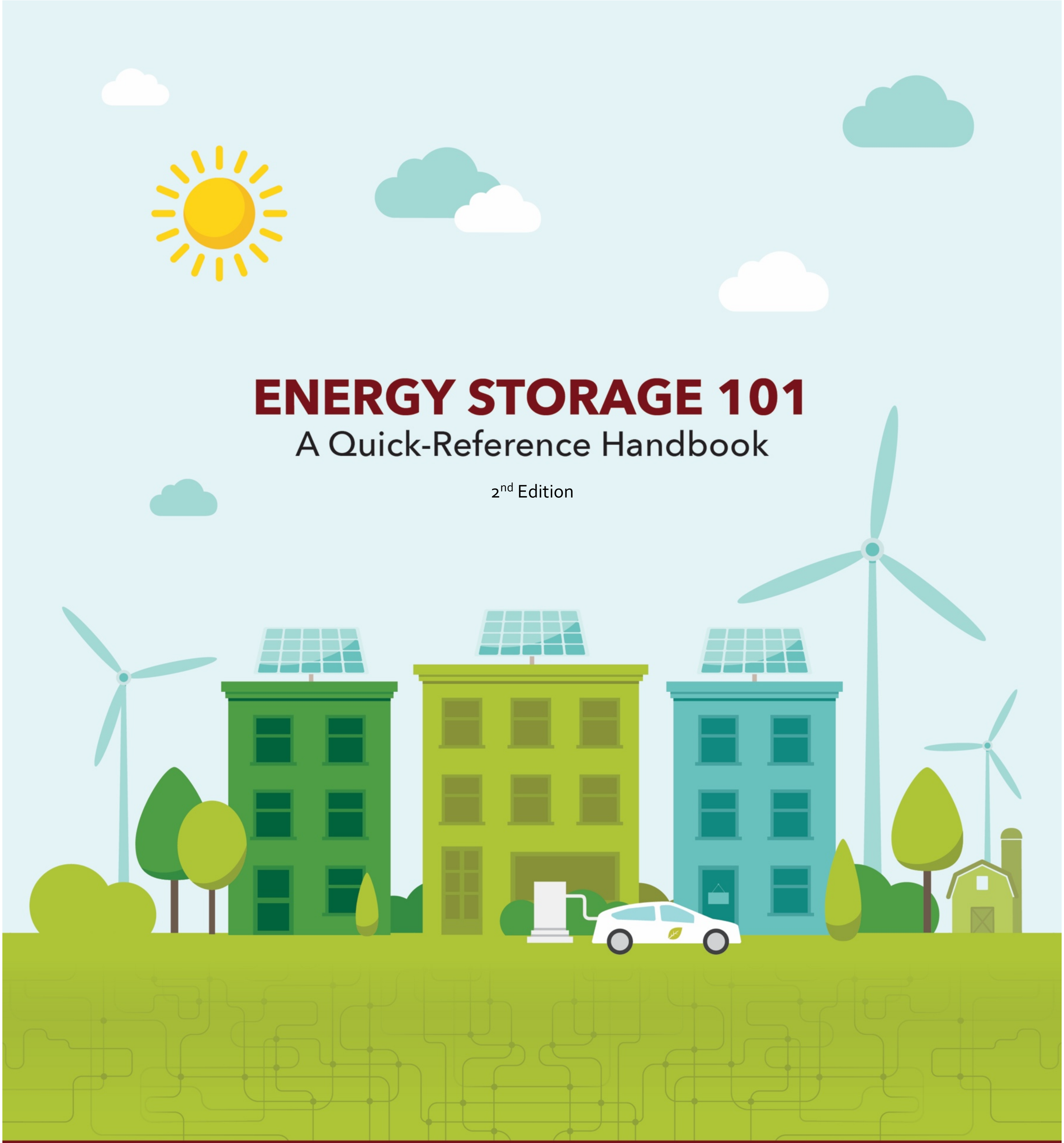

ENERGY STORAGE 101

A Quick-Reference Handbook

2nd Edition

ENERGY TRANSITION LAB
INSTITUTE ON THE ENVIRONMENT

UNIVERSITY OF MINNESOTA
Driven to Discover℠

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Introduction to Energy Storage

Energy storage has the potential to transform the energy landscape across the United States.
By storing energy, electricity can be redistributed from times of the day during which a surplus of energy can be generated to times of high energy demand. In the absence of storage, excess energy production may be curtailed,[1] while high demand necessitates the use of expensive gas-fired peaking plants that only are active for a few hours each year. Wide implementation of energy storage may smooth out the energy demand curve, reduce the need for peaking plants, bring about significant resiliency benefits, reduce carbon emissions, and result in an overall reduction in costs.

