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THOUGHT LEADERSHIP: POWER PLAY

LARGE SCALE ENERGY STORAGE IN A DECARBONISED GRID

WHITEHELM
ADVISERS

INTRODUCTION

The great energy transition is underway, with energy infrastructure at the heart of this tectonic shift towards a low carbon global economy. Savvy investors sit poised, with dry powder ready to deploy into assets that will power the global switch from fossil fuel based energy generation to renewable sources. But while renewables such as wind and solar are both low cost and low emissions, as standalone generation sources they are also unreliable and can pose a threat to the stability of the electricity grid.

The missing link is energy storage, that is, infrastructure that can be used to store renewable energy when it is generated and dispatch it when it is needed. Energy storage assets include those of grid-scale and smaller, behind-the-meter batteries implemented by households and businesses.

In this article, we focus on three large energy storage technologies – pumped hydro, lithium-ion batteries and underground hydrogen storage - considering the investment case for these asset types that are of growing interest to infrastructure investors. We also look ahead to emerging energy storage technologies, including compressed air and liquid air energy storage. Finally, we consider the successful decarbonisation of the UK Electricity Grid as a case study that may become a prototype for other grid operators around the world, generally and in terms of energy storage.

Large scale energy storage infrastructure is likely to play a key role in the decarbonisation of electricity grids around the world, a critical pathway to net zero by 2050. When it will make sense for infrastructure investors to allocate capital to this emerging asset type is less clear. Energy storage technology should still be considered nascent, applicable regulatory frameworks remain immature and energy storage projects still tend to involve some form of government support. Despite this, global energy storage capacity is forecast to grow quickly and so is the interest of global infrastructure investors in this asset type.

BACKGROUND

What is energy storage?

Energy storage is self-explanatory – it means capturing energy when it is generated and keeping it somewhere to be used at a later time. But energy storage as it is most often talked about now relates to the storage of intermittent, renewable sources of electricity such as wind and solar to decarbonise the global energy sector.

In the past, electricity grids haven't required masses of energy storage because the incumbent coal and gas fired power plants were able to balance demand and supply to create a reliable system. Baseload power was generated continuously throughout the year by both coal and gas fired power plants with low running costs and stable output levels. Dispatchable generation has tended to come from open-cycle gas turbines known as 'peakers', characterised by their ability to ramp up generation quickly, often within 15 minutes, to meet peak spikes in demand for electricity.

The global economy is now moving away from fossil-fuel power generation and renewables are increasing their share of the energy mix in electricity grids around the world. However, because renewables are intermittent (meaning they only generate power when the sun shines and the wind blows), they can only be a source of dispatchable power if they are used in conjunction with energy storage.

Future demand for energy storage assets

Demand for energy storage is set to take off. Globally, capacity is forecast to grow at a compound annual growth rate of 31% over the next decade, resulting in 741 GWh of cumulative capacity by 2030.[1] Close to half of this projected growth is forecast to come from the US (49% or 365 GWh) followed by China (21% of 153 GWh). In Europe, the UK and Germany are expected to be the most active markets for energy storage investment while in Australia, South Australia continues to be where most energy storage investment activity is happening. While Australia continues to face energy policy uncertainty and the availability of government funding for energy storage projects as provided by the Australian Renewable Energy Agency (ARENA) is running low, by 2025 Australia's cumulative energy storage investment is forecast to be A$8 billion or 12.9 GWh of storage.[2]

There are many different types of energy storage, and it can be split between front-of-the-meter (FTM) and back-of-the-meter (BTM) capacity. These splits literally refer to where the energy storage is located, with household battery systems being a good example of BTM energy storage. For this article, we focus on FTM energy storage as this is where the types of large-scale energy storage assets that infrastructure investors are seeking are located. Further, we focus on three specific large-scale energy storage technologies which we consider are most likely to dominate as the global energy transition unfolds. But we do note there are many different types of energy storage assets as well as innovative ways to gain exposure to the benefits of this asset type, most notably energy storage as a service (ESaaS), that are beyond the scope of this article.

[1] https://www.woodmac.com/press-releases/global-energy-storage-capacity-to-grow-at-cagr-of-31-to-2030/

