



White Paper

Energy Storage for the Decarbonizing Grid

Emerging Needs for Increasing System Duration

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Table of Contents

Executive Summary	iii
1. Market Drivers for Long Duration Storage	1
1.1 Accelerating Grid Decarbonization	1
1.2 Extreme Weather Events.....	3
1.3 Alternatives to Li-Ion.....	4
2. Evolution of Power Markets	5
2.1 Resource Adequacy and Capacity Markets	6
2.2 California Public Safety Power Shutoff Events	6
2.3 Locational Value.....	7
3. Long Duration Storage Technologies	8
3.1 Limitations of Li-Ion	8
3.2 Flurry of Investment.....	9
3.3 Key Technology Considerations	10
3.4 The Next Hurdle: Project Capital	11

List of Figures

Figure 1. Annual Installed Long Duration Storage Energy Capacity and Deployment Revenue: 2020-2027.....	1
Figure 2. Historical and Projected US Renewable Generation	2
Figure 3. Marginal Capacity Value of Energy Storage.....	5
Figure 4. Illustrative Unit Costs for Different Marginal Power and Energy Costs.....	10

Acronym and Abbreviation List

CAISO	California Independent System Operator
CEC	California Energy Commission
CLCPA.....	Climate Leadership and Community Protection Act
CPUC	California Public Utilities Commission
EIA.....	Energy Information Administration
EV.....	Electric Vehicle
GW	Gigawatt
HVAC.....	Heating, Ventilation, and Air Conditioning
ISONE	Independent System Operator New England
kW	Kilowatt
kWh	Kilowatt-Hour
Li-ion.....	Lithium Ion
MW	Megawatt
MWh	Megawatt-Hour
NFPA	National Fire Protection Association
NYISO	New York Independent System Operator
PJM	Pennsylvania-New Jersey-Maryland Interconnection
PPA	Power Purchase Agreements
PSPS	Public Safety Power Shutoff
PV.....	Photovoltaic
RPS	Renewable Portfolio Standard
SB100.....	Senate Bill 100
US.....	United States

Executive Summary

Most energy storage systems provide 4 hours or less of energy,¹ but the need for longer duration storage is growing, particularly with the rapid growth of renewables coupled with retirements of traditional baseload generation plants. As these trends create more challenges for maintaining system reliability, markets are likely to respond in ways that make the economics of long duration storage systems (4 hours or more) more viable. Further, a mix of commercially established and emerging storage technologies are positioned to capture greater market share as these markets evolve. This white paper discusses the drivers, market opportunities, and technologies that will help fuel growth of the long duration energy storage market.

The confluence of grid reliability needs, resultant economic opportunities, and associated technological solutions is expected to lead to rapid growth of the market for long duration storage (greater than four hours). Guidehouse Insights projects an average annual growth rate of 29% per year through 2027, reaching a market size of approximately \$17 billion annually.² The market for shorter duration systems (under 4 hours) is also expected to remain strong and continue to grow significantly, but the average duration will likely grow over time.

The trend toward decarbonization of the power grid—including massive adoption of renewables coupled with retirement of baseload generation such as coal—leaves a need for low carbon firm capacity. Supply and demand must be balanced in real time to maintain viable frequency and voltage on the grid, meaning that the grid must have enough firm capacity available to support demand during the highest peak hour of the year. With modest penetration of renewables, today's capacity and resource adequacy markets typically have a 4-hour requirement for capacity resources. As renewables penetration grows, longer durations may be required to provide the effective load carrying capacity necessary to facilitate grid reliability. As a consequence, regional power markets are expected to adapt to offer greater incentives for longer duration capacity resources, and storage is one of the few dispatchable and low carbon resources available to meet that need.

The confluence of grid reliability needs, resultant economic opportunities, and associated technological solutions is expected to lead to rapid growth of the market for long duration storage

Further, locational capacity resources are expected to be needed to address emerging, localized grid constraints. Growing wildfire risk in the western US has led to Public Safety Power Shutoff (PSPS) events that leave significant regions of the grid dark for extended periods of time to mitigate wildfire risk associated with power equipment. This drives a need for locational capacity resources that serve critical infrastructure for communities without power. Additionally, the available capacity on aging grid infrastructure is approaching limits due to growing penetrations of distributed renewables and electric vehicles, driving a need for expensive infrastructure upgrades. Long duration storage is well-positioned to offer a viable solution to these needs.

¹ Excludes pumped hydroelectric storage; duration (hr) is based upon the ratio of nominal energy (kWh) to nominal power (kW)

² Guidehouse Insights, *Long Duration Energy Storage*, 4Q 2018.

