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THE MOST BEAUTIFUL BATTERIES IN THE WORLD

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THE MOST BEAUTIFUL BATTERIES IN THE WORLD

Of all the large-scale storage technologies, pumped storage is the one that has by far the greatest share of electricity storage capacities in the world. Fast, flexible, highly efficient, versatile, powerful, durable and sustainable, pumped storage is the heptathlete of the energy system. In addition to providing demand-based storage of electrical energy in large quantities, it masters the entire range of system services. It ensures stable power grids and thus security of supply. To make full use of its strengths in an increasingly de-carbonized energy system, pumped storage must no longer be limited in its ability to pro-vide services to the system.

Pumped storage: The large water batteries

Pumped storage refers to mechanical storage systems that use water and gravity to store electrical energy. If there is excess electricity in the system, for example during high generation of renewable energy, water is pumped from a valley basin (lower reservoir) to a higher mountain basin (upper reservoir). When electricity is needed, water flows from the mountain basin back into the valley basin. In this process, the stored energy is recovered by turbines. The greater the drop height and usable volume of water, the greater the performance capacity of the storage system. Machines for pumps and turbines are usually located between the two basins, mostly in underground halls. The degree of efficiency for pumped storage is up to 88 percent in pump or turbine mode. This results in a so-called "cycle efficiency" – the entire cycle of pumps and turbines or charging and discharging – of up to 80% at its peak. The low-efficiency losses make them highly efficient.

Pumped storage: Great past, even greater future

The first operational pumped storage systems in Germany are approaching their 100-year anniversary and have been in continuous operation since they were commissioned. This shows that the technology is built to last. With regular maintenance and servicing, their lifespan is virtually unlimited. This means that the ratio of resource use in their construction, operation and effectiveness is outstanding. The long use of raw materials ensures an excellent eco-balance. The long service life is also advantageous in terms of cost. Pumped storage facilities with a total output of more than six gigawatts are currently installed in Germany. Most of these facilities can continuously feed energy into the supply system for four to eight hours under full load conditions. The installed power of the individual pumped storage systems ranges from the megawatt to the gigawatt class, such as in the facilities in Goldisthal/Thuringia (1.06 GW) and Markersbach/Saxony (1.05 GW). This is supplemented by facilities near the German border in Luxembourg and Austria that provide flexibility for the German energy system. Depending on their design, they contain much higher energy volumes and are therefore also used as weekly and annual storage. Including the facilities near the border, pumped storage systems with a total power of about nine gigawatts contribute to the flexibility and stability of the German electricity systems.

Pumped storage: Long-established players – with new tasks

In the past, the facilities mainly stored electricity at night and on the weekend and fed it back into the grid at midday. Today, the primary role of pumped storage is to balance out renewable generation, thus keeping the electricity system reliable and secure. With the goal of 100% renewable energies, this task becomes hugely more important.

The production of energy from wind and sun fluctuates with the weather conditions. Wind blows inconsistently, the light conditions change with the sun and clouds and during the day. This development in the energy system has also changed how it functions, so that pumped storage is now operated with high flexibility and can quickly respond to the fluctuating energy generation.

The public utility **Stadtwerke Trier** is planning a pumped storage facility called "PSKW Rio" – the name refers to the climate protection conference that kicked off worldwide climate protection in Rio de Janeiro in 1992. This project aims to balance the electricity consumption of the entire region with the planned pumped storage facility and to create the possibility of realizing a regional energy concept based on 100% renewable energy. The plan is to store regional renewable generation directly in the region without long transmission lines so it can be provided as needed.

Pumped storage: Sprinter and power athlete

From zero to one hundred in 90 seconds: This is how long it takes for modern pumped storage systems to ramp up to their full power of up to 1,000 megawatts available to the electricity system after a standstill. In a partial load operation, it even takes only a few seconds. It barely takes any longer to switch from full pumping mode to full turbine mode. The speed and efficiency of pumped storage systems make the rapid changes in renewable generation manageable and offer an option for replacing fossil fuel power plants. The German Federal Network Agency expects that the challenges caused by load cycles will drastically increase in the coming years. It estimates that in 2025, there will be about 420 events in which output changes of at least 20 gigawatts need to be managed. According to the Federal Network Agency, output changes of at least 30 gigawatts will also happen daily [1]. The increasing absolute forecast errors for the feed-in of renewable energies in the course of further wind and PV systems expansions are another challenge.

