Literature Review and Tables of Findings
Low Carbon Alternatives for Back-Up Energy Generation and Storage for Large Office Buildings or Complexes
The Cadmus Group LLC
November 22, 2019

Summary of Findings

Sources reviewed yield the following findings:

- Large commercial buildings seeking low-carbon alternatives to conventional generators for back-up energy generation for whole building loads tend to choose lithium-ion battery storage, despite its blemished safety record as a fire hazard in high-density buildings and its relatively high upfront costs. This preference is due to market factors (see below); functional considerations such as rapid start-up times and high efficiency; and the fact that for the handling of *all* building energy loads, thermal energy storage systems, a comparatively low-cost alternative, must install turbines capable of generating electricity from customer-sited energy storage transfer mediums.
- The market share of **lithium-ion (li-ion) battery systems** has expanded because of their scalability, consumer familiarity with applications other than in commercial buildings (i.e., in electric vehicles), and early interest and investment on the part of innovators such as Elon Musk. Li-ion energy generation and storage systems are designed and sold to the commercial market by such companies as Engie, Stem Energy, and Fluence (an AES-Siemens company with an outpost in Arlington). Because of li-ion's safety record, innovators are researching other battery types, including zinc technology and iron flow, as alternatives.
- Thermal energy storage (TES) is a proven technology with a track record of use in larger commercial building projects, typically as a low initial- and life-cycle cost system and a non-toxic way to accommodate peak usage management of HVAC load (often cooling load, through the generation of ice). **Electric thermal energy storage (ETES)** accommodates whole building energy loads by installing turbines to generate electricity in the event of grid disruption; these turbines depend upon customer-sited energy storage transfer mediums such as molten salt, rock, or water. Turbines are typically associated with utility-scale power generation, combined heat and power, and industrial applications, and not with commercial office buildings. Google X Labs has piloted a scalable alternative, Malta, which seems well-suited to the commercial sector. However, it is still in the design phase.
- The choice of a back-up energy generation method hinges on many factors, including cost (usually first-cost rather than life-cycle assessment), anticipated needs for energy storage duration (whether hours or days), the "comfort level" of building managers with conventional vs. "alternative" technologies, and the leadership of owner, designer, and operations teams to model alternatives, especially during the design phase. These factors help to explain the still-prevalent choice of carbon-intense generation methods; natural gas and diesel account for over 90% of all back-up generation methods.
- If considered on a whole lifecycle basis, the cost for low-carbon alternatives for back-up energy generation and storage is becoming increasingly competitive with conventional back-up generation fuels such as diesel and natural gas, especially in the presence of utility or public sector incentives. Conventional generator systems require continual purchase of fuel, space for back-up storage tanks, and floor area for large-sized generators with NFPA-mandated clearances; further, they incur substantial maintenance costs, have an average 15-

year life span in contrast to 20+ years for li-ion storage and 30+ years for thermal storage, result in noise and emissions, and are subject to failure in the event of fuel supply disruption.

- The economics of low-carbon alternatives seem to work best in the context of "value stacking," where building owners pursue multiple benefits from multiple energy generation system "roles" – for example, where systems function as a resilience strategy, as an energy-efficiency strategy, and as a way to reduce demand charges, especially as demand charges for commercial buildings are increasing year over year by as much as 16%.

Table, comparison by type of backup energy generation

Back-up generation/storage type	Literature review sources	Typical applications (size, building type, use type, etc.)	Capacity for rapid initiation / fast-start	Incentives available in Common-wealth of Virginia	Costs	Benefits	Return on investment	Other observations
Electric thermal energy storage (ETES)	Siemens; Google X Labs Malta project	Utility-scale installations; no single large office building applications to date	Limited; start-up time varies depending on turbine system used	None	Low-cost initially and over the life-cycle; turbines require management in operations	Can be paired with renewables; if customer sited rather than utility scale, buildings will experience peak shavings, demand management, and energy efficiency	Rapid	There is ongoing innovation in turbine combinations and rapid-start capabilities.
Thermal energy storage	CALMAC, CityLab, IceEnergy	Large office buildings, skyscrapers, military buildings, school districts, utility-scale installations	Limited	None	Low cost	Peak shavings, demand management, energy efficiency	Rapid (often less than 3 years), primarily because of savings from HVAC energy efficiency	Most current systems are only for HVAC loads, not electricity generation
Lithium Ion Batteries	Tesla, Business Insider, Fortune, Sandbar, Mosaic Energy	Utilities, commercial buildings, industrial uses (wineries/ breweries), residential applications	Yes	None	Higher upfront cost and lower lifecycle costs than high-	Easily scalability; can be paired with renewables, can be designed to go off-grid entirely	May be less than ten years when used for multiple purposes in	Toxicity and fire hazard; NYC forbids use in large comm. buildings/ skyscrapers

Back-up generation/storage type	Literature review sources	Typical applications (size, building type, use type, etc.)	Capacity for rapid initiation / fast-start	Incentives available in Common-wealth of Virginia	Costs	Benefits	Return on investment	Other observations
					carbon alternatives		addition to resilience	
Flow Batteries	Green Tech Media, Science Magazine, ESS, C&R, Windpower	Utilities, commercial buildings, industrial uses, residential applications	Yes	None	Compared with li-ion systems, more infrastructure (and cost) required for pumps, plumbing, and electrolyte tanks and management	Improved safety, lower degradation, and longer discharge times compared with li-ion batteries	Same as for li-ion	Various types of flow batteries – i.e., redox flow, vs. hybrid flow (zinc or iron-based) vary in performance; liquid electrolyte management may be problematic
Fuel cell storage (hydrogen)	NREL study	Commercial buildings, all scales	Yes	None	High upfront costs, yet cost competitive with diesel generators in 8-hour, 52-hour, and 72-hour run time scenarios	Peak demand reduction, 25 year life span, high efficiency, less frequent maintenance schedule than diesel generators		Hydrogen storage may be problematic for permitting

