

14 facilities in Germany

95 TWh

38 % of current capacity

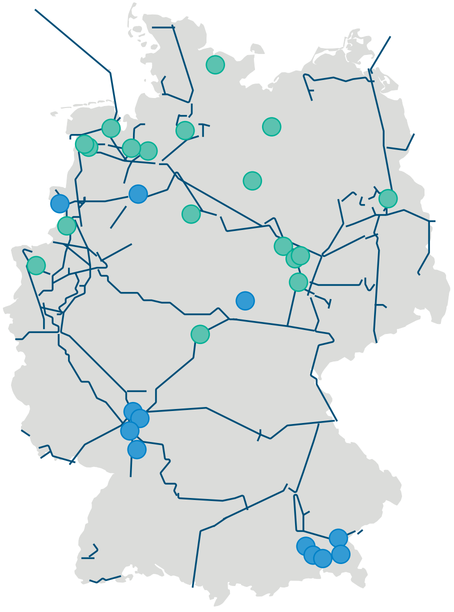


Schematic diagram of underground storage facilities for natural gas
Source: DVGW

Although conversion losses make hydrogen storage less efficient than some other storage technologies, it allows the storage of much larger quantities of energy for much longer periods of time.

With a storage capacity of around 250 TWh, Germany has the largest natural gas storage capacity in the EU, which could potentially also be used for hydrogen storage. These capacities are distributed across 29 cavern storage facilities, where gas is stored in cavities within salt formations, and 14 porous rock storage facilities, where gas is stored in rock pores. Cavern storage facilities can generally be converted for hydrogen storage. Porous rock storage facilities can also be converted but each site has to be individually assessed.

Many of Germany's existing storage facilities are strategically located near planned hydrogen import and production hubs, industrial regions with high hydrogen demand and along the planned hydrogen core network.



250 TWh
Current natural gas storage capacity

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50 TWh
Potential storage capacity for hydrogen

Storage capacities

- Cavern storage facilities
- Porous storage facilities
- Planned hydrogen core network (as of 10/2024)

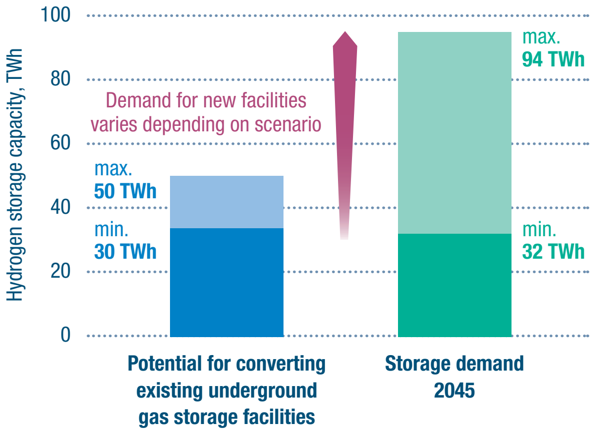
Source: DVGW, based on information provided by Landesamt für Bergbau, Energie und Geologie (LBEG)

To accelerate the development of hydrogen storage, existing natural gas storage facilities should be converted.

Demand for hydrogen storage

The amount of hydrogen storage required in the future will depend on how hydrogen demand develops relative to electricity demand. However, almost all studies conclude that hydrogen storage capacity will be needed, even in a fully electrified energy system.

Even if all the existing natural gas storage facilities were converted to hydrogen, new hydrogen storage facilities would still be needed.



Source: DVGW, based on various scenarios

In that case, hydrogen storage would mainly be used for power generation and to safeguard the significantly higher power demand.

Even if all existing natural gas storage facilities were converted to hydrogen, their capacity would still be insufficient. The reason is hydrogen's lower energy density, which reduces the effective storage capacity of a facility to around one-fifth of its natural gas capacity. In other words, storing the same amount of energy requires approximately five times more storage capacity.

Germany offers favourable geological conditions for the development of new cavern storage facilities, particularly in the North German Basin and beneath the North Sea. The technical potential is very high but is limited by legal and economic factors. At the same time, uncertainties remain regarding future hydrogen storage demand, as well as the development of hydrogen prices and storage tariffs. These uncertainties create significant investment risks.

Conversions and new construction take time

Both, developing a new storage facility, as well as converting an existing facility takes considerable time. Building a new cavern storage facility typically requires around eleven years, while a new porous rock storage facility takes about ten years. Converting existing storage facilities generally takes between six and eight years.