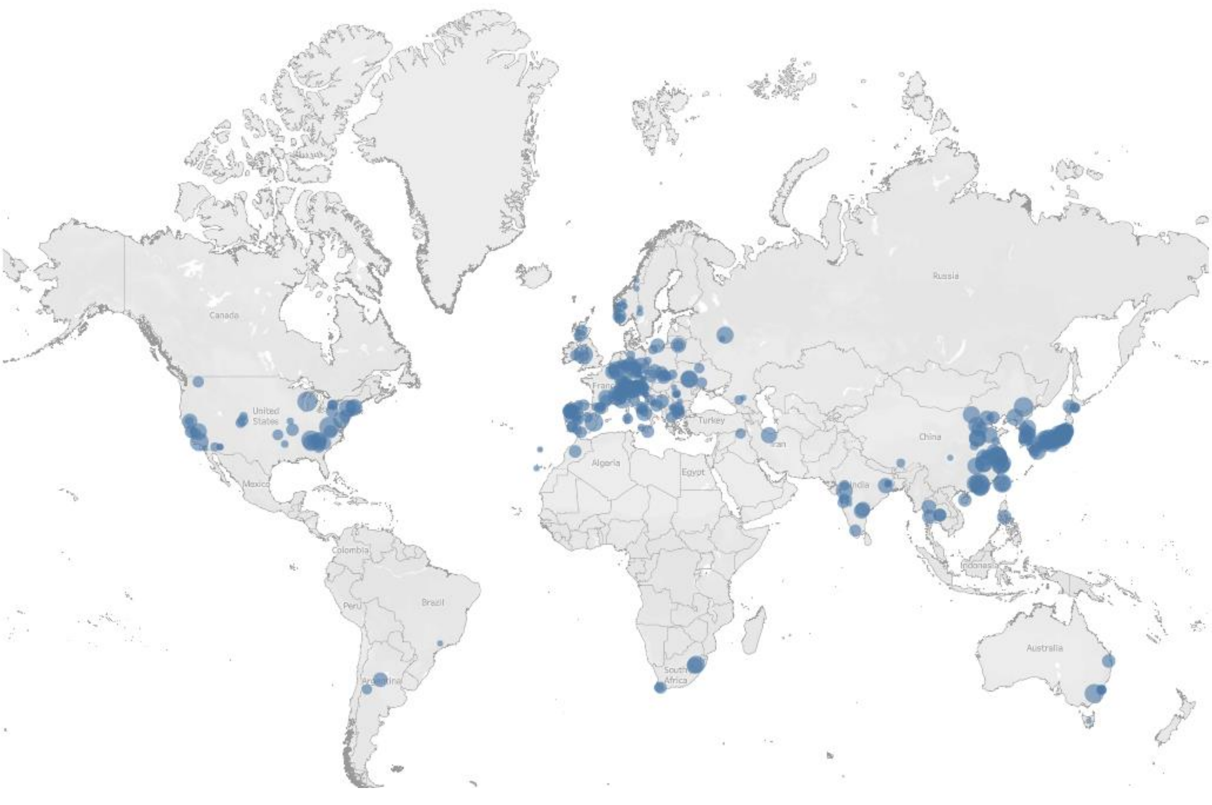
[2] https://www.woodmac.com/press-releases/australias-energy-storage-capacity-more-than-doubles-to-1.2-gwh-in-2020/

PUMPED HYDRO

Pumped hydro energy storage works such that water is pumped from one reservoir up a hill into another, elevated reservoir at times when there is surplus electricity supply. Then, during times of high electricity demand, the water is released downhill, driving turbines and thereby providing near instantaneous energy to the grid.

Currently, pumped hydro makes up around 97% of the world's electricity grid storage.[3] Chart 1 below provides a snapshot of the current installed capacity of hydropower pumped storage around the world and Chart 2 over the page shows capacity that has been planned, announced and under construction.