A study by RWTH Aachen University for Voith Hydro concludes that absolute forecast errors – despite improved prediction models – will increase to 2.5 times the 2012 value in 2033 [2]. This means that in numerous situations in Germany, there will be a significant short-term deviation of several gigawatts in the actual renewable generation compared to the expected one, which will have to be compensated by flexible systems such as energy storage facilities.

A high wind power production of over 9,300 megawatts continues to occur in the transmission network of the grid operator 50Hertz. On March 28, 2012, however, a malfunction caused the failure of the 380 kV **Wolmirstedt-Helmstedt** line. Since there was an unplanned shutdown of a major power plant at the same time, the north-south power lines were abruptly overloaded and posed the risk of a blackout. The Markersbach and Goldisthal pumped storage systems switched from turbine (2,400 MW) to pump operation (1,400 MW) within minutes. This immediately relieved the power grids; they were able to stabilize, and a blackout was averted.

Pumped storage: Life insurance for the energy system

To keep the grids stable even in times of volatile renewables, many different capabilities are called for. The indispensable grid helpers are grouped under the keyword "***ancillary services***". They run in the background of the grid operation, monitor it and balance the grids.
Until now, large-scale ancillary services were provided by coal, gas or nuclear power plants. In the future, these tasks must be handled in a renewable way. Pumped storage systems are so flexible that in addition to providing renewable energies as needed, they can provide these tasks for our electricity systems.

The electricity supply in Europe and especially in Germany is distinguished by its **security of supply**. But still, our energy system is not exempt from large-scale disruptions. On January 8, 2021, Europe's electricity grid was on the verge of collapse. Outages in power generated in Romania led to a shortfall in the grid. Then the southeastern European grid was disconnected from the rest of the grid and only resynchronized after an hour. As a result, the system was successfully stabilized again in this case. Calculated for Germany, each hour of a complete power blackout would cost between 200 and 600 million euros, depending on the time of day [3]. During disruptions and even in the event of a blackout, pumped storage systems can reestablish the grid and restart the energy system thanks to their **black start ability**. This is just one of many ancillary services that pumped storage can provide for the energy system.

Pumped storage: Innovative and smart into the future

Pumped storage systems are based on proven, robust and reliable technology. At the same time, there is still a lot of potential for development – not only to keep pace with the far-reaching transformation of the energy system but also to play a key role in enabling it in the first place. Germany is predestined to leverage this development potential since it can draw on many years of experience with the technology, while it is also a base for technological developments of turbines and power electronics.

Top to bottom:
Naturspeicher Gaildorf,
concept for pumped storage PSKW Rio,
PV-plant/ pumped storage Markersbach,
battery storage and pumped storage Pfreimd
(Image credits)

Technical progress and innovations

Variable-speed machines are an example of these developments. They can be used to individually and continuously adjust not only the power production in turbine operation but also the pumping power to the current demand. This makes it possible to take electricity from the grid very flexibly as soon as short-term surpluses arise. They are the optimal complement for the integration of fluctuating renewable energies.

In the next development step, **digitalization** plays an important role. It will increase flexibility and further reduce costs. In doing this, direct combinations of pumped storage systems with renewable energies are moving center stage.

Vattenfall has built two solar parks with a power of nearly seven megawatts on the upper basins of the pumped storage facilities at Markersbach and Geesthacht. Digital combinations of various storage technologies (pumped storage with batteries or chemical storage) are also in the planning stage.

In May 2018, **ENGIE Deutschland** already added a battery storage facility with a power of 12 megawatts to the existing pumped storage facility on the Pfreimd River. By pooling both plants, ENGIE is optimizing the provision of fast balancing energy.

The fact that the world of hydropower is in fundamental harmony with chemical storage is demonstrated by **Energiedienstholding** with its NaturEnergie hydropower plants on the High Rhine, where hydrogen is produced in Wyhlen as part of a research project. The waste heat generated during the electrolysis is used for the heating supply of the adjacent residential area.

