ESS INC

FURTHER BEYOND FOUR HOURS

REVISITING LONG-DURATION STORAGE

EXECUTIVE SUMMARY

Energy storage demand is growing significantly in North America and worldwide as the price of wind and solar generation assets fall to a level where they can outcompete traditional generation sources. With this growth in demand, there is also growth in the number and range of applications that electrical energy storage is tasked with performing.

Many of these services now last for multiple hours instead of minutes, posing both a challenge and an opportunity for developers.

The technology most widely used for electrical energy storage has been lithium-ion batteries thus far, but these may not necessarily be the best option for long-duration storage applications.

As with any technology choice, developers and project owners are trying to figure out which long-duration storage applications will provide the best return on investment and/or help to build an integrated application stack to boost revenues.

To gain insight into these and other long-duration storage issues, in 2016 ESS Inc. produced a report called Beyond Four Hours.

This report builds on that earlier study, reprising some of the key questions covered and adding further detail to areas such as what applications might be best served by long-duration storage and which technologies might best do the job.

Key findings from this report include:

- Long-duration storage is now commonly viewed as having a delivery time of at least four hours, and the need for it is growing. An impressive three-quarters of respondents believe it is relevant to their businesses.

- Renewable energy self-consumption is seen as the most promising application for long-duration storage. But many other applications, from backup power to short-term operating reserves, were also cited, highlighting the potential for revenue stacking.

- The most promising technology for long-duration storage is flow batteries and the key criterion for selecting a given asset is cost, particularly the level of capital expenditure required.

FOREWORD

By Craig E. Evans, President and CEO, ESS Inc.

Energy storage had a big year in 2017. We saw it being proposed to power a city the size of Berlin[1], and we saw it being added to critical microgrids in places such as Puerto Rico.

Perhaps most notably, we watched a bet unfold that ended in the creation of the world's largest battery storage project to date.[2] Tesla's ability to build a 100 MW battery plant in Australia in 100 days showed the world just how far energy storage has come.

However, it also exposed a flaw.

For all its might, Tesla's Hornsdale Power Reserve battery can only keep the lights on for about an hour.[3] It may provide temporary relief in the event of a loss of grid power, but it will not be enough to eliminate the blackout risk that led to the plant's creation in the first place. To achieve this, several hours more capacity will need to be added to Australia's grid, and it remains unclear whether lithium-ion batteries could or should be used to do this job.

Why use lithium-ion batteries in long-duration storage applications when there are other technologies that can do the job, and do it at a lower cost and with smaller environmental impact?

While lithium-ion battery deployments have grown over the last year, so have concerns over the availability and future costs of the raw materials needed for its manufacture.

Cobalt, lithium and graphite have all been cited as possible candidates for a supply chain pinch. Analysts have played down the likelihood of shortages of any of these materials individually, but as one report observed, "Taken together, the slim chances of a supply mismatch in any of these materials markets may add up to a significant risk to lithium-ion battery production."[4]

We could avoid this shortage by recycling the batteries, but because lithium-ion battery recycling remains in its infancy, there is a risk that the materials would be hard to recover after use. This is an important point, because lithium-ion batteries are not just used in grid-scale energy storage projects. They are also vital to the consumer electronics that power our society, and to the electric vehicles that will be critical in helping us achieve a decarbonized energy system.

There is a lithium-ion battery demand emanating from the automotive sector that should not be underestimated. The sector has barely started taking off, yet recent figures already show that it is growing 63% year-on-year,[5] buoyed by government initiatives such as Germany's plan to ban diesel and gasoline-powered vehicles beginning in 2030.[6]

It is in light of this that we believe a case can be made for alternative forms of long-duration storage. Why use lithium-ion batteries in long-duration storage applications when there are other technologies that can do the job, and do it at a lower cost and with smaller environmental impact?

The problem, then, becomes understanding which ones to pick for a given application stack. It is our hope that this report will shed some light on the matter, by gathering industry views on issues such as preferred long-duration storage applications and technology selection criteria.

I hope you will find it useful and insightful.

INTRODUCTION

The growth of energy storage shows no sign of abating. Quite the opposite, in fact.

In November 2017, Bloomberg New Energy Finance predicted the global energy storage market would double no fewer than six times between 2016 and 2030, rising to a total of 125 GW and 305 GWh of installed capacity.

