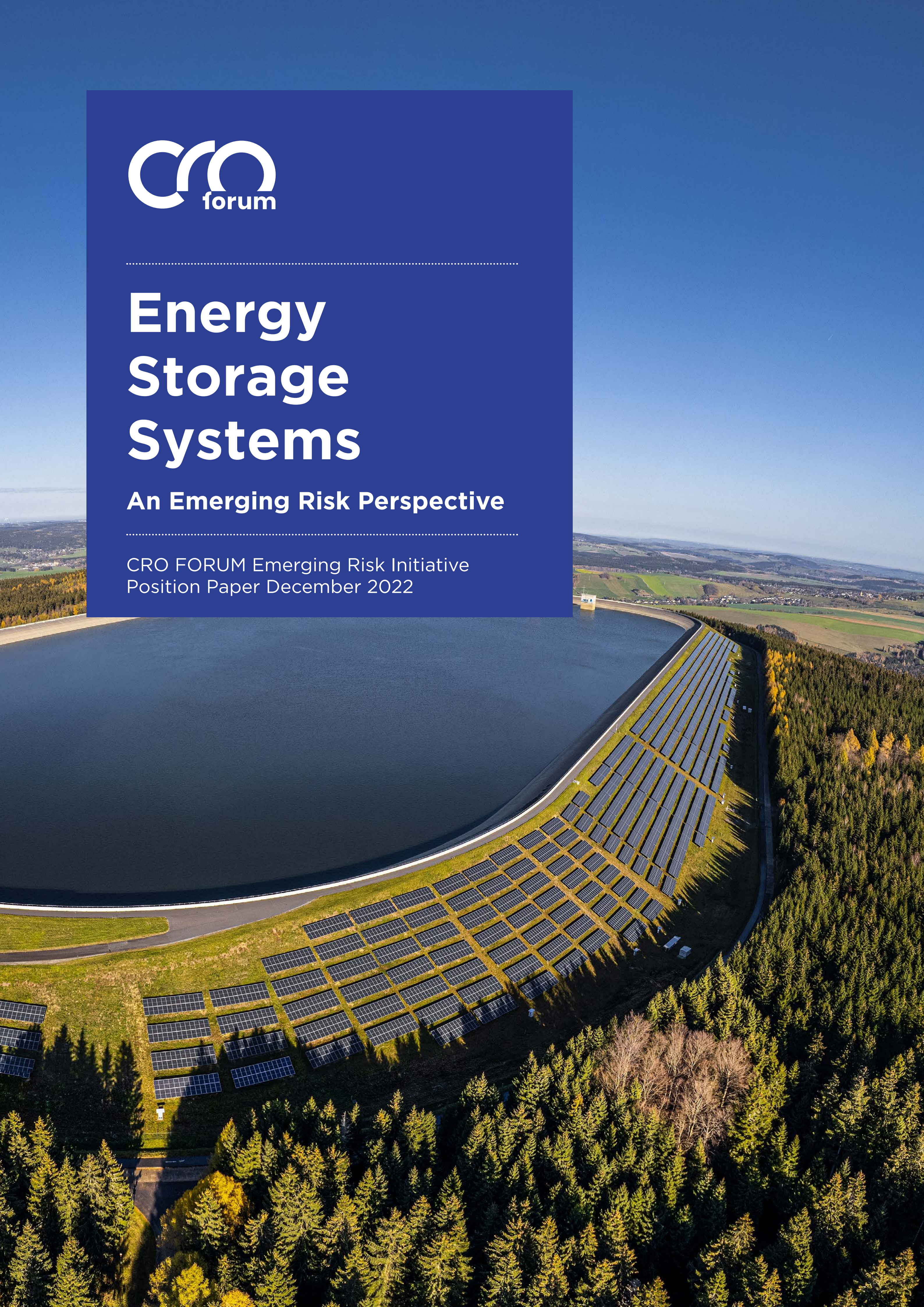

CRO forum

Energy Storage Systems

An Emerging Risk Perspective

CRO FORUM Emerging Risk Initiative
Position Paper December 2022

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Foreword

Russia's invasion of Ukraine has resulted in government sanctions and energy supply disruptions, adding urgency to discussions already taking place around energy storage systems. Western Europe has intensified efforts to secure backup supplies, with emergency power plants and energy storage. To avert blackouts and shortages, fuel tanks and reservoir lakes are being filled, while new construction has been accelerated, including battery plants, hydrogen storage infrastructure and liquid natural gas (LNG) terminals.

This geopolitical crisis has put a spotlight on Europe's fossil energy dependency, but it has also disrupted nations' focus on exiting fossil fuels and decarbonising their economies, at least for the moment. Energy storage, both traditional and innovative, now commands center stage in the push to balance supply and demand, manage peaks and gaps, and to ensure we have enough energy, when it is needed. However, the long-term goal of expanding renewable energy resources also requires more storage capacity, meaning these solutions will only gain in relevance, even when the current crisis is over.

To support this expansion, (re)insurers must venture proactively into this evolving risk landscape. Understanding emerging risks posed by different energy storage technologies, market uncertainty, and the threat of systemic risk lurking within connected, complex energy economies is critical. This publication, from the CRO Forum's Emerging Risk Initiative, lays out the fundamentals of what is known – and the open questions that remain – about energy storage technologies, their (re) insurance relevance and the challenges and opportunities that inevitably come with a dynamic, emerging risk subject.

Introduction

The concept of capturing energy for future use has always been central to human energy systems whether in the form of wood stacks to provide a cabin's heat, fuel tanks for cars, or facilities to trap water before unleashing its power to drive a mill or to deliver electricity to the grid. The ongoing transition of societies to a low-carbon economy and the rising role of renewable energy have pushed storage further into focus, not least due to the proliferation of intermittent solar and wind power. To manage swings in supply and demand, our energy future requires an array of alternatives: large facilities like dams and mountain reservoirs with pumps and turbines, in addition to novel storage technologies.

For households and consumers, energy storage is also gaining in importance, offering potential for autonomy from large energy networks or to bridge short-term supply gaps that may emerge more frequently. Lithium-ion batteries (LIBs) already supply smart personal devices but are also increasingly used by households and electric cars, or to manage spikes in consumption. Alternatives are also being developed to help remedy issues such as unsustainable production, waste or the threat of fire and explosion linked to LIBs. The market for Battery Energy Storage System (BESS) technology is growing rapidly.

Beyond batteries, many other innovative technologies are at experimental stages or already available. Green hydrogen represents a promising example for energy storage, although it harbors fire and explosion risks of its own. While the International Energy Agency (IEA) expects hydropower, including pumped storage, to remain the world's largest source of renewable electricity generation, the future of energy storage will be diverse, flexible and complex.[1]

The energy storage landscape will be accompanied by new risks, creating opportunities and challenges for the (re)insurance industry. Among these are prototype risks accompanying new technologies for which there is a dearth of loss experience data, as well as uncertainty surrounding a new technology's performance, not only in relation to other competing technologies, but also with regard to how markets and regulations develop.

Clearly, to wager on energy storage innovation is no trivial matter, given that many factors governing success or failure remain hidden from view. As the ground shifts, emerging risks – new and changing risks that are difficult to model but which may nonetheless have big impacts on (re)insurers and society – abound. Understanding the origins and drivers governing the evolution of energy storage will help us transform risks into opportunities. This publication explores these developments and evaluates emerging risk and opportunity scenarios through the lens of the (re)insurance industry.

This paper lays out important developments in energy storage, highlights a growing array of alternatives, and discusses related risks and uncertainties. It assesses the role of (re)insurers in helping surmount challenges. In such a dynamic field, focusing on emerging risks is critical. With innovation, shifting demands and new contextual conditions rapidly developing, the risk landscape we see today is merely a snapshot in time. Tomorrow, it may look very different, underscoring the urgency for us to address it now. As such, this publication is meant to be a momentary emerging risk compass for (re)insurers navigating the vast domain of energy storage systems, to foster awareness and risk dialogue concerning a subject that is in constant motion.

[1] "Hydropower's contribution is 55% higher than nuclear's and larger than that of all other renewables combined, including wind, solar PV, bioenergy and geothermal. In 2020, hydropower supplied one sixth of global electricity generation, the third-largest source after coal and natural gas." "Global cumulative hydropower capacity is expected to expand from about 1 330 GW in 2020 to just over 1 555 GW by 2030 – a 17% (230-GW) increase." IEA, Hydropower Special Market Report: Analysis and forecast to 2030 (July 2021) p. 7, 43.

1. Important energy storage technologies: maturity, relevance, risks

Technological advances and the promises they contain are of crucial relevance when assessing the emerging risk landscape around energy storage. This landscape includes a broad range of familiar and new storage technologies. They differ in their mode of operation, their capacity and withdrawal rate, as well as the current and expected capacity installed at different market levels and sectors. Comparative assessments of innovations and their maturity can provide a better sense of what is likely to come.

1.1. Overview of technologies and their application

Based on their underlying means of storing and releasing energy, energy storage technologies can be assigned to five groups depending on whether they rely on electrical, electrochemical, mechanical, thermal, or chemical energy transfer (see Figure 1.u).

For instance, pumped storage plants deploy mechanical force to pump water to a storage facility and then to release that energy. Batteries rely on the electrochemical potential between two materials. Sensible heat uses excess electrical power to heat water and store for later use, particularly in district heating systems. This is a popular way to increase service and supply flexibility from existing power plant sites. Supercapacitors store potential energy electrostatically, not chemically like batteries. Even though they can release energy very quickly, their storage capacity is very low.

When evaluating energy storage systems, performance can be compared in relation to specific energy or power delivery per entity of mass (energy density, Wh/Kg) and specific power density or capacity per entity of mass (W/Kg). In addition, the different storage systems are characterised by the time required for the energy transfer, including how long a storage system requires to be charged and how quickly it can deliver (response time). The chart in figure 1.v on the next page illustrates these relationships, which can be plotted in a 'Ragone chart' (Figure 1.v).

The chart highlights the capacity of various storage systems and how they relate to withdrawal time. A given system's properties may be better suited for one purpose, such as powering a tiny wearable electronic device, or another, like bridging seasonal volatility in a power grid. Large, long response systems, such as cavern storage and pumped storage, are also location dependent as they require

Figure 1.u: Overview of energy storage types

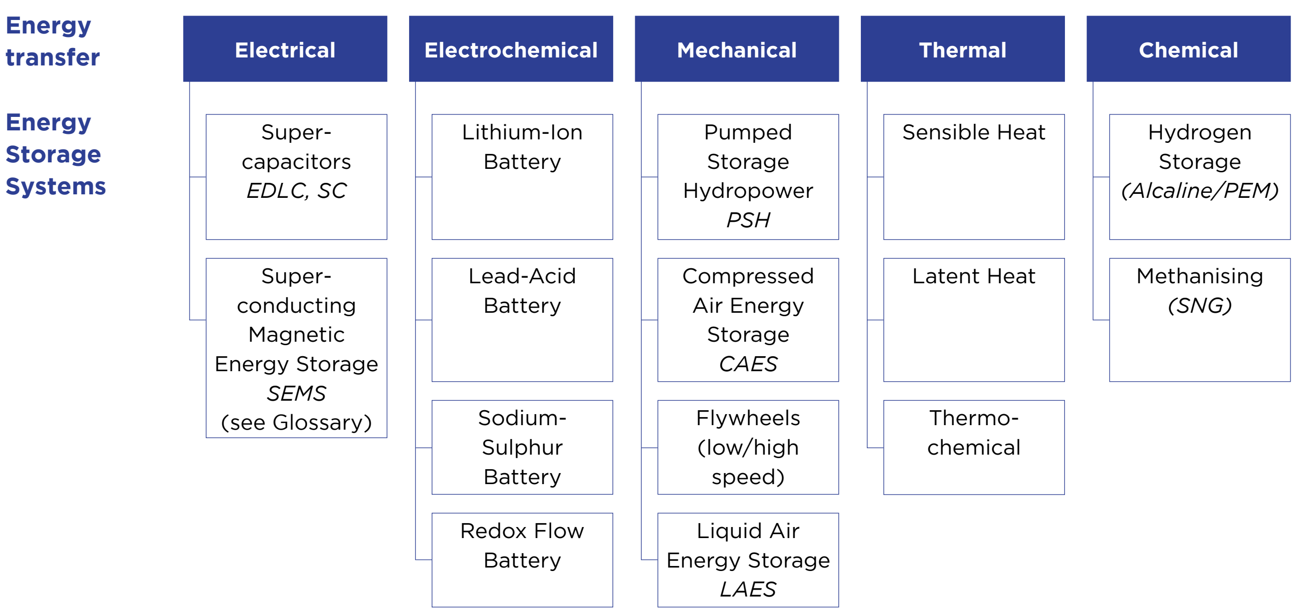
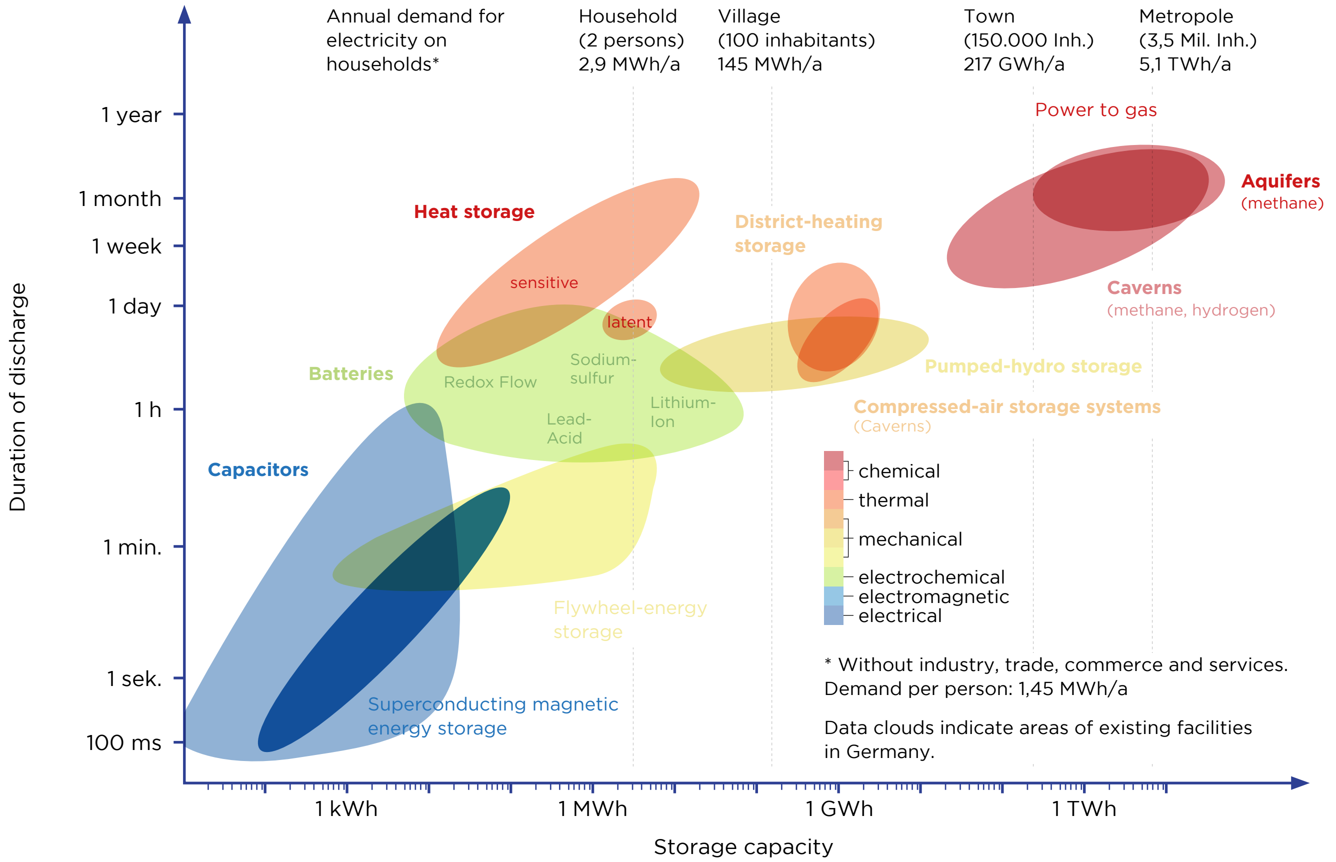