Investors have recognized the market opportunity and have responded with a flurry of investment in lithium ion (Li-ion) alternatives, including some options that are competitive today with 4-hour systems and systems that are even more competitive at longer durations. While Li-ion has some notable advantages, particularly at shorter durations, it has a relatively high marginal energy cost, making it less competitive at longer durations. Alternatives can also offer comparative advantages on factors such as safety and lifetime. The next few years will be pivotal as these technologies look to scale, which requires significantly more investment to grow manufacturing and win new projects. Companies that are able to attract this investment and achieve scale can improve their cost-competitiveness and bankability, supporting continued growth.

California is expected to be a key frontier for the long duration storage market. The state is already a world leader in energy storage, driven in part by storage mandates from Assembly Bill 2514 and by the favorable economics for renewables, where California is also a leader. In recent years, the rapid growth of energy storage has been primarily comprised of storage systems with durations of 4 hours or less, sufficient to address daily needs associated with the duck curve. However, with the passage of Senate Bill 100 (SB 100), which requires 60% carbon-free electricity by 2030 and 100% carbon-free electricity by 2045,³ California is expected to need capacity resources exceeding 4 hours in duration, and long duration storage is uniquely positioned as a low carbon option to fit this requirement.

Recognizing the emerging need for long duration storage, California has recently supported a variety of efforts to help accelerate the market in the state. The California Energy Commission (CEC) issued multiple Grant Funding Opportunities over the past year to support non-lithium and long duration storage technologies including development and field testing of non-lithium storage technologies, up to \$20 million for demonstrations of long duration storage technologies, and studies to inform policy development by assessing the long duration storage needs to support California's decarbonization mandates

While California leads the way in many respects, other markets likely follow similar trajectories, and the demand for long duration storage will continue to grow.

³ California Energy Commission (CEC), "Tracking Progress", 2019, https://www.energy.ca.gov/sites/default/files/2019-12/renewable_ada.pdf.

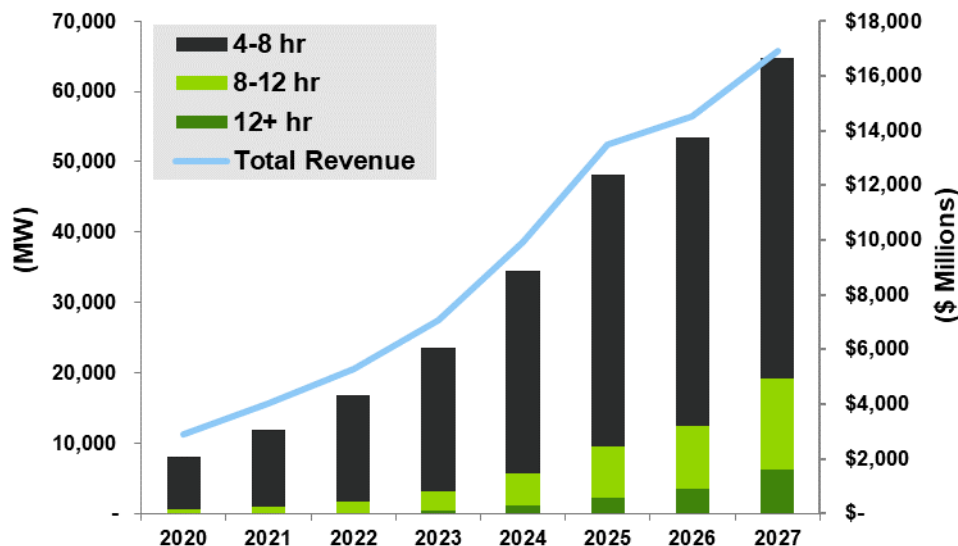
1. Market Drivers for Long Duration Storage

A few key factors are expected to drive significant growth of the market for long duration energy storage systems, including:

- High penetration renewables driving the need for long duration storage to mitigate intermittency
- Extreme weather events driving the need for resilient power during prolonged outages
- Technological advancements driving down the cost of long duration storage systems

Consequently, as Figure 1 illustrates, Guidehouse Insights expects the market for long duration storage to grow at a compound annual growth rate of 29% over the next 7 years.