“This is a similar trajectory to the remarkable expansion that the solar industry went through from 2000 to 2015, in which the share of photovoltaics as a percentage of total generation doubled seven times,” said the analyst firm.[7]

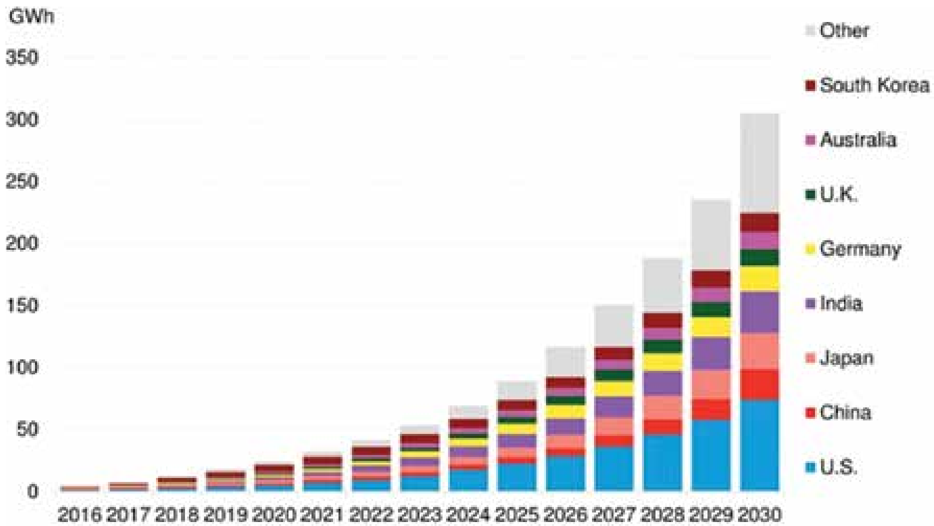

Figure 1: Global cumulative storage deployments. Source: Bloomberg New Energy Finance.

“With the very high shares of wind and solar PV power expected beyond 2030, the need for long-term energy storage becomes crucial to smooth supply fluctuations.”

The growth is set to eat up USD $103 billion in investment and will be led by eight countries: the U.S., China, Japan, India, Germany, UK, Australia and South Korea. These will account for 70% of all the capacity installed.

The implication is that many other nations will be waiting in the wings to power further growth when these major markets reach saturation.

And looking at Bloomberg New Energy Finance’s data (figure 1), it seems as though the global market for energy storage will barely have begun to ascend the S curve by 2030.

It is also logical to expect long-duration storage to make up an increasing proportion of overall capacity, if only because short-duration assets have a narrower range of applications.

This is affirmed by the International Renewable Energy Agency (IRENA), which points out: “With the very high shares of wind and solar PV power expected beyond 2030, the need for long-term energy storage becomes crucial to smooth supply fluctuations.”[8]

Long-duration storage has traditionally been served through pumped hydro which, as of mid-2017, still accounts for 96% of the total installed storage power capacity of 176 GW installed globally.[9]

Despite a rush of recent proposals in the US,[10] however, pumped hydro remains a challenge for project developers. It requires high upfront investment and the right kinds of geography, permitting flexibility and market setup.

For this reason, the power industry is still grappling with what technologies could best be deployed at the scale required for bulk long-duration energy storage.

Attempts so far have tended to focus on the scaling up of lithium-ion battery systems. But given its susceptibility to potential supply chain problems, relatively short lifespan, environmental impact, disposal challenges and high value for other applications, it is doubtful if lithium-ion is the best fit for megawatt-scale long-duration energy storage tasks.

Building on research from 2016, this study looks to delve deeper into the long-duration energy storage market and uncover some of the current preoccupations and preferences among its players.

Specifically, we asked energy storage experts to disclose:

- How they define long-duration energy storage
- How important it is for their business
- What applications they think offer the greatest potential for a return on investment in long-duration storage
- What criteria they use for evaluating long-duration energy storage systems
- Which technologies they might consider for long-duration storage
- What their biggest worry is regarding long-duration storage
- When they think long-duration might outstrip short-duration storage

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A NOTE ON METHODOLOGY

The findings in this paper are based on research carried out in November 2017 among the readers of *Energy Storage Report*, a specialized industry intelligence platform.

