Compressed and liquid air for long duration & high capacity

Variable and non-programmable renewable energy is making an increasing contribution to power generation. In parallel, 'electrification of everything' is a fundamental mantra of decarbonisation. These drivers combine to mean that long-term, high-capacity energy storage will become essential to balance supply and demand on the power transmission grid

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At present, pumped hydro is the highest capacity power storage technology. Much has been said about the use of lithium-ion batteries for power storage, but the timescale over which they can be depleted is relatively short and between 4 and 8 hours. This is not sufficient to support many requirements, such as continuous power delivery from a solar farm.

Liquid air energy storage (LAES) involves compression and liquefaction of air for mid-term storage. The stored cryogen is pumped, vaporised, and released through a turbine to generate power as required.

The world's first LAES demonstration plant was built by Highview Power at the Pilsworth landfill waste management site close to Manchester in the UK and commenced operation in 2018. Highview Power has since announced two commercial scale units for Vermont in the USA and Carrington in the UK. Each will have the capability to generate 50 MW of power and will have energy storage capacity exceeding 250 MWh equivalent to five hours of continuous discharge.

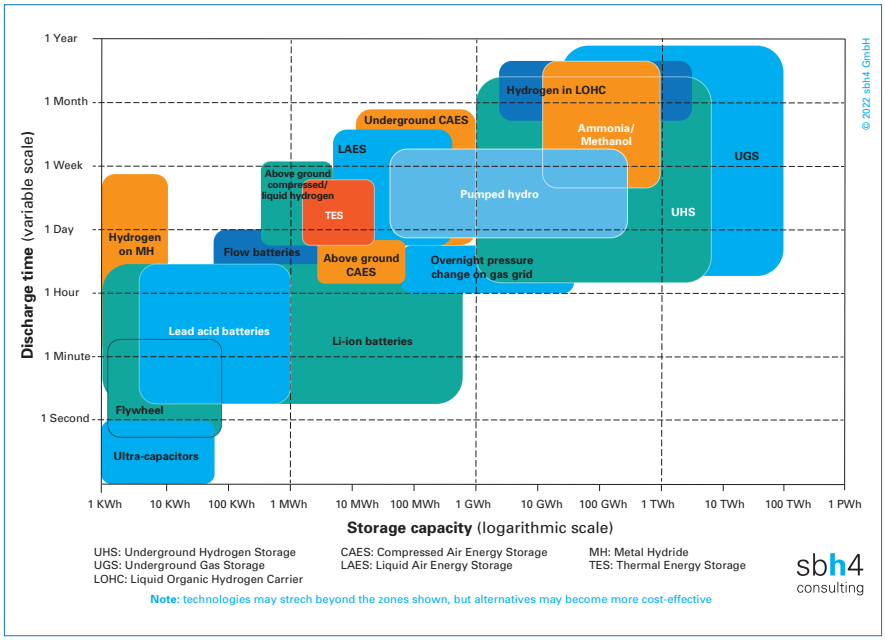
The start-up time of a LAES system cannot compete with ultra-capacitors or batteries, which react within milliseconds or seconds. However, the Highview Power plants can ramp up to be fully operational within less than 10 minutes from a "cold-start" or only a few minutes from a "warm-start".

Compressed air energy storage (CAES) works in a similar way to LAES, but instead of the air being converted to a liquid, it is contained in a large underground storage cavern. When the electricity grid needs a power top-up, the high-pressure air is released through a turbine to generate power.

CAES was first implemented at scale in Germany more than 40 years ago. The Huntorf CAES facility was constructed in 1978. Since then, CAES has evolved to integrate thermal energy storage to eliminate natural gas usage in the system and improve the overall cycle efficiency.

The LAES compression, liquefaction, vaporisation and expansion cycle

Within the LAES cycle, there are four requirements for high-speed rotating machinery. The first step is to compress air to around 15 bar. A 4-stage centrifugal compressor, as might be used as the main air compressor on an air separation unit, would be ideal. A second 2- or 3-stage centrifugal air compressor then boosts the main inlet air to around 60 bar. Liquefaction of the air is then achieved using an expansion turbine.



Above: **Energy storage technologies: capacities and discharge times compared** (source: sbh4 GmbH)

Power generation is achieved by pumping the liquid air to around 160 bar pressure and then vaporising it against ambient air. The resultant high pressure air is expanded on a power generation turbine.

The selection of the expansion turbine depends on the size of the LAES facility. Up to around 20 MW calls for a multistage radial expansion turbine rotating at speeds of up to 10 000 rpm. Such turbines have been used for many years for energy recovery in natural gas pipeline let-down stations and non-condensing axial steam turbines.