Figure 1. Annual Installed Long Duration Storage Energy Capacity and Deployment Revenue: 2020-2027



(Source: Guidehouse Insights)

1.1 Accelerating Grid Decarbonization

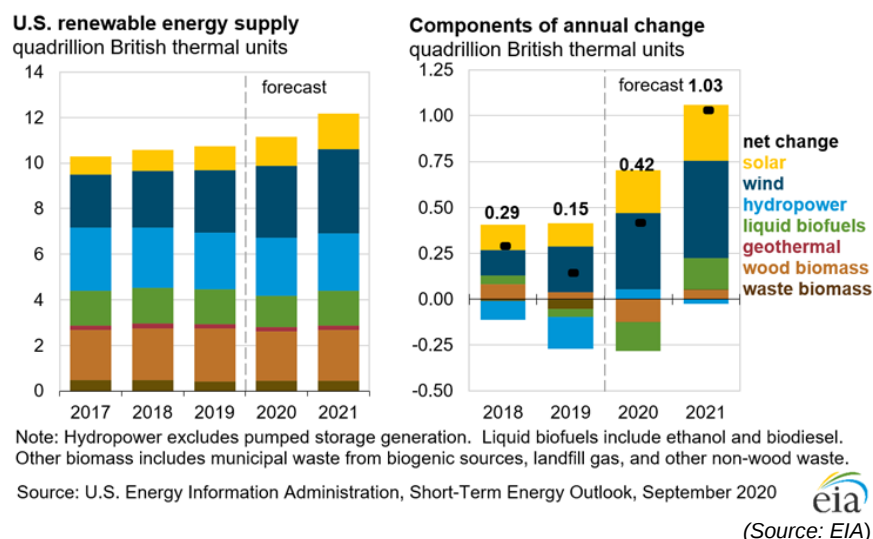
Renewables have been growing at a rapid pace for years, and that growth is only expected to continue. In the US, solar alone has grown at an average annual rate of 49% over the past 10 years.⁴ The economics have also changed. Renewables, such as solar and onshore wind, have become cost-competitive with fossil-fuels as costs have decreased and technologies have improved. About 17% of US energy production in 2019 came from non-hydropower renewables.⁵ This number is expected to grow rapidly, as solar and wind alone are expected to

⁴ Solar Energy Industries Association, "Solar Industry Research Data." <https://www.seia.org/solar-industry-research-data>.

⁵ US Energy Information Administration (EIA), "How much of U.S. energy consumption and electricity generation comes from renewable energy sources?" May 6, 2020, <https://www.eia.gov/tools/faqs/faq.php?id=92&t=4>.

represent 76% of new capacity additions in 2020.⁶ As Figure 2 shows, the US Energy Information Administration (EIA) forecasts that renewables, specifically solar and wind, will continue this rapid growth pace.

Figure 2. Historical and Projected US Renewable Generation



Coupled with rapid renewables growth is the retirement of existing baseload generation such as coal. According to EIA, 95 GW of US coal capacity was retired over the past 10 years and an additional 25 GW is expected to retire by 2025.⁷ The combination of rising intermittent renewables with lost baseload generation is setting the stage for significant dispatchable capacity needs for durations exceeding 4 hours.

Renewables growth is more concentrated in certain regions, particularly in states with high retail electricity rates and supportive state policies. Two states leading the way with low carbon policies are California (with SB 100) and New York (with the Climate Leadership and Community Protection Act [CLCPA]). California's SB 100 set three main targets: 50% renewables by 2026, 60% renewables by 2030, and 100% carbon-free energy by 2045.⁸ New York's CLCPA commits to 85% emissions reduction by 2050, 70% renewables by 2030, and 100% of electricity supply emissions free by 2040.⁹

Regions with high penetration renewables will likely be among the first to see significant growth of long duration storage capacity to address renewable intermittency over multiple hours, days, and even seasons. The following section, Evolution of Power Markets, discusses in greater

⁶ EIA, "New electric generating capacity in 2020 will come primarily from wind and solar," January 14, 2020, <https://www.eia.gov/todayinenergy/detail.php?id=42495>.

⁷ EIA, "As U.S. coal-fired capacity and utilization decline, operators consider seasonal operation," September 1, 2020, <https://www.eia.gov/todayinenergy/detail.php?id=44976>.

⁸ California Legislature, "SB-100 California Renewables Portfolio Standard Program: emissions of greenhouse gases," 2018. https://leginfo.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB100.

⁹ New York State, "Climate Act," 2019. <https://climate.ny.gov/>,

detail the impacts high penetration renewables will have on the demand and economics for long duration storage systems.

States are not the only driving forces leading the way in pushing low carbon investments. Cities and private companies have also adopted aggressive decarbonization targets that will drive growth of localized renewables and demand for long duration storage. San Jose and Austin are two examples of cities with aggressive renewable energy policies.¹⁰ San Jose set a goal to install approximately 1,400 MW of renewable energy generation capacity by 2050, with San Jose Clean Energy, the city's electricity supplier, targeting 100% of non-hydro renewable generation by 2050. The Austin Energy Resource, Generation and Climate Protection Plan committed to 55% of renewables by 2025 and 65% by 2027. Private companies such as Google¹¹ and Microsoft¹² have also established aggressive clean energy targets of being carbon free and carbon negative by 2030.

