PETER JUMPERTZ

BATTERIES

Distributed Battery Systems as Best-Fit

ARE

Asset Class for Seasonal Storage

FOREVER

PREFACE

The energy industry, with its sectors electricity, heat, and mineral oil products, is facing a key decision. What is the best way forward to a carbon-neutral future? Where should the money go? There is a global view of this problem. But since energy is a physical product with relatively high costs of transport, a regional perspective is a more powerful one to assess the challenges, envision solutions, evaluate risk, and appreciate the opportunities.

Europe is a special case with its densely populated countries and its relatively low access to sunshine energy called renewable energy resources and mainly consisting of direct sun irradiation and wind caused by differences in atmospheric pressure. Becoming independent of foreign forces while moving toward a carbon-neutral energy system is a particularly difficult task with several intricacies. Europe's future energy system is all but certain in almost any respect.

Especially in areas of such high uncertainty, a rational approach to decision-making is an effective insurance policy against avoidable errors like stranded assets and missed opportunities. The first step to rationality is to see the full picture, including any halfway reasonable option. Nobody knows today what will be tomorrow.

The majority of experts agree that Europe's roadmap to net-zero carbon leads over far-reaching electrification of upstream energy resources. Solar and wind energy is transformed into electricity as the first stage of the energy supply chain.

Yet, the next stages of this supply chain are far from clear. One of the parameters at stake is energy storage, in general, and longer-term - so-called 'seasonal storage' - in particular. Any energy system that is suitable for supplying an industrialized nation or region requires a large storage capacity of energy - either in the form of naturally stored fuels or man-made storage of fuels, electricity, etc.

For economic reasons, energy should be available as close as possible to the time when the demand arises. A flawed decision regarding storage technology will bring an extraordinary risk of stranded assets in case another technology turns out to be the better fitting alternative.

The present Green Book addresses this very decision. How will Europe ensure sufficient storage capacity in the continent's future electricity system? Does the future belong to hydrogen as storage media, or rather to batteries?

The book proposes a fresh view on available options to solve the problem of energy storage. And it derives the most important implications and corresponding political, financial, and business-related steps required to keep the system afloat.

The main idea of this Green Book is that batteries are the best-fit solution for seasonal storage. This thought originates from a comparison of the pure physical yields of different energy storage technologies. The term 'yield' refers to what energy experts call the 'roundtrip efficiency' of a technology-typical energy storage device.

Roundtrip efficiency is simply the energy available when unloading a storage device, divided by the energy initially loaded into the same storage device. Yield is the main driver of the economic return of an asset. Hence, it can be stated that the higher the yield, the more promising is the technology. The most fundamental statement of this book is that for long-term periods of storing energy, roundtrip efficiency values of the two technology types compared here are as follows:

- Hydrogen technology: less than 50%
- Electrochemical batteries: more than 80%.

The Green Book is not a reflection of detailed, quantified analyses. It is rather a consistent collection of viewpoints, plausible assumptions, and their underlying rationale. Its purpose is to open up the perspective and describe a likely scenario of the future as it may look 30 or even 40 years from now.

The assumptions and conclusions underlying this book shall encourage a broader discussion among the ranks of managers, experts, politicians, and the interested public. It is our contribution to an assessment of an alternative to conventional scenarios for an industrialized economy's decarbonized electricity system, fully independent of fossil fuels and rogue regimes.

The alternative presented here puts electricity batteries at the center stage. Although the odds are that there is no black-or-white solution, it is helpful to describe a very distinct view when developing one's own vision of the future.

The topic is complicated and complex. Single pros and cons are never sufficient to come to a conclusion. It takes a holistic perspective to keep track of the entire picture. One must avoid the trap of ignoring a specific line of thinking just because of a strong belief in a certain claim or argument. Three of such traps deserve special attention.

At first is the question whether there will ever be sufficient battery capacity to cover the amount of total seasonal storage required by a transnational electricity system like the European Union. Researchers and industry experts estimate widely varying power ratings for seasonal storage between 100 GW and 1,200 GW[1], and energy demand between 300 TWh per year and 800 TWh per year[2]. The spread demonstrates the level of uncertainty in the assumptions. This Green Book does not attempt to reduce this uncertainty. Any seasonal storage solution is faced with a similar challenge in this respect, though – that is the relevant point.

Hence, we can assume that the main issue is not if, but rather when a fully decarbonized electricity system with batteries as the main medium for long-term electricity storage will be attainable.

The second trap, often raised as an argument against batteries, is the problem of self-discharge. Electrochemical batteries demonstrate self-discharge rates of between 0.1% and 20% per day. A promising candidate for seasonal storage in this respect is lithium-based technology with self-discharge rates of between 0.2% and 8.0% per month.

Recent research with low-cost molten salt electrolyte batteries using aluminum as anode and nickel as cathode demonstrated 92% of energy retained after 12 weeks. The present Green Book is not conclusive as to the most likely battery technology for seasonal storage; however, it confirms that batteries are principally fit for this application.

The third trap is space. Lithium-ion batteries, for example, currently achieve a volumetric energy density of up to 500 Wh per liter. It is reasonable to assume that technical progress will double this ratio over the next decade. An assumed 500 TWh will in this case need the space of about 1 billion cubic meters. Compared to the average space a 500 MW thermal power plant uses today, this represents roughly 5,000 power plants with two generator houses on average. If the space used by cooling towers and other power plant equipment is included, Europe's roughly 300 large power plants currently in use could provide housing for about 20% of the required battery space. The remaining batteries would have to find other homes. This is a tall order, but it should definitely not be considered an impossible challenge.

[1] For example, see: 'Is a 100% renewable European power system feasible by 2050', William Zappa et al., Utrecht University, Copernicus Institute of Sustainable Development, 2018; Biogas and Biomass capacity as a proxy for seasonal storage

[2] For example, see: 'The Promise of Seasonal Storage', DNV-GL Position Paper 2020, p. 12

Lastly, it is important to bring the soft side of things to the reader's attention. They are at least as essential as all technical, scientific, and strategic considerations. Theron's advisory teams follow in all of their work a set of guiding principles. These principles also apply to this Green Book in every respect.

1. Use common sense! Conventional wisdom is a constant source of erring.

2. Use common language! It enables a broader discussion than expert jargon.

3. Give Nos their room! There is more to decision-making than just saying Yes.

4. Make it happen! Understand the future as a result of individuals shaping their world rather than as a row of events happening to society!

5. Never take anything for granted - not even the obviously impossible!

Number 5 is the key to the position we have taken in this book. Stanley Whittingham, Nobel Laureate in Chemistry for his invention of lithium battery technology in the early 1970s, was interviewed in 2019 during a visit to Volkswagen's Center of Excellence Battery Cell in Salzgitter, Germany. When asked whether there are any concepts that might sound like science fiction today, but from his perspective could soon be part of everyday life, he replied:

> *'Well, I think, 50 years ago, when we started out, with say these cars behind me, it would be science fiction. But now we've made it. So, I think we've got to believe that we can do it. We must believe in the unbelievable. Then we can make it happen.'*[1]

[1] https://www.volkswagenag.com/en/news/stories/2019/11/we-must-believe-in-the-unbelievable.html

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SUMMARY

Storing energy for later use has always proven to be a valuable capability for any human society since the early days of Homo Erectus. Because our ancient ancestors did not have the tools to exploit the energy, they had to retreat to wood as the primary means of storage.

The First Industrial Revolution taught humans how to use fossil - literally "unearthed" - energy for processing. This era is coming to an end with increasing transparency on the real cost of greenhouse gas emissions. We need to find new means of storing energy.

At the center of most industrialized nations' future energy systems lies the question of what the best technology and media will be for so-called 'seasonal storage'. Seasonal storage means storing large amounts of energy for weeks and months in which demand outruns wind- and solar energy supply, immediately available on the surface of the Earth.

Driven by the trend of electric vehicles, Asia, and North America tend to go for electricity stored in massive batteries, distributed across the power grid. Europe - with Germany as the most obvious case - seems to be betting on hydrogen as the best-fit storage medium. This decision is reflected in the amount of direct and indirect financial support that hydrogen projects are currently collecting in Europe.

Such a decision poses an enormous risk. There are many valid arguments pointing in the direction of batteries as the better storage alternative. A simple extrapolation of technology development for batteries over the last two decades supports two assumptions.

1. The battery path will produce storage capacity for energy significantly faster than the growth of the hydrogen energy economy.

2. In the end game's steady state, batteries will operate at economic productivity higher than a hydrogen energy economy across the board.

In the event that these assumptions are valid, the history of Silicon Valley - the appearance of the personal computer and the rise of the internet - repeats itself. Germany, and the entire European continent, could miss out on this next key technology for human life on Earth. Once again, Europe leaves this technology revolution to other players.

Different from Silicon Valley, though, Germany and Europe could have a head-start in seasonal storage batteries. The continent's competitive advantage comes from globally leading engineering skills in chemistry, physics, electrical equipment, and energy system-related software. These are undoubtedly the key ingredients for high-tech electricity batteries at scale.

However, neither industry juggernauts nor mid-caps or start-ups seem willing and capable of catching up with the electricity storage business' global leader Tesla Energy.

The reasons for such industry myopia are manyfold. The blind eye may be rooted in a lack of imagination and vision. The bias could as well originate from generally poor knowledge about the nature of industrialized electricity systems. Such a lack of knowledge comes paired with a careless reliance on conventional wisdom produced and conveyed by large public agencies, rigid energy incumbents, change-resistant electrical manufacturers, and power plant equipment vendors. Batteries are known for mobile and small stationary applications only. The role of very large batteries in electricity grids stays hidden from the public. A recipe for disaster is in the making, and it is time to wake up.

Politicians, the press, entrepreneurs, financiers, and the public need to recognize two fundamental truths about an electricity system since it is a super-critical piece of infrastructure.

1. Europe needs huge amounts of storage capacity - fast, at the right locations, and at costs that are bearable to society. Modern battery technology will be capable of delivering all of these needs.

2. Depending on the rate of electrification of the energy system, Europe probably needs up to five times the capacity of high-voltage power transmission lines existing today to transport electricity from sun-rich southern countries to the north - regardless of which storage technology will be in place.

The unanimous consequence is to channel public funds and start-up subsidies toward electricity infrastructure. Financing an energy storage-related hydrogen infrastructure with taxpayers' money instead, exposes the continent to prohibitively high economic risk and social dynamite.

Of even higher importance, though, is another issue that goes largely unnoticed by the public: price regulation. To earn money with large-scale batteries in a free energy market is a highly risky game. Frequent, strong, and hard-to-predict electricity price shifts caused, for example, by a crisis like the 'Cold War 2.0' can mean boom or bust for a battery asset owner. Allocating sufficient private capital in such a market is almost impossible. Hence, European member states' governments must speed up their efforts to establish grid-scale batteries as a crucial component of the electricity grid system. Only an adequate infrastructure pricing scheme can perform this job with efficiency and precision.

1 LESSONS LEARNED FROM HISTORY

Renewable energy is not really renewable. The term'renewable' means all energy not coming from fossils stored underground eons ago. Most of the renewable energy used today is the energy continuously sent from the Sun to the Earth.

Such sunshine energy occurs near the surface of our planet in the form of photon irradiation. Photons can either produce electricity directly in an electrochemical process, or they produce wind and rain when heating up the surfaces they hit, or they produce biomass when letting plants grow.

Gravity energy is the only kind of renewable energy that is not sent from the sun. It occurs either as heat from gravity of the planet's mass, or as tidal waves caused by the Moon's gravity.

1.1 THREE HORIZONS OF SUNSHINE ENERGY USE

Sunshine is by far the biggest energy source mankind can use. The time delay between sunshine energy's arrival on Earth and its use falls in one out of three categories:

1.1.1 FOSSIL FUELS

In past times, sunshine energy has been stored through global forces reliably below the surface as raw carbon-based fuels like coal, natural gas, and mineral oil. The First Industrial Revolution taught humans how to use fossil energy for processing. Exploring, mining, and refining unearthed fuels has long been the source of bulk energy storage.

Yet, unlocking underground energy has two major drawbacks with terminal consequences: greenhouse gas emissions and increasing scarcity. Both are very valid reasons to consider and develop alternatives. Hence, this era is coming to an end with increasing transparency on the real cost of greenhouse gas emissions.

1.1.2 SIMULTANEOUS STORAGE

Sunshine energy can be captured upon arrival on the Earth, turned into electricity, and simultaneously stored in a variety of media.

Refined fuels like gasoline, diesel, methanol, ammonia, methane, or hydrogen can store energy easily for months and years. Their temporal degradation rate is insignificant. The cost of storage and transport is largely driven by the risk of evaporation and explosion.

Besides refined fuels, energy can be stored in electrochemical devices called batteries.

Beyond batteries, there is a wide variety of non-chemical storage: Media like gravitation (water stored behind a dam, blocks of concrete on a string, etc.), inertia (a spinning flywheel, a running river, etc.), heat (hot water, hot steam, etc.), pressure (compressed gas, compressed fluid, etc.), and finally biomass and biomass-generated biogas.

1.1.3 CONCURRENT CONSUMPTION

The Sun's irradiation is transmitted to Earth, mostly in the form of high-energy photons. Photovoltaic panels transform such solar into electron-born energy, called electricity.

When hitting the ground, the Sun's irradiation heats water, air, and landmass, or is stored as biomass. Wind and ocean water circulation are a product of such temperature differences around the globe. This energy is transformed to electricity by an electromagnetic generator.

Sunshine energy is intermittent for any specific location on the planet. There is no place on Earth where the Sun shines and the wind blows at roughly constant levels all the time.

Energy intermittency induces opportunity cost from not having electricity when it could create value. Such an unwanted effect of unavailable energy, for example, is factories and organizations idling while incurring high costs of finance.

A second and similarly costly effect of a lack of energy is asset degradation and even destruction. For instance, as soon as the temperature of a melting pan full of fluid hot tin falls below a certain level, the metal will solidify and cannot be liquefied again.

1.2 TWO METHODS OF DEMAND-SUPPLY ALIGNMENT

Due to the physical nature of electricity, its generation (= supply) and consumption (= demand) must be fully aligned regarding a specific power rate at any given second to keep the electricity system stable and secure. Below a duration of a few seconds, such balancing is achieved without an adjustment of demand or supply explicitly. Conventional energy production, component-specific buffers, and the system-wide sum of micro-reserves warrant such resilience over the very short term.

Outside this threshold, balancing must be achieved by explicit reactions to shifting supply and demand. There are two basic methods how to align the generation of electricity with its consumption in this case.

1.2.1 SUPPLY-SIDE MANAGEMENT

Supply-Side Management means loading electricity immediately into the system at a rate equal to what is demanded at any given time. Maintaining the balance of the electricity system requires an immediate supply response to demand shifting up or down (= ramping). The prerequisite of a supply response is dispatchable energy - electricity supply that can quickly be increased, for example, by raising a thermal power plant's load utilization from 80 to 90% in a few minutes.

In an electricity system relying solely on solar and wind energy, Supply-Side Management to match demand at any time, becomes nearly impossible. Sunshine energy is not dispatchable - it is intermittent. It just happens, determined by weather and time of the day.

1.2.2 DEMAND-SIDE MANAGEMENT

Demand-Side Management - the other side of the equation - means loading electricity off the system only at a rate as it is available. To maintain the balance of the electricity system now requires an immediate demand response to the supply's shifting up or down.

Assuming that Demand-Side Management alone can solve the intermittency problem of sunshine energy, is flawed. It would require large portions of electricity consumers to fully adapt their consumption time to the stochastic appearance of sunshine and wind. It is obvious that most consumers will not be able or inclined to accept frequent and longer delays in electricity supply.

1.3 TIME IS MONEY

As said, demand response, in terms of waiting with any type of processing until new energy is available, has substantial opportunity costs. A full factory idling because of a lack of power is costly. Thus, in the past, active and extensive Demand-Side Management occurred only in edge cases of electricity consumers with high electricity price elasticity.

Typical cases are production companies in the energy-intensive step-processing sectors, i.e., companies not having to maintain a continuous production process flow. Such companies feel the pain of the high costs of electricity provided round the clock and full-year-long. At the same time, their opportunity cost of shifting energy demand is bearable for a defined period of time. They can maintain sufficient buffers between their processing steps to avoid full idling. Hence, these consumers are prepared to adjust consumption patterns already to relatively minor price reductions as a compensation for their demand response.

Regarding the share of electricity consumers, Supply-side Management has traditionally been the dominating pattern of any industrialized nation's electricity system until today. The main reason is that due to the relatively low cost of energy, consumers, businesses, and entire economies have taken comfort in the seemingly endless amount of power in their wide-ranging electricity systems. It simply did not pay, for most consumers, to either store electricity or to shift consumption to a time when electricity is available at a lower price.