Table, case studies of office buildings using alternative sources for backup energy generation

Case study name	Location	Literature review source	Size (in GSF or MWh) and configuration	Year of construction	Type of back-up generation used	Reason for implementation	Incentives or funding sources used	Costs	Benefits	Return on invest-ment
Siemens utility pilot	Hamburg, Germany	Siemens	130 MWh thermal	2019	Electric thermal energy	Utility pilot	Funded by the German		Low cost and	

Case study name	Location	Literature review source	Size (in GSF or MWh) and configuration	Year of construction	Type of back-up generation used	Reason for implementation	Incentives or funding sources used	Costs	Benefits	Return on invest-ment
			energy storage site		storage (ETES) for back-up electricity generation		Ministry for Economic Affairs and Energy		low carbon	
Durst Organi-zation	1155 Avenue of the Americas, New York, NY, 10036	http://www.calmac.com/energy-storage-case-study-1155-ave-of-theamericas	790,000 41 stories	1984 (Year of Ice tanks: 2002)	Thermal energy storage for cooling	Reducing grid dependency and easing strain on overtaxed electrical grid	NYSERDA Peak Load Reduction Program Award of $280,000			
McConnell Air Force Base	Wichita, Kansas	http://www.calmac.com/mcconnell-air-force-base	2 buildings	1929	Thermal energy storage for cooling	Shifting load off grid during peak demand to reduce costs associated with 24-hour air conditioning				
Goldman Sachs	New York, NY	http://www.calmac.com/energy-storage-articles-financial-firm-investment	43 stories	2009	Thermal energy storage	Shifting load off grid during peak demand to reduce costs			Saves $50,000 per month on summer power bills	30% more efficient
Rocke-feller Center	New York, NY	http://www.calmac.com/energy-storage-case-study-rockefeller-center	19 buildings		Thermal energy storage	For peak shavings during high demand, and for increasing operational flexibility to			Reduced depend ency on 2,500 ton electric chiller	

Case study name	Location	Literature review source	Size (in GSF or MWh) and configuration	Year of construction	Type of back-up generation used	Reason for implementation	Incentives or funding sources used	Costs	Benefits	Return on invest-ment
						reduce demand during shoulder months				
La Crema Winery	Sonoma County, CA	https://fortune.com/2015/06/26/winery-tesla-batteries/ https://www.energyandcapital.com/articles/a-california-winery-running-tesla-s-powerpack/76042	6 wineries, of which La Crema is one		Solar + Lithium Ion Battery			$10M for 6.5 MW of solar panels (company-wide)	Expected to lower company's electricity bill by 40% in 2016, or $2M (company-wide)	Payback period of about 6 years (company-wide)
GHP Office Realty – Office Building	Harrison, NY	https://www.nyserda.ny.gov/-/media/Files/Programs/Energy-Storage/ghp-office-realty-cs.pdf	130,000 SQ FT – 375 kW		Lithium Ion	Uses AI to reduce grid consumption during peak hours, thereby improving resiliency. This application is similar to a short duration UPS system, as described by Energy Storage Association.	Con Edison Incentive. Implemented shared-savings approach with Peak Power, where Peak Power retains a portion of the revenue in exchange for installing and	While this technology does not fully cover energy needs during an outage, it powers the transition to other backup systems	Lower energy costs, low risk due to incentives used and shared-savings approach	

Case study name	Location	Literature review source	Size (in GSF or MWh) and configuration	Year of construction	Type of back-up generation used	Reason for implementation	Incentives or funding sources used	Costs	Benefits	Return on invest-ment
							operating the system			
Mira Lima Substation	Ontario, CA	https://www.greentechmedia.com/articles/read/aliso-canyon-emergency-batteries-officially-up-and-running-from-tesla-green	70 MW	2017	Lithium-Ion	Due to Aliso Canyon gas leak which threatened to take down Southern California's grid, the utility decided to invest in energy storage. These large-scale batteries pull energy from RE sources,			Reduces risk caused by catas-trophic natural gas leaks in the future.	
Energy Storage in Southern California – Fluence	Southern California	https://blog.fluenceenergy.com/energy-storage-aes-alamitos-california	400 MWh	2019	Lithium-Ion	Largest energy storage project in the country, part of a modernization of the existing Alamitos generating station, part of the state's aggressive target of 100% clean energy by 2045.			Will allow for the increase of integra-tion of renew-able energy. Will be a stand-alone altern-ative to building new natural	Will contri-bute between $12/3 and $14/6 million annually to the local economy. Will result in more than $132 million in

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									gas plants.	local pur-chases
Ocracoke Island	Outer Banks, NC	https://www.mnn.com/earth-matters/energy/sponsorstory/ocracoke-island-goes-local-more-innovative-reliable-energy			Solar + Lithium-Ion microgrid	To partially substitute diesel generator, improve resiliency during storms and hurricanes, when power outages are most-likely to occur.			Reduced depen-dency on diesel, which must be shipped in from main-land	