1.2 Extreme Weather Events

Fueled by climate change, extreme weather events have grown in number and magnitude in recent years, increasing demand for resilient power resources that provide backup power. California has seen over 57,000 wildfires over the past 7 years.¹³ In the last 3 years alone, wildfires resulted in over \$50 billion in damage, including the five costliest wildfires ever in the US (all five in California).¹⁴

Given that power equipment can contribute to wildfires, California has established PSPS guidelines for utilities to de-energize regions of their networks when the likelihood of wildfire is particularly high (e.g., dry periods with winds). These guidelines outlined event notification procedures, coordination with emergency operation centers and incident command systems, among others. Over the past 7 years, there have been 33 PSPS events that lasted 1-2 days on average.¹⁵ Other states in the western US have implemented similar policies, such as the Public Safety Outage Management program in Nevada.

Backup power resources are also important for other extreme weather events like hurricanes. For islands and remote communities that rely heavily upon diesel fuel, alternatives resources could also help reduce power costs and associated emissions during blue-sky conditions. Backup power can be essential even for shorter and more routine outages, which can cause disastrous financial consequences for some industrial customers.

To provide resilient power infrastructure, utilities and their customers will need localized capacity to serve critical loads including hospitals, grocery stores, gas stations, emergency shelters,

¹⁰ ACEEE, *The 2020 City Clean Energy Scorecard*, October 6, 2020, <https://www.aceee.org/research-report/u2008>.

¹¹ Google, *24/7 by 2030: Realizing a Carbon-free Future*, September 2020, <https://www.gstatic.com/gumdrop/sustainability/247-carbon-free-energy.pdf>.

¹² Microsoft, "Microsoft will be carbon negative by 2030," January 16, 2020, <https://blogs.microsoft.com/blog/2020/01/16/microsoft-will-be-carbon-negative-by-2030/>.

¹³ California Public Utilities Commission, "Public Safety Power Shutoff (PSPS) / De-Energization," 2020, <https://www.cpuc.ca.gov/deenergization/>.

¹⁴ Insurance Information Institute, "Facts + Statistics: Wildfires," <https://www.iii.org/fact-statistic/facts-statistics-wildfires>.

¹⁵ California Public Utilities Commission, "Public Safety Power Shutoff (PSPS) / De-Energization," 2020, <https://www.cpuc.ca.gov/deenergization/>.

water utilities, and communications infrastructure. Serving critical loads is essential to support key community needs during prolonged system outages. With more distributed renewables being deployed, these assets could be leveraged to provide backup power to critical infrastructure, but their intermittency makes standalone renewables infeasible. However, long duration storage, particularly when coupled with renewables, provides a key component to support a power system that is clean and resilient. The New York Power Authority is deploying a 100 kW/1 MWh zinc-air energy storage system from Zinc8 that will provide backup power and help level grid demand.¹⁶ Eos Energy Storage deployed its zinc-based storage system paired with solar at a New Jersey wastewater treatment facility to improve resiliency of the facility.

1.3 Alternatives to Li-Ion

While the technical need for long duration storage exists and continues to grow, technology advancements (particularly those that drive down costs) are key to unlocking opportunities. A variety of commercial and emerging technologies are targeting longer duration use cases and focusing on driving down marginal energy costs (i.e., the unit cost of an additional kilowatt-hour of storage). Some technologies such as zinc-based batteries, flow batteries, and compressed air systems have already seen notable commercial deployments and are competing at 4-hour durations. Other notable commercial and emerging technologies, most of which targeting durations greater than 4 hours, include storage systems based upon hydrogen, liquid air, gravity, molten salts, aqueous sulfur, and thermal energy. Collectively, these technologies have attracted hundreds of millions of dollars in investment in the past couple of years.

As Li-ion costs have fallen, longer duration systems have become more economical. While this trend will continue, alternatives with low marginal energy costs have the potential to undercut Li-ion on cost, particularly at longer durations. These alternatives can offer other benefits such as longer lifetimes and improved safety. The Long Duration Storage Technologies section discusses these emerging alternatives in greater detail, including the opportunities and challenges ahead.

¹⁶ NY Power Authority, "NYPA Announces New Energy Storage Demonstration Project Supporting Further Integration of Renewable Power Sources Into the Grid," January 17, 2020, <https://www.nypa.gov/news/press-releases/2020/20200117-zinc>.