PRICE ELASTICITY

OF DEMAND RESPONSE AT HISTORIC STEADY-STATE PRICE LEVEL

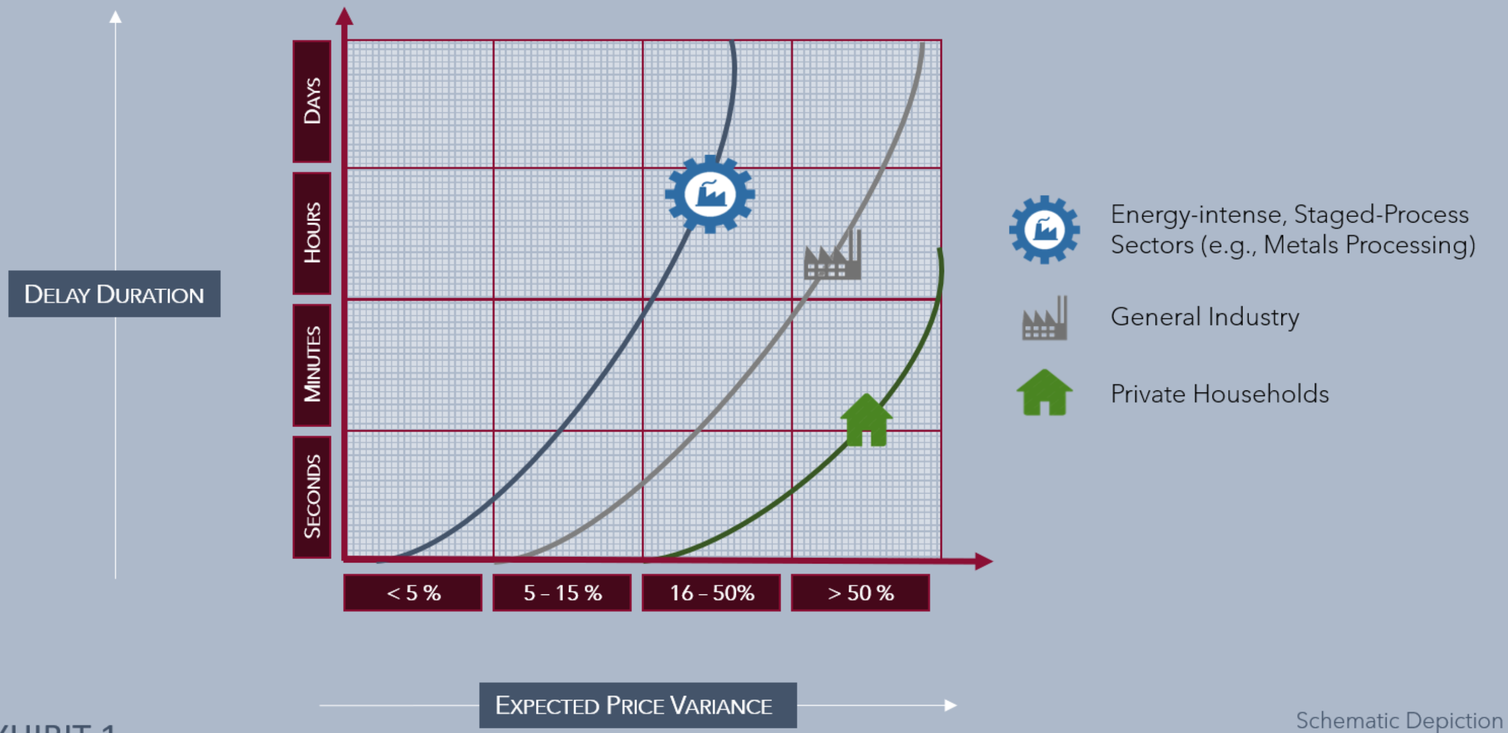


EXHIBIT 1

Schematic Depiction
Source: Theron Scienceworcs Energy Practice

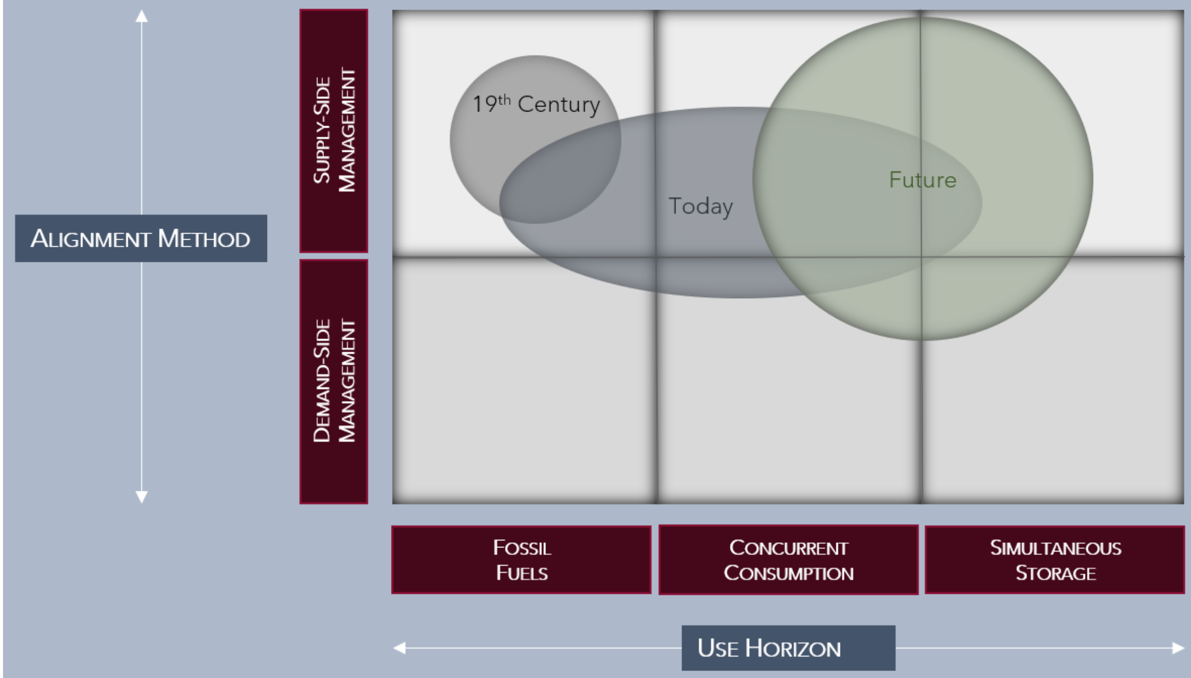
Exhibit 1 describes a typical pattern of price elasticity of demand response for three broadly outlined electricity consumer groups.

On the way toward a decarbonized electricity system, the proportions of the horizons of sunshine energy usage, as well as the demand-supply alignment methods, will change. One can predict two trends regarding narrowing the gap between sunshine energy rates and effective consumption rates, shown as a schematic depiction in Exhibit 2.

The switch to carbon-neutral energy is justified by the estimated negative external effects of rapid climate change. If these effects are taken into account adequately, it is presumed that the cost of converting fossil fuels into electricity is significantly higher than the cost of converting sunshine, wind, or rain into electricity. In this sense, fossil fuels have large conversion losses in comparison to solar panels or wind farms. Even their advantage of 24-hour dispatchability, i.e., the continuous availability of resources, cannot fully compensate for that disadvantage. This is the perspective of the promoters of energy systems sourced from renewable resources.

ELECTRICITY SYSTEM DEVELOPMENT

AREA PROPORTIONAL TO TOTAL ELECTRICITY CONSUMED



- More Concurrent Consumption "just-in-time"
- More Simultaneous Storage
- Overall, less consumption while higher share of electrification along energy supply chain

EXHIBIT 2

Source: Theron Scienceworcs Energy Practice

The clear message from this reasoning is that today's world is not to stay! If electricity needs to be sourced from sunshine energy instead of fossil fuel, two targets must be achieved.

1. The share of Concurrent Consumption must be increased by increasing demand response capability. Individual behavior must change for this to happen. The main driver for this change is increasing Demand-Side Management potential in mid-level price elastic customer groups due to increasing electricity prices in low-supply seasons (late Fall, Winter, early Spring).

2. For the remaining share, we must find and expand new Simultaneous Storage options, like non-fossil fuels or batteries. Increasing electricity storage will enable Supply-Side Management for low-level price elastic customer groups, i.e., the ones still willing to pay up for immediate consumption.

The prerequisite for such a world is to fine-tune demand-supply coordination at an individual consumer level, for example, through fine-grained and high-frequency pricing signals for as many consumers as possible, not just the edge cases. Why is this required? Simply because, efficiently aligning electricity demand and supply through valid pricing signals will be an even more important capability of competitive economies than it has been until now. Energy will become more expensive than today since Simultaneous Storage capability is man-made, and thus will incur additional costs.

2 MODERN ENERGY STORAGE STATE OF AFFAIRS

Man-made energy storage has been around for centuries. Regarding the electricity system, the most common and mature technology is water stored behind a dam. The drawback of hydrological storage is the geological prerequisite that must be met to produce electricity efficiently from large water basins.

About a decade ago, a very specific type of energy storage appeared in greater volumes: molten salt heat storage, directly charged from Concentrating Solar Power plants. These plants use mirror arrays to focus sunlight on a heat-capturing device. Regarding a country's electricity system, such applications play a niche role because of geographical constraints to regions with intense Sun irradiation, and due to the efficiency loss when transforming stored heat into electricity.

Electricity batteries have also been used for decades, but just in small units. These units do not yet contribute to the electricity system's overall performance and reliability at a noteworthy rate. It seems that lithium-ion technology is becoming a game-changer. Recent years have seen single battery assets with a power rating of above 100 MW and up to 4 hours discharge duration.

To assess the potential of this technology, a look at the most common applications for these so-called 'Utility-scale Battery Electricity Storage Systems' (UBESS) reveals the issues that need to be resolved.

Making specific statements about the use of batteries is somewhat hampered by the fact that for over 60% of existing battery assets in use, the asset owners do not clearly specify the application their battery is used for.[1] This observation can be explained by the need to learn how to use a new technology in the best way. It is not necessarily a negative sign, but rather proves the willingness to experiment with a promising concept.

From an economy's perspective, there are fundamental categories of how and why to use large-scale batteries in a nationwide electricity system. A lot of the specifics of these categories depend on the legal and regulatory context of a country or region. For example, the participants in the electricity exchange, the roles and responsibilities of wholesale market makers and grid system operators, the bidding procedures, the pricing mechanism, and even the remuneration schemes for renewable energy impact the storage application properties. Exhibit 3 presents a generalized overview of the categories[2].

[1] Source: Theron Scienceworcs READ Reliable Energy Asset Database

[2] BLSH = Buy-low Sell-high

CORE APPLICATIONS

OF UTILITY-SCALE BATTERY ELECTRICITY STORAGE SYSTEMS

Battery Application	Source of Value	Category
Energy Retail	Ensure availability of stored energy at the point of distribution	BLSH
Bill Management	Optimise power purchase, minimise demand charges, and maximise PV self-consumption	BLSH
Peaker Replacement	Ensure availability of sufficient generation capacity during peak demand periods	BLSH
Energy Arbitrage	Purchase power in low-price and sell in high-price periods on wholesale market	BLSH
Primary Response	Correct continuous and sudden frequency and voltage changes across the network	BLSH/Insurance
Tertiary Response	Replace primary and secondary response during prolonged system stress	BLSH/Insurance
Secondary Response	Correct anticipated and unexpected imbalances between load and generation	BLSH/Insurance
Seasonal Storage	Compensate long-term supply disruption or seasonal variability in supply and demand	BLSH/Insurance
Black Start	Restore power plant operations after network outage without external power supply	Grid Operating Service
T&D Investment Deferral	Defer network infrastructure upgrades caused by peak power flow exceeding existing capacity	Grid Operating Service
Congestion Management	Avoid re-dispatch and local price differences due to risk of overloading existing infrastructure	Grid Operating Service
Power Reliability	Cover temporal lack of variable supply and provide power during blackouts	Insurance
Power Quality	Protect on-site loads against short-duration power loss or variations in voltage or frequency	Insurance

EXHIBIT 3

Source: Theron Sciencеworcs Energy Practice

2.1 BUY LOW - SELL HIGH

BLSH businesses - buying at a low price and selling at a higher price - is the core of any trading business. In the business of operating rechargeable batteries at scale, this is achieved by time arbitrage. Electricity prices are subject to constant shifting up or down. This price dynamic is driven by fundamental mechanisms of shifting demand and supply. Participants in any wholesale-like electricity market can learn from their observations, and then forecast such price shifts based on observable underlying patterns - weekdays, seasons, the hour of the day, weather conditions, economic activity, etc. Like in any trading business, the player with the most accurate forecast will gain the largest profits.

The disadvantage of electricity trading is that, on the one hand, average demand and supply are almost fixed over a few years. This is due to the long-term nature of economic growth patterns, which determine an economy's electricity consumption. On the other hand, trading capacity in the form of electricity storage may be added relatively quickly. This results in rapidly shrinking margins when new players enter the energy storage market in short-term transaction segments, such as Intraday, Day-Ahead, and Balancing Markets. Short-term means here that buyer and seller have not signed longer-term Power Purchasing Agreements, but rather transact on an hourly or daily basis.

Buy-low-sell-high applications for electricity batteries are Energy Retail, Bill Management, Energy Arbitrage, and those parts of Seasonal Storage, Primary, Secondary, and Tertiary Response markets where physically delivered electricity is traded.

IMPACT ON THE DUCK CURVE

OF SOLAR INTEGRATED ENERGY STORAGE (SIS)

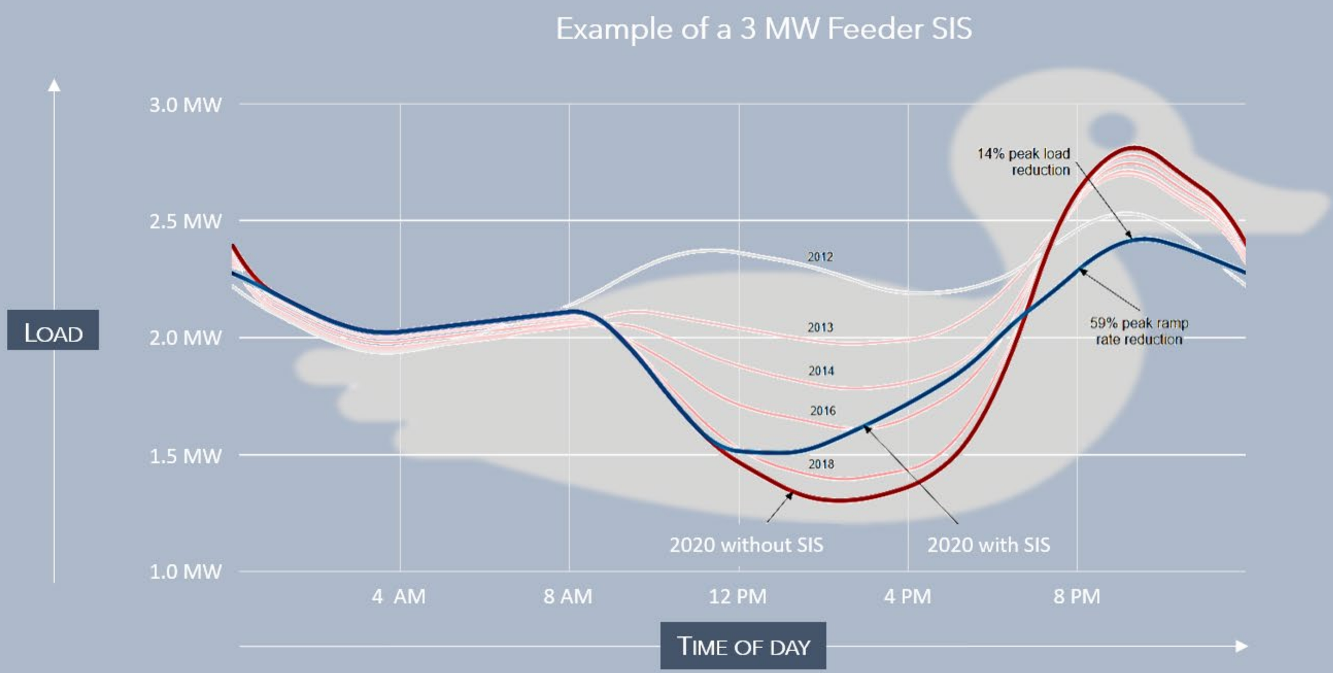


EXHIBIT 4

SOURCE: Integrated Energy Storage: An Answer to Addressing the "Duck Curve"?, Sunverge , Apr 8, 2015

Most of the larger-scale battery assets with power ratings of 10 MW and more are typically used to reduce the average electricity price for businesses consuming large amounts of electricity. The higher the share of wind and solar as sunshine energy sources in the electricity system, the higher the value this application creates. The reason is that in sunny regions, such as, for example, California, large parts of Australia, or the Mediterranean countries, sunshine and on-shore wind are usually stronger during daylight low-demand hours. This weather phenomenon increases the steepness of the so-called 'Duck Curve' - i.e., the total electricity demand minus the sunshine electricity supply. Exhibit 4 presents an example of the flattening effects that energy storage could have in California.

Almost all the battery assets currently in use for this application are owned or contracted by the local, regional, or national grid-operating utility. Total cost of ownership (TCO) is in these cases compensated by utility-determined electricity prices or grid services fees, i.e., by an administered pricing scheme.

This observation can be largely explained by the uncertainty that a market price mechanism would create compared to the administered pricing schemes present. A market for time arbitrage will quickly lead to a full leveling out of the duck curve, and thus leave all the benefits of the service with the electricity consumers or off-takers.

The problem is that in this case, battery asset owners would quickly start to lose money. This prospect is a significant obstacle to much-needed investments in grid-scale batteries. It must be addressed by regulatory action. Governments and energy market regulators can mitigate this problem, for example, by allowing the assets' use also for other revenue-generating applications (e.g., Primary Balancing Reserves) or by warranting minimum revenues for battery owners to the benefit of the entire electricity system.

2.2 MINIMIZE THE RISK OF FAILURE

Insurance against failure in the electricity system is very much comparable to insurance in other business and household sectors. The insured is guaranteed a service by the insurance provider in case of a claim. But there are two important differences between insuring parts of the electricity system and insuring the rest of human life.

1. In the electricity system, an insurance provider does not pay a claim upon the insured having experienced damage ('risk sharing'). Rather, the insurance provider avoids the damage from happening ('risk mitigation'). The price is paid for prophylaxis, not damage.

2. Hence, the value and, finally, the profit of the insurance provider in the electricity system does not originate from the collective (i.e., group of individual entities insured) but rather from policing the electricity system at an affordable cost. This only makes sense, if potential damages are highly frequent - even regular - events with significant impact but whosetiming or location are difficult to predict.

Insurance applications provided by battery systems are Power Reliability (avoiding varying electricity supply, brownouts, and blackouts)and Power Quality (avoiding ultra-short blackouts, voltage shifts, and frequency shifts). These services are in high demand from businesses that consume electricity for vital functions of their operations. Also, the operators of electricity transmission grids ask for insurance services. They need to assure the grid's stability by having access to sufficient electricity reserves. Such services are called 'capacity'. Capacity corresponds to those parts of Seasonal Storage, Primary, Secondary, and Tertiary Reserve markets where electricity is not physically delivered.

In the past, such insurance has been produced by fast-ramping power supply systems, constantly in operation, like large-scale diesel-fired generators, hydrological turbines, and gas- or coal-fired thermal plants operating with reserves at below full performance. For very fast reserves, very large capacitors and also batteries have been deployed. These devices, however, played in a small niche where potential damage from unreliable or low-quality electricity would have been prohibitively expensive.

Drastically lower cost levels have now theoretically opened up this gigantic market for modern-day battery systems with high ramping capability, like lithium-ion stacks. But the installed base of other fast-ramping machinery and their multipurpose capability constrain the batteries' growth trajectory in the insurance field. Growth rates are, however, picking up, whereas growth is driven by three interrelated trends:

6. Decommissioning of existing fast-ramping power generation machines due to their end of useful economic and/or ecological life.

7. Increasing frequency and impact of insured events due to the growing share of intermittency from concurrent consumption of solar energy and other renewable energy sources.

8. Increasing capacity size of consumption devices in local grids (EVs, heat pumps, etc.) driven by replacement efforts of fossil sources because of climate policies, leading to a significant increase in overload events at the lowest grid levels.