Figure 1.v: Storage types compared with storage capacity and discharging duration (Ragone chart): the *circled areas* indicate German facilities which have existed since 2013. Graph adapted from Sterner, Michael, and Ingo Stadler. Handbook of Energy Storage: Demand, Technologies, Integration. Berlin: Springer, 2019, p. 646.



favorable geography. Alternatively, smaller systems that can deliver quick responses, such as capacitors and flywheels, can be located in closer proximity to end users. However, inductors or capacitors are ill-suited for large capacity storage necessary to fulfill seasonal storage requirements. Battery storage is also not the first choice for seasonal storage but is rather better suited to balance daily to weekly fluctuations. The key measures for performance, capacity and transfer time thus determine appropriate applications for the respective storage technology. The performance is principally specified by cycle efficiency and cycle-related aging (calendric lifetime).

Categories by scale of installation and storage time horizon

- **Consumer and household level:** from smartphones over private vehicles to home storage

  The International Energy Agency (IEA) labels this storage capacity 'behind-the-meter'. Market development here benefits strongly from the electrification of the transport sector. Therefore, lithium-ion storage systems with a capacity of 5 - 10 kWh are mainly used at the household level. With the increasing use of electric vehicles (EVs), it is expected that a high storage capacity via car batteries (EV and second use) can also be deployed in the future. The intelligent coupling of solar thermal energy with latent heat storage (e.g. ice storage) and heat pumps provides a further storage technology seen as harbouring significant potential.

- **Larger organisations level:** company campuses, housing communities, public infrastructures (including hospitals, schools, and airports)

  The best-known storage applications here are latent heat storage systems. For air-conditioning of university complexes and skyscrapers during the day, surplus electricity produced during the night is temporarily stored in ice storage systems.

- **Regional, national and international levels:** grids, pipelines and other systems to provide energy

  This largest, regional and supra-regional level includes so-called smart grids, i.e. largely self-sufficient units (city districts, villages, etc.) in which optimal use of the available energy can be achieved through sector coupling and intelligent control of storage capacity and consumption.[2]

In addition to categorisation by scale, storage and its respective application can also be categorised in terms of time horizon (duration) as illustrated in figure 1.w, ranging from seconds to several months:

- Short-term storage systems are used for power quality and regulation of the grid.
- Mid-term storage systems, or 'daily storage systems', can bridge power fluctuations associated with renewable energies over a 24-hour period.
- Long-term storage systems, or 'seasonal storage systems', are used for 'energy management'.

Figure 1.w: Categorisation of storage systems according to energy to power (E2P) ratio, essential applications and duration. [Source Allianz].

Frequency of access ↑ / Storage time ↓

Category	
Power Quality & Regulation 'Seconds to minutes' Short-term energy storage systems mean E2P ratio: 0,25 h	Inductors Capacitors Flywheels Batteries
Bridging Power 'Daily Storage' Medium-term energy storage systems mean E2P ratio: 1-10 h	Batteries Redox Flow CAES/LAES Thermochemical Pumped Hydro
Energy management 'Weekly to monthly' Lorg-term energy storage mean E2P ratio: 50-500 h	Sensible heat Latent heat Power to gas

Application	Duration
Fluctuation suppression / Smoothing Dynamic power response Low Voltage ride through Line fault ride through Uninterruptable power supply (UPS) Voltage control support Reactive power control Oscillation Damping Transient stability	< 1 min
Spinning contingency reserves Ramping Emergency backup Load following Wind power smoothing	1 min - 1 h
Peak shaving / generation / time shifting	1 - 10 h
Transmission curtailment Energy arbitrage Transmission & Distribution Deferral Line repair Load cycling Wheather smoothing	5 - 12 h
Unit commitment Load leveling Capacity firming Renewable integration and backup	Hours - days
Seasonal storage Annual smoothing	> 4 moths

High capacity ↑ / High amount of energy ↓

Hydrogen storage

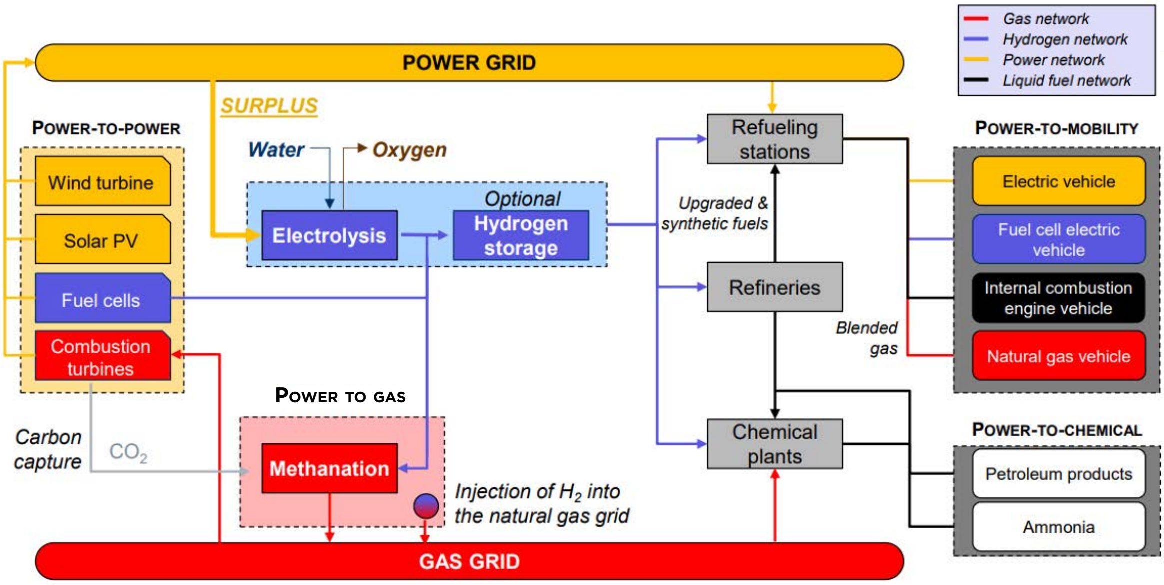
Hydrogen (H2) is versatile and can play an important role in the renewable energy transition. When produced using 'green' electricity (from renewable sources, such as solar or wind), hydrogen can become an invaluable tool to decarbonise sectors which are difficult to electrify, hard-to-abate sectors (HTA), such as steelmaking, and to store energy from renewables when their supply is scarce. Green hydrogen has numerous emissions benefits. Power-to-hydrogen projects are taking off, using excess renewable electricity, when available, to make hydrogen through electrolysis.

Hydrogen is a promising intermediary to store surplus energy – e.g. from photovoltaic systems – and as a means to deploy such stored energy in emission-free and efficient ways. It can thus bridge energy systems. As a multi-purpose technology, hydrogen can also directly be used as a fuel applied in mobility (power to mobility), transformed to chemical feedstock (power to chemical), or methanated and fed into the gas grid (power to gas).

However, hydrogen's unique features pose some risks - most prominently explosion or fire risk from interaction with air - and technical challenges. Being the most abundant and lightest element, hydrogen occupies in gaseous state a substantial volume of 11 m3 per kilogram in normal conditions of temperature and pressure. This is 14 times the volume occupied by air at the same conditions. In order to store and transport hydrogen efficiently, it is therefore absolutely necessary to reduce this volume.

[2] See Breakout Boxes in this position paper further below on 'Smart grids' and 'El Hierro island energy self-sufficiency the "Gorona del Viento" system'.

Hydrogen - Bridge between energy systems
Simplified value chain of hydrogen-based energy conversion solutions



Source: SBC Energy Institute analysis.

To reduce both the capital expenditure (CapEx) and operational expenditure (OpEx), hydrogen storage density must be increased. All the methods to store hydrogen at an increased density require some input of energy in the form of work (e.g. for its compression), heat or, in some cases, hydrogen-binding materials. Large-scale stationary hydrogen storage is critical if hydrogen is to fulfil its promise as a global energy carrier. Attending to the nature of the interaction between the stored hydrogen and the storage vessel, hydrogen may be stored as gas or a liquid in pure, molecular form without any significant physical or chemical bonding to other materials. While densified storage via compressed gas and liquid hydrogen is currently the dominant approach, liquid organic molecules have emerged as a favourable storage medium because of their desirable properties, such as low cost and compatibility with existing fuel transport infrastructure.

Stationary hydrogen storage systems are built primarily for on-site storage at either the production site or the end use and for stationary power generation or will be part of the coming hydrogen stations networks. At present, on-site stationary hydrogen storage and/or stand-alone stationary applications are mostly limited to compressed hydrogen storage in pressurised tanks (small scale) or underground (large scale).

In its liquid state, hydrogen requires cryogenic tanks that keep it at -253°C, which requires a considerable amount of energy. Other storage techniques are adsorption using Liquid Organic Hydrogen Carriers (LOHC), or in compressed form.

The European Hydrogen Backbone (EHB) plans the creation of a pan-European hydrogen network infrastructure that connects hydrogen supply with hydrogen consuming industrial clusters. Europe has defined a more ambitious hydrogen target of 20MT by 2030 in response to the RePowerEU plan to phase out Russian fossil fuel imports well before 2030. This includes a 10MT target of domestic EU hydrogen supply, as well as a 10MT target of hydrogen imports from outside the EU.

The initiative includes the identification of potential large-scale Underground Compressed Hydrogen Storage (UCHS) locations for seasonal hydrogen storage. Currently, there are five types of UCHS: depleted natural gas and oil reservoirs, aquifers, salt caverns, abandoned mines, and rock caverns.

Practical experience of underground hydrogen storage is still rare. In the US and UK, hydrogen is currently stored in salt caverns, but hydrogen storage in depleted oil and gas fields is still under research and discussion. Depleted oil and gas fields have a huge storage capacity, are well known from former exploration and production, and qualify therefore for hydrogen storage. However, the existing underground gas storages

(UGS) are designed for the storage of natural gas, which does not contain hydrogen (or only very low amounts).