The survey drew 58 full and 10 partial responses, 50% of which were from respondents who identified themselves as likely to either buy or specify energy storage systems (figure 2). The sample included analysts, energy storage system vendors, solar installers, industry bodies, consultants, engineering groups, supply chain providers and project developers. This quantitative data was supplemented with in-depth discussions with industry figures.

Where relevant, the findings in this study have been compared to those of our 2016 report, although the data set for the first study was considerably less robust and should be seen as offering indicative results only.

In the discussion, percentages have been rounded up to the nearest whole number. ESS Inc. and *Energy Storage Report* would like to thank all of those who gave their time to support this study.

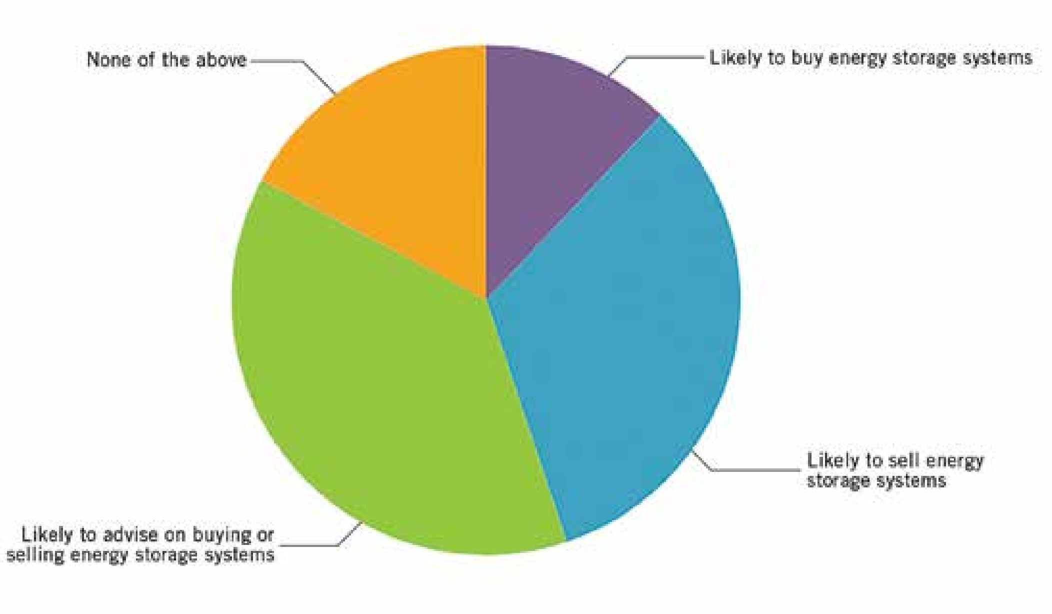

Figure 2: Which of the following best describes your organization?

DEFINING LONG-DURATION STORAGE

Since the timeframe of long-duration storage remains somewhat subjective, in this research we gave respondents 10 options to choose from, with discharge times ranging from 30 minutes to 24 hours.

In the 2016 study, 20% of respondents expected assets to run for longer than 10 hours. This time, however, a combined 25% were looking for a discharge time of 12 hours to a full day (figure 3). It is clear, then, that the mindset has shifted to expect long-duration storage to last even longer than before.

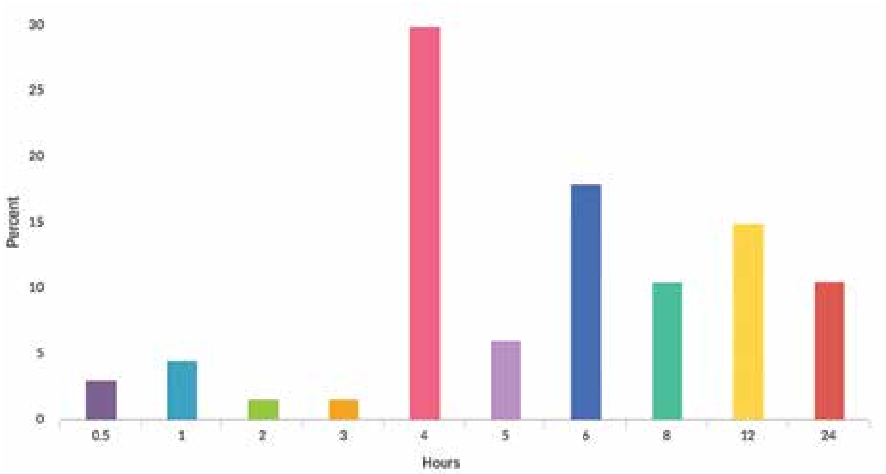

Figure 3: What is the minimum storage duration (in hours) that you would say qualifies as ‘long-duration storage’?