At the Naturspeicher Gaildorf storage facility near Stuttgart, the **Max Bögl Group** is combining wind turbines with pumped storage. Here the base of the wind turbines is used as the “upper basin” (see image 1); the tower foundation can be filled with water up to a height of 31 meters. The storage capacity of the four wind turbines is about 70 megawatt hours. The powerhouse is in the valley of the Kocher River. A flood basin that was planned in any case serves as the lower basin. The power of the pumped storage facility is 16 MW.

Specific **research projects** address the use of unconventional sites: Former underground mines, pumped storage offshore near coasts, artificial lagoons and more.

BLACK START ABILITY	In case of a blackout, pumped storage systems can also be put into operation without external power supplies, thus enabling **recovery of the grid**. Conventional power plants need a lot of energy from the grid to restart production after a blackout. Pumped storage thus plays a fundamental role in recovering the grid, by creating functioning subgrids that are incrementally reconnected into larger grid areas. They can also be relied on in an emergency case.
ROTATING INERTIA	Large rotating masses reliably **balance out minor fluctuations in grid frequency**. These are created by imbalances whose causes lie in unpredictable minor deviations from the forecasts regarding generation and consumption. In the past, this did not seem particularly volatile because nearly all generating plants were equipped with synchronous machines. The decommissioning of conventional power plants and strong addition of wind and PV facilities has led to the installation of more and more generating plants without this kind of kinetic buffer. As a result, the total rotating inertia for the electrical grid is reduced. Pumped storage can provide this rotating inertia function.
FREQUENCY STABILITY	The AC (alternating current) grids in Europe are operated with a **frequency of 50 Hertz**. The fluctuations of this frequency must stay within narrow bandwidths, otherwise, there is a risk of grid disruptions, including large-scale blackouts in extreme cases. Production and demand of electricity must always be in balance to preserve frequency stability. Grid operators compensate for unforeseen deviations by balancing energy. Various products are available for this, e.g. primary regulation, secondary regulation and minute reserve. They differ in terms of the speed at which they are available and the duration they must cover. All of these can be provided by pumped storage.
VOLTAGE STABILITY	To reliably transport electrical energy, the grids must be kept in a specific voltage range. Depending on the grid level, it differs between transmission networks, the regional and the local networks. Voltage fluctuations can result in severe damage to electrical devices and machines. Maintaining the **voltage at a constant level** is a demanding task. This is because the load flows in the grids change quickly and with large swings due to the volatile feed and consumption of the renewables and the growing international electricity trade.
REACTIVE POWER CONTROL	This refers to power that is needed to build up electric fields without contributing to usable output. Reactive power is an indispensable element in voltage stability. Pumped storage systems can provide reactive power very flexibly in addition to the active power generation and absorption, in pumping as well as in turbine operation. There is also the option of **synchronous condenser operation mode**, a type of operation exclusively for the supply of reactive power and inertia reserve by means of the rotating masses.

Pumped storage: Cutting-edge technology made in Germany

Germany is the technology leader for turbines and digital design of local plants. With **Andritz Hydro** and **Voith Hydro**, two world leaders in hydropower and pumped storage are at home in Germany. Both maintain production facilities in Germany – with many hundreds of employees and research facilities. A sustainable market for the construction and maintenance of pumped

storage facilities in Germany is an important calling card for success in the global market, which makes it significant for the long-term preservation of Germany as a production site.
Utilizing our technology developments and demonstrating the flexibility of modern pumped storage systems on site would not only be an added value for our energy system, it would also set an important signal to the booming world market. Germany should not miss this opportunity, because many things would also be possible and useful on the domestic market.