Salt caverns could be a good option since salt is inert to hydrogen. Salt formations have been exploited worldwide in the last decades to store natural gas, oil, and chemicals. Hydrogen has been successfully stored e.g. in two caverns in Texas (USA) since 1983 (storage capacity: 580,000 m3 and 566,000 m3) and in three caverns in Teesside (UK) since 1972 (storage capacity: 3 × 70,000 m3). Salt caverns may provide an ideal solution for high-pressure hydrogen storage, considering the numerous benefits of the realisation of underground hydrogen storage (UHS), such as high energy densities, low leakage rates and big storage volumes. Underground storage of hydrogen in salt caverns poses safety issues in terms of fires, explosions and toxic chemical release and dispersion.

Because the chemical and physical properties of hydrogen are different to those of methane (CH4)—the main component of natural gas—the effects of hydrogen on the reservoir rock, cap rock, and storage facilities must be analysed before injecting hydrogen into these storages.

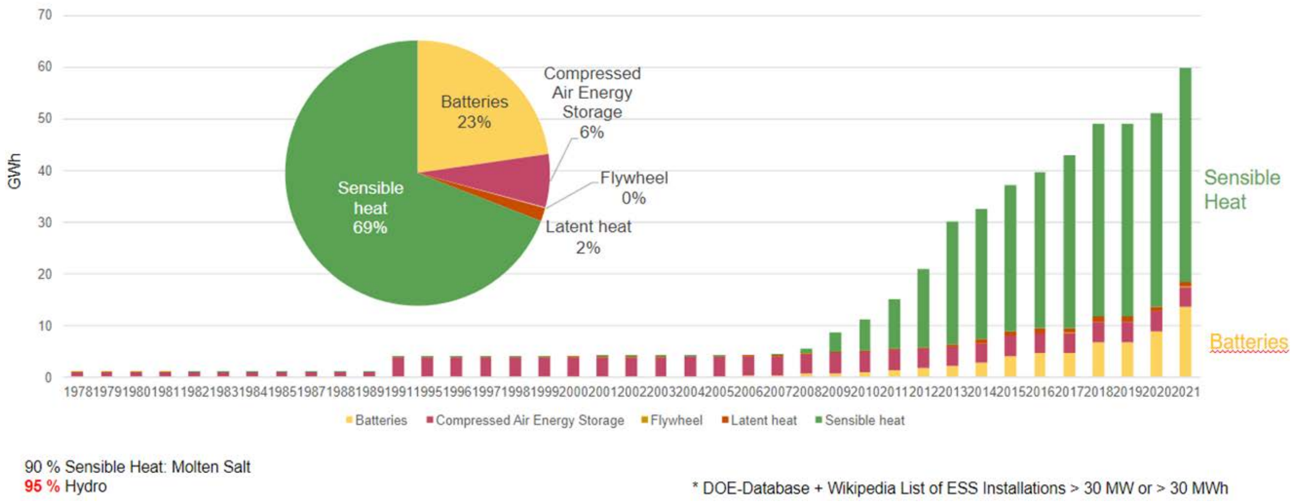
The risks of hydrogen storage in depleted gas fields include the natural conversion of hydrogen to CH4(g) and H2S(g) due to microbial activity – gas, water, rock – interactions in the reservoir and cap rock, which are connected with porosity changes, and the loss of aqueous hydrogen by diffusion through the cap rock brine. These risks lead to loss of hydrogen and thus to a loss of energy. It is recommended to choose depleted gas fields for hydrogen storage where the residual gas has low CO_2(g) concentrations.

Rock caverns are mined underground using conventional mining techniques and consist of a system of shafts or ramps and drifts, forming cavities in solid rock deep underground, for example, in granite. Although just as stable, unlike rock salt, solid rock is not impervious to liquids, and especially gases, because of fractures within the rock.

The most common storage system is high pressure gas cylinders, which are operated at a range of pressures from 20 MPa (200bar) to 95 MPa (950 bar). The safety of pressurised cylinders is a concern, especially in highly populated regions. Materials for tanks construction, including materials used in piping, valves and seals, must be carefully selected to account for their deterioration when exposed to hydrogen at the intended operating conditions.

In order to liquefy hydrogen, it must be cooled down to cryogenic temperatures through a liquefaction process. Gaseous hydrogen is liquefied by cooling it to below -253°C. The pressure of liquid hydrogen is no more than 5 bar. Regardless of the quality of the insulation, however, some heat will reach the tank over time and cause the liquid hydrogen to boil. The result is that hydrogen gas accumulates at the top of the liquid tank and causes the pressure inside the tank to increase. To keep the pressure from rising above the limits of the tank, the gaseous hydrogen must be vented from the liquid tank and either released or recompressed by a boil-off compressor to be stored as gaseous hydrogen. The main problem of cryogenic hydrogen is that it takes lots of energy to produce it. Using today’s technology, hydrogen liquefaction consumes more than 30% of the energy content of the hydrogen and is therefore very expensive. In addition, some amount of stored hydrogen will be lost through evaporation, or ‘boil off’.

Figure 1.x: DOE: Running Sum of Energy Storage Installations except pumped hydro - Capacity



1.2. Expected capacity development of different technologies in different sectors

The current dominant storage technology worldwide is pumped storage hydropower plants, with a share of 95% of the total storage capacity. Sensible heat holds second rank as per current energy storage installations in terms of Gigawatt hours (GWh). Sensible heat has grown tremendously over the past decade, primarily in combination with solar power installations. Battery storage follows with a smaller share, though it has nevertheless grown significantly. The chart in figure 1.x from the US Department of Energy (DOE) illustrates the evolution of the share of several technologies from 1978 to 2021.[3]

The installed base for energy storage is due to grow over the next decade. In terms of compound annual growth rates (CAGR) reflecting current and expected growth, four main categories of storage and their respective technology types appear promising:

1. Large installed base and moderate growth (CAGR≈4-7%): traditional water-based gravitational mechanical storage technologies, such as pumped hydro and hydro dams[4].
2. Medium installed base and medium growth (CAGR≈13%): thermal energy storage (TES).
3. Small installed base but high growth (CAGR≈40%): electrochemical, i.e. stationary Li-Ion-batteries.
4. Tiny installed base but huge growth (CAGR≈63%): green hydrogen economy enabled by electrolysis[5].

The installed base reflects a past technology's feasibility, while the prospects for growth reflect a readiness to invest in a technology, as well as the confidence and aspiration for it. There will be a greater business case for storage systems that can be deployed frequently. Consequently, short-term storage that is used often has a lower threshold for market entry than for medium- or long-term solutions that are deployed with lower frequency of charges and discharges. Thus, short-term storage (i.e. hours) has a lower threshold for market entry than a medium- or long-term solution (i.e. week, month).

[3] The US Department of Energy (DOE) hosts a Global Energy Storage Database with various useful international statistics on overall storage installations, specific technologies, geographical regions, etc.

[4] A 2022 hydropower status report that global installed hydropower rose by 26 GW to 1360 GW in 2021. It also states though that the 26 GW growth falls short of the 45 GW the International Energy Agency (IEA) sees required to meet net-zero goals by 2050. International hydropower association (IHA), 2022 Hydropower Status Report: Sector trends and insights

[5] "The past year has been a record year of electrolysis deployment, with more than 200 MW of capacity entering operation, a threefold increase on 2020. Total installed capacity has reached 0.5 GW and is expected to grow to over 1 GW by the end of 2022. The realisation of all the projects in the pipeline could lead to an installed electrolyser capacity of 134-240 GW by 2030, twice the expectations from last year. Also, electrolyser manufacturing capacity has doubled since last year, reaching nearly 8 GW per year. However, electrolysis capacity is growing from a very low base and requires a significant acceleration to get on track with the net-zero emissions by 2050 scenario, which requires expanding electrolysis capacity to above 700 GW by 2030." Electrolysers – Analysis - IEA

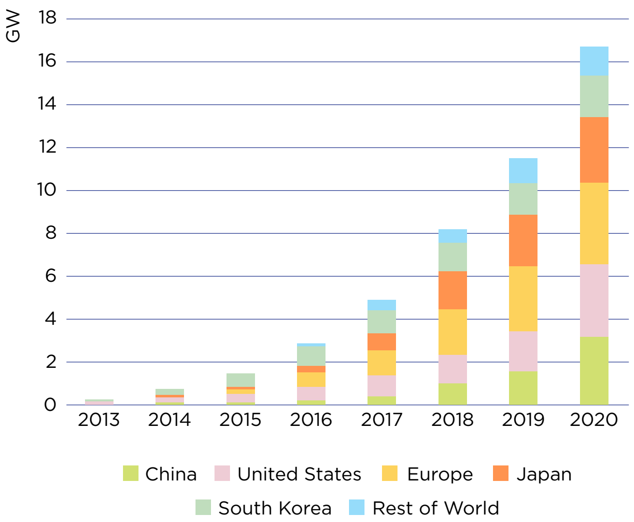
A detailed view on batteries

The worldwide development of battery storage systems (Figure 1.y.) has followed an exponential growth curve.[6] Lithium-ion storage systems are the dominant storage technology with a share of over 90%. By the end of 2020, 34 GWh of storage capacity with installed power of 17 GW had been realised worldwide. Just under 60% of this storage capacity is behind-the-meter. Political planning targets (such as the EU Green Deal) specify a 200-fold increase in battery-based storage capacities by 2050:

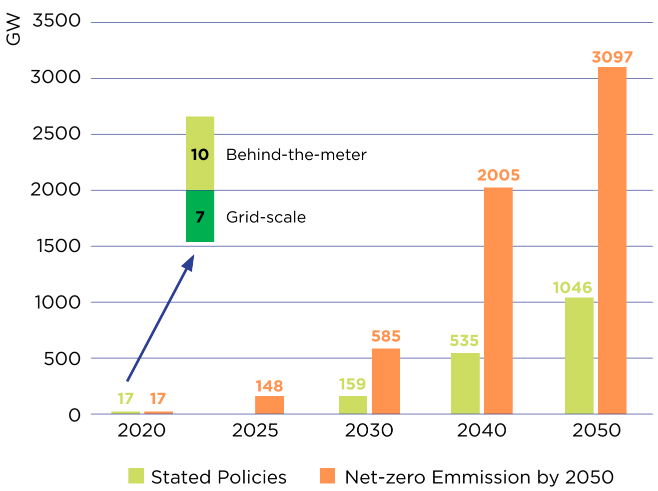
Figure 1.y: Data: IEA – International Energy Agency

Energy Storage Power in operation by region

Storage Capacity by end of 2020: 34 GWh



Expected Development of Battery Storage Power



Taking into account the grid-relevant share of battery storage, or large-scale installations that exclude behind-the-meter installations, additional battery technologies are used. With public subsidies that have enabled an extended period of technology openness, battery storage technologies have been evolving and gaining significance since early this century. Li-ion technology currently dominates battery storage usage, while flow batteries and batteries based on sodium, zink, lead or nickel represent small shares.

Batteries in electric vehicles play a special role: while having substantial growth potential with an estimated CAGR of 18-33%, they are currently used only to power vehicles. But bi-directional wall-boxes that integrate these vehicle batteries into the energy management of a building or the power grid are expected to play an important future role. One current (insurance) challenge in this context is the meagre probabilistic data for battery lifespan expectancy, i.e. how many cycles a battery will endure, and how performance will decrease over time. For car manufacturers providing battery warranties, additional dual use would only increase uncertainty and warranty questions.

There are also studies investigating the 'second life' of used car batteries, to determine the conditions and economic factors that would allow for extended use cases. For second life scenarios, used car batteries may need to come with a record of past usage in order to pass quality control before being integrated into a stationary battery energy storage system (BESS) that could extend the life of a battery by up to a decade (again with high uncertainty regarding performance/lifespan expectations).

[6] For batteries (daily storage systems), a relative high level of statistical data is available in comparison to other emerging energy storage technologies.

[7] The IEA's World Energy Outlook 2022 foresees battery storage to take off in the net-zero scenario, expanding 30-fold form 2021 to 2030. P. 139.

1.3. Innovations in the market

As green energy production gains traction, the need for innovative energy storage will increase in tandem. These innovations can largely be grouped into two categories: advances in existing technologies and new (or newly adapted) forms of energy storage. Research in this storage space may be shared between government agencies, private industry and universities, and includes projects with an extended time horizon before they are ripe for implementation. We focus on concepts that may come to market within the next 5 to 10 years.

The first category of innovation in the energy storage system space involves improvements to existing technology. By and large, much of the focus for research and development of energy storage systems is centered on batteries and the targeted improvements are wide ranging. These improvements focus on safety, energy density, cost reduction, and longer life, as well as less expensive and more sustainable manufacturing techniques.

The hazards of lithium-ion batteries (LIBs) are well known; the electrolyte found between the cathode and anode provides an internal oxidiser, allowing fires to occur without exposure to outside air. Because of this, battery fires are notoriously difficult to fight and can devastate property and equipment. One remedy could be by using solid-state batteries, which reduce fire risk. Since solid-state batteries are highly dense in energy, they lend themselves to stationary battery arrays. Safety improvements may also be gained through improvements in installation methods, improved means of application, monitoring, and by developing safety standards accordingly.