For larger liquid air energy storage facilities, an axial turbo expander would be more appropriate.

These machines can be direct coupled to the synchronous generator and can run at a synchronous speed (3000 or 3600 rpm), without the need for a gearbox.

Huntorf: gas-fired peaker with integrated CAES

50 years ago, the introduction of pipeline natural gas supplies and LNG imports gave rise to the concept of gas-fired power generation to meet peaks in demand. In contrast to nuclear power or coal fired generation, gas fired power plants can start up from cold very quickly. In Europe, North America and Asia many open circuit and closed circuit gas-fired power plants were built to balance regional power grids.

The combustion turbine on a gas-fired power plant operates at a pressure of around 30 bar. About 65% of the energy produced by burning natural gas is used to compress the combustion air up to the operating pressure. The compression energy requirement is parasitic to the overall system efficiency. This issue seeded the idea of using stored compressed air to mix with natural gas to avoid the air-compression energy losses during power generation.

Huntorf power plant followed this design concept. The wide spread between power prices during peak and off-peak periods was deemed sufficient to justify investment in such technology. During periods of low demand on

the grid, low-cost power is used to compress air into two underground salt caverns. When power generation is required and high prices can be achieved, the compressed air is released and blended with natural gas in the turbine to generate up to 321 MW of power. Start up from cold to 50% generation capacity can be achieved within three minutes, with full capacity reached after seven minutes.

The expansion turbines at Huntorf were manufactured by ABB. The high-pressure turbine is like a steam expansion turbine in a thermal power plant and the low-pressure unit is a typical gas fired power generation turbine.

Underground salt cavern storage for CAES, hydrogen and natural gas

Salt caverns are man-made cavities in naturally occurring salt deposits below ground and are created using a technique called 'solution mining'. During this process, a bore hole is drilled from the surface to the underground salt layer and water is then injected to dissolve the rock salts. When the cavern reaches the desired volume, gas is injected to displace the brine.

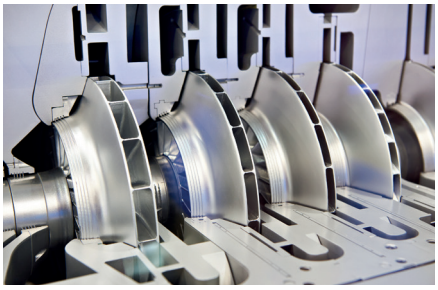
Underground geological salt formations in northern Germany allowed the creation of salt caverns for air storage at Huntorf. The two Huntorf caverns are 140 000 and 170 000 cubic metres in capacity. The tops of the caverns are 650 m below the surface of the earth. They are about 150 m tall and up to 60 m wide. To prevent geological shifts, they have a minimum operational pressure of 20 bar. However, the normal duty cycle is between 43 and 70 bar. The amount of air released during decompression can operate the turbine for about three hours.

Underground storage of hydrogen (UHS) in salt caverns is effective when terawatt hours of energy storage is required for release on a seasonal basis. Whilst UHS in salt caverns offers low-cost, low-carbon, seasonal energy storage at utility scale, it has a low round-trip efficiency (MW power required for electrolysis compared to MW power generated by a turbine or fuel cell) of the order of 40%.

Similarly, underground storage of natural gas (UGS) is used for seasonal energy demand balancing. The UGS facility operated by NAM at Norg in the NL stores 7 billion cubic metres of natural gas in a depleted gas field and can release that gas at a rate of 3 million cubic metres per hour at periods of peak demand, such as during a cold winter's day when heating demand is at its highest.

Advanced, adiabatic CAES

The future of CAES lies in energy efficient power storage to support variable renewable power generation and grid balancing. To increase the round-trip efficiency of CAES, various modifications have been made by innovators such as Hydrostor. One such development is to capture the heat of compression in a thermal energy storage (TES) unit. This heat is then given back to the air as it expands across the power generation turbine to avoid excessive cooling of the air. The innovative combination of TES and CAES is known as advanced, adiabatic CAES, or AA-CAES.



Above: **Air compressor for CAES and LAES service**

A further enhancement in some AA-CAES systems is that the pressure of air in the underground storage remains constant. This is achieved by the air displacing water in the underground cavern to an above-ground reservoir. In this mode of operation, the underground gas cavern must be mined into rock. The use of a salt cavern for such an application would not be appropriate.