Annotated Bibliography

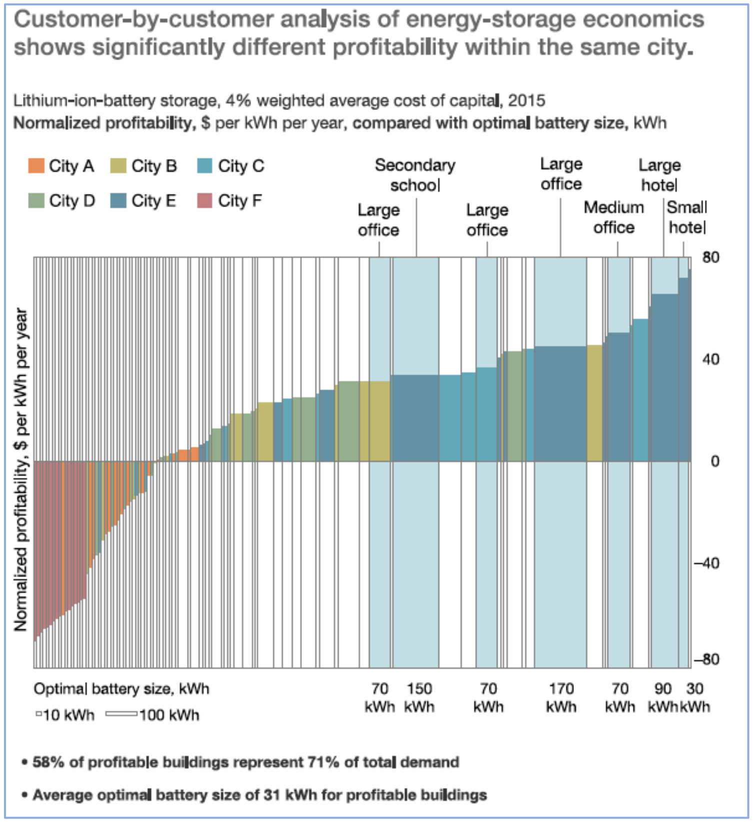
1. Perry, Christopher. *Emerging Opportunities: Energy Storage*. American Council for an Energy-Efficient Economy, February 7, 2019. https://aceee.org/topic-brief/eo-energy-storage .

This topic brief provides an introductory summary of the benefits to utilities and consumers of energy storage systems. The benefits to individual organizations or institutions include: (1) resilience during grid disruption; (2) avoiding demand charges in jurisdictions where utilities require customers to pay higher rates during peak demand; (3) the ability to participate in a utility's demand response program without the need to make major operational changes, such as having to reduce HVAC usage during high demand periods; (4) increased energy efficiency allowing the downsizing of HVAC systems; (5) frequency smoothing and the avoidance of grid ramping issues; and (6) the receipt of utility incentives for implementation. Local climate, type of storage system, and utility rate structure are important variables in the amount of possible lifecycle savings.

The brief monetizes benefits by type of alternative storage system. In the case of thermal storage systems, in climates where cooling loads are significant, a building's chiller system may be significantly downsized: "For a rough estimate of energy savings, if a building with an 800-ton chiller system used thermal storage to downsize to 400 tons, it would save over 400,000 kWh per year, equivalent to more than $40,000." Properties in states with high demand charges will see the greatest economic benefits from energy storage, where "demand charges greater than a threshold of $15 per kilowatt (kW) generally [make] energy storage cost effective (depending on the building load profile)." According to the brief, thermal energy storage (TES) has been most economically viable in large buildings or building complexes – Princeton University saves $700,000 annually through its (TES) system – and "has a quicker payback and longer lifespan than lithium-ion batteries, since it has a lower material cost and will not lose much capacity over time in the way batteries do." Considering and then combining multiple "value streams" -- such as "resource adequacy" in the event of grid disruption combined with frequency regulation and demand reduction during peak usage -- will create most value. Challenges to implementation of alternatives energy storage alternatives include high upfront costs, conflicting incentives, incorrect battery sizing, and storage type safety and regulation (New York, for example, restricts installation of lithium-ion battery systems). The brief concludes with recommendations for utility program approaches for overcoming these barriers by creating new incentives and storage system ownership or rental models.

2. The website of the Energy Storage Association (ESA: https://energystorage.org)

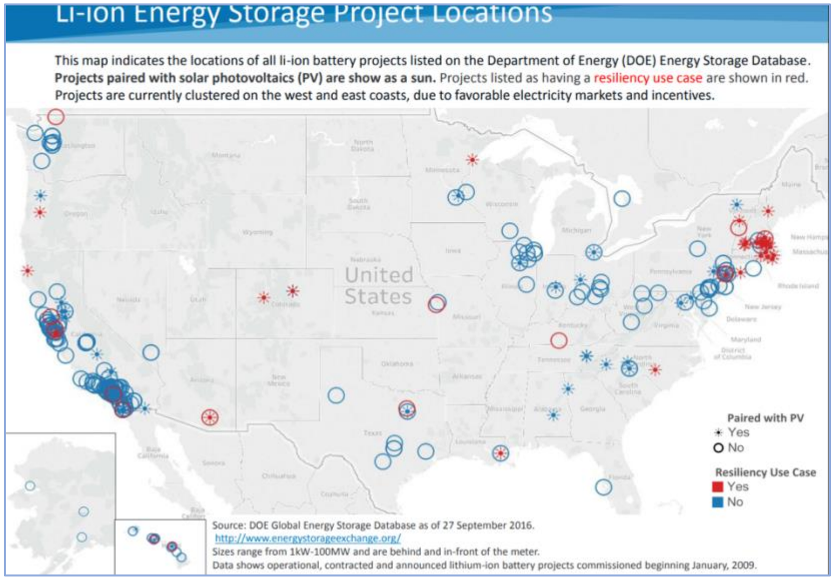
The ESA website explains the major energy storage technologies (https://energystorage.org/why-energy-storage/technologies/), including summary descriptions of various battery types and their comparative advantages, as well as an outline of "customer sited benefits" (https://energystorage.org/why-energy-storage/applications/customer-sited/), including such benefits as time-of-use energy cost management for customers subject to energy time-of-use tariffs (time-of-day, day of week, and seasonal).