Chart 1: Hydropower Pumped Storage – Operational Capacity

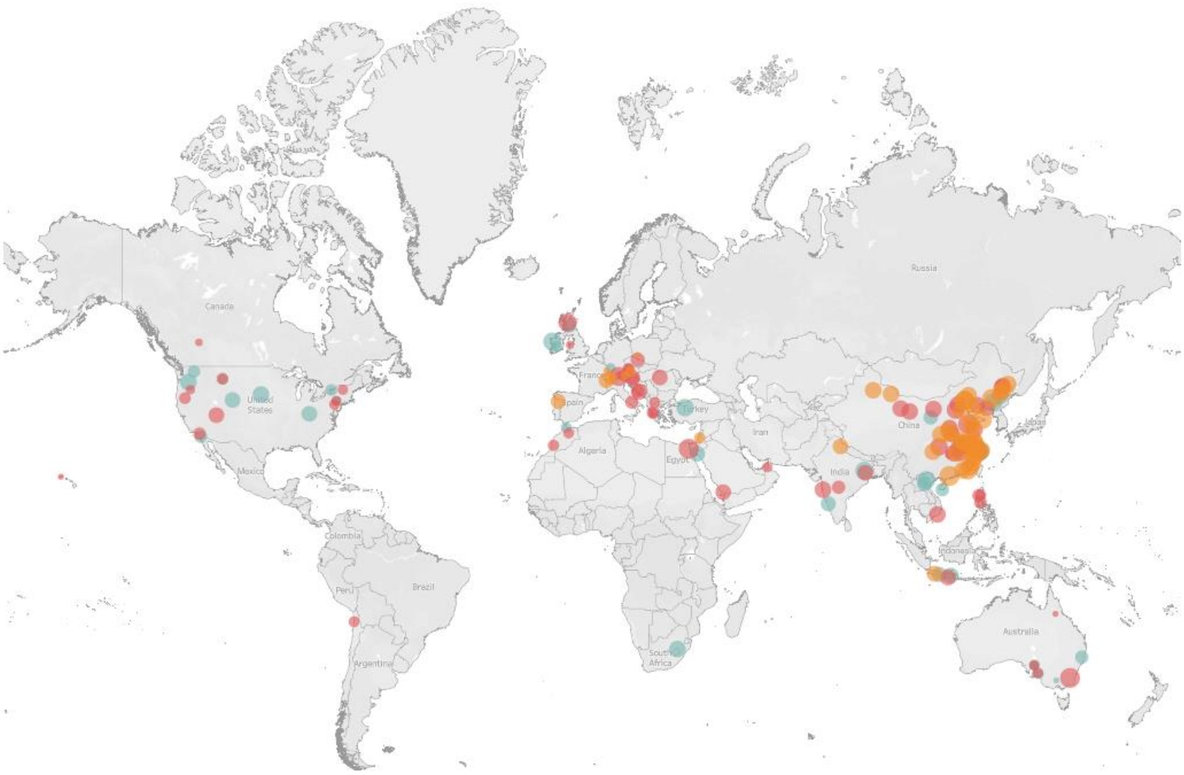


Source: International Hydropower Association[4]

[3] http://re100.eng.anu.edu.au/global/

[4] https://www.hydropower.org/hydropower-pumped-storage-tool

Chart 2: Hydropower Pumped Storage – Planned, Announced and Under Construction Capacity



Source: International Hydropower Association[5]

To access pumped storage hydropower, two connected reservoirs at different heights are required. Research completed by the Australian National University in 2019 identified about 616,000 potential sites for pumped storage hydropower around the world, capable of storing up to 23 million gigawatt hours or around 100 times more than what would be required to support a 100% global renewable electricity system, as shown below in Chart 3.

Chart 3: Global Sites with Potential for Pumped Storage Hydropower

Source: Australian National University

[5] https://www.hydropower.org/hydropower-pumped-storage-tool

Pumped hydro capacity is set to increase, with the International Energy Agency (IEA) forecasting a 7% increase to 9TWh by 2030[6], meaning pumped hydro will remain the workhorse of electricity storage over the coming decades. These assets are flexible and enhance grid security, characteristics that are essential for energy storage assets in electricity grids as renewables increase their level of penetration.

Despite this, the private investment case for pumped hydro is not straightforward. Greenfield pumped hydro projects are big, expensive and take a long time to build. These projects typically involve a high degree of regulatory complexity including on environmental aspects and social acceptance, and this increases uncertainty and can push out construction time. Investors considering brownfield pumped hydro assets should scrutinise future capex requirements, given that the stock of existing assets around the globe is ageing (average asset age is 45 years in Europe and 50 years in the US)[7] and typically in need of modernisation.

However, the inherent risks of pumped hydro assets can be successfully mitigated by locking in cash flows under a long-dated power purchase agreement (PPA) with a sovereign or highly rated corporate counterparty. In fact, we think the absence of long-term contracted cash flows for these capital intensive and complex projects largely rules out private capital. Governments wanting to attract capital for pumped hydro energy storage assets can support the private investment case (and in doing so access broader non-financial benefits relating to natural resource management and local employment), most obviously by facilitating long term PPA's but also by smoothing and speeding up the regulatory process.

We think opportunities for hydro power assets exist in many jurisdictions, however these opportunities typically differ between developed economies and emerging markets. Investors may find the opportunities to invest in pumped hydro assets in Australia, Europe, the UK and the US through brownfield assets that require steep up-front capex spending in order to modernise. For these transactions, investors can secure a sound IRR if the capex forecasts built into the cash flow models are comprehensive and realistic and the cash flows are contracted over the long term with a high quality counterparty. Alternatively, investors looking for greenfield assets would be well-advised to focus on well-structured projects in emerging markets in Asia, Africa and Latin America (subject to their tolerance for sovereign and currency risks) where most new construction is most likely to happen, ensuring of course that the risk premium is sufficient to compensate for the intrinsic risks of these projects.

[6] https://iea.blob.core.windows.net/assets/4d2d4365-08c6-4171-9ea2-8549fabd1c8d/HydropowerSpecialMarketReport_corr.pdf
[7] Ibid