Local penetration and growth rates in this market mainly depend on the willingness of electricity system regulators to accelerate the move to a decarbonized electricity system. Insurance premiums are typically set through auctions for shorter-term transactional markets (e.g., Primary and Secondary Reserves). Prices of longer-term contracts (e.g., Power Reliability and Quality) are usually negotiated between the parties and depend on the competitive rivalry at the location in scope.

2.3 HELP TO OPERATE THE POWER GRID

Several services are required to operate a transmission grid or a distribution grid: installation, maintenance, and repair of power lines; connection and disconnection of various participants from the grid; forecasting, measuring, and billing of grid segment loads; purchasing electricity to be transported via the grid; or purchasing insurance against damages. Most of these services are performed by human beings, often with the support of tools and instruments.

But batteries can also play a role in the grid services field by providing load for the grid. This is done for two very different purposes.

1. Black start power is the energy required for a power plant to start. This service is what cars use a starter for. It turns the engine until it fires up - that's it. Usually, power plants, after a standstill, draw a load from the grid to churn their engines. Hence, they do not need to implement an expensive starter engine on their site. Similarly, a battery sitting next to the power plant's generator just for start-up purposes would be too expensive compared to start-up power from the grid due to its very low utilization.

The problem starts, however, when the grid has gone into a full blackout. In this case, all generators must immediately stop loading electricity into the grid. Exactly then, the power plant cannot start up, and the grid would stay in constant blackout. For this case, certain power plants per grid segment have been equipped with their own electricity generators, like diesel-fired internal combustion engines or jet propulsion engines spinning the main turbine of the plant. Maintaining these engines just for the rare case of a blackout is expensive.

Batteries can do this job at significantly lower costs. Since battery capacity can also be used for other revenue sources as long as black start power is not needed, they have the advantage of multipurpose weapons, called "revenue stacking."

The black start market segment is of small size because per grid start-up segment only one battery is required. As soon as this battery has fired up the first thermal generator, this machine will provide plenty of power for all other thermal generators of the segment to start.

2. Transportation & Distribution Grid Investment Deferral means, a large battery can help to avoid or delay investments into new power lines and increased transmission capacity. Individual power lines may not be capable of transporting required peak loads. The conventional response to this problem is to increase the line's capacity above peak load level. Whether this is commercially viable, depends on the required investment relative to the amount of peak load electricity transported over the line's lifetime. Since long-term demand predictions are subject to significant uncertainty, the grid owner has to make a difficult investment. A battery is a much easier solution to this problem. It can charge during normal load hours and discharge toward peak load consumers during peak load hours. In-between, it can be used to exploit other revenue sources.

Congestion Management has a similar background - i.e., an under-capacity power line - but with different consequences. The grid operator solves the problem halfway, without investing in more capacity. Either dispatching electricity along a detour over other grid segments, buying electricity outside its own balancing domain, or even delaying the dispatch to non-peak load periods. This either raises the cost of transport, local price differences, and other commercial disturbances. Like before, a battery can solve the problem at relatively low cost.

Currently, there are only about 50 batteries globally with a total power rating of 200 MW, which are used for grid operation support service. This result demonstrates that most grid operators are not yet convinced of batteries as an alternative to installing new or thicker power grid lines. The main reason is that financial benefits are not yet large enough to overcome typical barriers to change, like the novelty of a technology or perceived technical risk. And also, the natural reflex of a grid owner to invest in reinforced lines and charge the cost to the customers is quite common in a business with the characteristics of a natural monopoly.

The overall conclusion is growth will depend on the legislators' or the regulators' willingness and capability to control the economics of power grid operations. These parameters vary from country to country. An effective Europe-wide standardized policy is not yet visible.

3 RATIONALE FOR A BATTERY FUTURE

One fact is for sure: None of the battery systems currently in use or under development is dedicated to the application called seasonal storage. Seasonal storage is what will turn intermittent sunshine energy into a fully dispatchable source of electricity all year long. Seasonal storage is the strategy to capture surplus sunshine energy for later use - and later means up to a few months in the worst case.

Seasonal storage - opposite to all other types of storage applications - requires just a few charge cycles during a year. Since seasonal storage must close the gap between the seasonal fluctuations of renewable power generation from winter to summer, it requires high storage capacities. Thus, from an economic point of view, a seasonal storage-system requires small expenses regarding the capacity and small losses over long residence times.[1]

3.1 SEASONAL BOTTLENECK

The fact of the matter is, no industrialized electricity system has ever worked without gigantic amounts of reliable energy storage - with fossil fuels the predominant type of storage media. This fact will also hold for the future. It is dictated by the physics of electricity in combination with the opportunity costs of demand response.

Demand response takes place in the form of shifting electricity demand to times of sufficient supply. Private households are generally not set up for demand response. Private consumers are not used to varying prices. In addition, very common and rather rigid daily behavioral patterns (sleeping at night, out-of-home work, or school during the day, etc.) limit consumers' flexibility to the hours of relatively low electricity demand. All hopes the energy industry put into demand-side management at the beginning of this century have thus been utterly disappointed.

This may change, though. For private households, demand-side management may become acceptable and even attractive as soon as two conditions are given

- Clear and perceptible pricing signals to trigger price elasticity-driven investment behavior
- Affordable local electricity storage devices take over the role of interim electricity supply

In fact, this type of demand-side management does not lead to a true demand response. Demand does not shift over time. It rather stays

[1] Seasonal storage and alternative carriers: A flexible hydrogen supply chain model, M. Reuß et al., Applied Energy 200, 2017

as it is, but consumers could play the game of time arbitrage or peak shaving. They buy electricity at low prices during the day in the trough of the Duck Curve. They later use this electricity during the evening hours or the next morning, when demand and prices are high. Distributed storage in the hands of private consumers will enable them to morph into digitally supported, sophisticated energy traders at low cost and high convenience.

As for private households, for many commercial endeavors, a true demand response will not be possible. Even local storage devices, with their relatively high cost of capacity, may not be economically feasible for many of these commercial consumers. Electricity prices of such customers are markedly below private household power rates. Time arbitrage will not deliver sufficient Duck Curve price differentials to pay for the battery. Concurrent Consumption will remain a mission-critical capability for large segments of commercial and industrial electricity consumers.

Energy imports from neighbors or distant sources may alleviate the stress imposed on the grid by inflexible demand and intermittent supply. But even in internationally well-interconnected energy systems, there will be times when neighbors cannot fill in the blanks of darkness and calms. Hence, it is clear that storage capacity capable of bridging days, weeks, and months of lacking sunshine and wind is the longer-term key to a zero-carbon future.

Consequently, to ensure round-the-clock electricity at a sufficient rate in non-fossil times, the electricity system's infrastructure must be able to store energy sourced from the Sun in amounts that can bridge even the worst case, longest-duration scarcity of sunshine energy. This is what the term 'seasonal storage' refers to. Important to note - the less access to sunshine energy a region has, the more seasonal storage it will need to keep running.

The question at the core of solving the seasonal storage issue is: What will be the main technology of the future, serving as seasonal storage?

The technology alternatives to implement seasonal storage fall into four categories:

1. Gravitation- and mass-induced kinetic energy potential of water behind a dam, heavy blocks strapped in a shelf, underwater compressed air, considerable flywheels, etc.

2. Internal Combustion Engines (ICE) like turbine-equipped thermal power plants burning stored fuel to spin a generator; in some cases, combustion turbines are combined with a steam turbine using heat waste to drive another generator

3. Fuel cells, using stored hydrogen or its derivatives to produce an electric current from a thermochemical reaction

4. Batteries, discharging electricity stored in a solid or liquid material

Without reasonable doubt, it can be assumed that several particular cases will not make it to the seasonal storage shortlist: heat storage (heated blocks of solid material, heat fluids in tanks, etc.), pressure storage (e.g., underground compressed air), and electrical storage (large-scale electrical capacitors) belong to these candidates. Their rate of self-discharge is far too high to compete in this arena. They cannot maintain the required level of energy stored longer than a few weeks.

3.2 HYDROGEN AND BATTERIES

Some of the short-listed categories can be crossed out early because of inherent constraints and complications. Kinetic energy needs a lot of surface and airspace. Storage types of this category are limited by geological conditions and will play a niche role, at best. They may function in countries with above-average elevation levels. But even there, the total storage capacity will not be sufficient to bridge a long winter.

Internal Combustion Engines are terribly inefficient and too expensive to operate continuously over extended periods of time.

Decarbonized thermal power plants can be fired either by hydrogen and its derivatives, or biomass and biogas. Biomass and biogas are constrained by local circumstances of agriculture (i.e., solid waste biomass, biogas substrate), forestry (i.e., solid woody biomass), and ambient conditions. Unforeseeable effects of climate change like droughts further weaken the chances of reliable supply. Most experts agree that lack of supply and cost of processing will confine these sources across Europe to niches, either. No imaginable technology will change the fundamental limitation of such biological materials, characterized by a very low energy density per mass compared to other fuels.

Fuel cells are still expensive. Their technology learning curve is still in its flat start-up stage. This will change, though. Regarding energy efficiency, a standalone fuel cell roughly matches a gas-fired jet turbine. But new developments, for example, a turbocharged fuel cell, promise to achieve higher efficiency rates of up to 70%. Such a fuel cell's turbo consists of a small gas turbine burning residual fuel not fully burned in the cell and using the energy to load the cell with pressurized fuel.

Both, thermal plants, and fuel cells use hydrogen or its derivates as fuel. So, the remaining options can be summarized in a simple pair: hydrogen versus batteries.

Virtually all recently published considerations, models, plans, and simulations of future electricity systems of European origin have hydrogen-fired thermal plants as a fixed assumption to provide for by far the largest portion of seasonal storage. For the bridging period toward the future system's steady state, these plants are supposed to be fired by natural gas in the beginning. At later stages, a natural gas-hydrogen mixture is foreseen. For the last stage of transformation to the zero-carbon endgame, a switch to 100% hydrogen-based fuels is expected.

Batteries do not play even a remotely comparable role in these considerations. It is difficult to pinpoint a clear reason for this observation. Humans have difficulties imagining a different world. When landline phones were present in most homes, the thought of billions of always-on cell phones with super-compute power was science fiction.

Ignoring batteries as means of mass seasonal storage device is presumably not happening on purpose or caused by conscious ignorance. Unconscious neglect may however be a force holding back an open discussion.

4 ROADBLOCKS OF UNCONSCIOUS NEGLECT

In the public, but also among many decision-makers and politicians, batteries are primarily looked at from an automotive perspective. The idea of batteries as the medium for seasonal storage of electricity is probably unknown and not obvious to many. The reasons are that the battery lobby has so far not achieved recognition outside the automotive industry. Some examples of presumed sources of unconscious neglect may be found in the common pattern of organizational rigidity.

4.1 BIG AGENCIES' FLAIR FOR POWER

Levelized Cost of Electricity (LCOE) has become the 'Gold Standard' for comparing different sources of energy regarding their cost-efficiency. Adapting this standard to energy storage has brought out the concept of 'Levelized Cost of Storage' (LCOS). The basic model is to divide all costs of owning, operating, and decommissioning a storage plant by the electricity discharged over its lifetime. It is comparable to a lifetime unit-cost calculation for a production asset at an assumed yield.

As with every standard, such a concept has its advantages, like global applicability and full comparability. However, the risk associated with a standard is often and easily overlooked - a lack of specificity. Every standard has this kind of trade-off cost.

Often, where standards are applied, this issue is negligible. An example is wall outlet voltage. Europe runs at 220 Volt or 240 Volt, the US at about half that value. In the early days of electrical products, devices had to be equipped with voltage-compliant power supply units. This increased the cost of manufacturing per unit. But the effect was ignorable because of the low share of cost of power supply in the overall cost of the device. In addition, transport costs across the Atlantic prohibited a global distribution, for example, of centrally manufactured TV sets anyway. Nobody had a reason to complain. In the days of electronic products, automated switches solved the problem of hardware standards now and forever.

This is different, for example, with standards applied to application software. Software does not have transport costs. Adaptation to specific functional requirements is tricky and still needs human-sourced intellectual effort. Artificial intelligence does not yet solve such tasks with sufficient precision. The trade-off of off-the-shelf software versus custom solutions is often too expensive to ignore.

It is worst with standards when applied to notions - the softest type of software. And this is precisely what LCOE is - a notional standard. Such ideas have the potential to set the minds of a community and even an entire population. An out-of-the-box view, critical thinking, and healthy skepticism are easily neglected. Slowly but steadily, conventional wisdom is replacing common sense.

A growing count of members of the Energy Industry population is becoming used to using LCOE and LCOS as benchmarks. Benchmarks often act as gatekeepers when breakthrough innovation is concerned.

Why is this a problem? Because individual decision-making in such complicated areas as national and transnational energy systems is a highly diffuse and nontransparent process. Bias and prejudgment can easily suppress economic reasoning, often unnoticed by the stakeholders involved.

It is easy to imagine a manager in charge of innovation desperately trying to convince the Board of a risky pilot project. Innovation is risky as per definition. When deciding on scarce capital and top management time allocation, Boards of culturally conservative utility corporations have a clear preference: the well-known, less risky alternative. Hence, investments in energy storage - for example, large-scale batteries - may not be supported. Their LCOS is with a high likelihood mentally anchored somewhere in the region of €300 to €400 per MWh.

€400 per MWh is the result when a 100 MW 2-hour duration lithium-Ion battery's configuration is entered into the Gold Standard web app of a well-known UK research institution. Such a battery asset would thus be far too expensive when compared to a gas-fired thermal plant. This kind of plant produces electricity at a full unit costof between €60 and €120in times of non-stressed natural gas markets.

But this reasoning is completely flawed - for two reasons. First, LCOS varies significantly with the case in scope. For example, the average total cost of battery ownership when used in daily energy arbitrage, i.e., when flattening the Duck Curve, can achieve values already below $100. That is €10 cents per kWh.

Second, the LCOS formula globally used is outright wrong. The inventors of the LCOS concept came up with a surprising idea. They propose to discount the amount of energy discharged over the lifetime of the asset by the weighted average cost of capital. The rationale behind this idea is that the electricity discharged 'implicitly corresponds to the revenue achieved in the future'[1], and thus is to be discounted. Just to be clear: Applied to a car manufacturing plant's

[1] Levelized Cost of Electricity of Renewable Energy Technologies, Fraunhofer ISE, June 2021. It must be stated that Fraunhofer ISE is neither the inventor of the LCOE method nor ignores the fallacies of the concept. Rather, Fraunhofer ISE has conducted in the document cited a detailed assessment of LCOE as an input parameter for management decision-making.

cost assessment, this would mean cost controllers would discount the number of cars produced by the weighted average cost of capital. This hard-to-digest concept has been conveyed by IEA, IRENA, and others - and then picked up by several leading research institutions around the globe as a key parameter for decision-making.

Looking at the simple facts, the issue described here is rooted in a somewhat odd concept of discounting production output with a financial interest rate. Economics is one of the social sciences, dealing with highly diverse patterns of behavior. To deliver scientifically proven insights, economists must apply utmost discipline. They would not allow such a misconception just for reasons of comparability, as the agencies and many of their followers state.

The damage done by this misconception is impossible to assess. The misperception LCOS has caused may already have postponed or derailed many valuable investments decisions. Regulators and legislative efforts may have been affected, too. With the path-determining power of installed-base methodology, such a standard can lead to a significant misallocation of capital on a global scale.

4.2 BIG ENERGY'S FLAIR FOR THERMAL GENERATION

Several sayings are firmly established in business. Two famous ones are: 'Never change a running system' and 'Never underestimate the installed base'.

These sayings capture the fundamental truth of organizational culture. That truth is called 'fundamental' because it is difficult to change without roughly destroying the entire enterprise.

In the Energy & Utilities industry of the western hemisphere, there are very few cases where such a change has been seriously tried out. All other players seem to be hooked on thermal power generation. This is what they know. This is where they feel well. This is what they want. Most of these players, if not all, dress up their portfolios with renewables. But this is not helpful for batteries at all.

In the thermal world, storage is seen as spinning reserve, inertia, and black start capability. It is treated like an ancillary[1], not like a raw material. It is treated even less as what it really is - storage is a warehouse full of products - a merchant's dream!

Battery statistics confirm this simple fact. Over 90% of utility-scale battery capacity currently operating or under construction are in

[1] Management Science knows three types of materials: 1. Raw materials, which are transformed during the production process into products. 2. Ancillary materials, which help to smooth, improve, and simplify a process. 3. Operative materials, which energize, i.e., drive a process.

transmission- and distribution service applications. Some are in behind-the-meter peak shaving. Some are in the balancing markets. Almost none are in bulk energy storage or energy arbitrage.

Now combine this fact with another lesson learned the hard way: legislation, at the national as well as transnational level, is strongly impacted by Big Energy's lobbyists as well as by the growing force of net-zero-carbon evangelists. At first sight, there are good reasons for highly interactive politics-policy procedures. Big Energy is in charge of the energy system's adequacy and reliability. So, politicians better ask Big Energy what can be changed without triggering a system meltdown.

But this is a bit too simple. Neither Big Energynor renewable energy evangelists are in charge of system reliability and availability. In a formal sense, providing a well-functioning electricity system is the responsibility of transmission- and distribution system operators (TSO, DSO). These entities exist in many shapes, forms, governance, and ownership models across Europe. The issue is often that there are strong personal relationships at the top level between the system operators on the one hand and the generation companies on the other hand. And political decision-makers either don't see the collusive risk or don't want to deal with it. This behavioral pattern is quite common in political circles, even in the most market-leaning economies of the West.

Consequently, batteries do not yet have a strong lobby. Pumped Hydro is still collecting more than 10 times the investment capital than batteries in Europe. And public money is going toward hydrogen infrastructure as the biggest hope of humankind.

There is a glimpse of hope, though. When dissecting the announced investments in large-scale Electrolyzers, one can recognize a somewhat peculiar pattern. The bulk of the hydrogen projects initiated by Big Energy is in the field of using hydrogen as raw material, not as energy storage. The hydrogen is supposed to go as feedstock into steel, chemicals, and other Processing industry applications. Once Big Energy players learn how to profit from producing and selling valuable feedstock to manufacturing companies, they may consider protecting their margins instead of using hydrogen as a storage medium.

4.3 BIG AUTO'S FLAIR FOR FUELS

Electrification of individual mobility seems to be on the way. At least for passenger cars, city transit, and short-distance travel, this trend is rapidly picking up speed. This not yet the case, however, for road freight - one of the backbones of industrial economies.