Energy storage has been experiencing a dramatic increase in deployment, and this trend is likely to continue for the foreseeable future. In fact, various forms of energy storage are already in use in a multitude of states across the country. Currently, pumped storage, or storage that relies on pumped water to harness potential energy, has by far the highest capacity of stored energy across the country, but other technologies have begun to catch up.

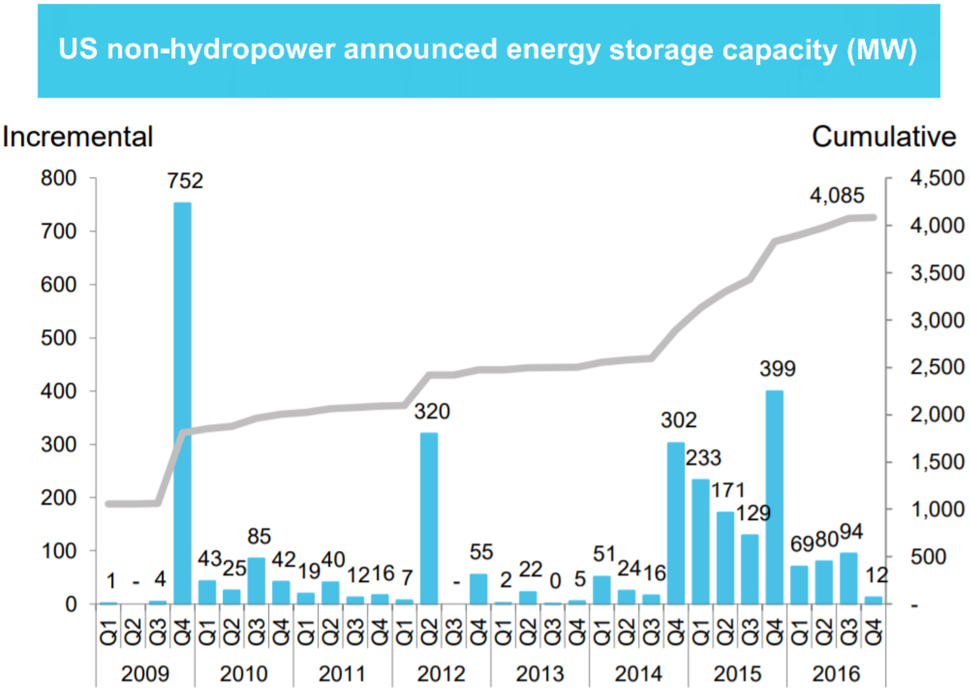

Image source: Bloomberg Finance L.P. and The Business Council for Sustainable Energy, 2017 Sustainable Energy in America Factbook (2017).

Types of Energy Storage

Batteries are probably the most widely-known form of energy storage, and make up an essential part of the industry, particularly when it comes to electric vehicles and integrating and adding value to variable renewable sources like wind and solar. But energy storage is so much more than the latest advancement in

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[1] A reduction in energy delivery due to high demand, essentially discarding the energy (see glossary).

lithium battery technology – from pumped hydro to magnetic fields, energy can be stored in a multitude of ways and put to a wide variety of uses.[2]