LITHIUM-ION BATTERIES

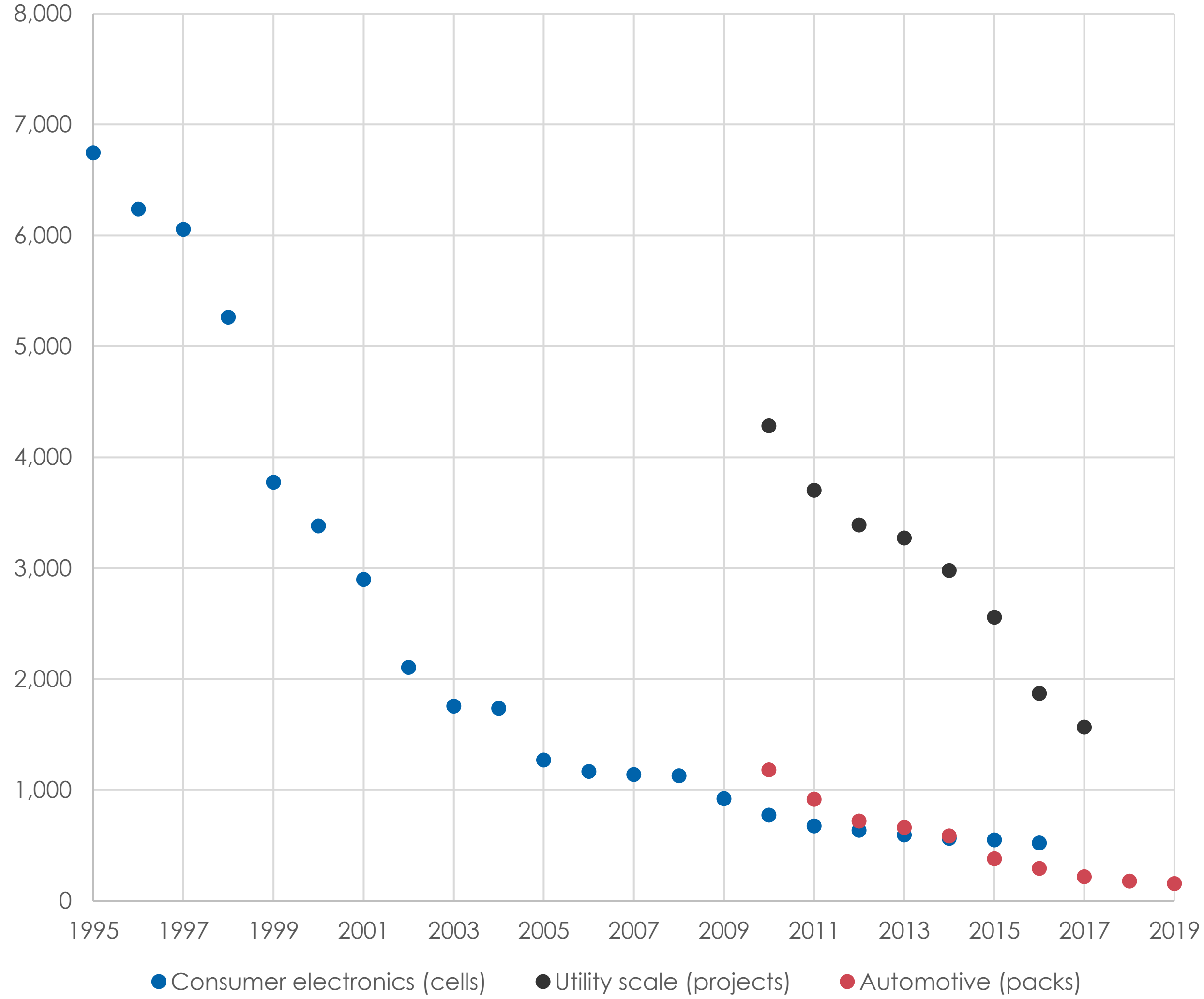
Lithium-ion batteries are not a new technology. In 1991, Sony produced the first commercial rechargeable lithium-ion battery, building on cobalt-oxide cathode technology invented by John Bannister Goodenough[8] – known as the father of the lithium-ion battery - a decade earlier. The first major use case for the lithium-ion battery was in Sony's hand-held video cameras, a gamechanger for these products because their high energy density made the devices lighter and easy to carry around. From here, lithium-ion batteries became widely used in portable electronic devices such as mobile phones and computers as well as power tools.

The advent of electric and hybrid vehicles brought with it a new use-case for lithium-ion batteries. Once again, the high energy density of lithium-ion batteries meant these characteristics of being small and light made them compelling technology by reducing vehicle weight and improving performance. While there are other types of large scale batteries available - including lead-acid, redox flow and molten salt, lithium-ion is the dominant technology. The reason for this is the same reason that lithium-ion batteries made sense for Sony camcorders, portable electronics and electric vehicles - that is, their high energy density.