The development of lower-cost sodium-ion batteries may challenge the lithium-ion battery technology of today, but sodium-ion battery systems contain an organic electrolyte that by themselves may present emerging human health risks through exposure through leakage or during recycling.[8]

In terms of per-unit cost, battery installations suffer a distinct disadvantage compared to other technologies, such as pumped hydro and compressed air. However, batteries are attractive for other reasons – ease of use, low maintenance, and the ability to install them nearly anywhere. That attractiveness drives some of the research to reduce the cost of batteries. An obvious area of savings is the reduction or elimination of high-cost metals used in conventional lithium-ion batteries, namely nickel and cobalt. Alternative battery chemistries, such as lithium sulphur, are being explored for this reason. Increasing the energy density of batteries may not reduce the overall installed cost but would lower costs per kilowatt-hour. Developments underway to increase density include improvements to cathodes such as protective coatings, doped metals and modified electrolytes. The cost of batteries decreased by 89% between 2010 and 2020. While cost is currently rising again such improvements may - at probably slower pace - continue the overall downward trend. This does not come without risks. An increase in battery storage system demand will see a comparable increase in demand for raw materials, driving up costs. According to some estimates, raw material cost increases could largely offset any reduction in battery prices.[9] Transformers, switchgear, cables and other equipment are needed for any electrical installation, so efforts to reduce these associated costs (e.g. from use of expensive metals such as copper) also contribute to making energy storage more economically viable.

The second branch of innovation covers novel technologies for energy storage. In some cases, these are based on existing technologies that address inherent issues.

Green ammonia will be used in energy storage. Once derived from an electrolyser, green hydrogen is combined with nitrogen (produced from green energy) in the 'Haber process', a well-established chemical process that produces ammonia. The advantage of this approach is that ammonia has higher energy density than hydrogen and requires less energy to store as a liquid. An additional benefit is that ammonia is much less flammable than hydrogen.

Flow batteries employ two chemical compounds dissolved in liquid and stored in separate tanks. The liquids are pumped to a membrane where they react to generate electricity. While providing lower energy density than Li-ion batteries, flow batteries can be more easily scaled and enjoy increased longevity. Manufacturing is also easier because flow batteries require less precision assembly than Li-ion technology.

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[8] The most commonly used organic solvents are carbonates such as propylene carbonate (PC), ethylene carbonate (EC), dimethyl carbonate (DMC), fluoroethylene carbonate (FEC) or vinylene carbonate.

[9] https://www.goldmansachs.com/insights/pages/gs-research/battery-metals-watch-the-end-of-the-beginning/report.pdf

Gravity has been used for some time as a driver in energy storage systems, in the form of pumped hydro storage. Gravity can be used to lift other media via electric motors, converting potential energy to kinetic energy when the mass is released. The media may be a fluid, a solid object raised vertically, or a solid object moved up a gradient. New types of gravity-based installations are in development and are being tested, but there are no large-scale commercial operations planned yet.

Liquid air energy storage (LAES) is a variation on the well-stablished technology using compressed air as an energy storage medium. As a liquid, air has higher density and, therefore, greater capacity. This makes above-ground storage a more realistic option, whereas most (if not all) compressed-air energy storage (CAES) systems use below-ground storage. Drawbacks include energy required to liquify and store air, a further drain on renewable sources. Small LAES plants have been developed and larger facilities have been announced, though their long-term development prospects are unclear.

1.4. Conclusion

Research and Development (R&D) efforts dedicated to new ways to store and release energy – and thus decouple energy generation and consumption over time – are intense. Energy storage technologies are multi-purpose technologies applied at different scales and in varied sectors and user segments. Advantages of one technology over another are largely context dependent, and there is no single storage technology that will be best suited for all purposes. Depending on use case, requirements for size, required storage duration (seconds to months), energy density, charge and release time, and other factors will play out differently.

Traditional technologies like pumped hydro storage will remain critical in years to come, but they will be complemented by innovations on all levels of energy economies from households and individual consumers to international projects. In past decades, we have witnessed groundbreaking innovations in the field of batteries. Gains in density and performance accompany development of ever smaller and lighter batteries, enabling the evolution of mobile digital devices and electrification of mobility. For larger storage purposes, trade-off considerations will play a significant role, as increased energy density reduces battery lifetime, while lifetime increase can bring down total cost of ownership. Batteries will continue to play a dominant role as their use extends beyond private households and small-scale deployment, and the currently prevalent lithium-ion type will be complemented by new battery technologies, such as solid-state batteries.

When it comes to storing and releasing thermal energy (heat and cold), latent- or sensible-heat storage is gaining importance for household and larger applications. The efficiency of such systems is challenged when used to store electricity, including when energy is transformed at storage and again when it is released to power activity. At larger scale, hydrogen storage is due to develop and gain importance in the coming years, particularly as a bridging technology between energy forms and systems. With the redeployment of existing storage capacity for natural gas, hydrogen can become a key technology to support the net-zero transition.

While large-scale facilities for pumped hydropower or hydrogen (H2) storage are suited to easing supply and demand peaks on daily and even seasonal timescales, other technologies, such as flywheels, are appropriate for applications like peak shaving on very limited timescales, around a minute or less.

In the energy economies to come, different storage technologies must coexist in their respective niches, and complement one another. How this landscape unfolds will hinge on technological feasibility, as well as on many other factors.

High intensity of R&D dynamics in energy storage technologies is expected to continue for the next decade. This offers the prospect of new opportunities, but also challenges, as novel technologies nearly always provide new risks and trade-offs as well. Innovation will not only depend on technological considerations, but also on economic and regulatory conditions. Proactive knowledge exchange on new technological trends will not only pave the way for insurance opportunity, but the insurance industry's risk expertise can also provide important guidance in relation to a technology's feasibility and promise.

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[10] Source: Joule Magazin 2020: Electricity Storage and the Renewable Energy Transition: https://www.sciencedirect.com/science/article/pii/S2542435120303408

[11] The cost of retrofitting a natural gas pipeline amounts to 10–35% of the CapEx for a new hydrogen pipeline with similar diameters. On the other hand, the cost of a new hydrogen pipeline would amount to 110–150% of a new natural gas pipeline/ retrofitted with similar parameters. Source: De-risking the hydrogen economy | Swiss Re

2. Energy markets: emerging energy storage demand

2.1. What is driving the need for energy storage?

Electrical demand is notoriously uneven and production from traditional hydrocarbon sources is one common possibility to ramp up and down reasonably quickly to follow demand. Power grids have also been designed to move power across vast distances to where it is needed, helping to find a balance between supply and demand. Green energy sources such as wind and solar are depending on weather, season and other environmental conditions beyond human will. They thus cannot quickly ramp up capacity on demand, meaning load balancing in the grid will become more important. More energy storage systems will be needed to provide additional stability and replace power plants driven by fossil fuels for such a role.

Short-term storage (4-hour) provided by batteries is well suited to sudden, unexpected outages as well as matching supply to demand swings. More uniquely, short-term storage can help optimise energy usage so that no power is wasted during periods of oversupply. Conversely, power plant expansion can be minimised if energy storage is used to meet short periods of peak demand.

Medium-term storage covers a range extending from 4 hours to several days. Energy storage systems geared towards this range will allow for a greater portion of grids (over 80%) to transition to green energy by providing reliable supply during longer electricity-generation outages, including when the wind does not blow or when the sun does not shine. Similarly, long-term storage, defined as a few days to several weeks, will allow full (100%) green energy supply to a given grid and replace gas peaking plants by offering a fully reliable supply.

Seasonal storage (one cycle per year) serves to cover periods inherent to generation shortages. This extra long-term storage can, for example, help eliminate the need for long-distance transmission lines between windy areas in the northern part of the northern hemisphere and sunny, solar-friendly areas near the equator. Such storage will enable autonomy by allowing communities to use locally generated power throughout the year.

The demand for energy storage depends on several factors, including the degree of renewable energy production or the size of the grid area to be served. One model scenario concludes that a grid with 60% renewable energy requires 9% of yearly load to be covered by energy storage capacity whereas a grid with 90% renewable energy requires 64% of yearly load as energy storage capacity.[10] In other words, demand for energy storage will rise disproportionately during the transition to predominantly renewable energy production.

2.2. Cost and relative prices – drivers and hurdles for energy storage markets

Beyond the economic realities of green energy installations, energy storage also has its own financial motivations. As gas pipelines see their traditional fossil fuel contents reducing in capacity, operators have converted (or are considering) some lines to carry hydrogen, either as a gas blend or as a pure product. However, the decision to use existing infrastructure depends on the cost of retrofitting natural gas pipelines as well as compatibility of pipeline material.[11] Many nuclear power plants across the globe are slowly being phased out, but those with some years of life remaining may see opportunity as producers of hydrogen via thermochemical cycles. These are strong financial motivators for utility operators looking to extract as much revenue as possible from existing assets by converting them to operate in the energy storage sector.

Renewable infrastructure is seen as an attractive asset class, potentially offering good returns and aligning with asset management investment strategies that are increasingly seeking to demonstrate the 'green' credentials.

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[10] Source: Joule Magazin 2020: Electricity Storage and the Renewable Energy Transition: https://www.sciencedirect.com/science/article/pii/S2542435120303408

[11] The cost of retrofitting a natural gas pipeline amounts to 10–35% of the CapEx for a new hydrogen pipeline with similar diameters. On the other hand, the cost of a new hydrogen pipeline would amount to 110–150% of a new natural gas pipeline, retrofitted with similar parameters. Source: De-risking the hydrogen economy | Swiss Re

Battery storage is a key technology in the transition to clean renewable energy and is increasingly becoming an integral part of the renewable energy infrastructure. Specifically, it enables the balancing of excess supply from solar renewable energy sources, peaks in demand, and broader network load balancing requirements.

It is becoming more difficult to match energy generation to demand and network pinch points are emerging. The use of synchronous power plants, whose electrical frequency is synchronised with the rotation of a turbine generator, ensures that power is produced at constant voltage and frequency. Examples are coal, gas, nuclear and hydro plants. Renewable energy generators are induction based and are asynchronous. In recent times, reducing system inertia has meant that national grids have had to curtail demand of large energy users or pay renewable generators to curtail output and replace them with synchronous plants. Large scale transfer to renewable generators needs to be managed properly and intelligently or will lead to major supply disruptions and higher energy bills in the future. The investment case for the (battery) storage element of renewable infrastructure is evolving with a range of factors determining the cost of investment and the returns available.

The use and further development of the various storage technologies, especially regarding bridging and energy management, is currently limited by the fact that the availability of electrical energy from fossil fuels severely restricts the market-based use of energy storage. In other words, the use of coal- or gas-fired power plants still has higher attractivity for investors. At the end of the day, all available storage technologies have to be integrated into the electrical grid and the overall energy systems in an economically feasible way. What this will look like and how it will develop are the topics of current research and studies.[12] In its 'Grid Flex Study' e.g. Deutsche Energie-Agentur (dena) is investigating how storage facilities can be used to increase flexibility in the electricity grid.[13] The aim is to identify operating models for storage facilities that are economically viable and that reduce the load on the electricity grid.

There is increasing public funding to support development of new energy storage technologies. In 2021 UK's Department for Business, Energy and Industrial Strategy (BEIS), unveiled funding of around GBP 7 million to support long-duration storage technologies in the pilot or prototype phase.[14]

To reach the climate goal of 1.5°C, the forecasts will not be enough and a fallback to – shortsightedly cheap – fossil fuels will always be a temptation. The criteria for success will be price decline per kWh storage capacity, footprint, flexibility of use cases (multi-use), earnings per cycle, and the roundtrip efficiency.

[12] https://www.iea.org/reports/grid-scale-storage

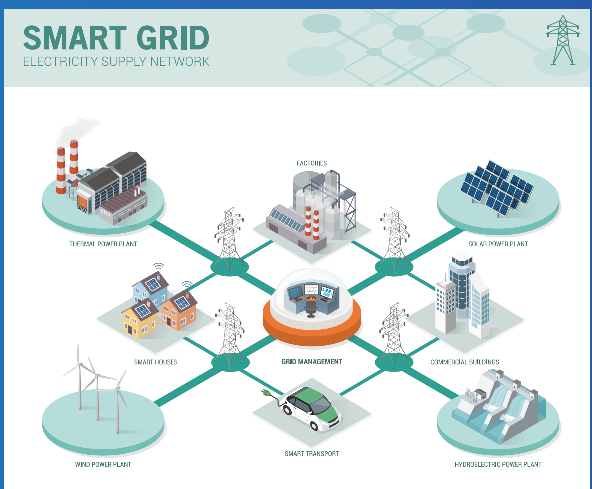
[13] https://www.dena.de/en/topics-projects/projects/energy-systems/grid-flex-study/

[14] BEIS unveils nearly GBP 7m long duration energy storage funding | Current News (current-news.co.uk). In the US, the Department of Energy (DOE) has launched many initiatives under the Energy Storage Grand Challenge (ESGC) to support the development of long-duration energy storage technologies. As part of this, in May 2022 the Biden administration launched a USD 505 million long-duration energy storage initiative. This initiative seeks to advance energy storage systems toward widespread commercial deployment by lowering the costs and increasing the duration of energy storage resources. Biden Administration Launches Bipartisan Infrastructure Law's USD 505 Million Initiative to Boost Deployment and Cut Costs of Increase Long Duration Energy Storage | Department of Energy. In February 2022, the DOE announced the investment of USD 3 Billion to Strengthen U.S. Supply Chain for Advanced Batteries for Vehicles and Energy Storage Biden Administration, U.S. Department of Energy to Invest USD 3 Billion to Strengthen U.S. Supply Chain for Advanced Batteries for Vehicles and Energy Storage | Department of Energy

Smart grids

The shift from fossil fuel to renewable-based electricity production and the increasingly distributed nature of power generation, for example from buildings equipped with solar panels, necessitate a complete transformation of the electricity grid, which is currently designed to allow for a one-way production and distribution of electricity from generation site to the consumer.