Hydrostor is planning to develop several AA-CAES facilities worldwide. One in Cheshire, in the UK will use a salt cavern for compressed air storage and the pressure of the stored air will rise and fall through the cycles of operation. Another project planned for Kern County, California, will use a rock cavern for the compressed air storage. In this project, water will be used to operate the cavern at a constant pressure. ●

Wärtsilä sets new benchmark for energy storage fire safety testing

Wärtsilä has reported completion of rigorous large-scale fire safety testing of its GridSolv Quantum energy storage system, claiming that the "programme has set a new standard for fire safety testing in the energy storage industry."

The large-scale fire testing exceeds the mandatory testing requirements of existing testing standards (such as UL 9540A) and was designed to simulate a worst-case scenario. Overseen by Wärtsilä's fire safety partners and stakeholders – including Fire & Risk Alliance, Energy Safety Response Group, and Energy Security Agency – the testing was completed at a facility in Piqua, Ohio, and run by the Energy Safety Response Group.

Above: **Wärtsilä has fire safety as a major priority for its GridSolv Quantum ESS, complying with UL 9540A unit-level performance requirements and designed to meet stringent safety and quality standards.** Photo © Wärtsilä

The testing involved intentionally igniting a fire within a Wärtsilä's GridSolv Quantum to reveal important information about how the system would react in the highly unlikely event of a catastrophic failure and demonstrate that, even in the worst-case scenario, a fire in a GridSolv Quantum unit would not spread to neighbouring enclosures.

Under the test conditions, a fire was ignited within a ventilated unit and was allowed to free-burn for more than eight hours. The results showed that a fire would remain contained within the initiating unit, doors would remain closed, and the fire would not result in unit-to-unit propagation.

This kind of bespoke, self-directed testing programme assesses the unit as an integrated system to provide a more complete understanding of fire risk than what could be achieved through mandatory testing alone, which largely assesses individual components. The testing helps ensure that authorities having jurisdiction (AHJs), the fire service, and other stakeholders have a complete understanding of the potential risk.

As part of the testing, the Fire and Risk Alliance (FRA) captured plume gas data to assess the potential environmental impact of the smoke emitted by an ESS fire. FRA's analysis concluded that the smoke from an ESS fire is no worse in terms of environmental impact than fires involving normal consumer products.

"Volunteering to complete testing beyond the minimum requirements provides confidence to key stakeholders that risks are being actively managed," said Darrell Furlong, director of energy storage product management and hardware engineering at Wärtsilä.

"Wärtsilä's bespoke testing is the ideal way to demonstrate that a fire will not propagate between ESS enclosures or from string to string. This outcome illustrates that with minimal or no response from the fire service or other responders, a fully involved fire is unlikely to spread beyond the initiating unit", said Noah Ryder, managing partner, Fire & Risk Alliance.

"As the risks posed by energy storage systems are better understood by AHJs, the desire to incorporate even more data into the safety analysis requires greater scale and evolution in

testing. Test results such as those from large-scale fire tests help inform this process, which overall allows for better analysis and satisfaction of code requirements," said Nick Warner, principal, Energy Safety Response Group. "In the case of Wärtsilä, once the system was fully-involved [fully on fire], the risk to neighbouring units was minimal and could be managed by a well-trained fire department with proper planning and support."

Wärtsilä says that "by design", GridSolv Quantum "solves many fundamental safety challenges such as thermal management, fire detection, short circuit handling and interconnection communication."

It was certified to UL 9540 by Eurofins MET Labs in April 2022 and CSA in March 2023 and found to meet UL 9540A unit-level performance requirements in February 2023.

GridSolv Quantum uses $LiFePO_4$, which is "less prone to fire risk than other lithium-iron chemistries, adding an extra layer of safety." ●

RWE starts construction of large-scale battery in NRW

RWE has begun construction of some of one of Germany's largest battery storage facilities, 220 MW (235 MWh), split between two of its power plant locations, 80 MW (84 MWh) at Neurath and 140 MW (151 MWh) at Hamm.

A total of 690 lithium-ion battery blocks will be installed, involving an investment of about 140 million euros.

The new storage system is scheduled to supply balancing energy to stabilise the grid from the second half of 2024. This will entail the plant taking excess power from the grid and feeding it back into the system when required, in order to maintain the required grid frequency. The battery storage facility will also be deployed on the wholesale market, with electricity fed into the storage system if electricity prices are low, and sent out when prices are high.

Above: **RWE mega battery installation**

The facility will also be "virtually networked" with RWE power stations in Germany, which will "make it possible to control whether the storage units work alone or in conjunction with other power stations to supply balancing energy" thus optimising "the use of RWE's German power station portfolio across a range of technologies." Building on its many years of experience with energy storage systems, RWE says it is "taking care of the detailed planning, modelling, system integration and commissioning of the project directly and entirely on its own."