The real price of lithium-ion technologies including batteries has fallen dramatically over the past 15 years. A recent study[9] found that battery prices fall by about around one quarter every time output doubles. Currently, the average cost of a lithium-ion battery pack is around US$140 per kilowatt hour. The so-called 'holy grail' of lithium-ion battery technology is US$100 per kilowatt hour, when electric vehicles become cost-competitive with those with internal combustion engines.[10] While predictions on when this tipping point will be reached vary, it could be as soon as 2023 according to IHS Markit[11]

[8] https://qz.com/338767/the-man-who-brought-us-the-lithium-ion-battery-at-57-has-an-idea-for-a-new-one-at-92/
[9] https://pubs.rsc.org/en/content/articlelanding/2021/EE/D0EE02681F
[10] https://www.economist.com/graphic-detail/2021/03/31/lithium-battery-costs-have-fallen-by-98-in-three-decades
[11] https://news.ihsmarkit.com/prviewer/release_only/slug/2020-09-23-milestone-average-cost-of-lithium-ion-battery-cell-to-fall-below-100-per-kilowatt-hour-in-2023

Chart 4: Evolution of Lithium-ion Battery Price 1995-2019



Source: Source: International Energy Agency[12]

Scaling them up – The case for Large Scale Li-ion BESS

Lithium-ion batteries become infrastructure assets when they are scaled up and incorporated into electricity grids. More generally, the advantages of incorporating large scale lithium-ion battery energy storage systems (Li-ion BESS) into electricity grids include increasing grid flexibility and reliability, provision of frequency support, load-levelling or arbitrage, the reduction in requirements for additional network interconnections and support to distribution and transmission system operators. In addition, Li-ion BESS can ramp up to full power within milliseconds, a key attribute of any provider of dispatchable power.

However, there are barriers to Li-ion BESS too, most pertinently persistent regulatory uncertainty in jurisdictions around the world and difficulties in getting the economics of battery projects to work in the absence of government support. There are many big battery projects under construction and operating now, including the Hornsdale Power Station in South Australia described over the page.

[12] https://www.iea.org/data-and-statistics/charts/evolution-of-li-ion-battery-price-1995-2019

Case Study - Hornsdale Power Station

In 2017, then-Prime Minister of Australia Malcolm Turnbull declared a national energy emergency following a warning from the Australian Energy Market Operator (AEMO) that there would be a shortfall in gas-fired electricity generation in the three states of New South Wales, Victoria and South Australia. AEMO said 'maintaining system security is becoming more challenging, increasing the risk of supply shortfalls in both gas and electricity markets'[13] and that 'the risk of short-term interruptions of electricity demand will increase when there is not enough GPG (gas-powered generation) to increase generation fast enough to meet demand.'[14]

The warning came as South Australia became the flashpoint for the politically charged debate on energy transition from fossil fuels to renewables (at the time, wind and solar made up around 40% of South Australia's power generation, significantly higher than other Australian states). The state had experienced a series of black outs over the preceding six months, including an instance in September 2016 where South Australia was cut off from the National Electricity Market following a destructive storm super cell.

In response, Lyndon Rive, Tesla's vice president for energy products, claimed the company could install 100-300 megawatt hours of batteries, enough to prevent the blackouts that were occurring in South Australia within 100 days of being asked, and his offer was printed in an article published in the Australian Financial Review newspaper[15]. Australian billionaire and co-founder of Atlassian Mike Cannon-Brookes forwarded the article to Tesla CEO Elon Musk via Twitter, asking 'how serious are you about this bet? If I can make the $ happen (& politics), can you guarantee the 100MW in 100 days?'[16], as shown below. As can be seen from Musk's response, Tesla confirmed the offer, stating the battery would be free if not installed and working within 100 days.

Source: Twitter

[13] https://www.aemo.com.au/-/media/Files/Gas/National_Planning_and_Forecasting/GSOO/2017/2017-Gas-Statement-of-Opportunities.pdf
[14] Ibid
[15] https://www.afr.com/politics/tesla-battery-boss-we-can-solve-sas-power-woes-in-100-days-20170308-gut8xh
[16] https://twitter.com/mcannonbrookes/status/839762954887180289

Fast forward 2 months and Tesla had successfully installed the (then) world's biggest battery – the Hornsdale Power Reserve ('Hornsdale') - with 100 megawatt-hour capacity and 129 megawatts of energy supplied by nearby wind turbines at an estimated cost of $A90 million.[17] Hornsdale reserved 70MW of its capacity for designated system security services under its power purchase agreement (PPA) with the South Australian Government (reported to be worth A$4 million a year over ten years), with the remaining 30MW of power capacity and 119MWh energy storage available for the owner/operator to participate in the market.[18] This big battery has since increased its capacity by 50% in a project that was supported by the Australian Government.

On all measures, Hornsdale has been success. It had proven credentials in increasing system stability and reliability since it became operational, one example of which was in 2017 when the battery kicked in in response to the unexpected offlining of a large coal plant, arresting the fall in frequency and likely preventing a cascading blackout.

In terms of investment metrics, Hornsdale's performance illustrates how market volatility can be lucrative for big batteries but that a percentage of contracted cash flows can underwrite day-to-day performance. Hornsdale was built and is operated by French company Neoen, that now has large scale energy storage assets in France, Finland and El Salvador in addition to Australia. Neoen reported a tripling in storage revenue in the first half of 2020, driven by the impact of a tornado which created one-off demand for Hornsdale for 18 days. Since then, Neoen's storage related revenues have been more muted but still favourable (no doubt underpinned by the long term PPA it has in place).