3. D'Aprile, Paolo, et al., McKinsey and Company, *The New Economics of Energy Storage.* August 2016, https://www.mckinsey.com/business-functions/sustainability/our-insights/the-new-economics-of-energy-storage#.

"Our research shows considerable near-term potential for stationary energy storage. One reason for this is that costs are falling and could be $200 per kilowatt-hour in 2020, half today's price, and $160 per kilowatt-hour or less in 2025. Another is that identifying the most economical projects and highest-potential customers for storage has become a priority for a diverse set of companies including power providers, grid operators, battery manufacturers, energy-storage integrators, and businesses with established relationships with prospective customers such as solar developers and energy-service companies." This research recounts that the technology of lithium ion batteries has "progressed the furthest" in terms of safety and lower price, accounting for 95%

of new energy-storage deployments in 2015. "Prices for lithium-ion batteries have been falling and safety has improved; moreover, they can work both in applications that require a lot of energy for a short period (known as power applications) and those requiring lower amounts of energy for longer periods (energy applications). Collectively, these characteristics make lithium-ion batteries suitable for stationary energy storage across the grid, from large utility-scale installations to transmission-and-distribution infrastructure, as well as to individual commercial, industrial, and residential systems." The lithium-ion storage type charges and discharges quickly. The data suggests that the "sweet spot" for energy storage economies for large offices is a battery system size between 70 and 170 kWh.



4. Joyce McLaren, Pieter Gagnon, Kate Anderson, Emma Elgqvist, Ran Fu, Tim Remo. *Battery Energy Storage Market: Commercial Scale, Lithium-ion Projects in the U.S.* National Renewable Energy Laboratory, October 2016. https://www.nrel.gov/docs/fy17osti/67235.pdf.

This is a slide deck that summarizes findings of an NREL study which collected data on twenty-eight lithium ion energy storage projects from among those in the U.S. (see image at left), with an average cost of $55,000, an average battery duration of around 2 hours, and an average energy rating per project of 37 kWh. Average cost to install proved to be $2,338 per kWh in 2016.

5. Ericson, Sean and Dan Olis. *A Comparison of Fuel Choice for Backup Generators*. National Renewable Energy Laboratory, NREL/ TP-6A50-72509, March 2019. https://www.nrel.gov/docs/fy19osti/72509.pdf.

This paper compares fossil fuel powered backup generators, specifically natural gas and diesel, which it judges equivalent in costs and benefits. It outlines the limits of such systems, including most prominently (1) noise and emissions concerns, (2) lifecycle cost considerations of the continuing need for substantial maintenance and purchase of fuel, (3) weaknesses in reliability, including systems failures such as failure to start, failure to run, and failure of fuel supply during infrastructural disruptions.

6. J. Kurtz et al. *Backup Power Cost of Ownership Analysis and Incumbent Technology Comparison.* National Renewable Energy Laboratory, NREL/TP-5400-60732, September 2014. https://www.nrel.gov/docs/fy14osti/60732.pdf

This 2014 study compares battery, fuel cell, and diesel generation systems as to their lifecycle costs and benefits across several run-time scenarios (8-hour, 52 hours, 72 hours, and 176 hours). It finds that a fuel cell system with incentives "is cost competitive with the diesel generator, particularly in the 8-hour, 52-hour, and 72-hour run time scenarios. The fuel cell system has a higher efficiency and less frequent maintenance schedule than the diesel generator, and the incentives offset the higher capital and installation costs . . . In the 72-hour run time scenario, the cost of ownership of the fuel cell system, without incentives, is approximately 1.2 times higher than that of a diesel generator and more than 5 times lower than that of a battery system. In the same run time scenario, the cost of ownership of the fuel cell system, with incentives, is approximately equal to that of the diesel generator."

7. Wes Doane and Jim Greenberger, "Top 5 Energy Storage Trends of the Year," POWER Magazine, 10/27/2019, https://www.powermag.com/top-5-energy-storage-trends-of-the-year/.

This article documents the downward price trajectory of lithium-ion energy storage technology: "Since 2013, prices have dropped by nearly 73%; in the first quarter of 2019, the market achieved a record-breaking 232% growth." It describes the rise of alternative battery technologies (such as zinc technology) as a response to lithium-ion safety concerns.

8. U.S. Department of Energy Better Buildings 2015 Summit panel presentation, "Energy Storage: Is It Right for Your Building?" https://betterbuildingssolutioncenter.energy.gov/sites/default/files/Energy_Storage_Is_it_Right_for_Your_Building_High_Impact_Technologies_WED.pdf

This source is helpful for its presentation of the rapidly escalating cost of demand charges, quantifying (for example) San Diego Gas and Electric's 16.1% year over year increase between 2005 and 2015.