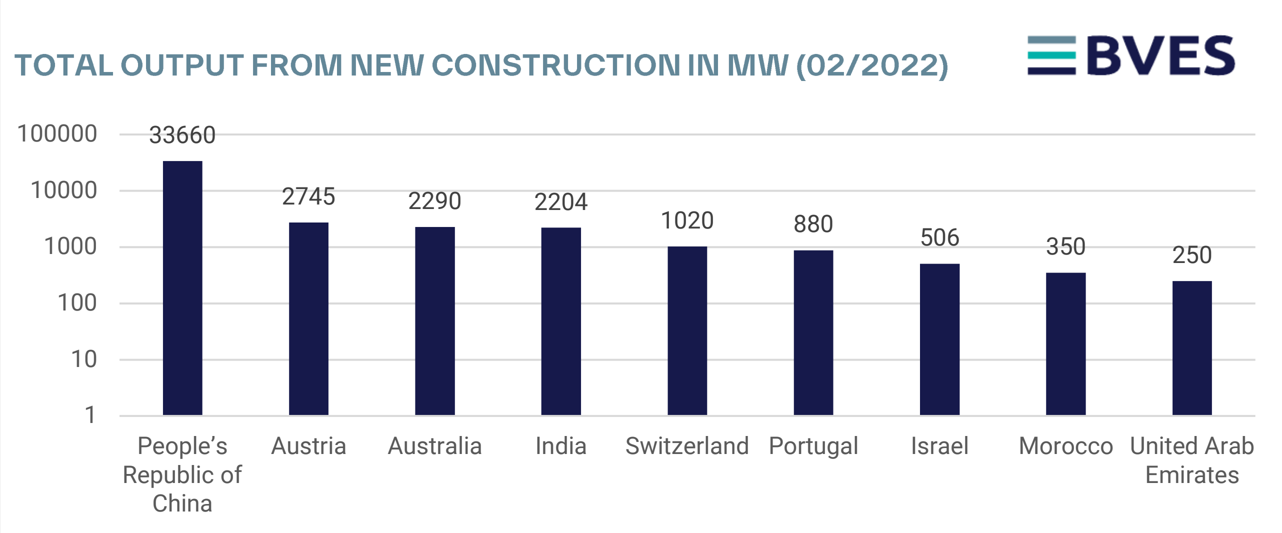
NEW CONSTRUCTION POTENTIAL FOR PUMPED STORAGE [4]

COUNTRY/ STATE	Number of potential sites	Installed power [GW]	Installed capacity [GWh]
Germany / Baden-Wuerttemberg	> 13	> 19	n.a.
Germany / Bavaria	16	11	66
Germany / Lower Saxony	83	19,6	98,2
Germany / North Rhine-Westphalia	27	9,4	56
Germany / Thuringia	13	5,5	44
Austria	n.a.	6 GW (planned)	n.a.
Italy	> 300	n.a.	> 1.800
Switzerland	15 (Storage hydropower projects)	n.a.	2.000
EU-wide	> 2.400	n.a.	> 12.000

Baden-Wuerttemberg, North Rhine-Westphalia, Thuringia and Bavaria each investigated the potential for expanding pumped storage systems in their states. Sufficient sites for new facilities are available in Germany as well as the entire DAICH region. Vattenfall Wasserkraft is now considering the construction of a new pumped storage facility Leutenberg/Probstzella, Thuringia, Germany with installed power of 400 MW. This could in the future become a valuable element in the stabilization and decarbonization of our energy system by providing the necessary flexibility.

Pumped storage: Globally needed

With the rapid worldwide expansion of wind power and solar energy, the global demand for pumped storage is also growing. In China alone, a total of 23 pumped storage facilities with a total capacity of 33.7 GW were ordered between 2015 and 2021. The International Energy Agency IEA is projecting the strongest decade of growth in history for pumped storage on international markets in the years up to 2030. According to this prediction, another 65 GW of pumped storage will be realized worldwide [5]. The storage capacity from new projects is expected to increase by 7 percent to 9 TWh (terawatt hours) by the end of the decade. When combined with the further development of existing plants (+ 3.3 TWh), pumped storage, ahead of battery storage, remains the most important storage technology by far.



Best practice examples of pumped storage worldwide

Portugal: In March 2018, Portugal was able to cover 100 percent of its electricity needs for several days with wind and hydropower for the first time. What is still an exception today should be commonplace in the future. However, the country's connection to the European power grid is in poor shape. To balance and integrate renewables into the electricity system, Portugal is relying on pumped storage. In March 2017, Voith Hydro (Heidenheim) commissioned Frades II, the most modern pumped storage facility up to that date – due to its variable-speed operation – in northwestern Portugal. More facilities are on the way. The second global market leader with production facilities in Germany – Andritz Hydro (Ravensburg) – also received orders in Portugal, such as for the construction of the Gouvães pumped storage facility near Porto and for the Foz Tua project.