There does, however, appear to be greater consensus around the idea that the transition point from short to long-duration is around four hours. Only 10.5% of respondents argued for discharge times of less than four hours, compared to 40% in the previous study. This implies a maturation of the industry and a broadening understanding of those working within it.

“Different products, maybe based on different technologies, need to be developed that are optimized for different duration times: a four-hour solution, six-hour solution, eight-hour solution, 12-hour solution, 18-hour solution, 24-hour solution, 36-hour solution.”

THE IMPORTANCE OF LONG-DURATION STORAGE

Although this question cannot be directly compared with our previous research, it appears that long-duration storage has increased in importance within the industry.

In 2016, 30% of respondents said long-duration storage was not applicable to their business or might become important, but was not currently.

In the present study, which went out to a more diverse base of respondents, 47% said they were considering long-duration storage in relation to some projects, while 27% said they were looking at it for most (figure 4).

In contrast to generation technologies, energy storage can be used for a large number of applications.

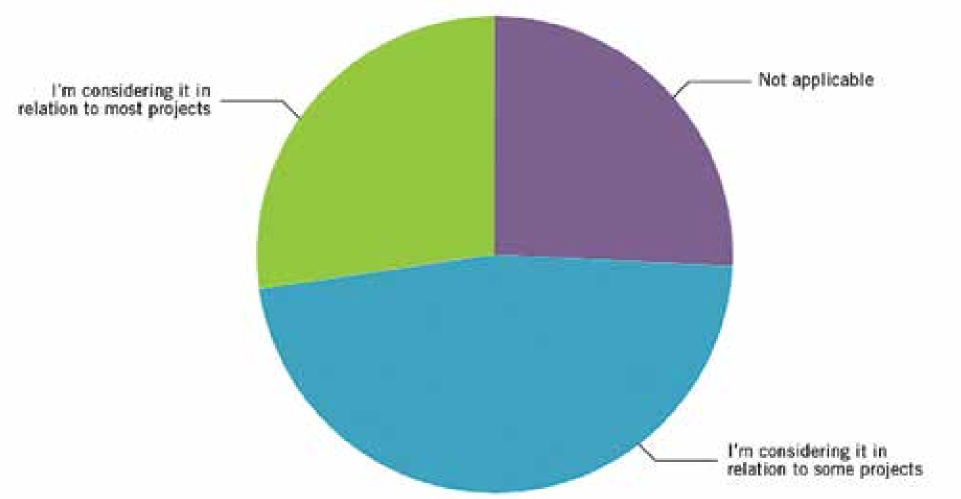

Figure 4: How important is long-duration storage for your business?

APPLICATIONS FOR LONG-DURATION STORAGE

In contrast to generation technologies, energy storage can be used for a large number of applications. The exact number, and the definition of each one, however, are not standardized. Thus, for purposes of this study, we used a categorization developed by Everoze Partners in the UK.[11]

Although the categorization is designed for the British energy storage market, which is currently set up to favor frequency response-related services, it has the advantage of being quite granular, covering 14 clearly-defined applications:

- Renewable energy self-consumption
- Backup power in the event of grid failure
- Capture spilt energy: storing energy that would otherwise be lost due to grid constraints
- Red Zone Management: shifting consumption to avoid periods of high network cost
- Capacity Mechanism: to guarantee capacity for any given year
- Wholesale markets arbitrage: buying energy cheaply and then selling when prices are higher
- Black Start: to recover from a total or partial shutdown of the transmission system
- Triad Avoidance: reducing consumption at periods where peak demand is forecast
- Retail markets arbitrage: based on customer's retail tariff, not prevailing wholesale price
- Fast Reserve: large blocks of reserve energy to respond within 2 minutes
- Enhanced Frequency Response: requiring a full response in less than a second
- Firm Frequency Response that can respond within 30 seconds
- Short-Term Operating Reserve: where a response time of up to 20 minutes is required
- Correct for forecasting inaccuracy: when generation is out of line with forecasts

These energy storage applications range from enhanced frequency response services, requiring sub-second response times, to retail or wholesale market arbitrage, where lengthy discharge times may be needed to maximize profitability.