Distant dreams of fuel cell-powered vehicles are still holding back globally leading OEMs from shifting full-force to battery-electric trucks. The main rationale behind this hesitance is less the additional weight a battery eats away from the cargo bay. Also, the need to build a high-capacity fast-charging infrastructure along the highways is not keeping OEMs off. It is first and foremost the issues of total distance that a tractor-trailer accumulates over its lifetime. The average travel distance of a highway truck in Europe is roughly 650 km per day. This travel pattern would require a replacement of battery cells at least twice a year. Such a replacement frequency makes the truck prohibitively expensive to operate. The buck stops here, and all the significant players, but Tesla, are still going for hydrogen.

But this may well change soon. When a battery module has reached the end-of-life in a truck, it still can be operated at 75% original capacity or more. This capacity is more than enough for stationary private household use, distributed storage, and specifically for seasonal storage of electricity in transmission and distribution grids. All it takes is a well-functioning, efficient second-live battery salvage business system. The first start-ups of this kind are already ten years old. Currently, venture Capitalists are searching for talented entrepreneurs with a background in the trucking industry, in battery re-use assembly, etc. Big Energy is also testing this business model with a more technical perspective on re-usability of car batteries for grid-scale storage.

The key trigger to this battery salvage business system is legislation with a corresponding price regulation. An immediately viable business model for seasonal energy storage is a capacity remuneration scheme. An infrastructure fee, designed as a cost-plus revenue scheme, is also a viable way forward. As soon as the legislative authorities like the idea, the roll-out will pick up speed. The nation that grabs this concept quickest, will help its Trucking industry to capture the biggest slice of the cake.

4.4 Big Electric's Flair for Moving Parts

One could assume, the globally leading manufacturers of electrical components like GE, Westinghouse, etc. are keen to kick off a new area of growth with large-scale batteries for electricity grids. However, this is not the case. Outside Automotive, battery-related R&D investments are funded by Venture Capital, Private Equity, the Chemical Industry, and the Asian juggernauts of Consumer Electronics. Big Electric, if active at all, is giving control into joint ventures with battery-only vendors.

Big Electric players are caught in the well-understood innovation dilemma.[1] They must choose between cannibalizing their existing business for rapid new business growth on the one hand and sticking to their thermal power plant roots while risking attractive business in the longer term on the other hand.

Their current view is to stay where they are. This means collecting public subsidies for early R&D work related to hydrogen-ready gas turbines and signing up a list of well-known customers where they can retrofit old-fashioned thermal power plants. This business comes with long-term revenue streams, composed of scheduled services, constant maintenance work, and expensive parts sold to largely captive customers. Their engineering departments will most probably be busy and well paid for the larger part of the time it will take to find out if this path could have made economic sense at all.

In contrast, batteries are rather boring from a power plant equipment manufacturer's perspective. Battery manufacturing is, in large part, loaded with chemical industry-type intellectual property, high-power electronics, volume production of low-cost standardized components, and software.

Moreover, battery servicing and repair can be executed without much effort by third-party service providers with lower-level staff instead of expensive gas turbine engineers. Spare parts are easier to commoditize, weakening an OEM's supplier power. Customers are hardly captive at all due to the relatively high standardization level of the many components a battery asset is composed of. For example, the world's largest battery plant at its Moss Landing facility in Los Angeles operates multivendor battery systems with a single operation and maintenance team. This proves that asset components from different vendors are rather homogeneous in the user interface.

The path-determination pattern here equals very much what happened in the automotive industry - before OEMs and First-Tier Suppliers saw Tesla ignoring the red light and crossing their way. One may assume that such a sudden surprise will also awaken Big Electric one fine day. But this prospect is rather dim. There is no immediate incentive to leave the comfort zone and fight with Elon Musk. Since as long as the political agenda is tied to hydrogen, there is no urgency to redirect the focus.

4.5 BUILD-BACK-BETTER'S FLAIR FOR COMPROMISE

The concept of Sustainability makes up the core of the political trend towards renewable energy. Whatever political intention is inside, using up limited resources – the depletion of fossil fuels, the climate

[1] The Innovator's Dilemma, Clayton M. Christensen, Harvard Business Review Press; May 1, 1997

change-induced loss of culturable land, etc. - is by definition not sustainable. Consuming any kind of fossil fuel is clearly not sustainable.

Nuclear reactors similarly consume limited fuel and risk the consumption of land, as Chernobyl has demonstrated. No expert would deny this fact. And still, the European Union has given nuclear power plants the seal of sustainability.

Compromise makes up the core of politics. However, a strategy - regardless of whether it is called 'Build-back-better' or 'Next Generation EU' - that allows individual member states to bail out at the cost of the others, is bound to fail. Countries like France and Poland have plans to build up a nuclear fleet that makes the seasonal storage of renewable energy entirely useless. Once - and if, at all - these fleets are operating, these players have an interest in producing synthetic fuels from their surplus atom energy.

On top of this, they have an interest in strengthening grid connections, enabling electricity exports from their countries outward. Cross-border power transmission lines outside this pattern and grid batteries will, with high likelihood, reduce their chances to profit from the system's imbalance. These players are already working actively against EU-funded investments in these fields.

If they succeed with their plans, the quasi-good news from such a scenario is: the need for seasonal storage will stay rather limited in Europe. Europe may miss out on an opportunity, but the energy system will have the chance to function.

The bad news is that in this case, the odds of dropping ambitious net-zero-carbon goals altogether increases by the day. The blame game among European nations will be very difficult to keep under control.

5 HYDROGEN AS A STORAGE MEDIA

Envisioning the 'end game' - the targeted solution - is a valuable exercise when planning a longer-term transformation of a complex and complicated system. This recommendation is founded on a hard-to-beat rationale, rooted in the very nature of uncertainty.

On the one hand, uncertainty poses a risk of stranded investments. Investments in technology, assets, or businesses with no chance of achieving product-market-fit, are lost. Such losses are partially compensated at best by lessons learned and salvage value.

On the other hand, uncertainty contains and creates degrees of freedom. Pushing a technology, asset, or business will regularly improve its odds of achieving product-market fit. Therefore, it makes perfect sense to assess the likely outcome of an uncertain transformation. Subsequently, investments in technologies, assets, and businesses that belong to exactly this likely outcome scenario are better spent and have a higher expected return.

Start-up subsidies have a higher expected return when invested in batteries instead of hydrogen. When it comes to electricity storage, the odds that hydrogen will beat batteries one day are disappointing.

5.1 TOO DIFFICULT TO DISTRIBUTE

Theoretically, the generally accepted view is that there are two topological concepts regarding the provision of energy storage.

1. 'Mainframe Storage Centers'. This is highly efficient storage, decentralized, location-bound, fit to local geographical context, producing high- to mid-level current, at scales of between 1 MWh to 1 GWh or bigger per asset.

2. 'The Battery Cloud': This is fully distributable or even mobile storage, with minimal geographical, ambient, and context constraints, at scales from tiny consumer electronics batteries to about 1 MWh.

Thinking of seasonal storage in particular just in terms of very-large-scale mainframe battery plants in the transmission grid is missing a major point - the Distributed Energy Resource. For example, the installed battery base in Germany in 2021 has an estimated 1,2 GWh y^{-1} of energy capacity. Over 50% of this capacity is installed in residential Battery Electricity Storage Systems (BESS).

This is the more surprising as Germany's regulatory scheme favors self-consumption only through avoiding the given penalty of exposing charged as well as discharged electricity to grid fees. It clearly shows the potential that the battery cloud offers in the future. Experts expect that over 95% of private customer photovoltaics systems will be sold with integrated storage modules in 2022 in Germany.

Another part of the battery cloud in the longer term is the fleet of electric vehicles. All in all, no nation in the EU can afford to ignore the battery cloud on the road to a zero-carbon electricity system. Distributed storage applications are a powerful and relatively easy to tap source of private investment capital.

Distributing hydrogen and its derivatives may be technically and economically feasible down to a middle level of a country's industrial, commercial, and residential infrastructure. However, distributing it all the way downstream to private households, offices, and small workshops needs extensive capillary logistics.

In its gaseous form, hydrogen needs relatively high pressure - too high for existing natural gas distribution grids - and expensive technical precautions against explosion. In the form of ammonia, it is highly flammable and cannot be used immediately in fuel cells. In general, and at least at this time, small-scale fuel cells for home or office use are expensive to build, difficult to operate, and difficult to maintain. Again, the capillary distribution chain is unpractical at best.

This constraint crosses out a large and apparently indispensable potential of financing for a country's seasonal storage fleet. Hence, compared to batteries, hydrogen demonstrates an unfavorable starting position.

5.2 TOO LIGHT TO STORE

Hydrogen is the fuel with the highest energy density per mass. A single kilogram stores about 33.3 kWh of energy. Next comes methane, with 13.9 kWh per kilogram. What looks like an advantage at first sight, may turn into a profound disadvantage on second thoughts.

Hydrogen at ambient atmospheric pressure is very lightweight. It is the very element with the lowest mass in the universe. Hence, a common way to achieve high hydrogen storage densities is via compression in gaseous form. Stationary tube systems have pressures of between 200 and 350 bar. A pressure of 700 bar is regarded as the most viable storage system for onboard hydrogen storage in vehicles. Even at this high pressure, though, density remains low. Another drawback is the high investment costs of high-pressure vessels and the special requirements for the vessel material. Low-pressure storage already has capital costs of about US$850 per kg of storable hydrogen.[1] Experience curve-driven cost digression in the future is assumed to be moderate.

Storing hydrogen at 700 times ambient atmospheric pressure has been presented as adequate storage pressure for onboard hydrogen in zero-emission vehicles. For stationary storage, however, it poses an incredible safety hazard. Compared to a large-scale mineral oil or gasoline tank in flames, an exploding high-pressure hydrogen tank can damage a much larger area in a very short time.

A second alternative is storing hydrogen underground - almost like fossil fuel. This is done today with natural gas in many places. But to achieve scale, the pressure of hydrogen stored underground must be multiple times higher. This requirement may limit the capacity of underground storage significantly.

In addition, charging and discharging at high pressure can degrade storage capacity quickly, depending on the geological conditions present. The full picture is not clear yet. Ongoing research and pilot projects are supposed to shed more light on this issue in the not-so-distant future.

Liquid hydrogen - a third alternative - offers the possibility of increasing storage density by cooling the hydrogen. Liquefied hydrogen can be stored in cryogenic tanks with robust insulation at less than 10 bar pressure. The low pressure allows the use of large storage systems with high energy densities. The drawback of this method is that the process of liquefication will consume amounts of 36 to 45% of the overall hydrogen energy content.

A fourth alternative of storing hydrogen is in the form of liquid organic hydrogen carrier material (LOHC). LOHC systems are composed of pairs of hydrogen-lean and hydrogen-rich, liquid organic compounds that store hydrogen by utilizing repeated, catalytic hydrogenation and dehydrogenation cycles. The advantage of this method is that it enables storing hydrogen in chemically bound form under ambient conditions.

The disadvantage is the energy required to dehydrogenate the LOHC when discharging. In principle, LOHC-based hydrogen storage and release is a reversible reaction. However, capturing, storing, and finally reusing the heat arising from hydrogenation for the dehydrogenation process represents a substantial challenge. It becomes almost unsurmountable in case of long time periods between charging and discharging the storage asset, as required for seasonal energy storage.

[1] Seasonal storage and alternative carriers: A flexible hydrogen supply chain model, M. Reuß et al., Applied Energy 200, 2017

The last well-understood alternative is turning hydrogen after production, from gaseous into a solid form.[1] Ammonia and methanol are among the most cost-efficient forms of solid or fluid hydrogen. One drawback ofthese reformation methods is the efficiency loss incurred during the reformation process.[2]

The most problematic issue with ammonia is the amount of nitrogen required to synthesize it. The amount needed for hydrogen as a seasonal storage medium would extract a sizable volume of nitrogen continuously from the Earth's atmosphere and cycle it back after use. Implications for the planet's ecosystem from releasing nitrogen or its compound uncontrolled may be manifold, risk-laden, and today largely unpredictable.[3]

5.3 TOO THIRSTY TO FEED

A single kilogram of hydrogen eats 22 liters of water during production. Hydrogen containing the energy of 1 MWh requires 660 liters of water. Considering an average fuel cell's electric productivity of about 60%, and ignoring energy for liquefaction and storage, this means to replace a single 50%-utilized 500 MW natural-gas fired thermal plant with hydrogen will need about 1.5 billion liters of water over a year. And this is not any water. It must be very clean water to work in an electrolyzer at scale.

There are first ideas and approaches on how this problem could be tackled. But today, even the hydrogen community has conceded that for industrialized nations with dense populations, producing large amounts of hydrogen on-site is simply not feasible because of the water demand. Regions with a lot of sun and wind are often already faced with the problem of water shortages. Climate change may either help or hurt - it is just unknown today. Desalination and

[1] *Hydrogen can be further converted to methane by reacting with CO_2, increasing the stability and energy density of the stored media, from 360 to 1200 kWh/m^3 at 200 bars. The existing natural gas infrastructure can conveniently store, transmit, and convert the synthesized methane back to the final form of energy use.*

[2] '*With the losses of 18–25% during the methane production process, it is estimated that the AC-to-AC efficiency of this storage process would be only 33–40% with today's technologies.',* Electrical energy storage systems: A comparative life cycle costs analysis, B. Zakeri, S. Syri / Renewable and Sustainable Energy Reviews 42 (2015)

[3] '*It is clear that our understanding of the mechanisms of the global nitrogen cycle is incomplete, in particular regarding the slow turnover in marine cycling of N-compounds. Hence, investment in technology development should also include investment in further basic science research on the environmental impacts of increased quantities of fixed nitrogen, and policy makers must mandate strong emissions standards and controls at an early stage.'* A Roadmap to the Ammonia Economy, Douglas R. MacFarlane et al., CellPress, Joule 4, 1186–1205, June 17, 2020

purification of seawater could help here. It will cost another estimated 10 to 15% of efficiency, though, and require lots of capital-intensive equipment.

5.4 TOO DISTANT TO CONTROL

If hydrogen can't be produced in large quantities in the country, it must be imported. The disadvantage of this solution is a lack of political power in a rapidly changing world.

The cost of electricity from renewable energy to operate an electrolyzer drives the cost of green hydrogen at a rate almost twofold the rate of the cost of the electrolyzer. In essence, to operate a large-scale electrolyzer efficiently, it takes a constant base load of electricity. Frequent ramping up or down of the plant reduces the asset's yield substantially. The economies-of-scale approach to drive down the cost of hydrogen requires abundant, cheap renewable energy resources.

The issue is that solar and wind are unevenly distributed around the world. There are very few geographies that rank highly on the list for both solar and wind. These areas will be favored over geographies with lesser resources or with strengths in just solar or just wind in green hydrogen production for two reasons: first, they offer the lowest renewable energy costs; second, mixing solar and wind resources enhances the capacity factor because both are often 'on' at different times of every day. Taking advantage of both of these benefits has a tremendous impact on the resulting cost of green hydrogen.

As a fact, constant base load from sunshine energy can be found only in certain geographical regions of the globe. Most prominent are the Californian coastal regions, Kazakhstan, and a few of its neighboring countries, some of the southern parts of Latin America, and a narrow, sub-Saharan corridor on the African continent. Australia is a borderline case.

Beyond renewable resources, the country is generally very dry, which reduces the net yield of production. Delays and hick-ups in the development of very ambitious venture capital-financed start-ups support this view.[1] Recently announced feasibility studies of other Australian start-ups chasing Europe's public subsidies and corporate venture capital pots may provide further proof of this assumption.

This means that most electrolyzers will have to be built and operated in politically unstable, rather non-democratic, countries. Western free nations can hardly afford to give hydrogen plants into the hands of

[1] See: https://intercontinentalenergy.com/western-green-energy-hub

dictators, despotic regimes, or rogue states. Large electrolyzers located outside the European Union's circle of influence will not help solve the problem of the economies' too much dependence on energy imports from unsecure sources. Hence, hydrogen may make the world less carbon-emitting, but it will not help solve any of the issues of geopolitical disruptions in the industrialized world.

5.5 TOO EXPENSIVE TO BURN

One frequently overlooked fact is that sunshine electricity is not for free. Wind turbines, solar parks, etc. must be built and maintained, and their lifetime is limited. As a consequence, the productivity of these devices and of any other component in the hydrogen supply chain is a critical issue.

Productivity can be measured as the Total Cost of Ownership of the supply chain, divided by the amount of energy produced over its lifetime. A typical supply chain of a power-to-gas energy storage

POWER-TO-GAS
ENERGY STORAGE SUPPLY CHAIN

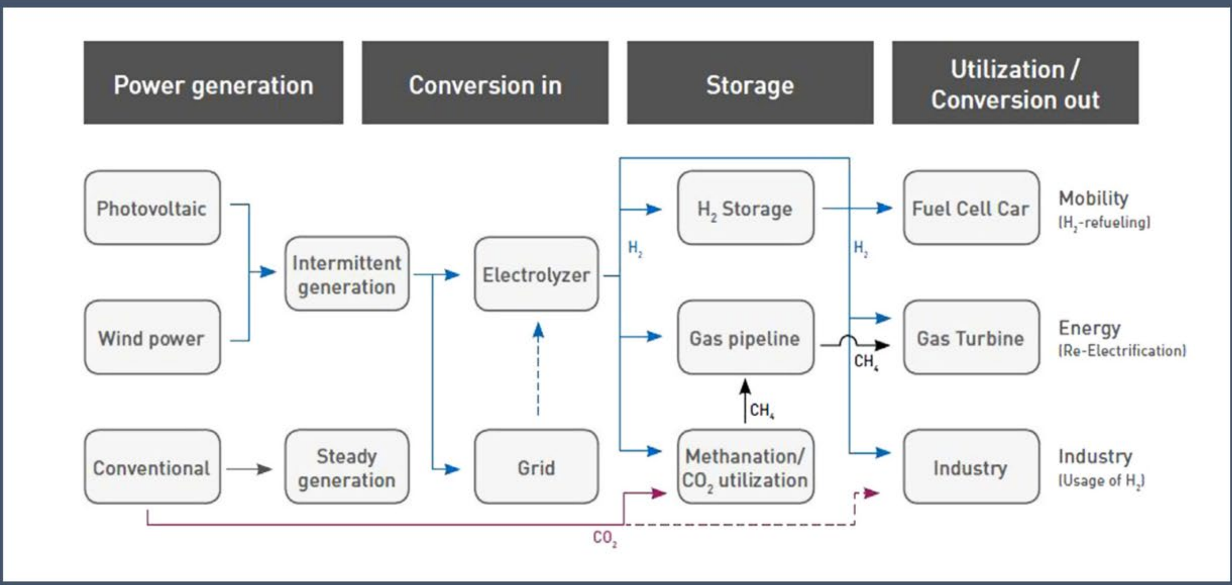


EXHIBIT 5

Source: Electrical energy storage systems: A comparative life cycle costs analysis, B. Zakeri, S. Syri / Renewable and Sustainable Energy Reviews 42 (2015) 569–596

business is shown in Exhibit 5.