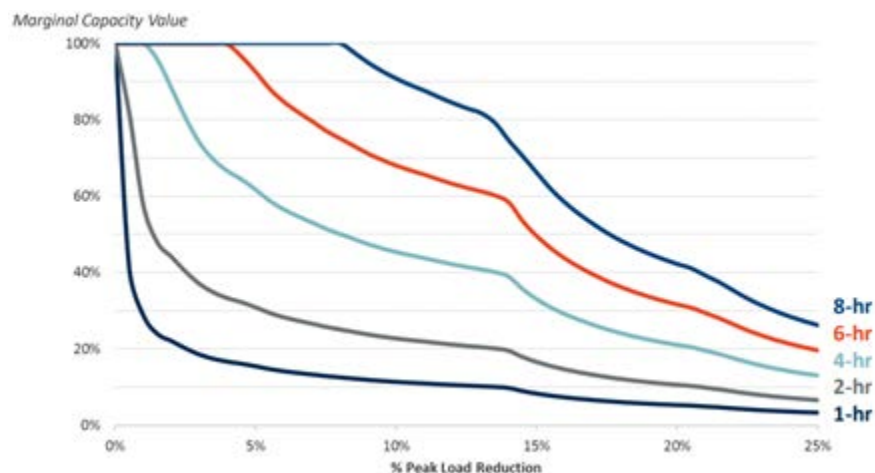
2. Evolution of Power Markets

Many US states are increasing renewable targets and decarbonizing, driving changes in the generation landscape. In regions with high renewable targets and low carbon policies like NYISO, ISO-NE, and CAISO, long duration battery storage systems will be an important component of the resource mix and long-term capacity buildout. The combination of both aggressive RPS goals and grid decarbonization goals accelerate the need for balancing capacity, and at the same time prevent the use of gas-fired resources to meet that need. Long duration storage will be increasingly necessary to balance variable renewable output and quickly respond to imbalances in supply and demand.

Even in the absence of policies designed incentivize storage to meet decarbonization goals and resource adequacy needs, storage is being developed based on economic merit. For example, ERCOT has no state-level policies mandating or incentivizing storage builds, but there is approximately 15 GW of storage in the interconnection queue (versus only 5 GW of gas plants). Long duration storage will be increasingly necessary to balance variable renewable output and quickly respond to imbalances in supply and demand.

Under high penetrations, 1- to 4-hour duration storage is able to move 1-hour peaks into surrounding hours, but in many regions, this will transform 1-hour peak events into longer duration events, especially as the sun sets in high solar regions. As a result, 1- to 4-hour duration battery systems will be less and less effective at meeting grid capacity needs. The effective load-carrying capability of 1- to 4-hour storage is expected to erode, necessitating longer duration storage in order to maintain reliability. As battery storage penetration increases, net peak periods flatten and longer discharge durations are required to provide the same capacity value that was provided by shorter duration resources when the system had less overall storage penetration. This dynamic is described in the NYISO Grid in Transition Study and shown in Figure 3.

Figure 3. Marginal Capacity Value of Energy Storage



(Source: New York Independent System Operator)

Maintaining cost-effective reliability is challenging given the nature of the capacity reserve requirement, whereby the marginal capacity resources on any system are largely needed for peak periods and emergency purposes and have relatively low capacity factors. In a system

with fossil fuel generation, this role is often played by aging thermal units or combustion turbines. In a system with a significant share of energy storage providing capacity, the marginal capacity resources will require longer duration capability to provide the same capacity value. The result is deration of the capacity value of battery storage, and storage becomes more expensive as the amount of storage grows. However, as discussed in the following section (Long Duration Storage Technologies), technologies with low marginal energy costs can minimize the impact on overall system cost as duration increases.

2.1 Resource Adequacy and Capacity Markets

Storage can participate as resource adequacy and in capacity markets such as NYISO, PJM, ISO-NE, and CAISO. Various jurisdictions require minimum durations for battery storage to ensure that the resource will be available to meet the needs of the grid when called upon; currently most ISOs require 4 hours for resource adequacy and capacity value.

NYISO has studied the declining capacity value of storage as more batteries are added to the system, with smaller duration batteries seeing a more significant decline. NYISO currently requires 4 hours of duration and is considering moving to 8 hours to receive full capacity value. In January 2020, FERC accepted NYISO's tariff changes on distributed energy resources and storage, which stipulate that battery storage needs to be de-rated once NYISO hits a 1,000 MW threshold.¹⁷ However, while Guidehouse expects NYISO and other jurisdictions to shift to longer duration batteries, 4-hour batteries will continue to be built and provide needed grid services including load shifting and ancillary services.