Remarkably, all of the 14 options were seen as potential targets for a long-duration energy storage application stack (see figure 5). The applications our survey respondents favored most were:

- Improving renewable energy self-consumption, cited by 59% of respondents
- Providing backup power (58%)
- Capturing energy otherwise lost due to grid constraints (55%)

The least popular applications, meanwhile, were:

- Delivering short-term operating reserves, with a response time of up to 20 minutes, and correcting forecast inaccuracies, both cited by 17% of respondents
- Providing frequency response services within 30 seconds (20%)
- Offering enhanced frequency response services, within a second (21%)

Respondents' top choice of application in this study mirrored the results in 2016, when renewable energy self-consumption was cited above all other use cases. Similarly, frequency response services also had a low rating in 2016.

"Long-duration storage will be critical to integrate high percentages of intermittent renewable resources as part of a 100% renewable energy goal. Efforts must be made to utilize excess renewable energy on a seasonal basis."

Nevertheless, the fact that no application was ignored points to significant potential for revenue stacking in long-duration energy storage assets.

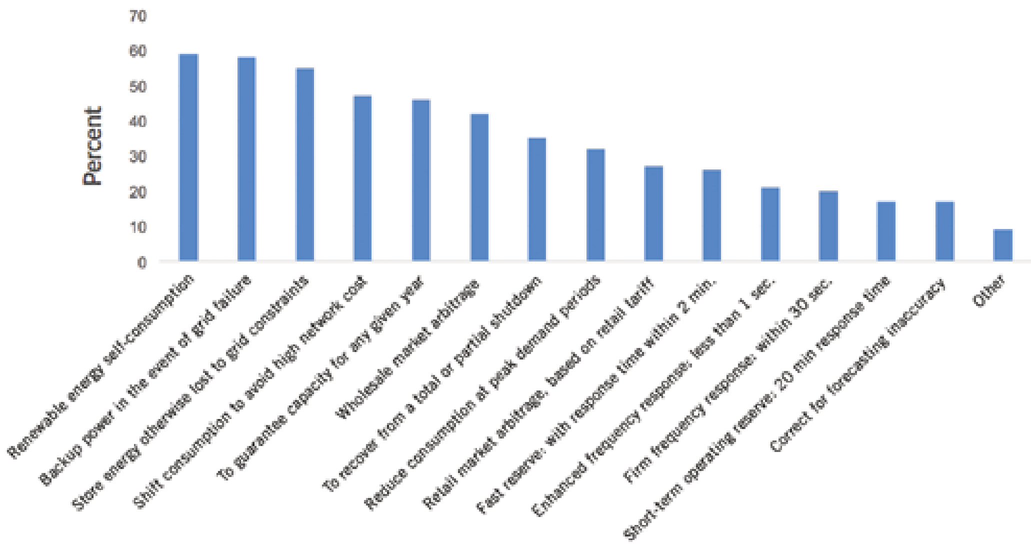

Figure 5: What applications offer the greatest potential for a return on investment in long-duration storage?

In addition to the 14 categories listed above, respondents offered several other potential applications for long-duration storage, including microgrids, mini-grids, solar-plus-storage systems and the covering of long demand charge windows.

CRITERIA FOR SELECTING LONG-DURATION STORAGE

Our respondents were presented with a dozen criteria for long-duration storage technology selection, ranging from capacity fade to quality of management software (figure 6).

The top choice was levelized cost of storage (LCOS), which offers "an objective, transparent methodology for comparing the cost and performance of various energy storage technologies across a range of illustrative applications."[12]

It was cited by 27% of respondents, compared to the 24% that chose capital cost or the 10% that selected the usable life of the system. The importance of capital cost, which mirrors our finding in 2016, is unsurprising.

This is, after all, a 'permission to play' factor: if you cannot afford to buy a technology then none of the other selection criteria will make a difference.

But while capital cost may be the most preeminent among financial considerations, others, such as operations and maintenance costs, are also significant.

Since LCOS can be used to aggregate these factors into a single number, it trumps even capital cost in the final analysis.

Since LCOS can be used to aggregate these factors into a single number, it trumps even capital cost in the final analysis. That said however, roughly half the sample chose neither capital cost nor LCOS as the most important technology selection criterion.