9. U.S. Department of Energy Office of Technology Transitions, *Spotlight: Solving Challenges in Energy Storage*, August 2018. https://www.energy.gov/sites/prod/files/2018/09/f55/2018-08-23_Spotlight%20on%20Energy%20Storage%20-%20Brochure%20and%20Success%20Stories_0.pdf

This inventory chronicles ongoing DOE-sponsored research projects in new frontiers of energy storage. Particularly intriguing is the project which uses large commercial building mass as a thermal energy storage medium, for an estimated reduction in site energy costs of 20-40%. In a 2012 Chicago summer demonstration, 1500 MWh of peak energy were displaced, saving one building (Willis Tower) $250,000.

10. Energy Storage Newsletter (online resource), "Investing in energy storage for resiliency: the business case in the US," August 28, 2018. https://www.energy-storage.news/blogs/investing-in-energy-storage-for-resiliency-the-business-case

The overarching message of the article is that as of 2018, the payback period for battery energy storage systems with full value-stacking capabilities is less than five years. Decisionmakers should chose the type of battery system based on the distinction between **batteries for energy efficiency** and **batteries for energy resiliency.** The majority of installed battery systems are for energy efficiency (peak shaving, demand management, time-of-use optimization). Batteries for energy resiliency can do all that batteries for energy efficiency do, in addition to keeping the lights on during an outage. The key difference in resiliency battery installations is the ability to safely island away from the grid during an outage. For such applications, plan to install microgrid controllers to optimize the separation between the grid and the building and its renewables.

In the past, backup generators and uninterruptable power systems (UPS) have been used by hospitals, data centers, and military bases. These emergency reserves preserve lives, data, and national security and therefore reduce risks. While adoption of this technology has been limited due to the traditionally long payback periods, there are now more incentives than before. Utilities pay customers to provide demand response services. This can reduce the payback period to less than 5 years. Certain organizations, such as NYSERDA, will provide incentives and funding for energy storage projects. Alternatively, some business models allow customers to receive the batteries for free and share the energy savings with the vendor.

11. Environmental and Energy Study Institute, "Fact Sheet: Energy Storage," February 22, 2019, https://www.eesi.org/papers/view/energy-storage-2019.

This overview reviews a panoply of energy storage types for implementation at utility and/or single building scale: pumped storage hydropower, compressed air energy storage, thermal storage, lithium ion batteries, flow batteries, lead-acid batteries, solid state batteries, hydrogen, and flywheels, citing that the price of energy storage systems will fall 8 percent annually through 2022. It also provides a performance comparison of the selected energy storage technologies, sourced from the World Energy Council.

12. Electric thermal energy storage (ETES) sources and case studies

- Siemens website, "Electric Thermal Energy Storage: GWh Scale & For Different Applications," n.d., https://www.siemensgamesa.com/products-and-services/hybrid-and-storage/thermal-energy-storage-with-etes

  This source features an explanation of a case study in a utility scale pilot of electric thermal energy storage, or ETES. Advantages cited are that, as compared with battery systems, no hazardous materials are used; there is 98% efficiency in heat storage and 45% for the electric cycle; storage duration for up to two weeks is possible; capital expenditure is up to ten times lower than batteries; ETES can be paired with renewable sources and can be used to convert conventional power plants for emissions reduction. The case study, in Hamburg, Germany, used rock as the heat storage transfer medium, where heat is re-converted into electricity through steam.

- Hanley, Steve, *Clean Technica*, December 21, 2018, https://cleantechnica.com/2018/12/21/google-x-spins-off-malta-molten-salt-energy-storage-business/

  This news article explains Google X Lab's development of the Malta system, which uses molten salt as a heat exchange medium: "the Malta system can store energy for more than 6 hours and can be charged thousands of times before its performance begins to degrade, giving it an estimated service life of more than 20 years . . . Energy gathered from renewables or from the grid is send to the Malta system; electricity drives a heat pump which converts electrical energy into thermal energy by creating a temperature difference. The heat is then stored in molten salt, while the cold is stored in a chilled liquid . . . the temperature difference is converted back to electrical energy with a heat engine."

- Collins, Leigh, "Google X spin-off Malta could change world, but lags behind rivals," Recharge News, August 9, 2019, https://www.rechargenews.com/transition/google-x-spin-off-malta-could-change-world-but-lags-behind-rivals/2-1-651240

  "The Malta system combines a range of well-known technologies in an innovative way. It takes electricity from the grid to drive a heat pump that creates streams of hot and cold air, which are directed to tanks of molten salt (heated to 565°C) and anti-freeze (cooled to minus 65C). This thermal energy can be stored for days or weeks due to effective insulation. Then, when required, the above charging process is effectively reversed using a heat engine — basically a compressor and a turbine — which drives a generator to produce electricity. . . . the Malta system can be scaled to pretty much any size."

13. Thermal energy storage (TES) sources and case studies

    - Calmac, "How can energy storage help your commercial building?" July 25, 2016, http://www.calmac.com/energy-storage-articles-how-can-energy-storage-help-your-commercial-building
      This article acts as an introduction for facility managers on the benefits of energy storage, with a focus on thermal energy storage (TES). Thermal energy storage is compared to an ice machine, as TES systems store energy in the form of ice, with pipes that transfer the heat to melt the ice.

      Of the many benefits, the main one mentioned in the article is about how TES systems reduce energy costs through peak shaving and time-of-use optimization. By reducing grid dependency during peak daytime hours (when energy rates can double or triple), and by buying from the utility during off-peak hours and storing the energy in ice tanks until needed during the day.