Guidehouse expects that shift to the increase minimum duration for capacity will be seen across the country's ISOs. While most ISOs currently require 4 hours of discharge for resource adequacy and full capacity value, longer duration storage will be needed as more storage comes online: as storage penetration increases, 8-hour batteries provide the same capacity value that 4-hour batteries provided when the system had less overall storage penetration. PJM currently requires 10 hours of minimum duration for capacity storage resources; however, many stakeholders have challenged the requirement and maintain that 4 hours is the correct discharge duration for storage to receive full capacity value.¹⁸

2.2 California Public Safety Power Shutoff Events

Due to the increase of destructive wildfires in California, CPUC has given electric utilities the authority to preemptively cut off power to reduce the risk of fires caused by electric infrastructure, known as PSPS. California utilities have been proactively de-energizing power lines as a preventive measure to mitigate severe weather conditions that contribute to wildfires. CPUC adopted the most current set of PSPS guidelines in June 2020.

PSPS events vary in duration, but utilities like Pacific Gas and Electric and San Diego Gas and Electric have a goal of restoring service within 12-24 hours of the shutoff notice. Compared against 1- to 4-hour storage, longer duration battery storage could be significantly more helpful in mitigating PSPS events by providing backup power to customers. The duration of backup

¹⁷ FERC Docket ER-2276-000, "Order Accepting Tariff Revisions and Directing Compliance Filing," January 23, 2020.

¹⁸ Docket ER19-469-000, "Order No. 841 Compliance Filing ESR Market and Operation Proposal," December 3, 2018, <https://pjm.com/directory/etariff/FercDockets/3872/20181203-er19-469-000%20.pdf>.

power support could be further increased by pairing long duration storage paired with solar resources.

2.3 Locational Value

Several market jurisdictions across the US, including CAISO and NYISO, have mechanisms that monetize the locational value of capacity, which is largely tied to its ability to avoid or defer costly grid infrastructure. Evidence shows that locational capacity needs tend to be long duration, which would require battery systems capable of discharging more than 4 hours. For example, the CAISO's 2021 Local Capacity Technical Study¹⁹ lists the characteristics required from battery storage technology to seamlessly integrate into local capacity areas. The nominal duration required ranges from 5 to 12 hours, with an average duration of about 8 hours for areas where batteries could provide local capacity.

In addition to storage's locational value tied to deferring or avoiding grid infrastructure investments, batteries have significant value in load shifting for renewables integration. This is currently seen in high solar penetration regions like CAISO (particularly rooftop solar). Storage soaks up solar generation in the middle of the day when energy prices are low and discharges during peak periods to meet the evening ramp and shift low cost solar output into peak periods to avoid firing up expensive peaking gas generators.

¹⁹ California ISO, *2021 Local Capacity Technical Study*, May 1, 2020, <http://www.caiso.com/Documents/Final2021LocalCapacityTechnicalReport.pdf>; nominal duration requirement calculated based upon ratio of energy required to power required.

3. Long Duration Storage Technologies

Li-ion batteries have claimed the lion's share of the energy storage market in recent years, which has consisted primarily of systems with durations of 4 hours or less; however, a variety of competing technologies are emerging to compete at 4 hours and beyond. While Li-ion does have certain advantages, a key weakness for longer duration systems is its relatively high marginal energy cost.

Given the market drivers and economic opportunities for long duration storage, the limitations of Li-ion, and the promise of competing alternatives, a variety of storage technologies (some commercial and some in development) are attracting significant investment. Achieving scale is key moving forward, which will require companies to attract significant investment from more risk-averse sources.

3.1 Limitations of Li-Ion

Li-ion leads the energy storage market today, and Guidehouse Insights estimates it comprises about 68% of the utility-scale energy storage market share in 2020.²⁰ However, despite its advantages and current position, significant opportunities exist for competitors to gain market share, particularly as the demand for longer duration systems increases.

Li-ion offers a variety of advantages. First and most importantly is cost, particularly the marginal power cost (i.e., unit cost of adding another kilowatt of power). Because of its ability to charge and discharge quickly and the relatively inexpensive cost to increase the power output, Li-ion is most competitive at shorter durations and is favored in a market demanding mostly systems with durations not exceeding 4 hours, though it is facing more competition for systems approximately 4 hours in duration.

Additionally, Li-ion also offers advantages in terms of efficiency, energy density, and modularity. Round-trip efficiencies can exceed 90%. Its high energy density limits area requirements for siting and drives down costs for balance of system infrastructure such as containers and wiring. Its high degree of modularity enables it to be used in kilowatt-scale residential systems and transmission-interconnected systems exceeding 100 MW.

Some of these advantages were gained through the existence of established supply chains and corresponding significant investment from industry giants. Before making their way into the stationary storage market, Li-ion batteries had been used for decades in consumer electronics and more recently in EVs. As such, large industry players were able to make significant investments to drive down costs. An analogous scenario played out in the solar market, where an established supply chain for silicon-based computer chips helped to position silicon as the leading material for solar cells.