Continuing our focus on Australian projects, almost all the country's large-scale energy storage projects have relied on funding from government bodies like the Australian Renewable Energy Agency (ARENA) or the Clean Energy Finance Corporation (CEFC).[19] The Victorian Big Battery project, a 300MW battery currently being built by Neoen, near Melbourne in the South East of Australia secured access to A$160 million in debt financing from the CEFC earlier in 2021 and will be underpinned by an 11-year contract with the Victorian Government. Incidentally, we note that just days ago, the battery bank at this project caught fire and burnt for four days, highlighting the physical risks associated with these projects.

While big batteries are being built in Australia and around the world now and these projects are being funded in part with private capital, standalone battery projects where public money wasn't also in the mix are few and far between. Our own experience has been that batteries integrated with renewables can make more sense, diversifying overall revenues and building in downside protection. We also consider there may be an early mover advantage to investing in big battery storage, whereby revenue sources linked to benefits provided to the grid that are not able to be locked in may become cannibalised over time as more batteries enter the market.

17 https://reneweconomy.com.au/revealed-true-cost-of-tesla-big-battery-and-its-government-contract-66888/
18 https://www.aurecongroup.com/-/media/files/downloads-library/thought-leadership/aurecon-hornsdale-power-reserve-impact-study-2020.pdf
19 https://www.pv-magazine-australia.com/2021/07/06/australias-first-privately-funded-big-battery-to-be-hosted-in-melbourne/

UNDERGROUND HYDROGEN STORAGE

Salt cavern storage is considered the most promising technology for hydrogen storage, based on its high operational safety, low investment cost, high sealing potential and low cushion gas requirement.[20] Salt caverns[21] have long been used for energy storage, principally fossil fuels including natural gas, oil and petroleum products but also hydrogen and compressed air.

A key advantage of hydrogen energy storage compared to lithium-ion battery is that the energy can last indefinitely (as compared to batteries which can store hours of energy rather than days). Hydrogen storage projects would likely operate on the premise of filling its capacity when electricity is cheap or costless and sell it as dispatchable power.

Hydrogen has been successfully stored in three different salt caverns around the world[22] and there are new hydrogen salt cavern storage projects currently under construction. The biggest of these is the Advanced Clean Energy Storage project (ACES) – the largest renewable energy storage project in the world – being built in central Utah in the United States with an aim of being operational by 2025. The project is being developed by a consortium including Mitsubishi Hitachi Power Systems of Japan and Magnum Development, which owns a salt formation which has already five salt caverns in operation for liquid fuels storage.[23] ACES aims to deliver power at the same price, or lower, than that from lithium-ion battery storage units.

This grid-scale energy storage infrastructure will include four energy storage technologies - renewable hydrogen, Compressed Air Energy Storage, large scale batteries and solid oxide fuel cells – with final capacity planned to be 1,000MW (enough energy to power 150,000 households for a year). To get a sense of the strategic importance of this infrastructure, the first phase of the project will have capacity of 150,000 MWh, close to 150 times the capacity of all lithium-battery systems currently stalled in the US. In May 2021, the project was invited to submit an application for funding of US$595 million from the US Department of Energy's Loan Programs Office.[24]

Hydrogen cavern projects are also being investigated in Europe, specifically in Germany, the UK, Ireland, France and the Netherlands. One such project is the HYPOS alliance consisting of more than 100 companies and institutions and funded by the German government aiming to build a salt cavern with capacity of 150,000 MWh in the Saxon-Anhalt area of Germany. Plans are reportedly with regulators now with filling planned to begin in the next 2 to 3 years.[25]

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[20] https://doi.org/10.1016/j.ijhydene.2019.12.161

[21] Salt caverns are manmade, formed by drilling a well into existing salt bed deposits and pumping water through the completed well to dissolve the salt. https://www.sciencedirect.com/book/9780128158173/handbook-of-natural-gas-transmission-and-processing

[22] https://www.gie.eu/wp-content/uploads/filr/3517/Picturing%20the%20value%20of%20gas%20storage%20to%20the%20European%20hydrogen%20system_FINAL_140621.pdf

[23] https://power.mhi.com/regions/amer/news/190530.html?utm_source=amerweb&utm_medium=release&utm_campaign=DOE

[24] https://power.mhi.com/regions/amer/news/20210511.html

[25] https://www.cnbc.com/2020/11/01/how-salt-caverns-may-trigger-11-trillion-hydrogen-energy-boom-.html

Energy storage in salt caverns is only available in places with sizeable salt deposits. Such sites are highly localised, with the US and Europe having significant salt endowments resulting in more than 2000 salt caverns in North America and over 300 in Germany. The ACES site in Utah is considered particularly suitable for this type of energy storage development given its geological characteristics but such locations are rare.[26] Recent research into salt cavern storage potential in Europe estimated 84.8 PWhH2 of overall technical potential, of which 7.3PWhH2 is onshore and within 50km to the coast (important in order to take into account the economic and ecological aspects of brine disposal pipelines). Germany was identified as having the highest national storage potential in Europe, while for the UK, this study identified the Cheshire Basin as demonstrating particular promise for salt cavern construction.[27]