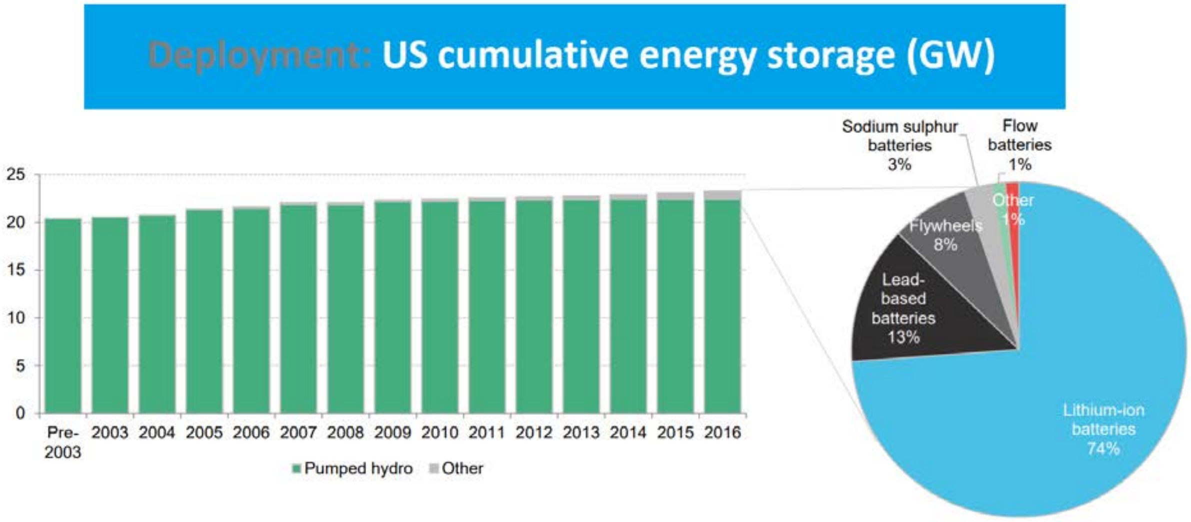

Image source: Bloomberg Finance L.P. and The Business Council for Sustainable Energy, 2017 Sustainable Energy in America Factbook (2017).

In broad terms, four families of energy storage populate today's market: chemical, thermal, mechanical, and electrical.

Chemical

Chemical storage includes such well-known technologies as dry cell batteries (for example, Duracell and Tesla) and traditional fuels (gasoline is a convenient form of stored energy). It also includes less traditional battery and fuel technologies, such as flow batteries, fuel cells, and hydrogen fuel. These forms of energy storage are valued for both their versatility and portability. Batteries can range in scale from smaller than a bacterium to as large as a house, and can be used individually or connected to form great battery banks that store a significant amount of energy. Fuels, especially liquid fuels, are easily transported and stored so that their energy is available where and when it is needed. Flow batteries and fuel cells essentially combine the two, resulting in batteries with nearly unlimited useful lives that can also be recharged quickly. Common issues with chemical energy storage include the costs of scaling up, as well as efficiency and capacity limitations inherent in the technology in use today.

Flow batteries promise to be one of the main chemical storage technologies of the future. Though their deployment as is still relatively new, flow batteries provide several significant advantages on the energy storage landscape, since they can be relatively low cost, rechargeable, have long lifetimes, and can be scaled up to store greater amounts of energy.[3]

Electrolytes are chemicals that conduct electricity and are used in batteries to allow current to flow, while

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[2] Energy Storage Association, *Energy Storage Technologies*, http://energystorage.org/energy-storage/energy-storage-technologies.

[3] Energy Storage Association, *Flow Batteries* (2017), http://energystorage.org/energy-storage/storage-technology-comparisons/flow-batteries.

electrodes are metal portions of the battery with either positive or negative charges. In conventional batteries, the energy is stored within the electrodes, but flow batteries store their energy within the electrolyte material. This represents the fundamental difference between conventional batteries and flow batteries, and explains some of the advantages of flow batteries.[4] After conventional batteries have been discharged, the electrodes are often irreversibly altered, resulting in relatively short lifetimes. However, since flow batteries store their energy within the electrolyte material, they can simply be recharged by reversing the electrical flow, resulting in extremely long lifetimes. Furthermore, flow batteries can be scaled up to store additional energy simply by increasing the size of the external tanks. By increasing the size of the external tanks indefinitely, flow batteries can store a seemingly limitless amount of energy. Additionally, flow batteries are less likely to cause fires since they are made of nonflammable liquid solution.