Instead, these respondents selected a wide spread of factors, such as capacity fade, environmental friendliness, usable life and safety (the latter also highly cited in 2016) as significant in today's market. These factors are perhaps the greatest inhibitors for lithium-ion technologies, which lose a portion of their lifespan on each cycle, and also pose a fire risk.

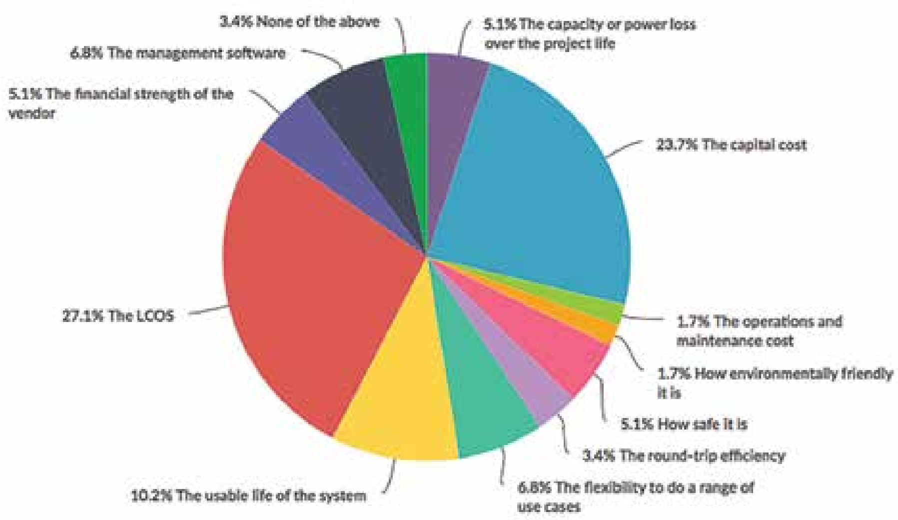

Figure 6: When evaluating a long-duration energy storage solution, how important are the following criteria?

Thus, long-duration energy storage procurement depends on a complex balance of many factors; there is no single key metric for energy storage success. The only one of the dozen potential selection criteria that was not key to anyone was the energy density or footprint of the technology.

For technology vendors, the implication is that there can be no one-size-fits-all approach to long-duration energy storage system sales. Cost is clearly important, but even that will be the deciding factor only half of the time.

To summarize the findings from this portion of the research, an ideal long-duration energy storage technology is, not surprisingly, likely to be one that is cheap, safe and lasts a long time without degradation.

THE BEST TECHNOLOGIES FOR LONG-DURATION STORAGE

As mentioned above and in our previous report, one of the challenges facing the long-duration energy storage market is that there is no single obvious technology to deliver services.

This is unlike short-duration energy storage, where lithium-ion batteries are increasingly preferred on the basis of cost, scalability and bankability.

Lithium-ion is an option for long-duration storage, but we've already discussed why it may not be the best option. Other technologies range from alternative battery chemistries or fuels, such as hydrogen, to pumped hydro, the current market leader.

Flow batteries sit neatly between these two extremes, providing storage durations that can go from a few hours to a few days and capacities of up to (potentially) hundreds of megawatts.

To determine which technologies might be at the top of procurement lists today, we asked respondents to identify what options they would most likely consider for long-duration storage.

We provided a list of 10 storage technology families, adapted from the classifications used by IRENA in its "Electricity storage and renewables: Cost and markets to 2030" report.[13] The top three technologies selected, in order of preference, were (figure 7):

- Flow batteries, cited by 63% of respondents
- Lithium-ion batteries (54%)
- Pumped hydro (37%)