The article then goes on to provide a case study where a commercial building in Philadelphia retrofit its old HVAC system. The Calmac IceBank thermal energy storage system was the same price as the old infrastructure but saved $40,000 each month through peak shaving and saved $10,000 each year through demand management. The full payback period was only two years.

- Green Tech Media, "How Does Thermal Energy Storage Reach Scale?" September 6, 2017, https://www.greentechmedia.com/articles/read/how-does-thermal-energy-storage-reach-scale

  This article explores the possibility of expanding thermal energy storage to various applications, as part of a greater narrative for decarbonization. It first acknowledges that lithium-ion batteries have taken the spotlight in current times, but also points out the scaling limitations with that technology. One of the main advantages of thermal energy storage over battery is that there is no need to convert between heat and work. Since TES systems rely on large tanks of ice for air-conditioning, the process is highly efficient, and costs less than lithium ion. Additionally, one of the main concerns with lithium ion scaling is the risk it presents as a fire hazard, which is something that thermal storage does not have to concern itself with at all. Thermal systems do not use any flammable or toxic chemicals.

  The article mentions various suppliers of thermal energy storage systems, such as Ice Energy, which mainly provides TES systems to commercial and residential customers in California, or Calmac, which develops systems for large skyscrapers and university campuses.

- Case Study: Calmac, "Sarasota County School District," 2014, http://www.calmac.com/energy-storage-case-study-sarasota-school-district

  The Sarasota School District in southern Florida focused on reducing its dependency on fossil fuels, and developed a sustainable solution to off-set their air conditioning loads. An existing air conditioning system that included a chiller plant was retrofit with a thermal energy storage system. The school decided to use Calmac's IceBank thermal energy storage to meet their needs. The storage system required minimal maintenance and was made out of 99% recyclable or reusable materials, and have a lifespan three times longer than a traditional air conditioning system. The system also led to peak shaving, as the school was able to purchase electricity at night when rates were cheaper and store the energy in ice to use for cooling during the day. The success of thermal energy storage in this school led to 36 schools in the school district adopting the same technology.

- Case Study: Calmac, "The Durst Organization chooses IceBank thermal energy storage to reduce energy costs," http://www.calmac.com/energy-storage-case-study-1155-ave-of-theamericas

Thermal energy storage systems, 28 in total, were installed in the basement of the Durst Organization's 790,000 square feet building in Manhattan, New York. These systems were installed to reduce grid dependency and to reduce energy costs for air conditioning. The result is a system that saves on energy costs but also provides the building owners with flexibility during peak hours, which in turn reduces the grid's need to bring on Peaker plants. New York State Energy Research and Development Authority (NYSERDA) awarded The Durst Organization with $280,000 under its Peak Load Reduction program.

- Calmac, "Three top markets for thermal energy storage," July 31, 2015, http://www.calmac.com/energy-storage-article-three-top-markets-for-thermal-energy-storage

  This article explains the target groups that are more appropriate for thermal energy storage applications. The first market is budget-conscious school districts that are interested in cost reductions. Due to the fact that funding for schools varies significantly across the country, there are many districts looking for ways to reduce their energy usage. As such, many turn to thermal energy storage as a strategy to reduce their air conditioning costs. The second market is military clients who value reliability and control. Military bases are more demanding than traditional sectors and need to be operational at all times. These bases need air conditioning systems that reliably operate on all-day schedules. The third market is urban high rises with secure space in basements. Large commercial buildings have large air conditioning loads during peak hours. Thermal energy storage is therefore an adequate solution for those interested in lowering their energy costs. Additionally, since real estate is expensive, buildings with basements are prime candidates for this technology.

- Case Study: Calmac, "McConnell Air Force Base," http://www.calmac.com/mcconnell-air-force-base

  Thermal energy storage systems were installed in two buildings of the McConnell Air Force Base to provide a reliable source of air conditioning for buildings that operate on 24-hour schedules. The system also reduces peak demand charges by shifting the load to the 100% ice storage system. The ice storage system delivers colder air, and therefore also reduces the power used by the fans.

- Case Study: Calmac, "Financial firm shows investment savvy with ice storage installation," August 5, 2014, http://www.calmac.com/energy-storage-articles-financial-firm-investment

  Goldman Sach's Manhattan building uses 92 basement tanks to freeze 1.7 million pounds of energy every night, which reduces peak demand on the grid during the day.

- Case Study: Calmac, "Rockefeller Center," http://www.calmac.com/energy-storage-case-study-rockefeller-center

Rockefeller Center uses thermal energy storage to boost energy efficiency around its massive complex. To relieve the demand on the main chiller plant, a second ice-creating plant was installed that would also be able to provide cooling to the campus. This allowed the main plant to operate at more efficient levels, thereby increasing the efficiency of the entire system.

- Power Magazine, "The Latest in Thermal Energy Storage," July 1, 2017, https://www.powermag.com/the-latest-in-thermal-energy-storage/?pagenum=1

  This is an overview of thermal energy storage system types for the power generation sector. Sensible heat storage, in which a liquid or solid storage medium such as water, rock, or molten salts may be heated or cooled to store energy, is most efficient and cost-effective as thermal storage system for large scale applications that require collected heat to generate heat to drive a turbine to generate electricity.