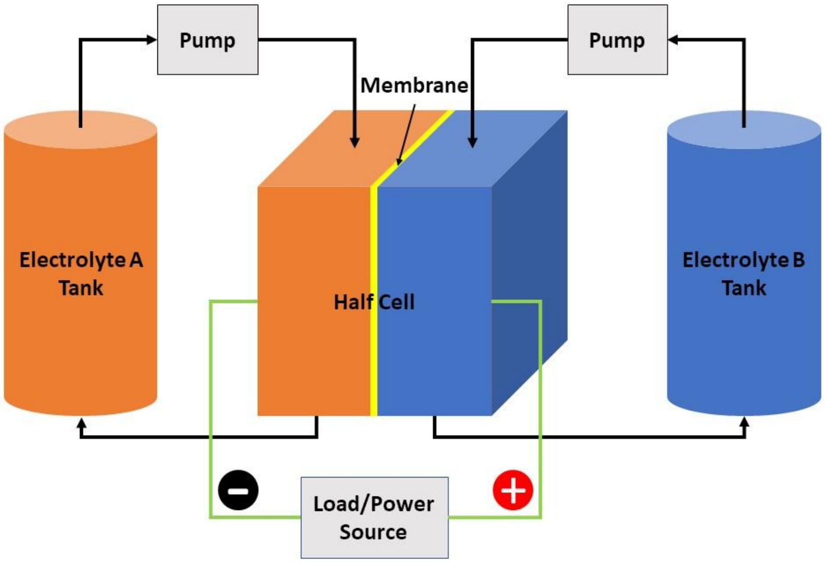

Illustration of a flow battery created by Max Foster, Energy Transition Lab, University of Minnesota's Institute on the Environment (2017).

One significant disadvantage of flow batteries, however, is that they have relatively low energy density. Flow batteries storing substantial amounts of energy are both large and heavy, rendering them unsuitable for mobile use. Nevertheless, flow batteries may soon become one of the most cost-effective forms of grid scale energy storage.[5] The most common types of flow batteries use some combination of either vanadium, iron, zinc, or chromium as the electrolytes. While some of these metals, especially iron, are relatively common and inexpensive, scarcity of metals could present an issue with large scale flow battery deployment. However, flow batteries made from nonmetal organic materials that would be even cheaper are being developed. Such nonmetal flow batteries could have extended lifetimes and, since their

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[4] Energy Storage Association, *Redox Flow Batteries* (2017), http://energystorage.org/energy-storage/technologies/redox-flow-batteries.

[5] Julian Spector, GREENTECH MEDIA, *Can a Flow Battery Steal the Throne From TEP's 4.5-Cent Solar-Plus-Storage PPA?*, https://www.greentechmedia.com/articles/read/can-a-flow-battery-beat-that-record-breaking-tep-solar-plus-storage-ppa (Jul. 19, 2017).

electrolytes are common, could help flow batteries become a common resource.[6]

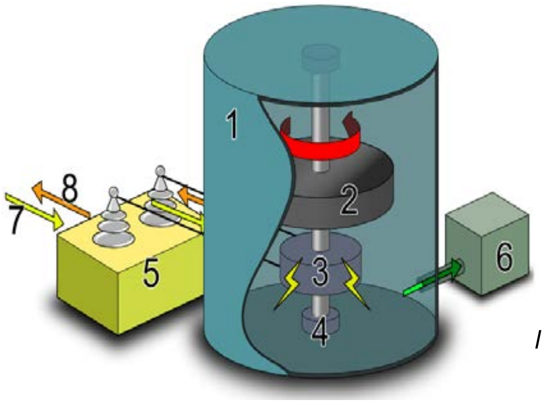
Thermal

Thermal storage is already commonly available. There's a program in Minnesota employing over a gigawatt-hour of energy storage every night.[7] It works by distributing large-capacity, well-insulated electric water heaters to residents and then giving them a discount for allowing the utility to heat the water only when energy is plentiful. The electricity from the grid is then stored as heat, which the customer makes use of throughout the day. This kind of storage works with water, sand, gravel, ceramics, and even molten salt, a popular grid-scale option. Additionally, the heat can be stored through a phase change, such as freezing water to ice at night when electricity is inexpensive, to be used for space cooling the following day.[8]

Mechanical

Mechanical energy storage, which often makes use of gravitational potential energy, is deceptively simple. It generally involves moving a solid or a liquid (or compressing a gas) when energy supply is high, and allowing it to return (or decompress) when demand is high. Pumped hydro is the largest form of energy storage in the United States, accounting for over 94% of grid-scale projects as of 2016.[9] Water is pumped behind a dam using electricity when prices are low, and then allowed to flow through the turbines to generate electricity for the grid when demand pushes prices up. By using large underground caverns, compressed air works similarly. One energy services corporation even uses rail cars loaded with gravel to accomplish grid-scale storage – electricity drives the heavy train cars uphill, and gravity pulls them back down. Work is currently underway to improve the efficiency of many of these technologies.