These advantages do not necessarily position Li-ion for success in the long duration storage market. First, the value of efficiency for Li-ion is often overstated, and real system efficiencies can be much lower than rated roundtrip efficiency due to parasitic loads such as HVAC equipment. Given its use mostly in peaking applications with limited throughput, energy losses have a limited effect on overall project economics. Also, considering that 1 MW of solar can

²⁰ Guidehouse Insights, *Market Data: Utility-Scale Energy Storage Market Update*, 3Q 2020.

require 100-1,000 times as much land as 1 MWh of storage, energy density is not usually a key factor for stationary storage.²¹ While modularity is helpful for small-scale residential systems, it is less important for large-scale, multi-megawatt systems.

Perhaps most importantly, Li-ion is constrained by relatively high marginal energy costs. While these costs are falling and will continue to do so, there is likely an inherently higher floor on marginal energy costs for Li-ion relative to many of its emerging competitors.

Li-ion presents some risks that are mitigated by some competing alternatives. Safety remains a concern, particularly in more densely populated areas. Although some of the fire and explosion risk are largely addressable and preventable, high profile events keep happening. For example, an explosion at an Arizona Public Service battery energy storage system in 2019 injured several first responders.²² Since then, the Arizona Corporation Commission has expressed interest in exploring alternative technologies due to the risks posed by Li-ion and Arizona cities adopted fire safety standards (NFPA 855) established for energy storage systems.²³ Even absent the safety concerns, thermal management and state-of-charge considerations can place limits on Li-ion operation, else risk eroding lifetime or voiding battery warranties.

Additionally, Li-ion has supply chain risks due to its dependence on a variety of materials, including rare earth metals such as cobalt and manganese that are only available from a few locations and suppliers around the world. This creates susceptibility to sudden price shocks, which are possible in the near future as supply chains become constrained by COVID-19-related impacts. These price shocks can create significant opportunities for competing technologies. Even competition with the EV market can keep prices high, as observed in 2019 when prices fell at a much slower pace than originally projected. As a parallel example from the solar market evolution, increased solar demand and limited manufacturing capacity in 2008 constrained the supply of polysilicon for PV modules and increased prices accordingly. An emerging competitor, FirstSolar, offered CdTe modules not based upon silicon and was able to provide the supply to meet demand, grew dramatically during that period, and has since sustained itself as a leading player ever since.

3.2 Flurry of Investment

Other analogous comparisons to the solar market highlight additional opportunities for energy storage technology alternatives to Li-ion. While solar cells have essentially one application (produce energy when the sun shines) the applications for energy storage are far more diverse due to its dispatchability and its varying levers of power and energy. This creates opportunities for multiple different technologies to gain advantages for different use cases, and long duration storage use cases offer particular opportunities for disruption.

Recognizing these opportunities, investors have increasingly placed bets on a variety of competing storage technologies in recent years, particularly for technologies that offer low

²¹ On average, solar size is approximately 6 acres per MW (per NREL) and storage is 0.01 acres per MWh (HDR)//

²² DNV GL, *McMicken Battery Energy Storage System Event Technical Analysis and Recommendations*, July 18, 2020.

²³ National Fire Protection Association, "NFPA releases a new energy storage system standard to inform designers, builders, facility managers, manufacturers, responders and others about potential fire hazards, September 11, 2019, <https://www.nfpa.org/News-and-Research/Publications-and-media/Press-Room/News-releases/2019/NFPA-releases-a-new-energy-storage-system-standard>.

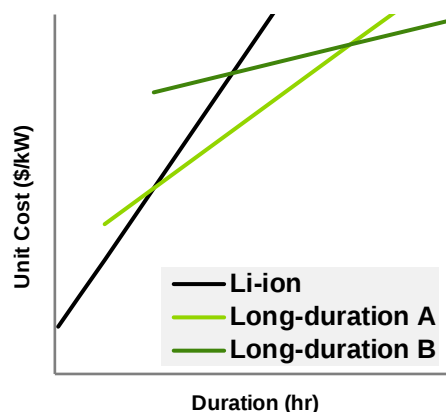
marginal energy costs relative to Li-ion, making them more competitive at longer durations. Some notable recent investments in long duration technologies include a merger between Eos Energy Storage and B. Riley Principal Merger Corp II providing Eos with \$225 million in financing,²⁴ and companies including Hydrostor, Highview Power, and Form Energy have each raised more than \$35 million over the past few years.