While new salt cavern storage will undoubtedly be built, existing salt caverns that currently store gas could be repurposed to store hydrogen. Across the EU and the UK, there are 63 salt caverns currently functioning as natural gas storage assets[28] and at least some of these could be converted for hydrogen storage. Existing owners of gas storage assets would need to be incentivised to undertake such a conversion by measures including clear regulation and financial assistance for research and development costs, as well as a compelling future demand scenario.[29]

[26] https://www.ft.com/content/3a145844-82f2-11e9-b592-5fe435b57a3b

[27] Ibid

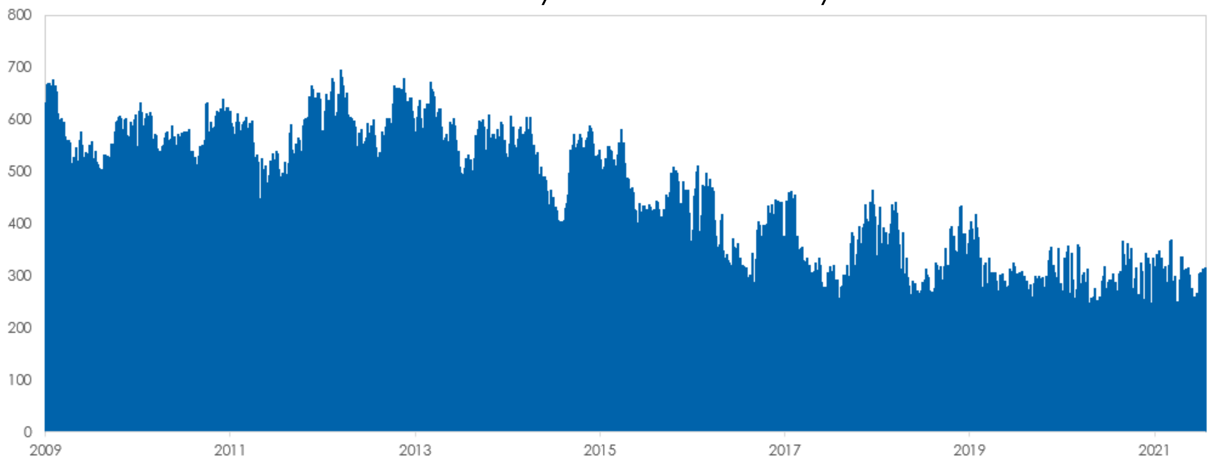
[28] https://www.gie.eu/wp-content/uploads/filr/3517/Picturing%20the%20value%20of%20gas%20storage%20to%20the%20European%20hydrogen%20system_FINAL_140621.pdf

[29] Ibid

Case Study – UK Electricity Grid

The energy transition is well underway in the UK Electricity Grid. Chart 5 shows how the carbon intensity of the grid has fallen gradually since 2009, using 30 minute power generation data

Chart 5: UK Electricity Grid – Carbon Intensity 2009-now



Source: National Grid ESO, Whitehelm Advisers

In 2020, coal generated just 1.6% of the UK's electricity mix and the National Grid ESO aims to operate a zero-carbon electricity system by 2025, meaning the market will provide the grid with 100% electricity generated zero-carbon electricity. In addition, we note that in every future scenario for the grid, all remaining coal fired generation plants will exit the system by 2023.[30] This is an astonishing achievement (particularly for this writer who is located in the shadows of Australia's parliament house, where energy policy has claimed more than one political scalp over the last decade) and one we note that no other system operator in the world has managed to do. Therefore, we consider the UK electricity grid to be a prototype for electricity grids the world over as they navigate the energy transition.

Energy storage has been assigned a key role as the system continues to transform, providing valuable insights into which storage technologies are likely to become future strategic grid assets. Currently, electricity storage plays a relatively minor role in the UK electricity grid with capacity of 3.5GW but this is projected to increase to somewhere between 20 and 43 GW by 2050 depending on which future energy scenario[31] the grid follows. The electricity storage technologies being considered by the grid are batteries and pumped hydro (both of which we covered in detail earlier in this article) as well as compressed air storage and liquid air energy storage.

However, we note that the far bigger shift relates to hydrogen storage which is virtually non-existent in the UK today but forecast to build to somewhere between 15 to 51 TWh by 2050, depending on which scenario the grid follows. This indicates the significant opportunity for future investment in hydrogen storage in the UK and in other grids that follow suit and we will be watching closely to see how technologies evolve in response to this massive uptick in demand.

In summary, the future pathways identified by UK electricity grid highlight large-scale energy storage as critical infrastructure for a decarbonised electricity grid, and identify pumped hydro, lithium-ion batteries and underground hydrogen storage as the technologies likely to become the mainstays of this transition.