Several studies on Total Cost of Ownership or Levelized Cost of Storage have been carried out and comparisons with other storage devices have been performed. With certainty, it can only be said today that:

1. Results are highly ambiguous - because of unknown experience curve or learning curve effects, as well as because of highly varying assumptions. Comparing supply chain variants requires standardizing their layout for seasonal storage applications. The assumptions needed to arrive at a standard typically favor one variant over the other one compared.[1] Hence, results do possibly correlate with the initial intention of the study.

2. Comparing a few key parts of the supply chain one-by-one clearly indicates a head-start for batteries in general.[2]

All in all, a fair conclusion is that hydrogen will stay too expensive to burn it in gas turbines. As one team of researchers convincingly put it:

"We find the projected dominance of lithium-ion technology is the result of good performance parameters, such as high round-trip efficiency and sufficient cycle life, and strong relative investment cost reduction due to a high experience rate coupled with moderate levels of installed capacity for stationary systems.

It follows that the development of alternative electricity storage technologies might become futile due to the challenge in matching the cost and performance advancement lithium-ion has achieved to date and is expected to achieve in the future.

This would mirror the continuing dominance of 1st-generation (crystalline silicon) solar cells despite significant investments in alternative solar cell technologies, which were initially expected to be significantly cheaper.

Just like crystalline silicon solar cells, 'lithium-ion' is collective for a range of technologies, offering the possibility of chemistry or design

[1] *"Since the cost of each power production method varies along with their advantages and requirements, it is not an easy task to establish consistent cost estimation for hydrogen-based systems. The capital cost of electrolysis itself varies among different configurations, projected €590/kW for solid-oxide electrolysis plants in 2020. These plants have power-to-hydrogen efficiency of 98% and net electrolysis efficiency of 83%, due to their heat demand. For alkaline electrolysis, the capital costs are in the range of € 1.400/kW while maintaining 43–66% power-to-hydrogen efficiency. Polymer electrolyte membrane (PEM) electrolyzer cell offers the power-to-hydrogen efficiency of 68–72% and net efficiency of 88% due to heat production. The cost of storage part heavily depends on the use of available infrastructure, for example, gas employing caverns or gas pipelines, or building new facilities. In general, it is estimated that the cost of above ground storage section would be around $15/kWh (€11/kWh), while for the underground caverns ranging from 0.002 to $49/kWh (0,002 to €0.41/kWh)",* Electrical energy storage systems: A comparative life cycle costs analysis, B. Zakeri, S. Syri / Renewable and Sustainable Energy Reviews 42 (2015)

[2] *"Today, the relatively low overall efficiency and huge capital costs are two major barriers in commercial implementation of hydrogen-based storage in grid scale applications.",* Electrical energy storage systems: A comparative life cycle costs analysis, B. Zakeri, S. Syri / Renewable and Sustainable Energy Reviews 42 (2015)

improvements that ensure the projected cost reduction for the technology group."[1]

5.6 TOO LATE TO WAIT FOR

As said before, envisioning the 'end game' is advisable. But it also bears a significant risk which must not be ignored! Even when the assessment of a vision's targeted solution is accurate, it may be advised to opt for a technology, asset, or business lying outside this targeted solution - either as a bridge or as a kind of life insurance. Because time is money, it may take far too long to wait for the targeted solution's break-even - in particular in case it is required to generate adequate interim returns simply to survive.

Hydrogen as the main medium for seasonal energy storage will probably be too slow to wait for its arrival in the energy arena. Industrialized economies will risk their position in global supply chains if the critical capacity to fulfill demand takes two or three decades. In a world where primarily, the Western nations feel obliged to move toward net-zero carbon energy, the willingness, and ability of sustained economic disadvantages against low-cost, high-carbon players seems highly questionable.

A solution must be comparably fast for the West to maintain its economic dominance as a convincing argument against political bullying and beggar-thy-neighbor strategies.

5.6.1 HARD-TO-BEAT PHYSICS

The process of learning drives down the capital expense of technical components. Battery manufacturing technology has seen a strong rise in productivity and a respective dive in cost per capacity over the last 25 years. Lithium-ion technology, in particular, has experienced a sharp decline in investment costs per energy capacity over the past ten years. Batteries, which are used in most electric vehicles, achieved a learning curve price digression of about 86% in the six years from 2012 to 2018 alone.

One highly likely driver of the favorable experience rate for large-scale lithium-ion batteries is the technology's inherent modularity. It favors knowledge spillover from other applications, for example, lithium-ion batteries for electric vehicles or household PV-integrated electricity storage devices.

[1] Projecting the Future Levelized Cost of Electricity Storage Technologies, Oliver Schmidt, et al., Joule 3, 81–100, January 16, 2019

The overall learning rate for batteries from 2010 to 2020 has been calculated at around 39%. Hence, the same rate of learning applies to grid-scale battery systems.

COMPARISON OF LEARNING RATES

BATTERIES VS. FUEL CELLS VS. ELECTROLYSERS

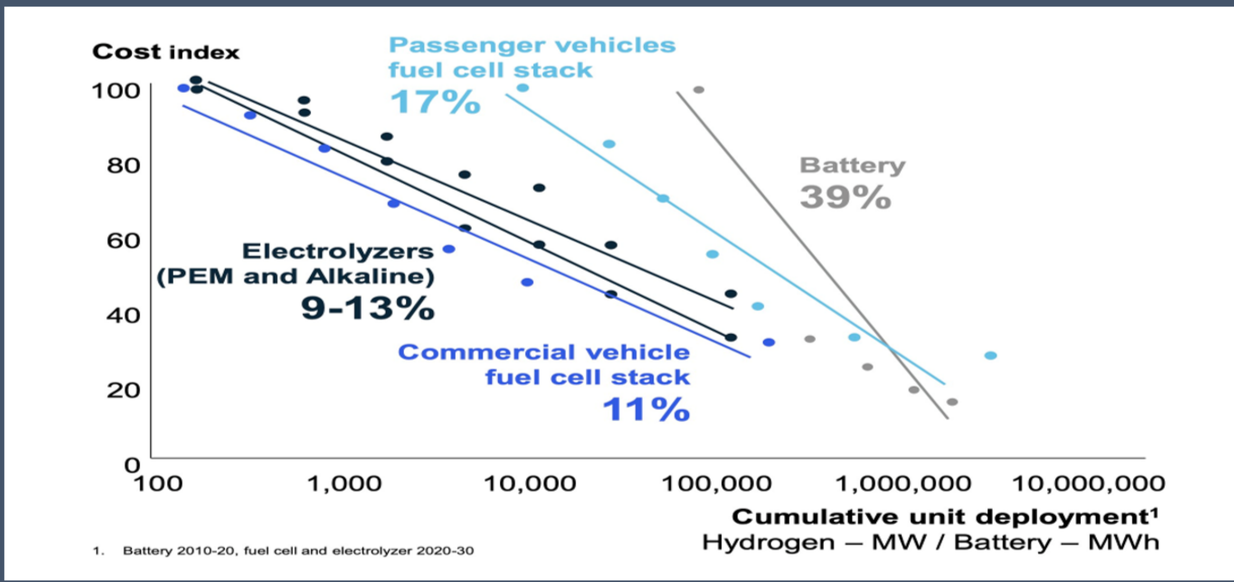


EXHIBIT 6

Battery 2010-2020, fuel cell and electrolyser 2020- 2030
Source: Hydrogen Council: Path to hydrogen competitiveness

Exhibit 6 compares lithium-ion battery past learning success with the hydrogen economy's estimated future learning rates.

Investments in research and development geared at efficiency improvements of the hydrogen economy are assumed to produce rather moderate results. The experience curve of hydrogen technology is flat, with estimated learning rates from 9 to 13% for electrolyzers. But one must be careful! This is not a full proof based on a detailed calculation of supply chain productivity.

It is a clear indication, though, that targets like the production cost of US $1 per kilogram of green hydrogen announced by John Kerry at the US American Department of Energy's Hydrogen Earthshot Summit in 2021 will be very difficult to achieve. Known physical barriers in the electrochemical process of hydrogen production are virtually impossible to overcome.

So, manufacturing economies of scale are left as the main source of expected expense reduction. The conclusion is that batteries are running away fast. The time when hydrogen will reach the economic productivity of batteries of today is almost certainly more than a decade away.

A forward-looking statement supports this point. It has been shown multiple times that learning curves, although composed of several underlying factors, have the typical shape of an S-curve on a linear scale. Accordingly, the rate of cost digression of lithium-ion batteries has slowed down significantly lately. Still, additional cost savings of approximately 65% are projected by 2030 based on the current observed learning rate of 18% per year for lithium-ion (Exhibit 7).

ELECTRIC VEHICLE

LITHIUM-ION BATTERY COST DEGRESSION

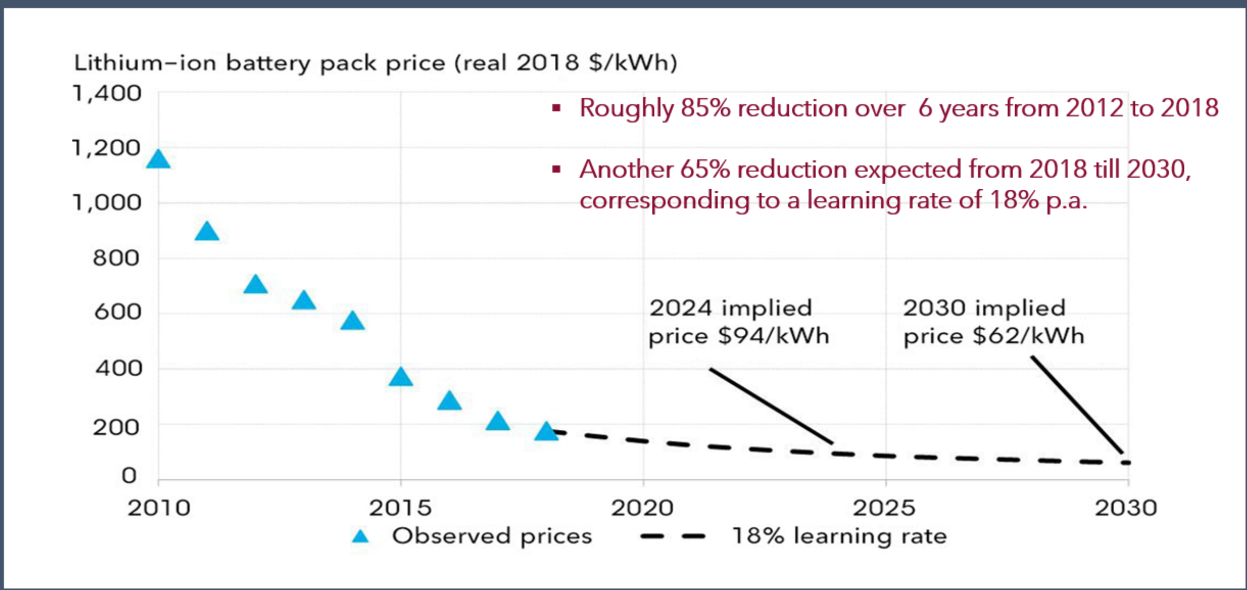


EXHIBIT 7

Source: Bloomberg NEF, 2019

And one must not forget that there is more than lithium. New ingredients have far greater potential. Leading researchers have already identified promising candidates. One may well expect more of the step-change innovation in battery development, as observed already a couple of times in the past. An example has been demonstrated recently by the US Department of Energy's Pacific Northwest National Laboratory. Scientists have developed an aluminum-nickel molten salt battery for seasonal storage. By using iron as the cathode material instead of nickel, the battery's materials cost is presumed to land at $6 per kWh. This is roughly 15 times less than the materials cost of today's lithium-ion batteries.

5.6.2 Hard-to-abate demand

New products entering new markets usually grow in a similar way. That is, after launch, any new product is first adopted by customers who place a high value on it. When markets mature and business system costs shrink due to scale and skill, it will attract growing interest from customer segments with a lower willingness to pay. More and more of this latent demand is being turned into acute transactions.

In most cases, the early adopter segments are small compared to the entire universe of addressable customers. But this is not the case for hydrogen because it is a multipurpose weapon. The Energy industry is hoping for hydrogen's arrival as a storable fuel, compensating for natural gas in a decarbonized future.

At the same time, the Process industry with sectors like Bulk Chemicals, Fine Chemicals, Fertilizers & Crop Protection, Fuels, Oil & Lubricants, Pharmaceuticals, or Steel and Aluminum Production are waiting for hydrogen. These so-called 'hard-to-abate' sectors have to rely on green hydrogen, produced from carbon-neutral sources, as fundamental feedstock in large quantities.

The term hard-to-abate describes a need to change the production processes in a profound way in order to decarbonize the output. Demand from these sectors will be enormous. Competitive cost pressure, topped up by rising carbon tax, levels will push up these industry players' willingness to pay for hydrogen.

The fact of high initial demand may not necessarily become a major constraint for the success of a new product. Comparable situations have been observed in several breakthrough innovation cases without becoming a mission-critical problem. The world is awash with stories of new businesses capturing global markets in very short periods of time. However, the main difference between these stories and the fate of hydrogen is the element's physical immersion in heavy hardware.

The amount of hydrogen available is closely dependent on the production, transport, and storage capacity released to operation. Building up such a supply chain is fraught with physical constraints. They are rooted in availability of raw materials to produce hydrogen infrastructure components.

Further constraints are component manufacturing capacity and engineering capabilities during plant design and construction. Finally, geopolitical control of site locations and the availability of operational supplies like electricity and clean water are setting strict limits.

As long as the demand for hydrogen in hard-to-abate industries is unmet, the world market price of hydrogen will make it a fuel probably too expensive to generate electricity. Thus, the energy industry risks facing prohibitively high fuel costs for a longer period of time.

6 BATTERIES ARE …

6.1 … BUILT FROM ABUNDANT RAW MATERIAL

Today, manufacturers around the world use more than 160,000 tons of lithium ores annually. In 2020, 71% of this material has been used to make batteries, according to the United States Geological Survey (USGS). And the amount of lithium used worldwide is expected to increase considerably. Most of the known lithium supply is in Bolivia, Argentina, Chile, Australia, and China. The quality is acceptable. Reports reveal that Brazil has lithium mineral reserves that are not only of higher quality, but also have lower extraction costs.

A large portion of the world's lithium reserves are found in China. With lithium demand expected to peak at over 4.5 million tons by 2030, there are security-of-supply concerns for Europe, the United States, and the rest of the world. In 2019, meanwhile, Western Australia has become the number one global producer of lithium. Australia is also the second-largest global producer of rare Earths, the third-largest global producer of cobalt, and the fourth-largest global producer of nickel.[1]

Lithium is currently mined on land. Estimates of the total amount of lithium in land-based sources vary widely. The global lithium reserve that is immediately and economically available through current extraction methods, is approximately 21 million tons. The USGS estimate, however, increases to 86 million tons if the count includes shipments of lithium that could be mined in the near future. The difference reflects the results of extensive geological surveys in Bolivia, Chile, Australia, and other countries to respond to the growing demand for the light metal.

At current energy density, 86 million tons can store about 85 TWh of electricity, which does not sound like an awful lot. It is important to keep in mind, though, that the lithium raw material in a Li-ion battery makes up only 1.5 to 2.0% of the weight and even less of the costs. A typical Tesla battery today contains about 5 kg of lithium. In terms of cost, it is only a fraction of one cent per watt, or less than 1% of the battery cost.[2]

However, what will happen when demand for large-scale grid batteries starts picking up? Because lithium is scarce on land and

[1] https://batteryuniversity.com/article/bu-308-availability-of-lithium

[2] Rather than worrying about a lack of lithium, there could be shortages of Rare Earth materials, should the EV replace the conventional car. One such material is the permanent magnet for the electric motors. Permanent magnets make one of the most energy-efficient motors. China controls about 95% of the global market for rare earth metals and expects to use most of these resources for its production. Export of rare earth is tightly controlled. See https://batteryuniversity.com/article/bu-308-availability-of-lithium

concentrated in just a few countries, researchers are looking at ways to extract the element from the oceans. The seas together contain 5,000 times more lithium than on land - that's 425,000 (!) TWh of batteries. This is an estimated 100 to 300 times seasonal storage for the earth, assuming that each human consumes electricity relative to today's industrialized nations. In addition, the inventors of lithium battery technology expect the energy density of future generations to roughly double within the next decade.

The ocean water extraction technologies are in their very first stages of development, though. They are not yet even nearly economically competitive with conventional lithium ore mining. But because of the raw material's low share in battery costs, the increase will not change the picture fundamentally.

In 10 years from now, the cost disadvantage may well have disappeared. And there are several other advantages coming with the ocean mining technology. For example, lithium from ocean water comes with a profound geopolitical advantage for each country with access to the sea. And ocean mining technology's combination with seawater desalination will create innovative designs under the energy-water nexus scheme[1], which will further improve the process's profitability.

In case the Earth runs out of lithium one day, other battery technologies will come to help later, with a very high likelihood. The race has started. Research is working on alternatives to cathode materials. Lithium is being substituted for other alkali metals like Sodium and Kalium. Multivalent-Ion batteries based on Magnesium, Calcium, Aluminum, or Zinc are further candidates for 2035 onwards.

At this time, the most promising path seems to lead via Sodium. A critical discovery by US researchers is expected to turn sodium-ion batteries into a safer and more affordable storage device with a greater range than lithium-ion batteries.

Tesla has already developed plans, on how to utilize sodium-ion batteries as their function improves. Sodium-ion batteries are manufactured with the same process as lithium. Hence, their time to market could outcompete other alternatives at a much lower cost. The cost to manufacture sodium-ion batteries is about 20 to 40% lower than for lithium-ion.

Battery manufacturers favor sodium over lithium because of the material's greater abundance and lower cost. However, sodium's go-to-market path has been hindered by its rapid performance degradation. But recently, scientists were able to watch in real-time

[1] See, for example: Addressing the Water–Energy–Food–Ecosystems Nexus to achieve the SDGs, Published in 2021 by the United Nations Educational, Scientific and Cultural Organization (UNESCO)

how the atomic structure of the cathode material degraded when being rapidly cooled. Based on these findings, an improved manufacturing process could deliver an estimated 20–40% increase in battery performance.

There are strong signals from the leaders in the battery industry that a breakthrough in sodium is not far away. The first fully industrialized sodium-ion battery production line will go into operation by 2023. The firm pushing this innovation says that at room temperature, the battery can charge to 80% in 15 minutes.