3.3 Key Technology Considerations

The key factor for long duration storage technologies is not so much about their ability to discharge over longer durations, but more about the cost to do so. For example, a 4-hour Li-ion battery can be discharged over 8 hours or more, but if the use case demands 8-hour discharge at full power, then there may be a variety of other technologies that could do so more cost-effectively.

Figure 4 highlights the impact of marginal power cost and marginal energy cost on overall system costs. Li-ion has a relatively low marginal power cost (the intercept in Figure 4), making it competitive at shorter durations. To increase the power (reduce the duration), the power capacity of the inverter and interconnection equipment must increase. For flow batteries, this would also require increasing the power rating of the stack, causing notable additional costs. However, Li-ion has a relatively high marginal energy cost (the slope in Figure 4), as adding energy (increasing the duration) requires the addition of more complex, microstructured Li-ion cells. For flow batteries, adding more energy simply requires increase to volume of containers of fluid. Figure 4 illustrates how multiple different storage technologies can gain advantage at different durations, depending on the marginal power and energy costs.

Figure 4. Illustrative Unit Costs for Different Marginal Power and Energy Costs



*Note: Not intended to reflect actual costs
(Source: Guidehouse)*

Figure 4 focuses only on capital cost structure. Alternative technologies can also claim advantages in terms of lifetime costs, such as the levelized cost of storage or levelized cost of energy. These parameters consider other factors such as operation and maintenance costs, degradation, and system lifetime. For example, while Li-ion systems often offer warranties of 10

²⁴ PV Magazine, "Proposed merger will make zinc battery developer Eos Energy a public company," June 26, 2020, <https://pv-magazine-usa.com/2020/06/26/eos-energy-storage-is-a-private-zinc-battery-developer-with-the-chance-to-go-public/>.

years or less, other technologies offering 20-year warranties can reduce annual debt repayment costs to improve the internal rate of return and offer a longer period of revenue generation to further increase net present value.

Emerging alternatives tend to offer lower efficiencies than Li-ion, but this is not necessarily a concern. First, while the round-trip efficiency of Li-ion can be high, it can also have high parasitic losses, for example from powering auxiliary equipment such as HVAC systems. For this reason, the CPUC found that storage systems in its Self-Generation Incentive Program, which were mostly Li-ion, had overall system efficiencies varying from about 5% to 95%.²⁵ Second, as noted above, efficiency has a limited impact on overall project economics. As renewables penetration grows, energy prices will approach zero or negative when renewables are generating, further reducing the economic impact of efficiency losses.

Emerging technologies can also differentiate themselves in other ways. Some technologies offering reduced or avoided risk of catastrophic failure (e.g., fire, explosion) or toxin exposure, which can be particularly important to certain buyers, such as electric distribution utilities, which tend to place a particular emphasis on safety. While some long duration technologies are less modular or require significant footprints, certain technologies with more modularity and smaller footprints will be better positioned to capture value further downstream on the network—with commercial and industrial customers or to provide distribution infrastructure services.

3.4 The Next Hurdle: Project Capital

A variety of long duration storage technologies have been able to attract significant capital investment to support technology development and initial demonstration projects. The next stage of growth may require orders of magnitude more investment. Companies that attract this investment and achieve scale can improve their cost-competitiveness and support continued growth.

To fuel growth, achieve scale, and drive down costs, long duration storage technology providers will need to mature their manufacturing base and supply chains, which will in turn require developing a significant pipeline of projects. A key factor to offering competitive bids at scale is having access to low cost project capital, and this depends upon the ability to mitigate financial risks, whether real or perceived.

Demonstration projects have a notable impact on reducing perceived technology and performance risk, but the system provider's bankability can remain an issue for debt lenders. However, this can be addressed through partners with large balance sheets that provide a financial backstop. Even in the absence of that, there are financial products that may be available to help mitigate these risks, such as warranty insurance and loan loss reserves. Further, green banks have emerged to help fuel growth of other energy technologies, notably solar. New York Green Bank is currently pursuing opportunities to invest in energy storage projects, and it is likely that such investment in storage will grow significantly in the coming years.

The merchant risk of revenue streams is a key challenge for storage projects to access low cost debt for leverage. Whereas solar and wind are typically contracted through power purchase agreements (PPAs) that provide long-term revenue certainty, storage revenue streams are often

²⁵ CPUC, "2017 SGIP Advanced Energy Storage Impact Evaluation," 2017.

more uncertain. However, in recent years, more procurements of renewable resources are demanding co-located storage to provide more firm and predictable capacity, and the associated PPAs provide more revenue certainty. Other market changes and business model innovations can also provide more certainty and will be warranted as the grid decarbonizes and demands more firm, low carbon capacity.

While barriers to project capital certainly exist, there are a variety of pathways that storage technologies have available to surmount them.