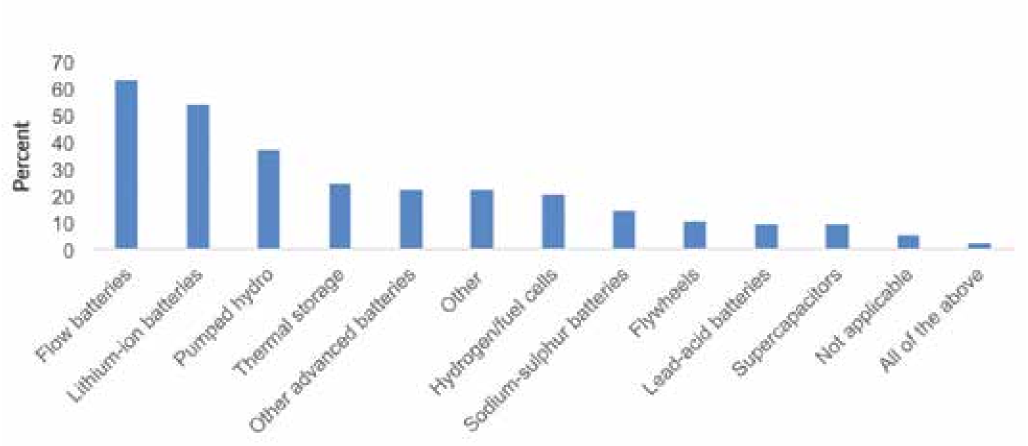

Figure 7: Which technology or technologies are you most likely to consider for long-duration storage?

What is interesting about this selection is that it potentially represents a gradation from smaller-scale, shorter-duration assets, typified by lithium-ion battery systems, to very large-scale, long-duration storage, typified by pumped hydro.

Flow batteries sit neatly between these two extremes, providing storage durations that can go from a few hours to a few days and capacities of up to (potentially) hundreds of megawatts.[14]

LONG-DURATION STORAGE IMPLEMENTATION CONCERNS

Reflecting the technology selection criteria outlined previously, the biggest worry in implementing long-duration energy storage projects was cost (figure 9).

Figure 9: What is your biggest concern/worry about implementing long-duration storage?

In particular, some respondents were concerned about the cost of storage assets in relation to their potential lifetime return on investment. Behind this obvious worry, though, were further queries including:

- Would storage assets live up to manufacturers' promises around quality and performance?
- Would market regulation favor the use of assets over time?
- Would the assets be easy to source, run and recycle?

While the presence of numerous, valid concerns should not be underplayed, it is also true that most of the worries that were voiced were ones that might be expected to diminish as technologies and markets mature: "In the power supply inadequacy of my environment, there is no debate that long-duration storage has a market if the cost is good and the service is available."

To summarize the findings from this portion of the research, an ideal long-duration energy storage technology is, not surprisingly, likely to be one that is cheap, safe and lasts a long time without degradation.

CONCLUSION: A WELL-DEFINED MARKET IS EMERGING

The research carried out in this report was completed against a backdrop of discussion around the ability of renewable energy to fully replace traditional generation.[15] Nobody doubts that this task will be challenging. Nor is there any doubt that energy storage could play a critical role. The question is how critical.

Despite high hopes for energy storage, studies show that even vast pumped hydro reserves would struggle to maintain a decent wind and solar-based electricity supply in temperate latitudes during long spells of calm, cloudy weather.[16]

This suggests that a fully decarbonized grid may have to rely on some form of non-intermittent, firm power; for example, from biofuels, hydrogen or new nuclear technology.

At the same time, though, energy storage is increasingly seen as a valuable aid to increasing renewable energy penetration, to take the greatest possible advantage of wind and solar resources.

It is in this evolving market and policy scenario that we are seeing discussions around long-duration storage. These are assets that perhaps will not deliver power for weeks on end, but can at least satisfy a grid's load for hours or perhaps days.

Since our previous report on this issue, we have seen growing consensus around what should be defined as 'long-duration' (more than four hours) and what assets could deliver it (flow batteries, flanked by lithium-ion and pumped hydro).

Energy storage is increasingly being seen as a valuable aid to increasing renewable energy penetration so as to take the fullest possible advantage of wind and solar resources.

One final question in our research provides insight into how quickly this market is maturing. We asked when respondents thought long-duration storage deployments might outstrip short-duration ones (figure 10).

For almost 9% of the sample, this is already happening. Another 9% expected it to happen within the next year. And around 36% said within two or three years.

Less than a third (30%) thought the switch might not happen for another three years at least. One key, if predictable, finding from our research is that the actual rate of change is likely to be strongly related to capital cost.