14. Sources on flow batteries

- Green Tech Media, "Iron Flow Battery Startup ESS Raises $30M From SoftBank and Breakthrough", October 29, 2019 https://www.greentechmedia.com/articles/read/ess-raises-30-million-to-scale-iron-flow-batteries

  This article focuses on a supplier of iron flow batteries. Flow batteries are traditionally made to rely on vanadium. However, vanadium is expensive and toxic, and therefore is not applicable for large energy storage needs in high-density areas. Iron flow batteries are an upcoming alternative that are not as toxic or expensive. ESS is one such supplier that manufactures iron flow batteries. They recently raised $30 million to take their technology from pilot phase to commercial scale. ESS is working with renewable energy producers to discuss potential combinations.

- Science, "New generation of flow batteries could eventually sustain a grid powered by the sun and wind," October 31, 2018, https://www.sciencemag.org/news/2018/10/new-generation-flow-batteries-could-eventually-sustain-grid-powered-sun-and-wind

  This article focuses on the technical potential of flow batteries. It reiterates the same point as other sources that mention the benefits of iron flow batteries and organic compound flow batteries over vanadium flow batteries. It also speaks to the advantage flow batteries over lithium-ion when it comes to providing large back-up power in congested cities.

- ESS, "The ESS Energy Warehouse," https://www.essinc.com/energy-storage-products/

This is a promotional webpage from a flow battery manufacturer's website, focusing on the technology that ESS uses in its iron flow battery systems. The battery is non-toxic, non-hazardous, and recyclable. It is stated to provide 20,000 power cycles with almost no maintenance, and the flexibility in energy management.

- C&R Technologies, "From Cell to Stack to System," https://www.crtech.com/applications/flow-battery

  This article dives into the technical potential of flow batteries. It highlights that these batteries can be used for various applications, such as peak shaving, peak shifting, and emergency backup for residential and commercial buildings. The article then goes into detail of the physical apparatus that makes up a traditional flow battery.

15. Lithium-Ion battery system sources and case studies

- Tesla, "Powerpack," https://www.tesla.com/powerpack

  This is Tesla's product page for its large-scale energy storage battery, the Powerpack. The page mentions that the battery is mainly used by utilities and businesses for peak shaving, load shifting, emergency backup, and demand response. The battery is also built for microgrid and renewable energy integration. The Powerpack is also capable of ancillary services, transmission and distribution support, and has a scalable design.

  Tesla promotes the Powerpack as not just a battery, but an all-in-one solution. It comes with a battery, a thermal control system, environmental protection, and an AC connection.

- Business Insider, "Tesla's massive batteries are powering everything from exotic islands to breweries," October 4, 2017, https://www.businessinsider.com/tesla-powerpack-uses-2017-7

  This article is focused on Tesla's Powerpack product. It promotes the Powerpack's features and provides a large number of case studies, domestic and international, that incorporate the Powerpack. These case studies focus on various applications, ranging from single buildings to microgrids for islands. Three main standout examples include Tesla's projects for Southern California Edison, La Crema Winery, and Ocracoke Island.

- Case Study: Mira Loma Substation. Green Tech Media, "Tesla, Greensmith, AES Deploy Aliso Canyon Battery Storage in Record Time," January 31, 2017, https://www.greentechmedia.com/articles/read/aliso-canyon-emergency-batteries-officially-up-and-running-from-tesla-green

Tesla Powerpacks were installed in the Mira Loma substation and in 2017 was the largest lithium ion battery storage project. The system improved grid reliability by taking on demands during off-peak hours, thereby reducing the demand placed directly on the grid. This project was undertaken as a risk-reducing measure after the catastrophic natural gas leak in Aliso Canyon, a critical failure point in the grid.

- Case Study: La Crema Winery. Fortune, "Why this winery is using a bunch of Tesla batteries," June 26, 2015, https://fortune.com/2015/06/26/winery-tesla-batteries/

  La Crema Winery in Windsor, California is part of the Jackson Family Wines brand. Six wineries in the family bought $10 million worth of solar panels, along with Tesla Powerpacks to store all that energy. The payback period for all six wineries is expected to be just under six years. Tesla Powerpacks, along with the Tesla algorithm, shift the winery off of grid usage during peak hours, thereby reducing grid dependency and electricity costs.

- Case Study: Ocracoke Island. Mother Nature Network, "Ocracoke Island goes local for more innovative, reliable energy," https://www.mnn.com/earth-matters/energy/sponsorstory/ocracoke-island-goes-local-more-innovative-reliable-energy

  Ocracoke Island in Outer Banks, North Carolina is especially vulnerable to hurricanes and storms. The fact that the island has minimal connections to the mainland grid, and the fact that diesel for its backup generator needs to be shipped to the island make matters worse. As such, the island decided to set up its first microgrid, in which some of the diesel power was substituted with a 15 kW solar array and Tesla Powerpacks with a capacity of 1 MWh. Ocracoke is one of North Carolina's first microgrids and serves as a pilot project for the technology.

- Sandbar, "7 Top Benefits of Commercial Battery Backup Systems," June 26, 2019, https://sandbarsc.com/news/benefits-commercial-battery-backup-systems/

  This article outlines the most significant ways how battery systems can benefit businesses. From an economic standpoint, batteries tied to rooftop solar can reduce demand charge by peak shaving. This leads to higher return on investment than if the two technologies were implemented separately. The following few benefits focused around energy security. Batteries can shield businesses from the risks associated with power outages, provide backup power, and improve a building's overall resiliency. Taking it a step further, batteries and renewable energy allow businesses to go entirely off the grid, if they choose, and create a better public image by portraying themselves as an energy-conscious entity.