[30] https://www.nationalgrideso.com/document/199871/download
[31] https://www.nationalgrideso.com/future-energy/future-energy-scenarios

OTHER TYPES OF ENERGY STORAGE

In this article, we have focussed on three large scale energy storage technologies but of course there are loads of others, including both established and emerging technologies for grid use and broader use cases too. We provide a description of some of these other types of energy storage assets below in Table 1. In compiling this table, we make two anecdotal observations that apply to all the energy storage technologies we have explored in this article. Firstly, we note that many of the technologies re-purpose existing sites including reservoirs, salt caverns, mine sites and mothballed coal fired power plants. Further, we note the tendency for energy storage projects to benefit from some degree of government money and/or assistance[32] (including at least three of the five projects we name in Table 1).

[32] Hydrostar received A$3 million from the South Australian Governments Renewable Technology Fund; Highview Power has benefitted from ~£12 million since it was founded; Gravitricity has received two Innovate UK grants;

Table 1: Large Scale Energy Storage Technologies – Description and Use Case

Technology	Description
Compressed air energy storage (CAES)	• Electricity is used to compress air, which is then stored in an underground tank. When it is required, the power is released from the tank through a turbine to generate electricity which is then fed back into the grid. • Scalable technology appropriate for utility use cases. • Existing mine caverns can be repurposed. • Two existing commercial scale CAES plants in operation globally (Germany and the US). • New developments include Angas Zinc Mine site at Strathalbyn (Australia) by Canadian company Hydrostor for incorporation into the South Australian electricity grid.
Liquid air energy storage (LAES)	• Thermal energy storage system, where electricity is used to cool air until it liquifies. This liquid air is then stored in a tank, and when it is required, released back into gas which then turns a turbine to generate electricity. • No geographical constraints, meaning they can be constructed anywhere. • Scalable grid scale energy storage. • Highview Power are currently building what will become the worlds largest liquid air battery in Manchester, UK, which will be able to store power for weeks. It is due to be operational in 2022.
Gravity storage	• Concrete blocks are lifted from a low point to a higher point (abandoned mine shafts make an ideal location). These blocks acquire potential energy and can release this energy they are lowered by turning a generator. • Gravitricity is a UK based company developing projects at existing mines in the UK, Europe and South Africa.
Vanadium redox flow batteries (VRFB)	• Vanadium ions in different oxidation states are used to store chemical potential energy. The electrolytes are stored in two large tanks and pumped through electrochemical cells. • Vanadium can store energy for 8-10 hours and have a lifespan of more than 20 years with no degradation. • Rongke Power and UniEnergy Technologies are building the world's biggest vanadium battery in Dalian, north-east China.
Hot Rock Plants	• Crushed volcanic stones are heated to at least 600°C, converting surplus electricity to heat. The stones stay hot for weeks and when required, a steam turbine converts the heat back to electricity. • This technology could utilise repurposed turbines located in closed fossil fuel power plants. • Siemens set up a pilot program in Hamburg in 2019, Germany, which is now operating.

CONCLUSION

The global energy transition will be driven by the incorporation of renewables into electricity grids around the world, a move underpinned by large scale energy storage. For infrastructure investors looking to allocate to assets that will power this transition, large scale energy storage ticks a lot of boxes, and philosophically, the long term investment case makes sense.

We have considered the three large-scale energy storage technologies we think are most likely to be incorporated into the decarbonised electricity grids of the future.

Pumped hydro is the incumbent technology, making up the vast majority of the world's electricity grid storage today. Looking forward, global capacity is set to increase, and significant investment is required to modernise existing brownfield pumped hydro assets around the world. We see opportunities here for investors, but also point out the risks associated with these capital intensive, long duration assets with complex sustainability aspects. We consider skilled transaction structuring and asset management will be key to the long term success of such investments.

Lithium-ion batteries are emerging as another critical large scale energy storage asset. An investment in battery technology may diversify a highly contracted portfolio, de-risk existing renewable assets and provide a vehicle to participate in potential future markets. This is despite regulatory and revenue uncertainty, which both remain opaque and can make building an investment base case challenging. However, on balance, we think an investor with a diversified portfolio of infrastructure assets who believes in the philosophical case for big batteries would be well-advised to at least dip their toes into this market.

Underground hydrogen storage is the third energy storage technology that we think will likely become mainstream as the energy transition progresses. However, we note that access to salt cavern storage is localised and opportunities to deploy capital into this type of energy storage asset is likely to remain limited for some time yet.

Large scale energy storage assets may not be for every investor, but we also caution that there is danger in dismissing what we consider to be one of the next mega trends in infrastructure investment. In deciding whether to deploy capital into large scale energy storage, we think investors should consider a collection of factors, including risk appetite, existing portfolios and the specific characteristics of the project under consideration (as for any deal). However, we do think this asset type will be propelled forward by significant structural tailwinds and that these assets should most certainly be subjected to investment due diligence if the opportunity arises.

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