To accommodate multiple feed-in points into the grid and to deal with the problems created by the fluctuating nature of renewable electricity generation, the concept of the ‘smart grid’ is being progressively developed and deployed. When fully deployed, a smart grid precisely limits electrical power down to the residential level, allows for small-scale distributed energy generation and new loads from connected storage devices and electric vehicle charging, communicates information on operating status and needs, and collects information on prices and grid conditions. The smart grid therefore allows the grid to move beyond a centrally controlled system, to become a collaborative network (see illustration below). Data flow and information management are central to the smart grid concept and integration of the new grid information is one of the key issues in the design of smart grids. In order to shift the traditional grid towards a smart-grid operating mode, electric utility companies need to make three classes of transformations: 1) improvement of infrastructure, 2) addition of the digital layer – which is the essence of the smart grid and 3) business process transformation, necessary to capitalise on the investments in smart technology.



As traditional energy networks become progressively more connected to modern digital networks and technologies, it will be essential that the seamless interconnection between devices and technologies across all parts of the grid is allowed, so that electricity supply and demand can be effectively stabilised when needed, not only within, but also between countries. This will be especially necessary as more electricity is generated from renewable sources and will enable electricity grids to become more resilient.

Despite the numerous benefits of the smart grid, there are, however, risks from a highly connected digital energy network. With multiple points of entry, increasing exposure to cyberattacks and cybersecurity incidents could jeopardise the security of the energy supply and the privacy of consumer data. The European Union has acknowledged the need for sector-specific cybersecurity initiatives, particularly for the energy sector and upcoming initiatives are planned that are designed to make critical energy infrastructure more resilient against physical, cyber and hybrid threats. The energy system presents specific security challenges, which will be amplified as smart technologies are integrated. Such challenges include the need for real-time reactivity of certain processes in the system (making current authentication processes too lengthy to impose), the threat of cascading effects of an eventual power outage, due to the connectivity of electric grids both within and beyond the EU, and the issues related to combining legacy energy systems with new technologies.*

From the perspective of the (re)insurance industry, a more decentralised and highly connected electricity grid potentially creates new risks related to the assignment of responsibility in the event of an incident, and the increased potential for systemic failures that resulting in high-impact and widespread power outage events. While the endpoint of the transformed smart grid is likely to improve the sustainability, resilience and security of the energy system in the long term, navigating the phase of transitioning from existing infrastructure towards this endpoint is likely to result in the materialisation of risks that could interact with insurance policies in unexpected ways and will need to be monitored on an ongoing basis.

* See Critical infrastructure and cybersecurity (europa.eu)

2.3. Conclusion

Regarding the energy transition and related requirements for energy storage on a grid level, there is continuing pressure from governments and society to provide cost-efficient storage solutions at the capacity needed to support a carbon-free power generation grid. Pumped hydro, battery storage, and the existing gas supply infrastructure repurposed for green hydrogen/ammonia have the potential for large storage capacity and will probably be key for the future storage infrastructure on this level.

In line with the transition to low-carbon renewable energy like solar and wind, the demand for energy storage at large scale is growing exponentially, and this expanding deployment will also bring down costs per unit, thus increasing economic efficiency of energy storage solutions.[15]

Pumped-storage hydropower is the most widely used storage technology and has significant potential for expansion in several regions. Batteries are the most scalable type of grid-scale storage, and the market has seen strong growth in recent years. Hydrogen is an emerging technology that has potential for large-scale (seasonal) storage of renewable energy, particularly when able to use existing infrastructures from fossil extraction.[16]

However, no single technology can fulfill the different requirements for various applications. All available storage technologies must be integrated into the grid in an economically feasible manner. What this will look like and how it will develop are the topics of current research and studies. What we can see today is that a range of technologies will compete on performance and cost in the market segments. A diverse group of storage technologies will be installed according to prevailing economic, geographic, and regulatory conditions.

New concepts, for example concerning gravity or flow batteries, are still in development with many technologies emerging and being tested in demonstration projects. Also technologies currently not yet on our radar may play a role in the future.

These factors, coupled with ongoing development in the main established technologies, mean that insurance will face many prototypical technologies with codes and technical standards lagging behind. This needs to correlate with adequate risk consulting efforts (see Chapter 3) to mitigate the risk and develop tailor-made coverage concepts. Furthermore, most applications have a high energy density, making them vulnerable to the risk of damage due to fire or explosion, which are currently the most impactful common damages in insurance of assets. The technologies need to demonstrate that their associated risks can be managed properly. When assessing single existing or emerging storage technologies with regards to inherent risks and potential impacts with the aim of offering feasible risk transfer, their risk pricing signals will also influence technological developments and energy storage markets.

[15] The IEA's World Energy Outlook 2022, p. 311f predicts falling costs. https://www.iea.org/reports/world-energy-outlook-2022
[16] IEA (2022), Grid-Scale Storage, IEA, Paris https://www.iea.org/reports/grid-scale-storage

El Hierro – a case study in the use of energy storage technologies to achieve energy self-sufficiency

El Hierro is a small volcanic island and part of the Canary Island archipelago, with a surface area of 278 km2 and a population of approximately 11,000. El Hierro was declared a UNESCO Biosphere Reserve in 2000, and since 1997 has been working towards an environmental sustainability plan, which incorporates aims to become energy self-sufficient, to adopt an environmentally friendly tourism model, to develop organic farming and a zero-waste refuse strategy.

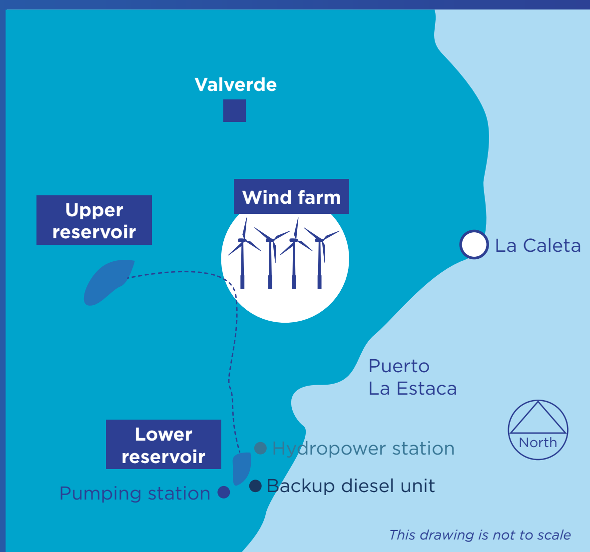
The backbone of El Hierro's sustainability strategy is the move towards energy self-sufficiency through reliance on largely renewable energy production. The island is uniquely positioned for this transformation, benefitting from a relatively stable climate with plenty of sunshine and windy days, and its unique geomorphology, owing to its volcanic landscape.

The use of energy storage systems is central to the island's energy self-sufficiency goals, with the inauguration of the Gorona del Viento wind-pumped hydroelectric power plant in 2014. The plant is equipped with two reservoirs – the upper reservoir is sited in a non-active volcanic caldera at 700m above sea level (capacity c. 500 000 m3). The lower man-made reservoir is located at 50m above sea level and has a much smaller capacity of 150 000 m3, which currently limits the efficiency of the whole system. The power plant includes five wind turbines that generate enough electricity on windy days to produce more than enough electricity to supply the island's entire electricity needs. The surplus electricity produced is used to pump water from the lower to the upper water reservoir, where it remains as a potential energy store. During times when it is not windy enough to produce electricity solely from the wind turbines, the stored water is released from the upper into the lower reservoir where the attached wind-pumped hydropower station uses the water flow to generate electricity from its turbines (see figure). This combined system enables the conversion of an intermittent and fluctuating source of energy provided by the wind into a constant supply to ensure that the grid remains stable. The system is backed up by a diesel engine power station – only used exceptionally – when there is neither enough wind nor water to generate renewable electricity.

To date, the wind-pumped hydropower station supplies around 60% of the island's energy needs, vastly improving the island's energy mix and independence, while also creating employment. El Hierro also recently created a record by supplying the island with 100% renewable electricity for 25 consecutive days. This is a pioneering achievement for an off-grid energy system, which is not connected to the European electricity grid. The result has been a reduction in the island's diesel consumption by around 7000 tons/year (an equivalent of 40,000 barrels per year) and preventing the annual emission of around 18,700 tons of CO_2 into the atmosphere.

The initial plan projected that the new wind-pumped hydroelectric power plant would be able to supply 100% of the island's energy needs and that household energy bills would fall. However, in practice, the lower reservoir of the hydro-electric plant could not be built to the capacity originally planned for, owing to restrictions that had to be enforced due to seismicity risks on the island. This has resulted in the power output from the plant being lower than expected, and consequently that diesel fuel still needs to be imported to top up energy needs. The next step of El Hierro's energy self-sufficiency project will be to further extend the wind-pumped hydropower plant to introduce wave power and solar power, including the construction of a fixed battery-storage bank to further supplement the plant's energy storage capability.

Figure: Illustrating the main features of El Hierro's wind-pumped hydroelectric electricity generation system.



3. The insurance market outlook: opportunities and challenges for (re)insurers

Emerging risks for (re)insurers can be discussed through the lens of each respective customer segment as well as the different scales of energy storage systems, and in terms of the emerging challenges for (re)insurers associated with different storage systems.

3.1. Energy storage value chains

There are three customer segments using different scales of energy storage systems from small (consumer) to medium (commercial organisations) to large scale (municipalities and governments with public-private partnerships). All have different current and emerging risk characteristics.

Consumer scale systems

Home or domestic energy storage systems, in particular battery storage, are becoming more popular, especially as more people install renewable energy sources in their homes. Solar panels and, to a lesser extent, wind turbines combined with battery storage (typically Li-ion) have become a packaged solution for consumers looking to reduce not only their energy bills, but to create a certain level of energy independence from central grid-supplied electricity.

The current insurance market for these systems can come as a bundled package (especially as part of branded systems installation) or may be an after-market add-on for consumers choosing a custom setup. Insurers already offer standard construction, property and liability coverage that reflects factors such as planned operational and maintenance contracts, periodic testing arrangements, fire protections, warranties provided by suppliers, local grid conditions and data on the energy source.

As more people install these systems, emerging risks relate to decommissioning (battery disposal and recycling costs) with potential liabilities for battery manufacturers. Another important emerging risk is the management of distributed power storage at grid scale, which does not yet exist because of the currently relatively small number of these domestic energy storage systems. This has two aspects, a financial risk for consumers and governments of feed-in tariff structures changing and saddling consumers with uneconomic equipment, and a technological risk linked to grid design.

On the opportunity side, there is potential for significant growth in the dimensions of the consumer energy storage market and the opportunity to develop retail- and consumer-oriented energy storage system insurance products. These can leverage the underwriting and risk engineering data and loss-insights gained through the use of energy storage systems in the commercial customer segment where sufficient (loss) experience has been gathered.

Commercial scale systems

At larger scales the technologies deployed for energy storage in commercial settings will be more varied than in domestic situations. Battery energy systems will be larger with different chemistries beyond Li-ion (see Figure 1.x) and require adequate protection concepts and systems to avoid catastrophic losses through thermal runaway. Key is always to understand the cell characteristics and develop a proven battery management system. Simple design principles like adequate distance between battery containers are unfortunately not always taken into consideration (see section 3.4. discussions of BESS design standards and data partnerships).

Other energy storage systems such as pumped hydro, sensible heat, liquid air storage, hydrogen, flywheel and supercapacitor systems will all be deployed depending on the application (power quality / regulation, bridging power or energy management). The emerging risks of these systems are varied and are related to technology type (especially novel technologies as described in Figure 1.w). Pumped hydro storage is mostly associated with environmental, societal and political risks related to dam construction. Use of hydrogen as an energy store has significant risks associated with the physical characteristics of liquid or compressed hydrogen, including embrittlement of certain metals e.g. nickel and the requirement for strong, yet lightweight plastics or composites to contain pressurised vessels.

Municipalities, governments and interconnected energy systems

At the largest scale, energy storage becomes a strategic decision for local, regional and national governments, often working together in interconnected energy systems where energy system security and resilience will depend on diversification of the component energy sources, the management of demand and supply and the ability to store and transport energy in different formats.

At this scale, complexity and interdependencies with energy storage technology are elevated and the risk landscape takes shape accordingly. One example is the implementation of hydrogen into energy economies where the storage risk profile is closely interconnected with other elements that are still to be developed and thus come with many uncertainties. These range from generation to transport (via pipelines or vessels) to transformation and end uses (such as filling stations and vehicles driven by H2), storage (e.g. in tanks, cavern, depleted oil & gas fields) and novel tech risks, combined with existing risks (see the breakout box on hydrogen).

Another risk complex surrounds the supply and demand control through smart grids, which beyond mere energy management also gives rise to cyber, data and privacy risks (see respective Breakout Box). Commercial, economic and political risks in relation to energy markets and potential systemic risks of energy system failure also play a distinctive role at this level.