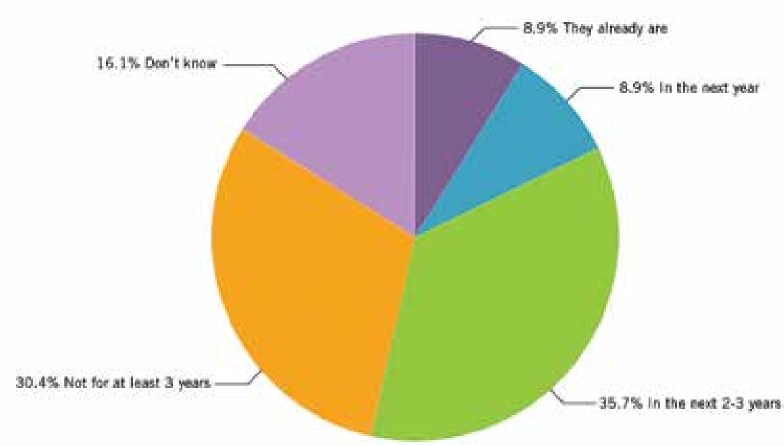

Figure 10: When you think long-duration storage deployments might outstrip short-duration storage deployments?

This finding echoes other research. A recent white paper, for example, concluded that “capital costs must decrease for a given system as durations are scaled beyond those typically utilized for daily cycling.”[17]

This focus on capital costs naturally favors flow batteries, which is an increasingly mature and technically unchallenging technology.

The cost issue also puts the spotlight on materials: ultimately, as we head towards ever-greater amounts of long-duration storage, the advantage will most likely lie with those technologies that use the cheapest, most plentiful materials.

In practice, these are likely to come from one of two groups: the rock-forming elements, which include sodium, silicon and carbon, and the major industrial metals, such as aluminum, magnesium and iron (figure 11).

Relatively few energy storage technologies are based on such materials today. But for tomorrow’s bulk long-duration storage applications they will be increasingly critical.

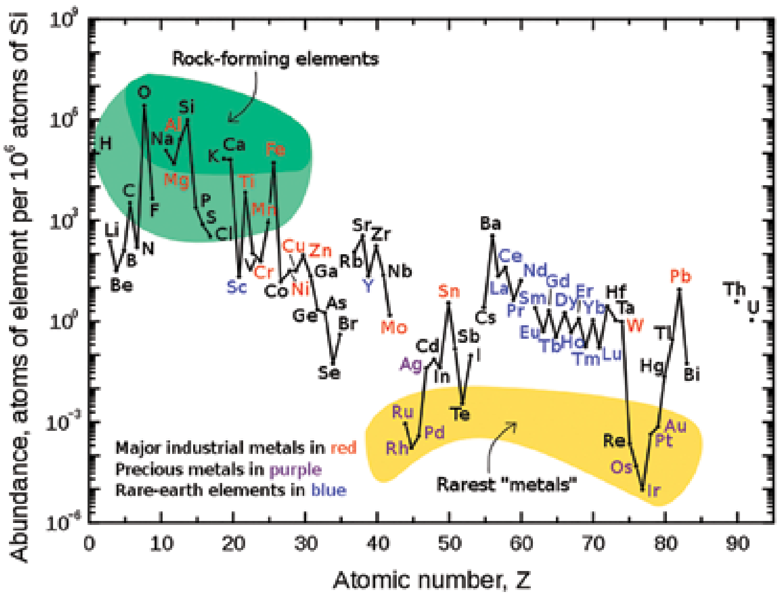

Figure 11: Abundance (atom fraction) of the chemical elements in Earth’s upper continental crust as a function of atomic number.[18]

Capital costs must decrease for a given system as durations are scaled beyond those typically utilized for daily cycling.

ABOUT ESS INC.

Established in 2011, ESS Inc. develops and manufactures the low-cost, long-duration Energy Warehouse™ (EW).

The EW is an iron flow battery for commercial and utility-scale energy storage applications, capable of providing four-plus hours of flexible energy capacity throughout 20-plus years of operating life with no capacity degradation.

The EW utilizes earth-abundant iron, salt and water for the electrolyte, and delivers an environmentally safe, long-life energy storage solution for the world's renewable energy infrastructure with the lowest levelized cost of storage per kWh.

For more information, visit www.essinc.com.

This white paper was produced with assistance from Energy Storage Report (www.energystoragereport.info). We are grateful for the assistance provided by the readers who participated in the research.

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26440 SW Parkway Ave. Wilsonville, OR. 97070
(855)-423-9920 | www.essinc.com | info@essinc.com