RWE currently operates a total installed battery storage capacity of around 300 MW (380 MWh) and is implementing battery storage projects of more than 900 MW (2300 MWh) worldwide. Globally, RWE aims to have 3 GW of battery capacity in operation by 2030.

At the beginning of 2023, RWE commissioned its Lingen and Werne battery, total capacity 117 MW, which it plans to virtually connect to its run-of-river hydro plants on the Moselle River.

In March, RWE acquired UK-based JBM Solar, with an advanced development pipeline of 2.3 GW of battery storage projects.

Following commissioning of the Indeland solar farm with its 4.8 MW battery storage facility, RWE is currently constructing further similar storage projects at the Garzweiler open-cast mine.

In addition, RWE recently won an Australian tender for 50 MW/400 MWh of long term storage. ●

US battery boom faces scaling constraints

Global energy storage firms pivoting towards the US battery market on the back of the transformational Inflation Reduction Act (IRA) are facing up to scaling constraints on battery supply and access to skills, while hopeful that external intervention will ease interconnection queues and policy uncertainty.

In its industry insight report, Taking charge: inside the US battery boom, US law firm Troutman Pepper finds that while firms are accelerating their US battery storage plans in the wake of the IRA, they are nonetheless alive to the market 'growing pains' that lie ahead.

The report reflects upon the views of a range of market actors involved in funding, developing, advising on, and operating US battery storage assets. With current constraints on battery supply and workforce set to compound further amid a rapidly scaling sector, these commentators have identified short-term fixes while the longer-term solutions set out in the IRA take hold. They include competing for battery supply from Asian manufacturers while US battery gigafactories are developed and making greater use of external consultants to ease capacity bottlenecks on early-phase project development.

The market is also optimistic that intervention from the Federal Energy Regulatory Commission and the Department of Treasury will address respectively the growing challenge of interconnection queues and questions over how certain key elements of the IRA, such as tax credit transferability, will work in practice.

The fact these market growing pains are compounding tells its own story regarding the positive global industry reaction to the IRA. Less than six months after it became law, the US Energy Information Administration reported a steep increase in battery storage projects under development, with the 26.5 GW of pipeline capacity it recorded in February, up 58% on the pre-IRA figure, expected to expand further throughout 2023.

Troutman Pepper's report argues that the introduction of an investment tax credit (ITC) for standalone battery storage projects is the single biggest catalyst behind this growth. As well as triggering an influx of newly viable storage projects to the market, this move has brought developers greater flexibility across their entire portfolios, encouraged higher installed capacities, and started to create a 'buyer's market' for investors.

John Leonti, partner and co-leader of the Energy Industry Group at Troutman Pepper, commented: "We've been active in the US energy storage sector for over a decade, so are well aware of the industry's current buoyancy. But we've also seen how rapid growth in the development pipeline post-IRA has placed even more stress on the supply chain."

The report concludes with Troutman Pepper's forecast of five post-IRA investment trends expected to shape the sector in the years ahead:

- Significant inward investment into the US battery sector from established renewables markets in Europe, Asia, and South America will also bring expertise to build the integrated battery supply chain in North America.
- Battery developers and investors in the US will be exposed to trade disputes between the US and China. They will turn to the solar sector for lessons in handling such short-term volatility.
- Standalone storage may be grabbing the headlines but there will be plenty of activity in the co-location space, especially with the addition of battery storage to operational wind and solar projects.
- Large institutional investors will enter the tax credit market on the back of tax credit transferability measures. This will change the due diligence dynamic for projects.
- Utility-scale battery storage projects are booming under the IRA but, in time, investors will begin to look at how they can apply the IRA rules to projects with emerging long-duration storage technologies. ●

CSI's SolBank pipeline expands

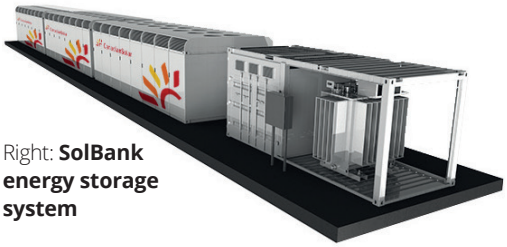
CSI Energy Storage has entered into an agreement to provide its SolBank utility scale lithium iron phosphate (LiFePO4) battery technology to Cero Generation and Enso Energy for their 49.5 MW/99 MWh battery energy storage system to be co-located with the Larks Green solar PV project in South Gloucestershire, UK. The Larks Green solar PV project is the UK's first transmission-connected solar farm. Also owned and operated by Cero and Enso, it was energised in May 2023.

Cero's 11 GW development portfolio is one of the largest in Europe, covering utility-scale solar as well as integrated energy storage systems.