Partnerships in energy storage

As outlined, energy storage is a critical part of the transition to net zero. In particular, more long-duration (6+ hours) energy storage capacity will be needed as intermittent renewable is increasingly deployed.[17]

Using storage systems for load shifting to ensure uninterrupted supply of power would require significant expansion of storage systems and such an increase would require significant investment in the sector. However, the uncertainty around suitable long-term technology and the risks around batteries (based on currently available technology) would affect perceptions around the financial viability of such projects and hinder investment flows. Also, high capital costs and a lack of financing options and incentives make it difficult for large scale energy storage to be realised.[18] Consequently, the public sector has a key role to play either through direct investments in storage systems, support for research and development or through supportive policy measures to encourage investments in the sector. Accordingly, several governments and multinational banks have been supporting the development of long-term energy storage technologies.

Challenges around financing energy storage plants in emerging markets can adversely affect their transition to renewable energy, thus increasing the gap in the adoption of clean energy between advanced and emerging markets. Governments in emerging markets and development banks are also looking to support the development of energy storage facilities to achieve net-zero targets. For example, in India, the World Bank and International Financial Corporation (IFC) are jointly developing a plant, comprising solar, wind and storage, one of the largest in the world. Similarly, the World Bank is helping to develop 1.44 GWh of battery storage capacity in South Africa.[19] In 2021, the World Bank Group also provided financial support of USD 465 million to West Africa under the Regional Electricity Access and Battery Energy Storage Technologies (BEST) Project.[20]

Current partnerships are encouraging and are moving in the right direction. However, the lack of familiarity with storage solutions and their performance without a specific well-functioning market is slowing their adoption at scale. As such, there is a need for expanded partnerships across stakeholders, including funding from the public sector, international organisations and large corporations, to drive this agenda forward.

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[17] Long duration energy storage technologies, Barclays, 10 November 2021.

[18] A review of energy storage financing—Learning from and partnering with the renewable energy industry - ScienceDirect

[19] The Structuring of Utility-Scale Hybrid Solar Power + Battery Storage PPPs, International Financial Corporation

[20] Unlocking battery storage systems in ECOWAS with PPIAF support | PPIAF

3.2. Risk challenges for (re)insurers

Construction and operating risks inherent in energy storage technologies and best practices to mitigate risks and limit exposures

Due to the rapid expansion of the renewable energy industry, energy storage projects are also undergoing rapid developments, especially in the US and China.[21] In terms of insuring many of these energy storage technologies, the industry is still on a learning curve, requiring engineers, risk managers and underwriters to remain alert to the new and emerging risks and hazards.

Depending on whether a given energy storage technology is in the development phase (e.g. hydrogen/thermal energy storage technologies), the more advanced technology ('continuous improvement') phase (e.g. Li-ion battery storage) or is a mature technology (e.g. pumped hydro), the risks associated with each and the mitigation strategies to limit their exposure will vary.

Examples of recent incidents involving battery energy storage system (BESS) technology

Battery energy storage system (BESS) fires caused by thermal runaway of Li-ion batteries are the most common kind of major incidents that have occurred across multiple jurisdictions, including the US, Asia, Australia and Europe in recent years.[22] Fires are inherent to this technology, but investigations of incidents also point to factors including poor workmanship and lack of installation experience.[23]

As electric vehicles become more common, the risks connected to their use are also starting to materialise. With Li-ion battery storage systems, fires originating from the vehicle battery are the main cause for concern, bringing the possibility of claims from both vehicle damage and personal injury. Electric vehicle fires have recently been under scrutiny from regulatory bodies and fire services alike, due to the difficulty in extinguishing them and also due to their spontaneous nature. Electric vehicle battery fires have been known to reignite hours or days after an initial fire, heightening safety concerns for vehicle recovery services that transport and store damaged vehicles involved in road traffic accidents.

Transport incidents under investigation include the Felicity Ace, a ship that sank near the Portuguese Azores archipelago on 1 March 2022. It remains unclear whether there is a link between thousands of luxury electric vehicles being transported and the fire on board, which eventually caused the vessel to sink after burning for two weeks. Other examples include the Conception dive boat, which caught fire in 2019 in an area where Li-ion batteries were being charged. Electric surfboards were the probable cause of a 2018 fire aboard the MY Kanga, which was anchored at Dubrovnik, Croatia.

Asset/investment risks related to battery plants

The following considerations are focused on battery facilities, while many of them would apply also to other energy storage systems. Central risk factors to consider when evaluating investment opportunities are listed below.

Location

The location of the battery storage asset is a key factor in an investment decision. Co-locating the battery storage with the renewable energy source assets provides opportunity for efficient configuration, with greatest optimisation of the battery storage asset achieved where it is located with network interconnectors. The ability to locate storage near interconnectors can result in the value of the land asset actually exceeding that of the technology itself.

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[21] Global Energy Storage Market Set to Hit One Terawatt-Hour by 2030 | BloombergNEF (bnef.com)

[22] For example, South Korea experienced 28 fire events linked to BESS between 2017 and 2022. BESS Failure Event Database - EPRI Storage Wiki. Recent examples of some BESS fire incidents include:
- 2019, Arizona, US: BESS thermal runaway event that caused an explosion, injuring several firefighters. The cause was found to be an internal cell failure in a 0.24kWh NMC battery cell that triggered a thermal runaway which cascaded to surrounding devices (NMC stands for 'Nickel, Manganese, Cobalt' and is one of the two most commonly used chemistries in lithium-ion batteries.). The explosion occurred when emergency responders opened the door to the battery storage room, igniting gases that had built up inside.
- 2021, Victoria, Australia: Tesla Megapack BESS fire that occurred during the testing of one of the 13-tonne Tesla Lithium-ion batteries at the Victorian Big Battery in Australia. This battery storage site is expected to become the largest in the southern hemisphere.
- September 2021, February 2022, California, US: California's Moss Landing BESS, the world's largest energy storage facility owned and operated by Vistra Energy, suffered two separate events that involved the overheating of battery modules. Although the modules did not catch fire in either event, owing to the activation of sprinkler systems as expected, both of the storage facilities had to be taken offline while the causes of the incidents were investigated, which, after the second event in 2022, caused disruption to the operation of the entire facility.

[23] Battery Energy Storage Systems and the rising risk of thermal runaway. Marsh, 21st July 2021; Battery Energy Storage Systems - Insurance Risks | Marsh Commercial, February 2021.

Asset selection

Optimal sizing of battery storage assets will minimise the cost of the grid connection and the cost of spill electricity, with storage capacity typically being required to cover the 2-to-4-hour period between peak generation and peak demand. Battery projects themselves can be deployed at the same rate as new renewable projects. However, short lead times and relative ease of planning create a low barrier to entry, meaning investment returns on battery projects on their own may be marginal. Co-ownership of renewable energy and battery storage assets can protect against this risk, as well as risks from renewable assets that also arise from surplus generation outside of peak demand periods.

Revenue generation

A number of factors will impact the outlook for revenue streams from the battery asset. These include government policy, the ability to achieve arbitrage in supply and demand and the evolving nature of the technology. The creation of additional non-carbon baseload capacity, such as nuclear power plants providing baseload capacity as well as alternative storage systems (e.g. pumped water storage) will shape demand and specific requirements for BESS technology and its profitability. Limited historical data on revenue generation, also presents challenges when assessing the suitability of the asset for the backing of long-term insurance liabilities.

Wholesale markets

Monitoring of electricity markets (electricity can be traded a day ahead) and buying and selling times can be aligned to daily energy pricing fluctuations (day/night factors).

Investors always have to find the right balance; waiting could mean they miss future opportunities; competing technologies could make their investments worthless. Battery earnings were strong in 2021, encouraging investors to consider larger projects despite increased cost of materials. Investors are also looking to invest in longer durations of battery capability – over 2 h, in the pursuit for differentiation and resilience. The high returns on investments expected from investments made in 2021 are likely to be dampened for future investments, especially in the short to medium term due to the cost of delivery of new battery projects (e.g. just in the last year lithium has increased its cost by 400%).

While recognising the challenges, investors also need to consider the importance of battery storage units as necessary for the success of the green energy transition and its benefits. Supporting these projects would ensure the success of other green energy asset classes, such as wind power and solar solutions.

Potential risks inherent in some non-battery and developing energy storage technologies

Although battery storage technologies are set to dominate the energy storage landscape into the 2030s, other non-battery technologies are in development and likely to be part of the energy storage mix too. These include thermal energy storage (TES) technologies, which temporarily store energy by heating or cooling a storage medium such as sand, rocks, water or molten salts. This stored energy can be used at a later time for power generation, a heating or cooling application. Thermal energy storage is advantageous as some applications can allow longer term energy storage as compared to batteries (e.g. meeting heating or cooling needs at the scale of individual buildings or districts over seasons) and can therefore more effectively decouple the supply of energy from demand, enabling the wider integration of variable renewable energy from solar and wind power into the grid. However, for those TES technologies that are currently most mature – such as using molten salt storage in conjunction with concentrated solar power plants – construction costs are very high and they are only viable in certain locations, for example, those with year-round sunny conditions. Technology challenges around the materials used for the tanks also exist. A main risk for thermal energy storage is its limited commercial viability, as the very high investments needed to build and the specific conditions required for location, which restrict usage, form a barrier to scaling and wider commercialisation.[24]

Hydrogen storage currently holds more promise as a potentially scalable and long-term (i.e. over seasons) energy storage solution. However, there are still future challenges to be addressed, relating to scaling the technology at different stages of the value chain. For example, for hydrogen to be a credible part of the green economy, cost-effective ways to produce green hydrogen need to be found. Currently, the production of green hydrogen using electrolysis is costly, prone to fire risks and requires large amounts of water and renewable energy. Once produced, to be scaled to sufficient levels, hydrogen

[24] Innovation outlook: Thermal energy storage (irena.org)

needs to be stored in large quantities. Currently, underground storage is the only potentially viable large-scale storage option, but it still remains to be seen whether long-term and reusable underground rock or salt caverns can be used without significant leakage or contamination taking place (see the Breakout Box on hydrogen storage for more information). Transmission risks relate to the materials that are used for gas pipelines. Repurposing current natural gas pipelines could be a less costly solution to transmission (rather than specially constructed pipelines), although the properties of hydrogen could cause eventual pipeline failures in pipelines previously used for natural gas, due to embrittlement. Distribution risks and issues are also significant, given the lower specification and variability of the materials currently used for distribution lines and their proximity to population centers, increasing people's exposure to the risk of explosion in the case of an eventual leak. Significant losses on property, liability and/or L&H lines may be incurred in case any of the potential hydrogen risks materialise.

Pumped hydro storage, as a mature and tested technology, is also likely to remain important for short-term energy storage, although there are issues related to the environmental and social impacts of such projects (e.g. land degradation, population displacement and use of water resources, as many plants are located on rivers) and could therefore come with significant reputational/ ESG risks for an eventual insurer (for more information, see section 'Energy storage systems and reputation: ESG trade-offs and challenges' in this chapter).

Wider issues relating to the energy storage risk landscape include the huge amount of investment capital that is currently available to start new energy storage projects and the speed at which they are developing. This is attracting new companies to enter this space without significant experience in scaling, or working with the technologies in question, which could result in an increasing number of manufacturing defects and, therefore, potential claims due to poor workmanship. If unaddressed, skills shortages in the engineering sector may also exacerbate this risk in the future.

Energy storage systems and reputation: ESG trade-offs and challenges

The growing demand for energy storage creates environmental and social challenges, and insurers should take a sustainable perspective when supporting projects to make energy storage an important aspect of the green economy.

Though the overall net-zero transition should be accompanied by significant improvement to environmental impacts, ESG-related challenges of energy storage systems must be considered carefully. Some solutions carry significant ESG and reputational risks and there is thus a trade-off between the need for efficiency and the importance of limiting negative impacts on the planet and society at large.

Environmental impacts

Mining minerals for batteries can damage land and water resources, while factories that produce materials for energy storage may generate air pollution.[25] This raises the question of limiting exploration/ mining for raw materials in high demand in the battery/storage economy.[26] Additionally, accidents, including chemical fires, may create acute threats to neighboring populations and the environment.[27] Beyond batteries, other energy storage systems could bring issues for the environment, such as pumped hydro, in particular from the perspective of environmental degradation due to the land needed and also from a water-use perspective (as many plants are located on rivers). Pumped hydro storage systems often cause upstream flooding that destroys wildlife habitats and farming land. Finally, hydrogen can be considered as an indirect greenhouse gas with the potential to increase global warming and might also lead to increased operational risk of pipelines and power plants. Hydrogen might be grey, blue or green, depending on how it is produced, and the non-green hydrogen could also be necessary to provide energy storage. On the other hand, 'green' hydrogen production is energy-intensive and its environmental impact may also be scrutinised. Trade-offs, greenwashing potentials and related reputational risk need to be proactively addressed.

[25] Mining of critical components for lithium-ion batteries is concentrated in a few countries (i.e. Chile, Australia, or China), bringing them also in focus regarding potential environmental damage. Air pollution has been reported, e.g. in Chinese villages that are affected by factories that produce graphite which is an indispensable resource for lithium-ion batteries. In Argentina, locals claim that lithium operations have contaminated streams used by humans and livestock, and for crop irrigation. Given these conflicts, exploration and mining activities for raw materials in high demand in the battery/storage economy could face limits.

[26] Apart from lithium, also many other elements are in high demand, e.g. nickel and cobalt. Copper is used in transmission cables.