Furthermore, recent M&A activity indicates a new wave of innovation at the gates. India's Reliance Industries has acquired a UK-based sodium-technology start-up, to compete with market leader CATL. Both Reliance and CATL claim to be able to reach an energy density of 200 Wh kg^{-1} when launching their next sodium-ion battery generation.

6.2 … BUILT FROM SIMPLE BRICKS

Compared to chemical processing plants, like thermal power plants and industry-scale hydrogen processing, batteries are rather boring stuff. There are few moving parts with low energy (e.g., cooling fans, circuit breakers), andno high pressures or heat to deal with. Batteries come in standard racks inside standard containers.

Operation control is highly automated and doesn't need a full-time multidisciplinary team of engineers. Scheduled service activities, as well as replacement and repair tasks, can be performed by a rather small team of certified electricians with special training. Thus, the costs of Operation & Maintenance are relatively low.

Physical and digital interfaces within a battery plant and to the outside world are also highly standardized. This modular architecture allows for inexpensive scalability by adding more bricks to the platform.

Compared to the sequential processing architecture of thermal plants and hydrogen processing, a battery plant has a highly parallel architecture. This architecture constrains the impact of irregular events during charging and discharging to a relatively low level, without the extra costs of planned redundancy.

6.3 … BUILT TO LAST

The public's opinion may be coined by the perception of rechargeable batteries have a relatively short useful lifetime. For example, users are used to the fact that the smartphone battery runs out, and the device becomes obsolete within a maximum of four to five years. A frequent long-distance driver of a modern Tesla car expects even shorter battery replacement cycles. But this perception is misguided.

First, expected seasonal storage discharge cycles are in the range of two to three per year - much less than 300 cycles of a smartphone, or 200 cycles of a frequently used electric car. Temporal degradation, i.e., a lithium-ion battery's wear and tear without discharging, turns out to be only about 1% every year.

Second, the relevant health indicator of a battery is capacity. Capacity determines the amount of energy a battery can hold and suggests the price of a refurbished battery. Used vehicle batteries, being replaced because of the unacceptably short driving distance when slipping below 80% of their original capacity, will find a second engagement in grid-scale applications. Almost all vehicle OEMs using battery-electric propulsion technology are already testing such second-life business models with players from the Electricity and Utility industries.

Third, there is even a battery life afterlife. Lithium-ion batteries can be recycled with high raw material round-trip efficiency. Various methods have been devised and are currently in the process of industrial upscaling. For example, hydrometallurgical processing turns cathode and anode materials into battery-grade end-products for reuse in lithium-ion battery production or other applications in the broader economy. Beyond lithium, this process also produces battery-grade nickel, cobalt, and other rare materials.

Today, recycling of lithium is not yet economically competitive with lithium ore mining. Once the recycling technologies and processes have been refined, raw material costs from constantly recycling the globally available feedstock will presumably reach levels near the cost of mining.

7 WORLD AT STAKE

Nobody knows what the future holds. But a technology gap that must be bridged for certain products to become profitable, can be assessed based on current knowledge at any time. It is not necessary to wait until all experience has been gained and technology has matured. Making educated decisions early is often a strong source of competitive advantage.

The task of assessing future potential is at the core of every individual or organization making decisions about where and when to invest and how much. Politicians and regulators deciding where to subsidize technology research and business development are very much comparable to a Corporate Board making strategic decisions.

After all, the energy system of a country or region can be compared to that of a company in terms of its bidirectional implications - internal opportunities and risks on the one hand and external ones in a globalized economy on the other.

7.1 THE DOMESTIC FACTORY FLOOR

The energy system determines, to a large extent, an industrialized economy's chances to succeed in the world's markets. The cost of electricity is an important parameter for many industry sectors. Even more so, the opportunity cost of unreliable energy supply is a heavy burden for any business in an industrialized economy. The more industrialized a nation's or region's economy is, the more interconnected its supply chains are.

This trivial fact has dire consequences. Because small disruptions like lack of finance or bankruptcy, caused by cost overruns in non-critical industry sectors, can rapidly propagate through large parts of the ecosystem.

An example is the risk of rising fuel costs for Germany's highly fragmented trucking industry. Long-distance trucking is certainly a commodity in terms of highly standardized services and low switching costs for shippers.

However, if a rapid increase in diesel prices causes numerous companies to go out of business in a short timeframe, physical supply chains will be disrupted. In a domino effect, this has an impact on all the companies that rely on just-in-time delivery of goods.

A government needs to take care of a functioning and well-balanced energy system if it wants to protect taxable income. This simple truth causes the typical close relationships between politicians and Energy industry players from the municipal level all the way up to the Confederation or the Union. This fact must be kept in mind when considering the government's role in transforming the energy system as foreseen.

7.2 THE GLOBAL PLAY OF NATIONS

Nations, blocks, and super-powers compete for influence and control on a global scale. The truly global scope of national efforts beyond traditional circles of influence can be interpreted as the main consequence of economic globalization.

The risk Germany's and Europe's societies are currently subjected to from the future of the energy system is excluding the most while selecting a less preferable path of innovation. This risk is serious because it has a societal component significantly larger than economic losses in terms of a country's Gross Domestic Product.

The risk lies in the world's struggle with climate change. Again, not the economic outcome of climate change-caused disasters is in scope, although they may be ruinous to some players. Of even greater concern are the growing political tensions between superpowers and regional allies. Such tensions are caused by growing popular awareness of an unfair distribution of climate change-inducing economic benefits on the one hand and climate change-induced economic and social costs on the other hand.

The Western industrialized nations have started the processes leading to man-made climate change and benefited from the industrial revolutions. This is the emerging markets' justification to extend the use of fossil fuels into the future.

In case the West cannot convince the East and the South to follow suit on the road to net-zero carbon, tensions will grow. Economic inequality may trigger all kinds of unfriendly actions and reactions.

It takes time to get there, but after all, energy storage means independence. This is true in an immediate as well as in a strategic sense. As long as stored energy can carry on the system, bargaining for the next transaction can go on. The owner of stored energy is less subject to short-term extortion and exposure to spot market price fluctuations.

In a strategic sense, electricity storage turns intermittent energy resources into dispatchable ones. The faster electricity storage capacity grows, the sooner the European continent can vertically integrate the upstream parts of the energy system andthereby become independent of longer-term global power players' ambitions.

8 BETTING BIG IS NOT AN OPTION

8.1 STRATEGY CHOICES

Looking at energy storage as an indispensable component of a truly sustainable energy system, the uncertainty can be reduced to one main question: Will hydrogen turn into an economically viable medium for seasonal storage of energy in general, and electricity in particular? From a strategist position, such a situation is coined a Level-2-Uncertainty' on an ascending scale from 1 to 4. It describes a situation of so-called alternate futures.

The future can be described as one of a few alternate outcomes, i.e., discrete scenarios.[1] A typical property of such a situation is that analysis cannot identify which outcome will finally occur. But the analysis will help establish probabilities - the odds that one or the other alternative will prevail.

The value of a strategy depends mainly on competitors' strategies because all players' strategies combined will foster a certain outcome in an industry. Thus, the best strategy is the one that is most precisely directed to the outcome that will most likely occur.

8.2 MONEY MAKING BATTERIES

In a Level-2-Uncertainty situation, a key player must answer the question, what will be the most likely outcome as to the seasonal storage media? Several indicators are pointing in one direction.

Most battery factories under construction in the automotive industry are still subsidized by public money. But the share of such grants or other financial benefits has already reached the terrain of average subsidies targeted at community-related job creation and local economic development. The days when Tesla booked profits on factory subsidies alone are long gone. Hence, few experts doubt that batteries in general and the lithium-ion variants, in particular, are already a profitable business today. Green hydrogen is not!

Technical solutions to hard problems of producing, storing, and using hydrogen for electricity are far from solved. Compared to what lithium batteries already can do today, hydrogen is a minimum of two to three decades behind. The technical productivity of lithium-ion materials is about three times the productivity of hydrogen. In economic terms, the advantage is a multiple of this. And the rapid innovation driven by the adoption of batteries in electric vehicles will further increase lithium's lead.

[1] Strategy under Uncertainty, Hugh Courtney, Jane Kirkland, and Patrick Viguerie, Harvard Business Review; November–December 1997

This observation and the high value of hydrogen as a raw material are forceful hints that batteries have much better chances of becoming the preferred medium of seasonal energy storage. Anybody who plans to bet should pick this candidate!

8.3 CONTEXT COUNTING

The strategist has learned that the strategy choice depends on a player's so-called 'strategic posture'. Do you want to shape the future actively? Or do you want to adapt to what the future brings?

Shapers intend to drive an industry toward a new structure of their own devising. Their strategies are geared at creating new opportunities. In contrast, adapters choose a strategic positioning in terms of where and how to compete. Their strategies are predicated on the ability to recognize and respond quickly to new developments.

From a government's perspective, a country's energy system is of very high relevance. Of course, it is reasonable for the government to make fundamental decisions with the ambition to shape the future. But a burning ambition alone is not sufficient to win the game.

A player must also be capable of making a difference, a property that is determined by the economic prowess of a nation or federation. The European Union is in such a position. The EU represents a population of almost 400 million, and a total GDP of ca. $US17 trillion each year, surpassed only by the USA's performance of about $US 21 trillion in 2021. The Union is certainly capable of shaping the future if resources are allocated effectively.

8.4 MOVING FORWARD

Where should the resource be allocated to? Picking a posture is not enough. It clarifies strategic intent. But it lacks the specific actions and strategic moves required to accomplish what is intended. Decision-makers in management face three basic types of strategic moves when it comes to the allocation of capital: No-regret Moves, Big Bets, and Developing Options.

The same holds for governments when allocating subsidies to alternative technologies, business concepts, start-ups, etc. Each of these types is characterized by certain properties that determine risk as well as adequacy in a specific situation.

8.4.1 NO-REGRET MOVES

The No-regret Move is the easy one. Whatever a future scenario may come up, the money is well spent. Many day-to-day decisions are of this type, whether they are perceived as strategic or not. No-regret Move examples in business are cost-cutting projects, skill-building, and collecting competitive intelligence.

In public services, typical examples are investments in maintenance, repairs, and extensions of any infrastructure that has clearly proven value to society - public roads, railways, ports, telecommunications, etc.

No-regret Moves are rare in situations of breakthrough innovation or profound transformation, such as those presently happening in the global and regional energy systems.

8.4.2 BIG BETS

Big Bets are a totally different instrument. The term describes focused choices with positive payoffs in just one scenario but negative effects in all others. In a business setting, the main driver behind betting big is management's risk appetite. The key factors of success in such situations are the player's relative competitive strength and its risk-bearing capability. Tesla is a prominent example of a bet that almost failed. Uber is a prominent example of a bet that almost won.

In geopolitics, winning and losing have far more severe consequences than in business. One must keep in mind that the term 'negative effect' on the stage of the Play of Nations can mean outcomes spanning from diminishing economic and cultural power all the way to serious conflicts - even outright war! Betting big in politics is a recipe for disaster. Examples of current times range from Germany's bet on Russian natural gas to Brexit.

8.4.3 DEVELOPING OPTIONS

Developing Options is positioned between No-regret Moves and Big Bets. Different from No-regret Moves and Big Bets, the term option describes a continuous decision process rather than a single decision point to be implemented. Developing Options requires constant attention, agility, and sophistication.

Unlike a bet, an option is never geared toward a single outcome. The investment may pay off or not because options are designed to secure the big payoffs of the best-case scenarios while minimizing losses in the worst-case scenarios. The amount invested in developing the option grows over time in proportion to the odds of success. Most options involve modest initial investments that will allow players to ramp up or scale back the investment later as the business evolves.

This type of strategy is the most common case in the typical Energy industry-related asset investment decisions. The reasons are that high uncertainty reduces the No-regret Moves to a very few. Big Bets are usually too risky before the backdrop of the impact of failing big.

Best-practice leadership teams in politics, as well as management, devote at least 75% of their time and attention to the activity of developing options. One can say it is the art of strategic management as well as the art of politics.

8.5 EUROPE'S BEST-FIT STRATEGY

As a rule of thumb, one can say if uncertainty is high and the future should be shaped, it will probably take Big Bets to get there. The logic behind this reasoning is that by betting big, the shaper increases uncertainty for the other players, improving his odds to win - however at a risk.

If uncertainty is lower, though, like in the case of seasonal energy storage media, shapers do not need to bet big to succeed. They rather can bring uncertainty further down by investing in the creation of options. They can help their economic actors to get to a winning position by capturing experience curve effects. They can help by opening countless opportunities for technology exports. At the same time, they can help by speeding up a cost-efficient journey toward net-zero carbon energy.

Another important argument in favor of options is timing. Even if one could assume that hydrogen will be the more economical alternative three or four decades from now, pushing batteries today still makes perfect sense. The simple rational lies in a concept called 'Discounted Power Flow'(DPF). Governments must factor in political power when discounting future cash flows of electrical power! In global politics, time is not just money - sometimes it is survival.

The faster and the easier a nation or region can switch from one supplier to another, the higher the chance of surviving geopolitical bullying! The faster and the better Europe can live on its sustainable energy resources, the better. Since the financial market regularly does not account for the catastrophic risk of war, DPF-related interest rates are far higher than rates used to calculate Discounted Cash Flows (DCF).

The summary of this line of thinking is: The European Union and its Nations pushing for hydrogen and leaving batteries a bit on the sidelines is dangerous.

Other nations have come to a different assessment. The USA is leading the pack for batteries used in the electricity system, outside the automotive industry. Public and private investors are pumping rapidly growing funds at a per-capita rate of roughly twice the European level into the battery arena. China is also fostering batteries. Australia and the UK are fast followers (see also Exhibit 8).

BATTERY STORAGE INVESTMENT

2014 – 2021 (IN $ US BN, 2019)

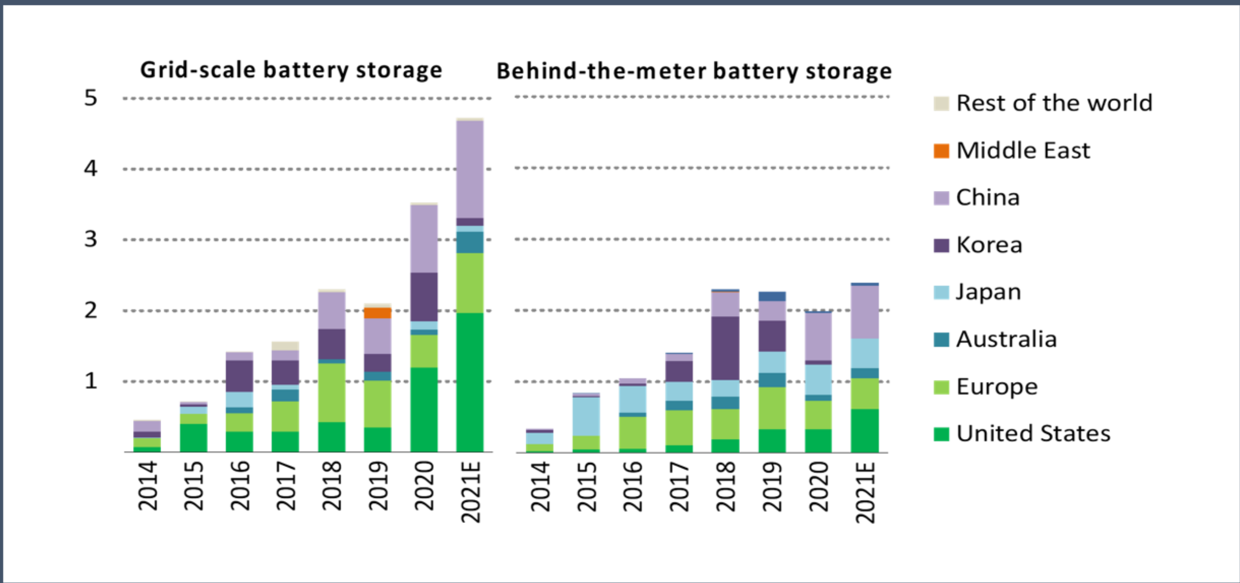


EXHIBIT 8

Source: IEA

9 SAY NO!

A strategic decision typically has more than just two alternatives to choose from. Making such a decision is therefore more about saying No than about saying Yes. This is true for every player in the electricity system arena.

Governments, whether at the EU level or in the Union's member states, are not the only players in this game. But they are the most important players. They wield enormous power, steering investments, intellect, invention, and interest.

Still, each player, regardless of size or type, must take a clear position based on her own assessment of capabilities, opportunities, and risks.

9.1 ELECTRICITY SUPPLIERS: STAY AWAY FROM HYDROGEN-READY GENERATION ASSETS!

The hydrogen hype has been underpinned by the tendency to hold on to and further develop apparently well-understood technology. At the center of this trend are electric generators propelled by combustion fuel turbines. For more than a decade, several power suppliers have been tinkering with the idea of building hydrogen-ready gas-fired thermal power plants.

New technology (NT), like hydrogen-ready turbines, captures most of the attention of the leaders in the engineering team. Ahead of building such NT assets, regular maintenance, retrofit investments, and potential life extensions of existing old technology (OT) are frequently deprioritized, delayed, overlooked, or ignored. The risk of such a strategy has several aspects.

1. Wasted residual lifetime

Regularly, a minor investment in an extended asset life will achieve a significantly higher return than going for hydrogen-ready NT from day one.

2. Unplanned OT replacements

Often, the arrival of new technology is delayed - for example, due to unforeseen or harder than expected technical occurrences during pilot projects. An extended delay of the NT solution creates, in these cases, a profound disruption when OT assets cannot be salvaged any longer. Asa consequence, unplanned, valueless costs have to be spent on implementing quick and, hence, expensive replacements for these underserved, unmaintainable OT assets at some point.

3. Beta tester syndrome

The risk of playing the Guinea Pig role for a technology provider is quite high during early-stage NT introductions. For example, hydrogen-ready turbines are facing an intricate challenge with a problem called 'embrittlement'. Hydrogen embrittlement is a widely known phenomenon in high-strength materials. Hydrogen ions tend to creep between the metal alloy molecules, creating tiny cracks. These cracks continue to grow until the component fractures and eventually undergoes catastrophic failure. Loss of mechanical properties such as ductility, toughness, and strength are embrittlement's fatal consequences.

This risk can be reduced by treating a metal's surface and performing a few other technically sophisticated procedures. However, the data required to give accurate projections of the meantime between failures cannot yet be made available for first-generation hydrogen-ready gas turbines. Such data can only be generated in practice, not in a laboratory environment.

At this point, a human phenomenon called 'The Conspiracy of the Optimists' kicks in. Either consciously or by unconscious neglect, the vendor's product champions tend to conspire with the customer's NT engineering leaders. The history of technology development is rich with such cases. Famous examples are NASA's space shuttle launched at sub-zero ambient temperature, Berlin BER airport's air ventilation management, or Boeing's 737 MAX disasters. The vast majority of cases do not make it to such a level of publicity. But they are all caused by insufficient data from practical, longer-term operations.