- Interview, Tim Effio, Fluence (AES + Siemens li-ion batteries), November 22, 2019

Fluence's li-ion phosphate technology services large office buildings around the globe, as the largest energy storage integrator in world. Local large scale deployments include Siemens load centers. According to Effio, in a state like Virginia where there are no incentives nor a carbon tax, adopters of this technology do so because of corporate and institutional commitments to carbon reduction. Cost varies depending on two factors: (1) how big is the needed system – how much power does it supply; (2) discharge capacity / duration, in hours. Comparing conventional backup generation systems with Fluence's li-ion systems, the footprint – size of area needed for either system – is about the same for a 3MW energy storage system.

- Case Study: Fluence, "AES Breaks Ground on 400 MWh Energy Storage Project in Southern California", June 27, 2019, https://blog.fluenceenergy.com/energy-storage-aes-alamitos-california

  This article is about an upcoming project in Southern California where AES is moving install 400 MWh energy storage capacity as part of a modernization and replacement of the AES Alamitos Generating Station. The project will help accommodate renewable energy technologies to meet the state's climate action plan of 100 percent clean energy by 2045. The project is expected to be completed by the end of 2020 and will contribute between $12.3 and $14.6 million annually to the local economy.

- Forbes, "Three Ways Energy Storage Can Generate Revenue in America's Organized Power Markets," June 27, 2018, https://www.forbes.com/sites/energyinnovation/2018/06/27/three-ways-energy-storage-can-generate-revenue-in-americas-organized-power-markets/#4d5e879d5503

  This article focuses entirely on the economics of energy storage. At a high-level, it proposes that energy storage systems can collect revenue through platforms, products, and pay-day business models. The article dives deeper into each business model and its limitations.

  In the platforms method, energy storage systems are thought of as reliability assists. As such, energy storage plays a similar role to transmission, and ideally should reap the same revenue streams as reliable transmission systems. However, independent system operators (ISO's) are currently hesitant to follow this model, because if they manage energy storage systems, that means they need to manage when to buy and sell power from the system. This will invariable affect energy prices and might cause the ISO to seem partial. The workaround is to conduct transparent cost-benefit analyses to understand when and where it is best to procure and send energy.

  In the product business model, the energy storage system is located in a technology-neutral location and only generates revenue when called upon by the grid. Some limitations with this model revolve around the idea that much of this market and business model was designed before renewables and energy storage were introduced, and as such, the benefits of these technologies are economically downplayed, such as their ability to lower emissions.

In the pay-day model, energy storage systems compete directly in energy markets by buying low and selling high. When connected to the grid managed by the ISO, the energy storage system can procure energy at times when energy demand is low, according to ISO trends, and then sell the energy when a spike occurs. The closer the energy storage system operates to a real time market, and the higher the power ratio, the more revenue can be generated.

- Energy Storage Association, "Uninterruptible Power Systems," May 24, 2013, https://energystorage.org/uninterruptible-power-systems/

  An Uninterruptible Power Supply (UPS) is an energy storage system that reduces the risks associated with power outages. There are two types of UPS energy storage durations during a power outage. UPS with shorter durations are only meant to provide electricity to critical systems until a backup generator kicks on, usually powered by natural gas or diesel. The purpose of these systems is solely to maintain a stable current so that reliant systems are not damaged by an abrupt electrical outage. Longer duration UPS that can provide continuous power to all systems until the grid comes back online are few and far in between. This is mainly due to the cost, compared to the cheap rates for diesel.

16. Hydrogen fuel cell sources

- Whole Building Design Guide, "Fuel Cells and Renewable Hydrogen," October 21, 2016, https://www.wbdg.org/resources/fuel-cells-and-renewable-hydrogen

  Fuel cells are electrochemical devices that run on oxygen and a domestic resource and are similar to batteries but are replenished instead of recharged. One advantage to fuel cells is that they can work with multiple resources, including natural gas, biomass, and water electrolysis. Water electrolysis can generate hydrogen by splitting water molecules into hydrogen and oxygen, and when paired with renewable technologies can provide clean energy generation and storage.

- U.S. Department of Energy, "Energy 101: Fuel Cell Technology," https://www.energy.gov/eere/videos/energy-101-fuel-cell-technology

  The Department of Energy's website provides a brief overview of fuel cell technologies in the form of a video with an accompanying transcript. Fuel cells provide critical backup energy for facilities, and primary energy in some cases. Fuel cells are also used for transportation and residential sections. The technology uses hydrogen and oxygen, and exhausts water. In the apparatus, hydrogen enters through one end, and oxygen enters through another. As the hydrogen is attracted to the oxygen, it passes through the fuel, generating an electrical current. Individual fuel cells are stackable and therefore easy to scale. Hydrogen is an energy carrier, which means energy from another source can be used to generate hydrogen. Hydrogen then carries the energy needed to generate the hydrogen to begin with.

- Medium, “Hydrogen: the building block of an all new energy industry,” March 1 2019, https://medium.com/@cH2ange/hydrogen-the-building-block-of-an-all-new-energy-industry-39ec03ba5b86

  This article focuses on fuel cells in transportation and begins with mentioning the California Fuel Cell Partnership, which began as an experiment to test the possibility of creating a hydrogen fuel cell, zero-emission vehicle. Currently, Fuel Cell Partnership is a venture of automakers, energy companies, and governments at all levels.