One highly specialized use of mechanical energy storage comes in the form of flywheels. Flywheels are large, heavy cylinders that spin in near frictionless environments. Large banks of such flywheels provide grid stabilization services in much the same way as other forms of mechanical energy, but for very different purposes. Energy is stored as kinetic energy as the cylinders are sped up to over 50,000 rpm; when rapid



Flywheel Battery

1. Case
2. Flywheel (Rotor)
3. Generator/Motor
4. Bearing
5. Inverter
6. Vacuum Pump
7. Charge
8. Discharge

Image source: Tosaka (CC BY 3.0), Flywheel-battery (Model), via Wikimedia Commons.

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[6] B. Huskinson, et al. "A Metal-Free Organic-Inorganis Aqueous Flow Battery" *Nature*, vol. 505, no. 7482, 9 Jan. 2014, pp. 195-198., doi:10.1038/nature12909M3.

[7] Great River News, Co-ops Push Back on Water Heater Issues (Jan. 2013).

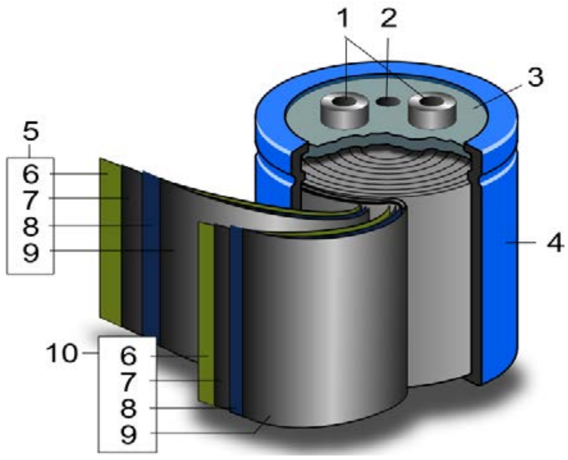
[8] International Renewable Energy Agency, *Thermal Energy Storage: Technology Brief* (Jan. 2013).

[9] Center for Sustainable Systems, University of Michigan, *U.S. Energy Storage Factsheet* (2016).

fluctuations in the balance of generation and load on the grid work to destabilize the system, the energy from the flywheels can be harvested very quickly to offset these fluctuations, maintaining system stability and power quality.[10]

Electrical

Finally, electricity can be stored directly by using electromagnetic fields, capacitors and supercapacitors. Outside of their specialized uses in advanced electronics, these forms of storage are best suited to grid stabilization and power quality purposes.



Wound Supercapacitor

1. Terminals
2. Safety vent
3. Sealing disc
4. Aluminum can
6. Separator
7. Carbon electrode
8. Collector
9. Carbon

Image source: Tosaka (CC BY 3.0), Electric double-layer capacitor, via Wikimedia Commons.

The many types of energy storage vary not only by cost, but also by power capacity and discharge times.