In May it was announced that CSI Energy Storage would deliver 363 MWh of SolBank battery storage to an Aypa Power project in Texas, with commercial operation expected by Q2 2024.

This is in addition to an agreement announced between CSI and Aypa in February for the supply of 487 MWh of SolBank energy storage to support Aypa Power's Cald project in Southern California.

Dr Shawn Qu, chairman and CEO of Canadian Solar, said,"Aypa Power has one of the most robust pipelines of standalone energy storage projects across North America and CSI Energy Storage is pleased to be a trusted partner as Aypa continues to execute on its late-stage energy storage and hybrid development projects. We look forward to bringing these two impactful projects online to support the rapidly expanding energy storage market in the United States."



Right: **SolBank energy storage system**

CSI Energy Storage has deployed around 2.7 GWh of battery energy storage solutions to date across the United States, Canada, the UK, and China. As of 31 January 2023, CSI Energy Storage's total pipeline had reached nearly 25 GWh. ●

NGK presses on with sodium–sulphur

NGK Insulators has supplied a 1 MW (DC)/5.8 MWh (DC) NAS battery system to a Korea Electric Power Co (KEPCO) test programme at Naju City aimed at comparing the performance of various types of stationary storage batteries. NGK has previously delivered NAS batteries to South Korea, to G-Philos in 2020, for a power-to-gas (P2G) demonstration project carried out by Korea Midland Power Co (KOMIPO) at Sangmyung wind farm, Jeju Island. According to NGK, the sodium–sulphur NAS battery can be installed safely in close proximity to hydrogen manufacturing equipment and has thus been evaluated as suitable for such P2G applications.

Above: **NGK NAS battery installation at Kepco's Naju demo site**

A future Korean P2G demonstration project, to be conducted by G-Philos and Korea Institute of Energy Research (KIER) in 2024, will employ 2 MW (DC)/11.6 MWh (DC) of NGK NAS battery storage to provide back-up power for stable hydrogen production using renewable energy.

NGK has recently installed its first NAS battery in Australia, for a 250 kW (DC)/1450 kWh (DC) demo project at the Nova nickel-copper-cobalt mine, alongside PV systems. The NAS battery was considered suitable for this project, with its high capacity and good tolerance of harsh operating environments, with temperatures approaching 50°C. NGK says the NAS battery operational track record in the Middle East has verified its ability to deliver stable performance in extremely hot environments.

The National Battery Testing Centre, operated by the Queensland University of Technology, will remotely monitor the performance of the Nova battery and the University of Western Australia will use performance data to model its behaviour to better understand the NAS technology and how it can be best utilised within Australia.●

Increasing grid stability in the Philippines

As the Philippines makes the switch to more renewable energy sources, it is aiming to stabilise the grid with its largest ever integrated grid-scale battery energy storage system, in Limay in Bataan Province. It was supplied by ABB to Universal Power Solutions Inc. (UPSI), a unit of San Miguel Corporation Global Power Holdings Corp.

The Limay installation forms part of a broader contract with UPSI, for a 240 MW capacity packaged battery storage system to strengthen the reliability and stability of the Philippine grid on the islands of Luzon and Visayas.

The Limay energy storage system was inaugurated by the president of the Philippines, Ferdinand R. Marcos Jr, in March 2023. At this site, ABB provided a 50 MW battery storage system, with the aim of improving the reliability and stability of the grid on the main island of Luzon. The energy storage system is designed to avoid the occurrence of large frequency deviations.

A significant amount of the Philippines' energy supply is still fossil fuel-based, making the country vulnerable to rising energy costs and market volatility while the energy production is at the same time CO_2 intensive. It is also exposed to tropical storms and natural disasters that adversely impact energy infrastructure. To address these challenges while accelerating towards a net zero energy supply, the Philippines aims to achieve 35% renewable power generation by 2030 and 50% by 2040. As of 2022, the Philippines had reached a 22% clean energy mix.

UPSI collaborated with strategic partner ABB to develop an innovative solution to transform the reliability of the area's grid, which was highly susceptible to automatic load shedding and frequency fluctuations. It is also supporting the integration of renewables into the grid.

The Limay installation is the first ABB eStorage Max, pre-engineered, modular, large-scale battery installation to be delivered within the Philippines and APAC region.

Above: **ABB Limay battery installation includes the provision of battery enclosures, EcoFlex eHouses, UniGear ZS1 medium-voltage switchgear, and integrated skid units with transformers and inverters**

The project uses the ABB eStorage OS Energy Management System to act as the intuitive interface to the BESS, allowing users to make real-time decisions based on grid parameters to ensure performance stability. ●