[27] There have been several fires for instance at recycling plants where lithium-ion batteries have been stored improperly, and this kind of accident could harm the local environment. Similarly, there has been a recent case of a raging fire on an abandoned cargo ship in the Atlantic Ocean due to burning lithium-ion batteries inside the cars on board the vessel, producing toxic gases which required the intervention of specialists.

Social impacts

The social impacts of projects aiming to support expanded energy storage must also be considered. First, local communities are particularly affected by the production processes and search for raw materials for energy storage systems. In Chile and Argentina, for instance, where the Atacama region is well known for the extraction of lithium by tech companies, indigenous people living there are impacted by these activities and have lodged complaints over mistreatment (i.e. mining activities consumed 65% percent of the region's water, affecting local farmers who also rely on the resource). As the impacts of climate change become more visible, such conflicts will likely become more frequent and severe. Pumped hydro storage systems can also have significant social impacts with requirements for resettlement of local population as well as impacts on farming, forcing agricultural production losses and affecting traditional livelihoods. Besides the impact on local communities, supply chains for producing energy storage technologies also carry significant ESG and reputation risks notably due to human rights violations. For instance, tech firms have been directly named in litigation brought by families of children killed or injured while mining in Congo for cobalt, an essential element needed for rechargeable lithium batteries.[28]

Recycling is a developing sector that could contribute to the reduction of negative ESG impacts, offsetting e.g. the need for extraction of key components for battery storage. Other alternatives could also be explored to reduce environmental impact, such as lithium extraction from geothermal waters (i.e. geothermal energy naturally powering lithium extraction from solid rock), or the emerging technology based on lithium iron phosphate batteries that use non-toxic materials. These batteries are also more easily recyclable and have a longer lifespan which could reduce the overall carbon footprint, as manufacturing new batteries takes energy and resources.

Insurers will have to refine and strengthen their ESG frameworks to address emerging environmental and social risks associated with energy storage solutions as part of their underwriting. ESG guidelines could be developed to better consider the impact of projects on the environment and on local communities, and to identify activities that could have a negative impact on human rights. Informed decision making, accompanied by mitigation actions by insurance companies, has the potential to reduce ESG and reputational challenges associated with energy storage, starting from the supply of raw materials through production activities.

Political risk

The rapidly evolving political landscape, the uncertainty about ongoing geopolitical tensions and the politicisation of energy projects magnify the importance of carefully considering political risk in underwriting and investing in projects for energy storage. Emerging geopolitical tensions are particularly relevant for the issue of energy storage, given that shifting to renewable energy sources has taken on new urgency. Regional differences in transition plans and progress will produce uneven dynamics that contribute to political, economic and social uncertainties, in both emerging and developing markets. Finally, global supply chains and dependencies shape interconnections and potential accumulation of risk.

Four main risks could be identified for insurers when assessing the opportunity to support energy storage system projects:

Sovereign risk

Investments in renewable energy and related storage systems in developing countries are often associated with a relatively high degree of sovereign risk. Most projects in emerging markets involve direct interface between investors and governments which may lead, by its very nature, to a greater sovereign risk. Insurers acting as foreign investors and entering energy storage system projects in developing markets should carefully consider the regulatory framework and take steps to protect their investments. Indeed, in some countries where investments have been actively promoted by governments, disputes will likely arise, and some governments may stop payments or seek to renegotiate prices, which poses a question about a potential country's solvency impacting negatively the delivery of projects.

Geopolitical tensions and trade/economic sanctions

The rise of geopolitical crises and tensions is also a key factor of interruption for energy storage system projects, having severe and negative impacts on insurance activities. In June 2021, the US Commerce Department ordered a ban on US imports of a key solar panel material from a Chinese-based company in the context of the US-China trade war

[28] 50-60% of cobalt mined comes from Congo. Ann Kelly, Apple and Google named in US lawsuit over Congolese child cobalt mining deaths, The Guardian, 16 Dec 2019

started in 2018. The US Commerce Department has been investigating Chinese solar firms suspected of illegally dumping low-cost panels onto the international market and of using Uyghur forced labour in making their products. It is reasonable to think that trade wars and geopolitical conflicts, such as this example of Chinese solar imports in the US, will harm the renewable energy industry overall and also have a negative impact on energy storage system projects.

Terrorism, social unrest and war

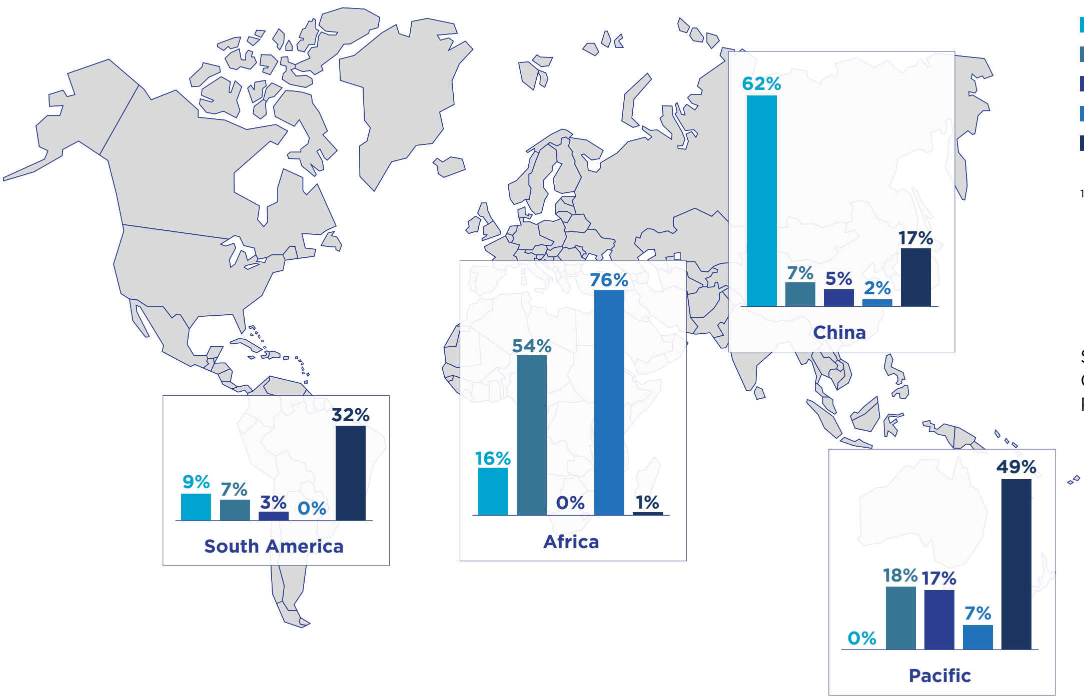
Energy storage systems – either in construction or at work – may be targeted by terrorism, military action and social unrest. In this regard, energy storage systems could be subject to both physical and cyberattacks. There have been multiple incidents with energy infrastructures already, such as in 2019 when a renewable energy developer in the US was hit for the first time by a cyberattack that briefly cut contact to a dozen wind and solar farms, revealing the vulnerability of the power grid (this attack was the possible result of an intelligence operation). Such attacks could be state-sponsored in a context of political tensions, but terrorists and extremists also view energy systems as a particularly attractive target according to security agencies. (Re)insurance implications have to be considered not only for the physical damage at location, but potentially also in terms of service interruption, i.e. regarding business interruption (BI) and contingent business interruption (CBI) covers.

Disruptions in supply chains

Secure supply of raw materials for energy storage systems such as batteries is vital (e.g. for electric vehicles). With the increased demand in the context of the green transition, new supply chain risks will arise. For instance, some crucial resources to battery production are concentrated in a small number of countries (cobalt/Congo) (cf. graph below, Figure 3.z), sometimes prone to political instability or subject to diplomatic tensions (i.e. lithium extraction dominated by China, which is also monopolising chemical processing and manufacturing, as well as battery cell production). There is a risk that the manufacturing of key technologies is disrupted due to political turmoil in a country with a production monopoly. Conversely, concerns over supply chain disruptions and over-reliance on a single region for supply could lead to the construction of cell production factories in a wider array of markets (e.g. in Europe) in order to mitigate such supply chain risks, which could be an opportunity for insurers to support those projects.

Interest in supporting new energy storage solutions and projects will grow parallel with political concerns and insurers will need to monitor and stay informed so they are able to address the broad range of political risks arising from geopolitical conflicts, disruptions in supply chains, and sovereign risks.

Figure 3.z: Supply chain risks: resources distribution with large political risks
Virgin raw materials supply, 2020 [% share of global][1]



Graphite
Manganese
Nickel
Cobalt
Lithium

[1] China shown separately. Excludes data of countries either due to small amount or proprietary data

Source: United States Geological Survey, Roland Berger

3.3. Impacted insurance lines

For insurance, the potential claims related to energy storage projects have the potential to affect all business lines. For instance, battery fires for vehicles transported by cargo ships could impact Marine insurance. Liability insurance policies could also be impacted due to possible negative consequences on the environment (depending on the technology, both during the construction, operational and/or disposal stages) and due to defects in the design or manufacturing process causing damage.

There is a double issue to consider when looking at the operational risks inherent in underwriting, with risks both relating to a potential accident at the energy storage project in question, in addition to the risks related to its potential consequences, such as disruption in energy supply and the possible business interruptions that this could cause.

Insurance policy types that could be impacted include:

- Property: (PD / BI / loss of production)
- Transportation / Installation
- Builder's risks: Construction All Risks (CAR) & Erection All Risks (EAR)
- General, Product Liability, Employer's Liability: overheating / overcharging / obsolescence; electrification / electrocution; pollution / intoxication (due to toxic fumes from batteries); traffic accidents; explosion; maintenance and professional responsibility; fires / burns / personal injury; transport-related risks (marine); public transportation (potential bodily injuries), cyber
- Marine/Cargo
- Natural hazard coverage could be a challenge for 'traditional' insurance as weather conditions are worsening even in areas that were not traditionally highly exposed to natural catastrophes
- Environmental liability
- Entertainment (e.g. e-motorsport events, etc.)
- Life & Health (trade-offs between accidents, pollution etc. from incidents with energy storage facilities on the one hand, improvements from making fossil energy redundant in terms of air quality etc.)

3.4. Mitigating risks inherent in energy storage technologies

The ability to mitigate the risks inherent in various energy storage technologies will depend on the maturity of the technology and therefore the amount of experience and knowledge that has been accumulated in dealing with potential incidents. In this way, mitigation strategies, in terms of developed design standards, handling protocols and performance monitoring are more mature for Li-ion batteries and large-scale storage facilities that already use this technology. In the case of hydrogen as an energy storage solution, although the industry already has the necessary risk knowledge, the potential new risks associated with its application at larger scales and its wider distribution, including to residential areas, should be reassessed in order for it to become a viable storage solution. For other storage technologies that are in the development phase, the risks associated with each will only materialise as the technologies are tested and more widely deployed.

Until the industry has the experience necessary to develop more stringent underwriting guidelines to mitigate known risks, insurers seeking to limit their exposures will necessarily rely on insurance terms and conditions developed for other prototype technologies. However, there are methods that can be used to assess the risks associated with a given prototypical energy storage project, as described in the Breakout Box on loss prevention strategies (below).

Standards: the example of BESS design standards

Numerous standards have emerged governing the design and deployment of new BESS. These standards incorporate current understanding of the risks and learnings from past events and will evolve according to loss experience with the technology. For instance, insurers currently require or encourage fire protection measures such as failure indication monitoring and sprinkler systems, battery module separation to prevent fires from spreading, and an emergency response plan developed in conjunction with local emergency service providers. Other crucial factors relate to the construction of the BESS site, including that contractors are experienced with BESS technology. The site should also have a dedicated maintenance schedule including monthly preventative checks and spare parts available to minimise business interruption losses in the case of an incident.[29]

[29] Battery Energy Storage Systems - Insurance Risks | Marsh Commercial. February, 2021.

Construction phase

Similar to limiting exposure to foreseen risks during the construction phase of Property, Erection All Risk (EAR) and Construction All Risk (CAR) policies, there are initial 'design' considerations applicable to each specific technology. Policy wordings are continuously developing and maintaining information on market practices for the renewable energy sector to establish underwriting practices is essential. Manufacturer's warranty conditions should be considered first, since insurance is not meant to cover loss or damage from defects due to material workmanship, design plan or specification.

Operations phase

Once operational, policy wordings should reflect the risk assessment performed and should correspond to any other type of insurance provided. Coverage should focus only on fortuitous/unforeseen events. As soon as experiencing a loss becomes inevitable, the fundamental principles of insurance no longer apply. This could apply to instances where defective materials result in a series of subsequent losses. As discussed previously, loss potential could also increase due to the exponential growth in energy storage, in which new and inexperienced contractors may deliver flawed installations and inferior construction. Maintaining knowledge of trusted partners in the construction industry becomes an important consideration. Furthermore, it is important to discuss revenue volatility and clauses defining daily Business Interruption (BI) and Delays in Start-up (DSU) limits. Common exclusions to limit coverage, similar to other property and engineering lines of business, are terrorism, pandemic or national emergency.