4. Full reverse

In the worst case, NT will not materialize at all - either because of unmanageable technical difficulties or because of economic obsolescence. The latter case is the core of the Green Book's key statement: Economic obsolescence from battery technology having gained an unmatchable lead over burning hydrogen in thermal plants or large-scale fuel cells.

In this case, a full reverse of strategy is required - typically with significant costs of missed opportunity. Missed opportunity comes in various embodiments, such as, for example, lost customers, foregone profits, or critical market positions being preempted by competitors.

The history of power generation technology knows examples of the full reverse. Many are to be found in nuclear power plant technology. But also, conventional thermal plants have a history of failed component developments. For example, several reports have been published about cracks in the welding seams of water-cooled walls, superheater tubes, reheater pipes, and economizer tubes in boilers after the introduction of new metal alloys.

The conclusive recommendation for electricity suppliers is: Don't attempt to jump too far, especially when you can't see the landing space! If hydrogen turns out to be the solution of choice, bridging the gap by extending existing technology is clearly the No-regret Move.

9.2 GRID OWNERS: DEFER THE EDGE CASES!

Congested power lines call for reinforcements. The natural reflex of grid operators in such cases is to draw new power lines with increased transport capacity. This has been the measure of choice for over a century.

The disadvantage of infrastructure assets, in general, is the high rate of step-fixed costs. Once a new line needs to be drawn, expectations of continuously growing demand need to be determined and capacity fixed. This is often done by adjusting the target capacity to the demand level forecast for the last third or quarter of the line's expected technical lifetime.

As a consequence, for the first half of the line's useful life, it is equipped with substantial over-capacity. Valuable capital is wasted, and the rate of return diminished. If the grid fee regime allows the operator to charge investments directly to customers' bills, customers will pay for the waste.

A battery solves this issue to a large extent. A battery installed at the correct location in the grid can take care of the congestion problem. The grid operator can charge the battery with power drawn from the congested edge[1] during low-load periods and feed it back into the system toward the adjacent high-load edge during congested periods. In addition, the battery can be used to exploit other revenue sources when congestions are not expected in the near future.

Regularly, this approach will produce better financial returns for the grid already in the short term. If congestion rates keep increasing and power line reinforcements become unavoidable in the longer term, the battery can be fully devoted to other revenue sources available at this specific location. Even, moving the asset to another location may make economic sense.

9.3 INVESTORS: DROP FUEL CELLS, DRIVE ELECTROLYZERS!

An issue frequently observed at the beginning of a breakthrough innovation cycle is thinking of technology classes as asset classes.

[1] In network theory, connections between network nodes are called "edge"

Such a technology class is the hydrogen economy. Investment funds with a strategy of investing in companies instead of individual assets are particularly exposed to this risk. They tend to put industrial manufacturers of electrolyzers, fuel cells, storage devices, and transport infrastructure in the same cluster. Also, other industry players may overlook the fundamental differences between these asset classes. Large-scale electrolyzers, their manufacturers, and their operators will be able to prosper without the existence of large numbers of fuel cells.

But large-scale fuel cells will only be able to achieve product-market fit if hydrogen plays a major role in the energy storage business as well. Fuel cells produce electricity from hydrogen. The largest share of fuels cells is supposed to serve the energy industry.

If seasonal storage is contained in batteries instead of hydrogen tanks, the global demand for fuel cells will be far below expert's optimistic expectations of today. There are still many useful applications for fuel cells. But the shakeout among fuel cell developers, manufacturers, vendors, etc. will presumably turn out very intense as well as very early compared to a normal shakeout in an NT industry sector during its maturation.

Today's carbon-intense industries will long for feedstock, less for electricity. Demand for hydrogen outside the seasonal storage business is supposed to be a multiple of the seasonal storage capacity required. Hence, the growth rate of electrolyzer for years and decades to come will be limited by production capacity constraints, not by a lack of demand. Hence, electrolyzers' fate is far less risky than large-scale fuel cells' future.

Preferring electrolyzers over fuel cells has two independent positive effects.

- First, it will limit the risk of capital loss for private as well as for public investors. Like public funds, most hydrogen-related private venture capital in Europe is also going toward fuel cells. Investors should refocus and reallocate venture capital accordingly.

- Second, it will help to focus scarce resources like R&D skills, critical raw materials for technical components, and engineering and construction capacity on the more promising parts of the hydrogen supply chain. To bundle resources and generate scale, R&D efforts and corresponding investments should thus concentrate on electrolyzers, not on fuel cells.

9.4 GOVERNMENTS: MIND HYDROGEN MYOPIA!

Broad subsidies for the hydrogen economy as means of fostering and accelerating innovation are not required. Taxpayers' money flowing into the hydrogen economy is wasted.

Large chunks of European Union subsidies are geared at high-risk, so-called 'non-bankable' NT start-ups. Non-bankable hydrogen-related start-ups must not be supported at all. The industry sectors these start-ups are targeting on are fully capable of funding their innovation need. Instead, public money should be strictly limited to public goods insufficiently profitable to be provided by the private sector.

The assumptions supporting this recommendation are simple.

- Hydrogen will primarily be used as a feedstock, raw material, and ancillary input in process industries.

- For Logistics & Mobility, outside the battery-power vehicle world very few and highly specialized use cases will remain - e.g., air transport, special purpose vehicles, military vehicles, mining vehicles, and vocational trucks.

- Process industries are fast and productive. Today's politically anchored carbon tax expectations are sufficient to trigger a transformation toward hydrogen.

- Process industries command abundant amounts of capital. Strong players will be able to pay for the transition to hydrogen. The entities not able to finance the transition are not worth the subsidies. They are marginal players with very little chance to survive in a competitive setting.

However, the hydrogen economy seems to have established itself already inside the pockets of the'regular' policy process. What does this process of political subsidizing look like, and what are the potential consequences? The process goes a bit like Communist central planning:

1. Bureaucrats in central departments determine amounts of money that the taxpayer must write off for a better future of all citizens.

2. Lobbyists start jockeying for the money by tweaking the criteria for grants and tax reliefs toward their employers' capabilities.

3. Industry Experts, recommended by the Lobbyist and hired by the Bureaucrats, evaluate the applications for subsidies.

4. The money is disbursed, and nobody feels in charge of keeping track of the results.

This procedure is the feeding ground of current hydrogen myopia. As a result, money is given to numerous hydrogen-related infrastructure projects, manufacturing start-ups, and R&D activities.

Most of the funds are going to ventures supposed to be important building blocks of a hydrogen storage and transportation infrastructure for Germany and Europe. Virtually all of these projects have been initiated by very large corporations with well-established relations with financial markets. It is silly to claim that these juggernauts are incapable of carrying the risk and paying for their highly promising ventures on their own.

Even worse is the conclusion one must draw from the recently published 'Osterpaket' (Easter-Package), a legislative draft of Germany's Federal Ministry of the Economy and Energy. This document wraps up the government's vision of the country's electricity system. Regarding electricity storage, the draft does not mention batteries. Storage in this law refers to hydrogen only.

In a Batteries-are-Forever scenario, as described in this Green Book, public subsidies, or taxpayers' grants to ventures of nationwide hydrogen electrification are wasted. The bulk of stranded asset risk lies in fixed hydrogen transport infrastructure, which isa fully immobile, hard-to-permit, and hard-to-construct asset class. Avoiding these stranded assets requires a clear map of the future. Such a map must follow an economic rationale with strong guiding principles.

- Hydrogen must be available in bulk amounts at large-scale process industry sites.

- Wherever possible and economically feasible, electrolyzers should be collocated with the site of consumption. For cost-efficiency reasons, the main portion of energy transportation should use electricity as a medium.

This tactic can also raise the returns from new and extended electricity transmission lines. These lines come at high financial as well as significant social costs. Hence, each percentage point of increased utilization is of significant economic worth.

- A system for hydrogen distribution comparable to today's car fueling station network is redundant and a strong candidate of a stranded asset. Hydrogen in transportation will remain a niche application for airports, containerized freight terminals, army, air force, and naval infrastructure, as well as some large municipal facilities, etc.

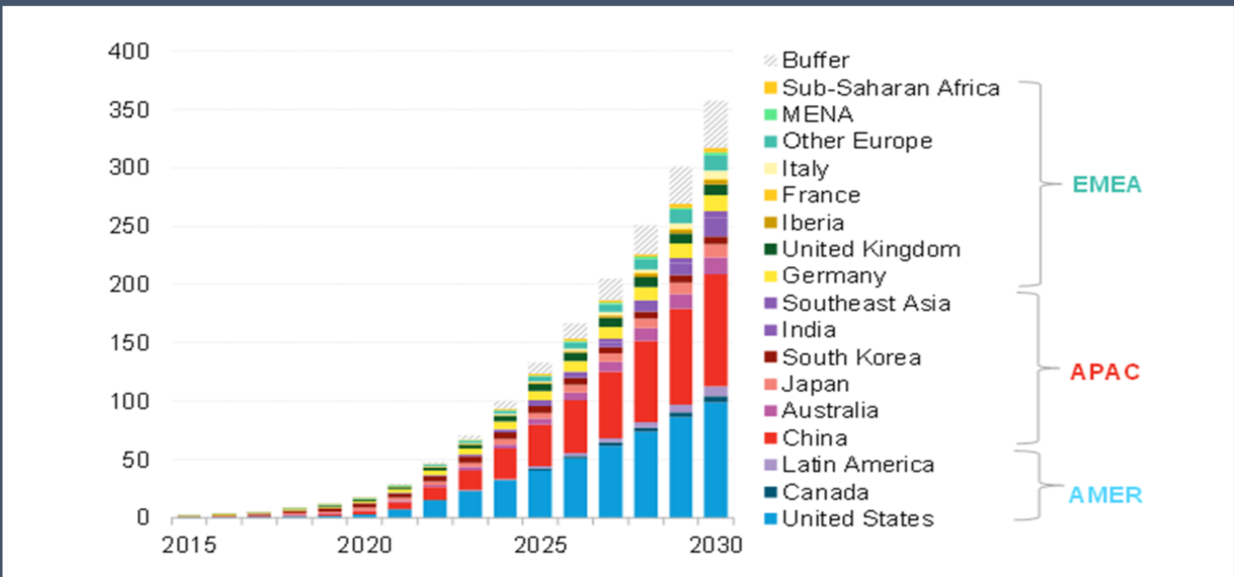
10 SAY YES!

One must be cautious and assess powerful trends as early as possible. Playing against a trend is always an expensive endeavor. In particular, when strong competitors are moving in a different direction,alarm bells should ring.

A recent statement from a Bloomberg Press Release says:

"*Regionally, Asia-Pacific (APAC) will lead the storage build on a megawatt basis by 2030, but the Americas will build more on a megawatt-hour basis because storage plants in the U.S. usually have more hours of storage. Europe, the Middle East, and Africa (EMEA) currently lags its counterparts due to the lack of targeted storage policies and incentives, which may be surprising, considering Europe's ambitious climate targets. Growth in the region could accelerate as renewables penetration surges, more fossil-fuel generators exit, and the battery supply chain becomes more localized.*"

GLOBAL CUMULATIVE
ENERGY STORAGE INSTALLATIONS, 2015 – 2030 (IN GW)



NOTE: MENA = Middle East & North Africa; Buffer represents markets and use-case that were unable to forecast due to lack of visibility

EXHIBIT 9

Source: Bloomberg NEF

Exhibit 9 summarizes the situation as to future prospects.

The European Union is handing out subsidies that member states may use to co-fund large-scale energy storage projects - pumped hydro, compressed air, hydrogen, and any technology deemed 'innovative'.

At the same time, technology from Germany or any other European country is not yet positioned to play a major role in the rapidly growing field of battery technology. At least, Germany seems to be betting the economy's fate primarily on hydrogen. In the year 2020, the Federal Ministry of the Economy came up with a hydrogen strategy. Investors and other industry players are following this path now. It seems to be their best chance to collect the significant subsidies and grants associated with strategic ventures.

This investment bias could backfire painfully. Each player must review her plans now!

At least this point is certain - there is no immediate switch from fossil fuels to solar energy. Time-boxed bridges are a must on the road to the future. Such bridges, whether technology or tactics are concerned, are required to transform base-load electricity generation from fossil fuels like lignite and hard coal toward capacity-firmed wind and solar. They are also required to transform commercial and residential heating from oil- and gas-fired boilers toward electrical heat pumps. Most relevant, though, is the bridge leading peak-load electricity generation away from natural gas-fired thermal plants toward batteries. Peak load and quick ramping of power are the final bottlenecks of an electricity system fed purely from sunshine.

A publication from 2012 may shed more light on the issue. Germany's VDE, the country's Energy Industry Association, had commissioned a study on the future of the energy system in general and the demand for energy storage in particular.[1] A central insight - one of 11 in total -reads,[2] 'Insight 9: Power plants and long-term energy storage will also take care of the future of security of electricity supply'. Nothing appears to be wrong with this statement. But another insight published in the paper is "Insight 3: Up to a Renewable Energy share of ca. 40%, energy storage will be required only at a very modest rate".

The main rationale behind this statement was that natural gas will be available at the full discretion of thermal plant operators. At this time, this assumption may have been correct. Today, it is not anymore. Statements like number 3 may create a false feeling of security and safety - most probably not on purpose, but they do. The message is

[1] Energiespeicher für die Energiewende, Speicherungsbedarf und Auswirkungen auf das Übertragungsnetz für Szenarien bis 2050, VDE, Juni 2012

[2] Translation from German to English by the author

'Don't worry! There is enough time to act sometime in the more distant future.' Such luxury is gone now.

10.1 POWER SUPPLIERS: BRIDGE THE GAP!

The most climate-friendly media to provide for this bridge is natural gas - this is an undoubted fact. Consequently, power suppliers and investors should make a few fundamental decisions.

1. Treat natural gas as what it is - as a bridge resource, not as a solution! Invest all discretionary funds in extending the lifetime, improving the efficiency, and increasing the utilization of existing assets. The economic gain from this strategy will be needed dearly to finance the more expensive energy world of net-zero carbon generation.

2. Treat hard coal plants as what they are - an asset either with an extendable lifetime or to be decommissioned. Burning hard coal emits much more carbon dioxide than burning natural gas. Thus, hard coal plant owners are considering upgrading their assets into a natural gas-fired plant, instead of either decommissioning these assets or investing in hard coal retrofits geared at improved efficiency.

Between 2011 and 2019, 103 US American coal-fired plants were converted to, or replaced by, natural gas-fired plants.[1] This does not mean, though, that conversion is a No-regret Move, not even an Option at this time. The reason is that for the foreseeable future, Germany and large parts of the EU will not have access to sufficient amounts of natural gas.

The Chemical industry and the existing gas-fired thermal power plants will need more or less all the natural gas imported for their production. Natural gas is facing a similar fate in the short term as hydrogen in the long term: it is too expensive to burn. With high likelihood, even a doubling of today's carbon tax level won't compensate for the economic disadvantage of natural gas versus lignite as a power plant fuel for years to come.

3. Treat any thermal power plant's grid substations as what they are - a valuable time-boxed collocation option for large-scale batteries. Hard coal plant owners should be aware of the fact that collocating their assets with a large-scale on-site battery storage may make much sense.

It is cost-efficient since safety features of power plants are also useful for large storage assets and because power plants have high-throughput connections to the transmission grid. The electricity

[1] https://blog.parker.com/site/usa/en-US/details-home-page/coal-power-plant-conversion-to-natural-gas-us

transmission system knows all the technical details given at the site. Security and safety measures are already in place. Environmental concerns have been addressed and solutions developed over decades.

Most relevant in this respect is a fact from the field of energy trading. Coexistence of generator and battery on one site allows for quick portfolio optimization without any cost of electricity transportation. In a number of scenarios, it can be profitable to store the thermal plant's electricity in a battery for short periods of time. For example, the fast-ramping capability of a battery can turn a relatively slow-ramping lignite plant into a multipurpose weapon if controlled by a single operator.

Last but not least, learning how to operate batteries early on may give plant operators a significant strategic advantage over their competitors.

10.2 INVESTORS: STAY AGILE!

It is important to understand that the path to battery electricity storage will have many junctions, detours, and dead ends that are currently unknown. The most relevant parameters in this respect are battery technology, electricity storage applications, and battery landscape topology. These parameters are interrelated. Decision-making along the way faces complexity and significant uncertainty. The best strategy, when faced with high levels of uncertainty, is to stay agile - i.e., alert, conscious, cautious, quick, and reasonable.

10.2.1 Battery technology

From today's perspective, lithium-ion is the most promising battery technology for storing electricity. Over 90% of investments in manufacturing capacity are currently flowing in this technology category. But one must be cautious!

This trend is largely dominated by the Automotive industry's hasty shift toward electrification. Lithium-ion technology represents a watershed for this industry. Its emergence has for the first time enabled the electrification of the overwhelming number of typical use cases of a passenger car-type automobile at an acceptable cost.

This trend may not sustain itself in other applications. The entire history of the development of battery technology is marked by a surprising pattern of leap-frogging innovation. A doubling of weight- or size-related storage capacity from one generation to the next, as well as from one technology to another, has occurred several times.

There is no reason to assume that this pattern will end soon. New, and highly encouraging, breakthrough technologies are already showing up on the horizon. Hence, one must not be surprised to see that the current mainstream of mobile electricity storage technology spilling over to stationary applications will not sustain itself in the longer term. A continuously cautious scanning of technology development is the best insurance against unfriendly surprises.

10.2.2 STORAGE APPLICATIONS

Electromagnetic batteries have a couple of application-specific advantages over other types of storage media, for example, mechanical parts (water, flywheels, compressed air, etc.), chemicals (fuel, cryogenic materials, etc.), or heat (molten salt, solids, etc.). Regarding electricity system-related applications, the most important of these advantages are modularity, scalability, and partial mobility.

Equipped with these capabilities combined, batteries are multipurpose weapons. On one side of the spectrum, they may be used in high frequency but miniscule amounts for millisecond balancing of power grids. On the other side, a fleet of distributed small-scale units may be digitally coupled to serve for bulk storage of electricity, backing up intermittent wind and photovoltaic generation for hours and even days.

Essential is the fact that, in theory, a single unit may be allocated flexibly to any application on demand. But the prerequisite of such flexibility in practice is physical and logical integration - and this can quickly turn out to be prohibitively expensive.

Furthermore, the requested performance parameters for batteries are different depending on intended use. Thus, asset manufacturers, asset owners, and grid operators must come to aligned decisions about preferred applications of individual battery assets.