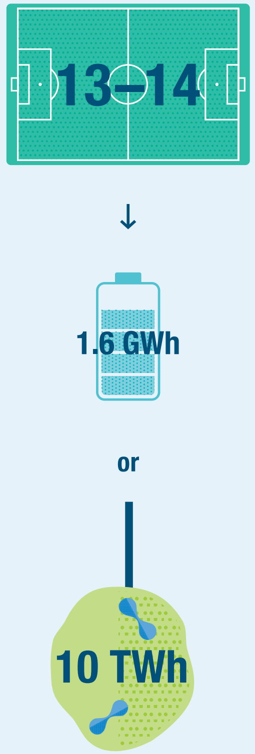
Underground hydrogen storage facilities require significantly less surface area than battery storage systems. Current pilot facilities can store 4.2 GWh of energy on just 4,000 square metres – roughly half the size of a football pitch. At industrial scale, this advantage becomes even more pronounced: porous rock storage facilities can hold around 10 TWh of energy while requiring only 9 hectares of surface area. This corresponds to approximately 7,000 times the amount of energy that a large-scale battery storage facility could store on the same space.

A rapid and targeted expansion of hydrogen storage capacity is essential for a stable and resilient energy system.

To ensure that underground storage facilities are available when hydrogen demand grows, planning must begin now. It is important that:

- Permits for existing gas storage facilities remain valid when they are converted to hydrogen, as this accelerates the process.
- Financing mechanisms for the development of hydrogen storage are introduced to reduce risks and encourage investment.
- Regulatory gaps are closed.

Energy storage is crucial for a reliable and climate-neutral energy supply. Storage systems balance fluctuations in energy generation and demand and are a fundamental enabler of the energy transition. Without storage – whether batteries, hydrogen or other technologies – a secure energy future based on renewable energy sources cannot be achieved.



Using a similar surface area, battery storage systems can store approximately 1.6 GWh of energy, while hydrogen storage facilities can hold up to 10 TWh.

The first hydrogen storage facilities are taking shape

Germany's first commercial hydrogen storage facility is being developed at Gronau-Epe in North Rhine Westphalia. RWE is converting two huge salt caverns, about as large as Cologne Cathedral, for hydrogen storage. With an injection and withdrawal capacity of 50,000 m^3 per hour, this storage facility will help balance fluctuating hydrogen production from wind and solar power and ensure a reliable supply for energy-intensive industries.

This site is part of the GET H2 initiative and will be connected to the core hydrogen network. Filling of the storage caverns with green hydrogen from Lingen is scheduled to begin in mid-2026, with commercial operations expected to start in mid-2027. Around 70 percent of the storage capacity has already been allocated, with the remaining 30 percent becoming available from 2028 onwards.

Further information on the project:

"With the storage facility in Epe, we are laying the foundation for a secure hydrogen supply. It is a key enabler for making renewable energy available when needed and for supporting the industry's transition to climate neutrality."

Sandra Hüttemann
Project Manager, RWE Gas Storage West GmbH

RAG Austria's Underground Sun Storage (located in Gampern, Upper Austria) is the world's first porous storage facility that will store 100 % hydrogen. During the summer months, surplus solar electricity is converted into hydrogen through electrolysis and injected into a porous sandstone formation more than 1,000 metres below the ground. The countless microscopic pores within the sandstone act like a natural sponge, absorbing the hydrogen. Overlying impermeable rock layers ensure that the gas remains safely contained underground over the long term. The facility has a total storage capacity of approximately 43.5 GWh, equivalent to the summer electricity surplus generated by around 1,000 rooftop photovoltaic systems on single-family homes.

"Seasonal natural gas storage facilities are the backbone of energy security in Central Europe today. In the future, surplus electricity from solar, wind and hydropower can be preserved for use during the winter months, making it possible to provide green energy all year round."

Stephan Bauer
Head of Green Gas Technologies, RAG Austria

The project demonstrates the potential of porous storage reservoirs for large-scale, safe and long-term energy storage, thereby helping to strengthen energy security as the energy transition progresses. Over the next few years, RAG Austria intends to forge ahead with this technology in the follow-up project EUH2STARS and other upscaled projects.

Further information on the project:

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Hydrogen is set to play a central role in achieving climate neutrality and driving Germany's energy transition. For more than a decade, DVGW has engaged in hydrogen research and innovation. Our research institutes are working on numerous projects to advance the production, transport, distribution and application of hydrogen. In addition, many of the DVGW codes of practice have already been adapted to cover hydrogen.

With “DVGW Wissenswert”, we present this expertise in a compact and accessible format. We explain current research findings, technological developments and regulatory frameworks across the energy and water sectors. If you are interested in the latest developments in renewable gases and water, you can find the information here – in brochures, short studies, webinars, fact sheets and audio or video features.

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Source

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Edited by:
DVGW Deutscher Verein des Gas- und Wasserfaches e.V.
Technisch-wissenschaftlicher Verein
Josef-Wirmer-Straße 1-3, 53123 Bonn
Germany

Phone: +49 228 9188 5
Email: info@dvgw.de
www.dvgw.de

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