Spain: The small Canary Island El Hierro, which has barely 10,000 residents, leads the charge: Away from diesel generators to wind energy. A small pumped storage facility with 11.3 MW helps supply a seawater desalination plant and contributes at times when there is no wind.

Australia: In the Kidston hybrid project in Queensland, solar energy will be combined with a pumped storage facility from Andritz in a former gold mine. A 50 MW solar energy system was built in the first construction stage. A second construction stage will complete a second solar power plant with a capacity of 270 MW and a 250 MW pumped storage facility. This will make it possible to supply about 170,000 households in Queensland reliably, securely and as needed with electricity from photovoltaics. In 2019, Voith Hydro received the order to supply the electromechanical equipment for the Snowy 2.0 pumped storage facility. This is a pumped storage system with an output of 2 GW and 350 GWh of storage capacity. Three variable-speed units will be installed in addition to three fixed-speed units. The upper and lower basins are existing reservoirs and when the pumped storage facility is completed, their large volumes could make numerous existing and future wind and solar farms nearly base-load capable.

Pumped storage: Sprinters with political handicaps

Even the best sprinters won't win any races if they are put in chains. However, figuratively speaking, this is the political situation for pumped storage in Germany.

Planning and approval processes: Under the current planning and approval law, the new construction and expansion of pumped storage facilities is almost unfeasible. Projects that were still planned in 2016 with a total output of 4.4 GW and storage capacity of 40.6 GWh have mostly been discontinued since then. The inclusion of environmental and water laws along with countless other permit law requirements is delaying the approval of these projects by up to ten years and already costing high amounts in the millions. At the same time, no legal or investment security is provided. The multilayered processes and complexities are pushing permit authorities to their limits. The relevance of the facilities to the system must be given greater consideration. A uniform approval process under energy law is needed: One that is leaner and faster but not weaker when it comes to protecting the environment and nature.

Implementation of the energy storage definition: To enable upgrades of the storage systems, an appropriate, independent regulatory system must be established. Now that there is a storage definition established in Germany, analogue to the definition in the European Electricity Market Design Directive, concrete conclusions must be drawn from this within the planned storage strategy by the federal government. Due to their role as a temporal shift of energy consumption, energy storage must be considered differently from generation and consumption and market entry must not be impeded. An unlimited exemption from network charges would make sense since there is an undeniable benefit for network stability.

Remuneration of system services: The need for system services is increasing in conjunction with the energy transition. Pumped storage systems are ideally positioned to provide these. To ensure that what the system needs tomorrow can be provided, it must be remunerated accordingly. A fair and clear market regulation is needed for the provision and remuneration of these services. A transparent system and clear remuneration benefit the entire power supply system.

Pumped storage is currently the large-scale storage technology that is proven on a long-term basis, reliable and still cost-efficient, offering high market potential. The first systems have now been in operation for nearly 100 years. The long service life of the facilities is an advantage not only from a cost perspective but also considering the use of resources. With their new role in the necessary development towards a stable green future, they are becoming multi-talents for system stability and security of supply. As a partner to renewable energies, pumped storage opens the door to a stable, green energy future around the clock. This applies to the existing facilities as much as to possible new constructions, for which there is great potential. Policymakers are called on to provide a fitted regulatory framework for energy storage including pumped storage for a successful energy transition and a more independent energy system.

UNITS, DEFINITIONS AND ABBREVIATIONS

Megawatt (MW) = 1,000 kilowatt (kW)
Gigawatt (GW) = 1000 MW = 1,000,000 kW
Terawatt (TW) = 1,000 GW = 1,000,000 MW = 1,000,000,000 kW
Storage capacity = maximum amount of energy that can be stored with a full charge, unit: MWh
Nominal power = maximum power that can be provided during proper operation without time restriction and without impairing the service life and security, unit: MW, GW, TW (see above)

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IMAGE CREDITS

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