This is a very complicated matter. Any centrally planned approach will highly likely fail to solve this puzzle. Just market forces will be capable of finding an adequate path to a solution. It may look more expensive than a centrally devised plan.

Stakeholders must view the money spent on wrong decisions, detours, and dead-end roads as an insurance premium against total failure. Compared to the cost of failure, this premium is miniscule.

10.2.3 BATTERY TOPOLOGY

A landscape topology describes where which things are concentrated at what rate. Regarding batteries, the crucial topology-related question is: how should storage capacity be distributed along transmission and distribution grid components?

Alternatives and options are endless and specific to the existing topology of an electricity system. There is no easy way to determine an optimum, and even less to plan the roadmap for the future.

But one statement can be made with high fidelity: Due to their scalable architecture, batteries can easily pervade an electricity system that is marked by a high share of distributed energy resources. Such a distributed topology is the most likely final state of a decarbonized electricity system.

The energy system of the past was characterized by a mainframe-like architecture. It consists of regionally centralized, large-scale generators supplying capacity for all types of electricity consumers inside a segregated balancing circle. Planning and control of generating capacity and transmission of load are typically done from a centralistic point of view. Overarching national grid governance oversees interconnections between these segregated systems.

In the future, this topology will, with a high likelihood, transgress toward a truly distributed system. The term 'distributed' refers to hardware as well as software - meaning that the central planning functions will be increasingly replaced by local decision-making.

To be concrete, this means that, for example, each electric vehicle will have the digital brain to decide when to charge or discharge its own battery. This also means that current fantasies of corporate operators using quantum computers to run the system with almighty intelligence will end up in the rubbish bin of history.

The main driver of this change is the economic pressure of capturing and consuming sunshine energy at as many points across the system as economically viable - quasi as a gapless screen covering a country's entire physical surface. This trend has already started to cause a rapid growth of Distributed Energy Resource on the upstream (i.e., energy generation) as well as on the downstream (i.e., consumption) parts of the energy supply chain.

With this vision in mind, the question of where to put how much battery capacity can be reduced to a simple statement: 'As distributed as possible, and as concentrated as required for a specific location'. Hence, the good news is that for the foreseeable future, asset owners will only face a marginal risk of local overcapacity - at least as long as they avoid playing in the championships of 'The World's Largest Battery'.

10.3 ENTREPRENEURS: CONSUMERIZE THE COSTS!

There is more good news when it comes to sources of financing for batteries, called 'consumerization'. This term describes certain users' willingness to overpay. Consumerization is well known from the Consumer Electronics sector. It regards consumers buying affinity-type products (e.g., smartphones, multimedia devices) and investment-type goods (e.g., electric vehicles, household appliances, or distributed energy resources). Certain customer segments in these markets are less price-elastic to the technical properties of the markets' goods and services. In fact, they will pay up for properties, features, and capacity they most probably do not consume during regular use of the product.

Consumerization is capable of easing large parts of the investment riddle the energy industry is facing. A sizable share of the Total Cost of Ownership of batteries can be consumerized. This behavior can be utilized in two ways.

1. During the useful life of a product, like an electric vehicle, some of its intrinsic value can already be consumerized. On average, buyers will be receptive for options to earn a bit of additional money with the peak storage capacity of their device (compare Tesla's robotaxi story). It is very hard for the product's owner to estimate the true value of such capabilities that are rather distant from her own experience. This source of funds may thus be tapped at very low costs for an operator of a 'Virtual Battery Plant' across a fleet of vehicles, for example.

2. At the end of a product's useful lifetime, some of the product's components can be brought to their second life - batteries are promising candidates, as already pointed out before. The initial owners of products like electric vehicles may only request a moderate share of the residual value when replacing a car or its batteries at the end of its useful life. Even if they are aware of the true residual value, they will not feel betrayed if somebody else captures most of it. Driving forces behind such behavior are the affinity to the product and the awareness of the product use they have already benefited from.

10.4 NATIONAL GOVERNMENTS: BACK THE ENTREPRENEURS!

Since parameters like battery technology, storage applications, and asset topology are interconnected, decision-making along the way faces high complexity and significant uncertainty. Therefore, central government planned action will not produce fast and efficient results.

Development risk should be managed by the most effective system an economy has to offer - venture capital, risk-takers, and entrepreneur-minded managers. The role of the state, the nation, and the Union must be concentrated on supporting the areas of communication, financing, innovation dynamics, and platform provision.

10.4.1 GET THE MESSAGE RIGHT

National governments must ensure that the message is clear, consistent, and well-received. Avoiding misleading signals from politics is presumably the most prominent task to perform. It has the strongest impact in terms of overall allocation of capital. The picture to be drawn is starting to become clearer. Some key messages to be sent with fidelity to industry, economy, and the population are the following:

- We need to warrant Process industries' hydrogen attainability for our economy to survive intensifying global competition.

- We need to make batteries the primary technology class for bulk energy storage. We have to confirm the battery strategy of all road-going vehicles. Synergies between these two areas will help to solve our energy problem. At the same time, new opportunities for high-tech leadership will originate in the battery arena.

- We must plan and build rather too many than too few renewable energy generators for the foreseeable future. Chances are that currently, we are underestimating two crucial parameters – peak load levels incurred by growing total electricity demand and average cost of electricity. Being an economic risk in an electricity system with marginal storage capacity, overcapacity comes with the benefit of lower average cost of electricity production in case sufficient and cost-efficient storage capacity exists. Up to a certain capacity level, none of the power produced needs to be lost.

Why will average electricity costs go up? The publication of Germany's energy association on energy storage as of June 2012 mentioned before contains another interesting statement. Insight 7 says, "The levelized cost of electricity during the energy transition will only rise by about 10% until 2050 compared to 2010, even with the use of storage." Today and in hindsight, such a statement may look a bit awkward. But in 2012, it may have made a lot of sense.

The main difference between 2012 and 2022 is that the interest rate of discounting for the political power flow (DPF) has shot up from near zero in 2012 to over 30% per annum today. In financial terms, having access to natural gas today is three times as valuable as having access to natural gas three years from now.

This observation is simply an outflow of a fact people tend to forget: An industrialized nation's energy system must be hard-wired, fixed, and sturdy in order to be reliable and efficient at the same time. This will not change in the future.

That insight leads to the conclusion that, even in the case of shrinking electricity demand, the cost of electricity in 2050 will most likely be significantly higher than the average cost between 2012 and early 2022. If natural gas goes away as the main source of energy cost inflation, nickel, copper, rare earths, etc. have already lined up as successors.

But careful! The statement regarding unlimited growth of renewable energy generators deserves more attention because not all energy produced is worth storing. The value of storage is directly dependent on the value of the energy when needed. The system must find the right balance between three directly related parameters – intermittent generation capacity, storage capacity, and demand response.

10.4.2 KICK-START FINANCING

Outside of fundamental research support, governments have two principal methods of fostering certain developments in the economy, one of which is predestined to foster battery storage.

- Direct and indirect subsidies in the form of lost grants and tax benefits.

Direct or indirect subsidies, for example, non-redeemable grants and tax benefits, are the best fit as start-up support. Public funds given as start-up support should help to propel a technology, product, or service to the scale required to develop the offering toward product-market fit and churn a profit. Subsidies are typically handed out to producers as compensation for costs, but also to their customers and end-users as factual price reductions. Regarding batteries, the automotive industry has already benefited from this method, and more is still to come.

Subsidizing utility-scale batteries could help in the same way as for e-mobility. But this strategy is also fraught with considerable risk. Economic incentives for lithium-ion manufacturers of battery cells may give the leaders windfall profits, stabilize their position against their follower competitors, or may use entirely for low-value cost items. Controlling the use of public funds of this kind is intricate and often ineffective.

Furthermore, the amounts of subsidies required may increase due to industry structural forces. The contribution margins that grid-scale battery operations can achieve in the open market come from revenue sources like wholesale electricity day-ahead-, intraday trading, electricity futures, or primary balancing. They depend on demand and supply. These segments are all significantly affected by shifting electricity prices.

Hence, profits from market price-determined stored electricity are factually unpredictable in times of heavy disruption. Disruption originates from several sources, like technological change, customer preference swings, and geopolitical power shifts. Even a state-funded CAPEX grant of 40 or 60% may not reduce the risk sufficiently to justify an investment. This statement is true for almost any of Europe's electricity markets.

- Benefit attainment assurance in the form of administered prices for specified products and services. Ensuring benefit attainment could be a more effective strategy for start-up support. It is the preferred funding method in the United States' grid battery segment, and it is working very well there.

The bottleneck that utility-scale battery projects are currently facing is not supply-side-driven. Battery manufacturers currently have sufficient capacity in production to meet global demands. The sensible constraints to growth are clearly rooted in a lack of demand. A high level of uncertainty of future revenues lets investors sit still and hold their powder dry for better times to come.

Attainment assurance is a strong cure lacking demand in this case. The term describes mechanisms helping to align the revenues an asset's owner receives with the benefits the asset generates for the entire system it operates in. Grid batteries generate benefits in a platform setting - the electricity system of a country or a region - for service providers and electricity consumers. In energy systems, the most fundamental of such services is available generation capacity matching the existing demand for electrical power.

If a country desires to replace dispatchable electricity from fossil fuel thermal plants with zero-carbon sunshine energy, investors should be entitled to an adequate capacity remuneration.

In the beginning, to get the process started, a remuneration that overcompensates system benefits is presumably justified. Later, the level can be lowered in line with shrinking costs from battery operations' economies of scale, experience curve, indirect network effects, etc.

The world has learned about the power of such mechanisms when investments in photovoltaics and wind farms flourished on must-run privileges, feed-in tariffs, revenue floors, and the like. There is no obvious and strong reason now against using the same leverage in high-tech electricity storage.

As a prerequisite, society must agree on the value of electricity storage for its economic and social welfare. And most importantly, the mechanism must ensure in the future that the payers are also the beneficiaries of the value created. With Germany's Renewable Energy Law from 2020, for example, the German economy has funded the start-up of a flourishing Chinese PV industry.

10.4.3 REMOVE RIGIDITY

The role of politics in fostering innovation through reducing rigidity is strong in many economic sectors. In the Energy & Utilities sector, it is tantamount. Even in the most capitalistic of the industrialized economies, governmental stakeholders at local, state, and federal levels have substantial influence on decisions across the board. This pattern corresponds to incentive systems and revenue sources tied to stability. These systems reflect the innate purpose of a utility.

Regarding innovation, this cultural property favors waiting for established solutions over trial-and-error learning. In the case of acutely needed change, the unwanted outcome is rigidity.

To avoid unwanted rigidity, it takes a government capable of estimating adequate innovation while valuing minimum-viable stability. Often, economic or ambient condition shocks are the precursor of a government's change of mind. In other cases, lighthouse examples have a similar effect.

It is not a coincidence that California is by far the most active state in the USA in terms of the use of large-scale grid-connected batteries. The spirit of Silicon Valley, the original home of Tesla Motors, the care for nature, and the perceptible effects of climate change amalgamated into a driving force hardly matched by any other region on the globe.

California has given grants to Tesla and the likes for battery manufacturing capacity. In parallel, public utilities have been entitled to invest in installing battery systems in their power grids and chargeback the cost of ownership to their grid-related service fees.

Europe in general, and Germany in particular, should look at California as their lighthouse case. Electricity distribution grids are primarily owned and operated by municipal stakeholders, partially associated by private energy companies. This group alone could initiate a swift shift toward a storage-based electricity system of the future.

10.4.4 PROTECT THE PLATFORM

Electricity systems of industrialized nations are platforms in their most original sense. A platform regulates transactions between suppliers and buyers, the production of products and services to be provided via the platform, and finally the delivery between provider and user.

In a context of strong and acute demand, platforms emerge on their own, i.e., without triggering, guidance, or other kinds of political support. Examples are the early, locally concentrated electricity grids of the late 19th century, the mobile phone networks, and the internet.

The battery market is different. Most probably, it will stay for an extended time in a state of latent demand from a small group of early innovator-type customers. Therefore, governmental action is required to stipulate platform development. The purpose of such platform-warranting action is to trigger growth of applications with 2nd level network effects, i.e., the sharing of network costs among a larger group of network users.

This argument is even stronger in cases of 1st level network effects, i.e., where a single user's benefit from using platform services increases with each new user on the platform - telecommunication networks are the most prominent example of this class.

Distributed battery fleets show a similar property, since charging and discharging is constantly happening throughout the network, largely comparable to calling parties connecting with called parties in the cell phone grid.

In practical terms, if distributed batteries ought to be used as coordinated bulk energy storage devices of the electricity system, charging, metering, billing, and other key functions must comply with generally applicable rules and procedures to become economically viable. Foremost, this will be the case in distributed battery fleets, like electrical vehicles, local PV systems, or household heat pumps. Other devices with similarly high levels of electricity consumption will follow.

10.5 EUROPEAN UNION: TAKE CHARGE!

The old world's fate is at stake. Europe wants to lead the way to climate protection. Nobody doubts that this venture is for a good purpose. But it is very costly. Europe must stay competitive to generate sufficient funds to finance the transition. Europe's people must be willing to forego a piece of their wealth, at least for a certain period of time. It will probably be way more difficult than expected by the public today.

10.5.1 MORE ATTENTION

The population will support this transformation only if the role, an item, a technology, a concept, a vision, or a notion may have for the future is well understood.

Large-scale electricity system batteries currently have not yet occupied any real estate in the minds of the public. People do not yet see the fundamental role storage plays in reliability of energy systems and adequacy. And therefore, it is natural that they are not at all willing to pay for it.

It seems that, like with the personal computer and the internet, the continent and its member states are missing out on this next key technology of human future on this planet – energy storage. As with Silicon Valley, once more Europe is leaving this revolution to other nations.

This is even more surprising before the backdrop of Europe's competitive advantage – globally leading engineering skills in chemistry, physics, electrical equipment, and power plant operating systems. These are the ingredients for high-tech electricity batteries at scale.

But German, Italian, Spanish, Dutch, or French technology is not positioned yet to play a major role in this field of rapid and profitable growth. Neither industry juggernauts nor start-ups seem to be willing and capable of catching up with battery electricity storage leader Tesla Energy.

What could be done to change this picture? A true wakeup call is needed. A time of radical change forced upon society by harsh outside pressure is the best soil for innovative thinking. During such times mankind has often embarked on its most surprising endeavors.

10.5.2 MORE CONNECTION

The lack of focus on batteries is not the only make-or-break problem of the European electricity system. There is a time bomb ticking in a much more fundamental way than the lack of people's attention. The time bomb arises from the nearly unsurmountable scarcity of money, construction capacity, environmental, and finally social capital available for nationwide and European infrastructure reinforcements.

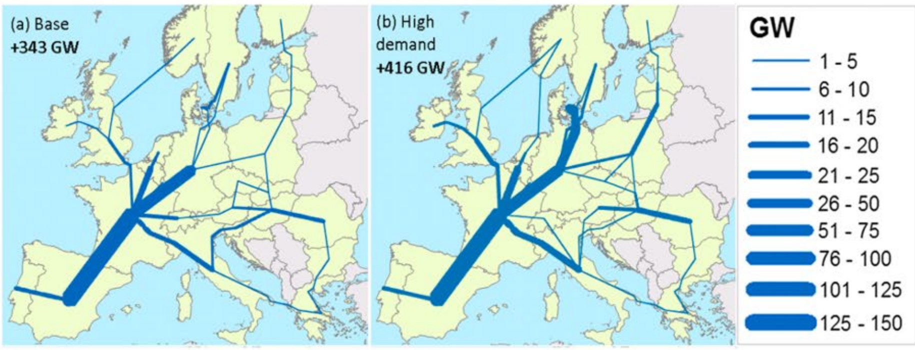
It is a huge challenge to overhaul and extend Europe's power transmission grid. But it also is a prerequisite. Without a high-performing high-voltage grid, none of the strategies toward a net-zero carbon energy future that does not rely on a large nuclear power fleet will bear any fruit.

In the past, the main role of a national transmission grid was to collect electricity from a set of national power plants and then transport it to the country's distribution grids. At country borders, national grids have been interconnected to support frequent cross-border imports and exports as required or economically intended.

This role will not fully disappear in the foreseeable future. But the far more important task of the transmission grids will be providing a Europe-wide backbone for channeling sunshine energy from the southern points of collection to the northern points of consumption. Experts like to call such a Union-wide high-bandwidth transmission system a copper plate.

TRANSMISSION GRID

REINFORCEMENTS REQUIRED ON TOP OF CURRENT CAPACITY



- 2019 Reference Capacity: 60 GW
- Cases shown requiring additional capacity of 343 and 416 GW, respectively

EXHIBIT 10

Source: Is a 100% renewable European power system feasible by 2050?, William Zappa et al., Copernicus Institute of Sustainable Development, Utrecht University, 2019

Exhibit 10 indicates the dimension of this challenge at European level.

If researchers and scientists are correct, the continent has about 30 years to build a cross-border transmission infrastructure that has five times the capacity of today's grid. In the case that this problem is not addressed in time and with vigor, the historic experiment of building a European Union is seriously at risk. There are two fractions acting with controversial agendas and interests.

Countries like France, Belgium, and some Nordic states command large fleets of nuclear power plants. They will most probably invest in renewing and innovating nuclear power assets. Under the current EU taxonomy, they are entitled to benefit from such investments in the same way as when investing in renewable generation. In addition, these member states are not interested in and are even strongly opposed to drawing new power transmission lines through their countryside.

The other fraction is fully dependent on these power transmission lines, though. These countries will have dismantled their nuclear fleet, the lignite plants, their hard coal plants, etc. in 10 or 15 years from now. Their industries will only have a chance to survive if they can import renewables from safe and certain regions like the Mediterranean.

As a consequence of this risk, the European Union should neither waste any time nor a single cent of taxpayers' money on updating or extending nationwide hydrogen transport pipelines instead. All public funds will be required to solve the cross-border electricity transmission grid problem.

The good news is that private infrastructure funds will take care of this task without state subsidies anyway.

ABOUT THIS BOOK

The EU and its member countries focus a large part of their public funding on hydrogen infrastructure. According to many experts, only hydrogen can perform the task of seasonal energy storage. At least the US and China see things differently. There, battery storage is used to expand the infrastructure for renewable, independent energy. Particularly Germany, as an industrial nation, risk running out of energy in the future if countermeasures are not taken quickly.

The author, Peter Jumpertz is a highly experienced top management consultant with a focus on Business Strategy, Competitive Strategy, Information Technology, and Innovation. Over the last 30 years he has worked on assignments in a variety of industries and sectors. He is CEO of Theron Scienceworcs AG and Head of Client Value Management

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