Data partnerships: the example of BESS

Modeling overheating and thermal runaway losses for battery energy storage systems (BESS) remains a challenge, due to the variety of factors involved and limited data availability. This risk is higher for larger batteries, where the rate of heat generation increases exponentially compared to heat dissipation. To tackle this risk challenge, insurance companies are partnering with tech companies to provide data-driven risk covers. Recently, Tokio Marine Kiln (TMK) has partnered with Insurtech Altelium to provide a data-driven BESS warranty program, which is built on an understanding of battery properties, behaviours and data analytics.[30] In addition to property loss risks, there are also increasing concerns around risks related to non-performance or low-performance of batteries. While such risks may not currently be a major concern, they will gain importance as utility-scale batteries expand and are integrated into the grid. Insurers are already partnering with battery manufacturers to cover performance warranty of battery manufacturers.[31]

Skills

The booming energy storage systems sector will impact on skill needs and labour markets. Similar to the solar panels boom, energy storage installations will require engineering professionals to construct and maintain facilities, and new roles will be in demand for repair, energy storage consultancy and other roles. Insurance assessments for energy storage systems will also require new risk management and actuarial skills. Conversely, a continued transition away from fossil fuels will leave many professionals working in co2-intense sectors without work. Some of the new professional roles required by rising energy storage markets may be filled with former professionals from oil and other fossil-based industries. Many of these professionals may be excellent candidates for reskilling. Likewise, insurance professionals formerly dedicated to risk prevention and management in the fossil energy industry may benefit from opportunities in energy storage. Areas where existing skillsets may be beneficial include hydrogen storage and transport.

3.5. Regulations and policies

The framework of regulations and policies shapes both the energy storage industry and the insurance industry engagement with this industry.

Regulations and policies are key to foster (or hinder) the development of energy storage markets and to enable the insurance industry to support developments via risk transfer solutions and investments. Regulatory interventions and policy programs can range from those that are technologically focused, where standards, certifications and controlling mechanisms define licenses to operate. While convergence of technical

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[30] Altelium is founded by a team at the Lancaster University, that built the data-driven diagnostic models on chemistry-related battery failure, after recognising that data about battery history, state of health and future performance was crucial to the future economic viability of the electric vehicle (EV) battery market. Developing Diagnostic Models to Warranty Batteries - The Faraday Institution. TMK partners with Altelium on battery energy storage warranty - Reinsurance News

[31] Ariel Re has partnered with Powin LLC to provide Battery Storage System Replacement Cover to backstop Powin's contracted capacity guarantee in the event of unexpected defects and/or accelerated degradation of the storage systems causing a warranty default. Ariel Re delivers innovative insurance to support Powin Storage Solutions - Ariel Re.

standards, requirements and controls largely enable risk management and risk transfer solutions, divergence and fragmentation shape emerging risks for energy storage operations and (re)insurers alike.

Similarly, there is a need to establish common standards around safety. Absence of detailed and internally agreed standards affects the bankability of storage projects. Governments, regulators, producers and (re)insurers need to work together to facilitate safe adoption of energy storage systems. As large-scale storage systems mature, stakeholders will need to collaborate to share data, and create tailored risk management products and services to enable safe use of energy storage solutions.

Standard setting, as opposed to lack of or divergence from standards, is also an issue along the supply chain and trade routes. This pertains to the rules governing trade (e.g. for hydrogen) and the labour force that is employed in extraction activities (minerals mining) related to battery storage systems, and extends to trade agreements between countries. These subjects where rules must be defined extend beyond a single jurisdiction, making them dependent on international cooperation.

Regulators and policy makers also shape market conditions via taxes and subsidies, with these harbouring the potential to be either beneficial or to become a drag on the sustainable growth of energy storage solutions. As storage technologies gain in prominence, they should be afforded more consideration as regulations governing the electricity market are revised to reflect the future energy landscape.

Loss prevention strategies and ways to assess prototypical technologies

When engaging (with a risk engineering and consultancy perspective) on an energy storage system, a general approach to assess and prevent risk is advised as follows.

The Loss Prevention Strategy is based on the evaluation of the Research & Development (R&D) processes to reduce or avoid third-party losses caused by the insured's new energy storage project development.

Prior to on-site risk dialogue, the insured submits available documentation on the new energy storage project for review.

- Definition of the system to analyse:
  - Nature of the Storage system: (e.g. Electrochemical – Batteries; Chemical – Hydrogen; etc).
  - Timeframe of the Storage System: (Large-scale – seasonal; Mid-scale – daily; small-scale – minutes / seconds).
  - Size of the Storage System: Industrial purposes / final users.
- Overview of the R&D activities, certification process (if applicable).
- Stage gate processes and release procedures.
- Test environment and tools.
- Clients' participation.

On-site dialogue with the R&D, project team and risk managers to discuss and evaluate the maturity of the technology and the existing loss prevention and control measures regarding the energy storage project:

1. Introduction and overview of the R&D activities.
2. Management of the project and definition of specifications.
3. Contract management.
4. Advanced product quality planning.
5. Tools. e.g. FMEA – SWOT.
6. Quality Management, Stage Gate Process, Functional Safety Workflow.
7. Test Factory - Mockup Tests – Simulation – Computational Engineering Science – Accelerated Aging Tests / Fatigue Tests – Chemical Compatibilities (e.g. Hydrogen –> Steel Embrittlement).
8. Fire prevention, containment, extinguishing systems.
9. Standards and rules applied in the development.
10. Production Part Approval Process
11. Clients' complaints and claims management / lessons learned.
12. Survey system: sales and market vigilance.
13. Data management (traceability, document control and archiving, electronic batch recording).

The insured receives a detailed report with a comprehensive risk evaluation of his new energy storage process. If applicable or necessary, appropriate recommendations are suggested.

3.6. Conclusion

In order to replace fossil fuel as a main source of energy and become efficiently reliable, renewable energy sources need to have environmentally friendly, affordable, and competitive energy storage technologies which can be financed and insured.

The insurance industry is keen to engage in the energy storage markets – on consumer and industrial insurance levels as well as more broadly. For this to happen, it will require not only thorough risk assessment, prevention and risk transfer solutions but also favorable market conditions and regulations, standards and policies – areas in which the insurance industry has only limited influence but nonetheless depends on as it seeks to offer risk solutions.

When implementing, building and maintaining an energy storage system, projects must be critically evaluated through the insurance industry lens. From property risks to operational threats, projects should be carefully examined before an insurance policy can be written. The stakes are high, since negligence or miscalculation can lead to large losses for the insurer in the event of accidents, fire or other mishap due to flawed design, poor operational or safety practices and other variables. Profitability and financial aspects in the short and long terms should also be taken into consideration.

When a project secures insurance coverage, this sends a signal to banks, regulators and stakeholders that it has been thoroughly studied, well designed and sufficiently assessed against potential risks. As a result, the actions of insurers play a crucial role in driving energy projects forward in pursuit of ESG goals, a shift to renewable resources and the maturation of the green economy. Through their underwriting, insurers can ensure that energy storage developers design robust, future-proofed facilities, and that they continuously improve their practices with an eye toward mitigating emerging risks and eliminating negative impacts associated with new technologies.

New risks and uncertainties may arise from single energy storage devices and applications as well as from broader networks and supply systems where risks accumulate a potentially significant impact on insurance products and coverages.

Environmental concerns and other ESG-related questions regarding everything from mineral extraction, issues linked to the development of hydroelectric projects, recycling and resource management are challenges (re)insurers may play a role in helping to mitigate. Trade-offs and reputational issues in the realm of sustainability demand attention as well, since the proliferation of traditional and innovative energy storage technologies could have significant adverse environmental and social impacts.

Energy storage is relevant to many lines of (re)insurance business, and it offers many opportunities and challenges beyond investment and ESG considerations. Risk transfer solutions to support construction and maintenance of larger energy storage facilities may be offered particularly through property and speciality as well as casualty lines. In addition, life and health impacts may be worth considering, not only in regard to potential threats from accidents, spills etc., but also in terms of beneficial risk factors, such as improved air quality from replacing fossil energy production. Policy-driven risk of moving too quickly or prematurely locking in certain technologies that become quickly outdated is a structural risk that the insurance industry may encounter. Conversely, risks associated with underinvestment into storage facilities or an overabundance of caution exist, as well as do timely worries that have emerged recently, including inflation and impending recession. Immediate concerns such as these could conspire to divert our focus away from climate, sustainability and energy security risks – all forces that largely support the development of energy storage capacity.

The insurance industry has a natural interest and role in loss prevention, ranging from prevention of accidents to avoidance of reputational damage. On the operational side, new expertise will be needed, particularly in relation to prototype risk and dealing with the gaps in loss experience.

For (re)insurers, energy storage system engagements to a large extent begin as classic risk engineering tasks. To tackle the emerging risks involved, thorough processes, methods and skills are needed. When dealing with new technologies, prototype risks abound. Thorough and broad risk assessment is necessary for any given project. To proactively foster risk appetite, also diversification of risk taking will be advisable. Portfolio diversification may be sought among energy storage technologies and projects, but also by balancing energy storage risk taking with entirely uncorrelated risk taking.

General conclusion

Energy storage solutions are taking center stage in the global economy. This development is not only driven by the necessity of transitioning to a low-carbon future, but also by technological progress, consumer behaviour and the increased urgency for energy security. Political will, the exigencies linked to tackling climate change and other factors have all incentivised researchers, investors, and public and private sectors – including (re)insurance companies – to engage in development, implementation, and adaptation of energy storage solutions.

Research & Development dynamics, changes in markets, regulations and incentive structures to frame markets, the sheer growth of energy storage markets, its diversity and complexity – all these forces shape an exciting but volatile landscape of opportunities and risks. Some risks are known and understood and can therefore be quantified, modelled and priced. However, some are entirely novel or are rapidly changing and others are even currently unknown – i.e. they are emerging risks.

In terms of capacity, pumped hydro storage is currently still the dominant storage solution – with largely known risks attached. Sensible heat and battery systems have grown tremendously over the past 15 years, with risk expertise and loss experience of these evolving technologies growing accordingly. In contrast, future technological solutions such as large-scale hydrogen storage are predominantly unchartered risk territory.

The transition to sustainable energy systems is high on the political agenda and an important issue for consumers. As efficient, cost-competitive and reliable storage systems are vital for the transition towards renewable energy production, the demand for energy storage is both high and rising, encompassing not only overall capacity but also functional diversity. In order to ensure that energy generated from such green sources is available where and when it is needed, an optimised energy storage system becomes as important as energy itself. From the perspective of (re)insurers, providing cover for the development of new energy storage projects offers vast new opportunities; however, the risk horizon includes not only accidents, leaks, fires or explosions, but also extends to any risk that might emerge from the installation, maintenance, and the whole life cycle of such projects.

Shaped by technological innovation and market demand on the one hand, and economic policies and regulations on the other, energy storage markets are evolving rapidly. The (re)insurance industry – and financial industry in general – will play an important role. By providing risk transfer solutions as well as being investors, (re)insurers are a key building block in the financing and securing of energy supply and in developing energy storage projects. They can also contribute their expertise in risk and prevention, and their price tags for specific risks provide important signals to all stakeholders involved with energy storage systems. Successful development of individual projects and entire markets will, therefore, depend on the support of (re)insurance companies that are willing to venture into this dynamic space. Each (re)insurer must assess their own risk appetite, exposures and methods to optimally diversify risks – including across storage technologies, familiar and prototypical risks, and across lines of business.

Acronyms / Glossary

BEIS	Business, Energy and Industrial Strategy (USA)
BESS	Battery Energy Storage System
BEST	Battery Energy Storage Technology
BEV	Battery-powered Electric Vehicle
BI	Business Interruption
CAES	Compressed Air Energy Storage
CAGR	Compound Annual Growth Rate
CapEx	Capital Expenditure
CAR	Construction All Risks
CH4	Carbon and Hydrogen (Methane)
CO2	Carbon Dioxide
DOE	Department of Energy (USA)
DMC	Dimethyl Carbonate
DSU	Delays in Start-Up
EAR	Erection All Risks
EC	Ethylene Carbonate
ELCD	Electric Double Layer Capacitor
EHB	European Hydrogen Backbone
EPRI	Electric Power Research Institute
ESG	Environmental, Social and Governance
ESGC	Energy Storage Grand Challenge (USA)
EV	Electric Vehicle
FEC	Fluoroethylene Carbonate
FMEA	Failure Mode and Effects Analysis
GWh	Gigawatt-hour
H2	Hydrogen
H2S	Hydrogen Sulfide
HEV	Hybrid Electric Vehicle
HTA	Hard to abate
IEA	International Energy Agency
IFC	International Financial Corporation
LAES	Liquid/Liquified Air Energy Storage
LFP	Lithium Iron Phosphate
Li	Lithium
LIB	Lithium-ion battery
LOHC	Liquid Organic Hydrogen Carriers
MWh	Megawatt-hour
NMC	Nickel, Manganese, and Cobalt
PC	Propylene Carbonate
PD	Property Damage
PEM	Polymer electrolyte membrane
PHEV	Plug-in Hybrid Electric Vehicle
PSH	Pumped Storage Hydropower
OpEx	Operational expenditure
R&D	Research and Development
SMES	Superconducting Magnetic Energy Storage
SNG	Synthetic Natural Gas
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TES	Thermal Energy Storage
TMK	Tokio Marine Kiln
TWh	Terawatt-hour
UCHS	Underground Compressed Hydrogen Storage
UGS	Underground Gas Storage
VC	Vinylene Carbonate
Wh/Kg	Watt-hour per Kilogram

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Laan van Langerhuize 1, 1186 DS Amstelveen, or
PO Box 74500, 1070 DB Amsterdam
The Netherlands

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