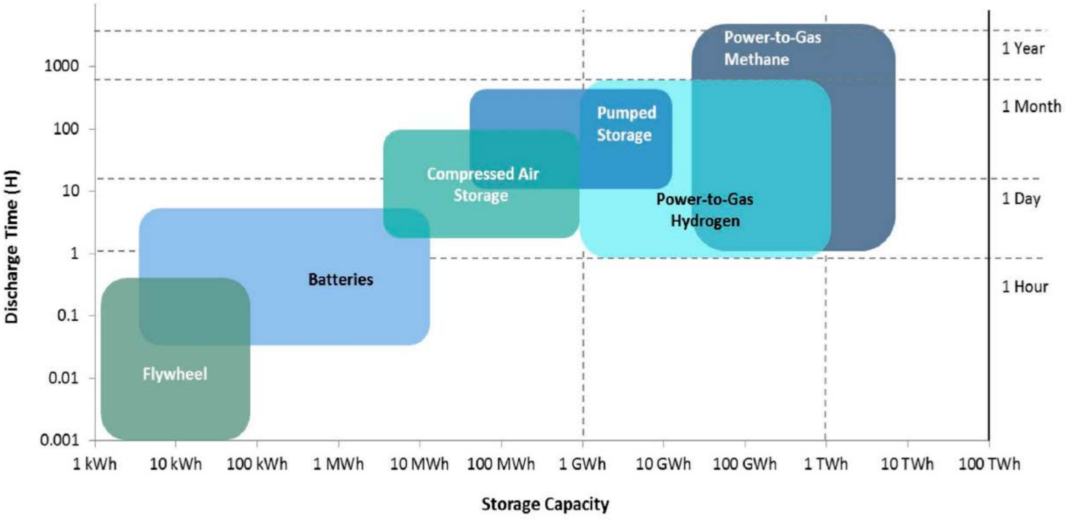


Image source: Jason Moore and Bahman Shabani, A Critical Study of Energy Storage Policies in Australia in an International Context: The Role of Hydrogen and Battery Technologies, published in Energies (2016).

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[10] Energy Storage Association, *Flywheels* (2015), http://energystorage.org.

Uses for Energy Storage

Storage is an integral part of a smarter grid. Energy storage will allow the modern grid to be more flexible, able to integrate large amounts of distributed energy generation, and more efficient. Storage has the potential to bring significant benefits to the grid beyond simply storing electric energy for later use. Integration of the electric grid with complementary systems (thermal energy, electric vehicles, etc.) allows storage to serve many useful functions at the transmission, distribution and customer scales:

"

> · Managing Supply and Demand – energy customers [on demand-based rates] can reduce their bills by shifting energy use to low demand periods or by reducing their maximum energy use in a given month. Energy storage can cost-effectively supply capacity and backup power that has historically been provided by expensive quick response "peaking" fossil fuel power plants.
>
> · Reinforcing Infrastructure – power lines, transformers and other grid infrastructure wear more quickly when operating at peak capacity. Energy storage can shift energy demand to ease stress on expensive equipment, [as well as avoid expensive equipment upgrades to manage points of congestion in the grid.]
>
> · Supporting Renewable Energy – [...] Energy storage responds quickly and effectively to variations in renewable energy output, enabling [cost-effective integration of] penetrations of wind and solar on the electric grid [in excess of 50%].
>
> · Delivering Ancillary Services – at every moment supply and demand of electricity must be in balance. Energy storage can respond more quickly than most existing technologies, helping maintain the voltage and frequency of the electricity system to avoid damage to connected electronics and motors, and avoid power outages.[11]

"

Ancillary Services

Various types of energy generation sell the benefits of the services they provide to the grid through energy markets where they are available. Some of the ancillary services that storage can provide in a modernized grid include:

"

> · *Load Following/Ramping*: Load following is the matching of generation to load as it fluctuates during the day. Historically the market for this service required the device be capable of altering its power output as frequently as every five minutes, however recent standards now also allow for markets with some resources responding in seconds. The output changes in response to the changing balance between electric supply and load within a specific region or area. Load following is a particularly valuable service that storage can provide as the system accommodates greater

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[11] John Farrell, Institute for Local Self-Reliance, Energy Storage: The Next Charge for Distributed Energy (Mar. 2014), used with permission.

> amounts of variable generation. Storage has the ability to respond within seconds, which makes its service particularly valuable. It may also reduce the wear-and-tear associated with using traditional generators for this service.
>
> · *Electric Supply Reserve Capacity*: Operation of an electric grid requires reserve capacity that can be called upon when some portion of the normal electric supply resources becomes unavailable unexpectedly. There are three types of reserve: spinning reserve (synchronized), non-spinning reserve (non-synchronized), and supplemental reserve.[12] When serving as electric supply reserve capacity, storage cannot typically serve other applications simultaneously.
>
> · *Voltage Regulation/Support*: The purpose of voltage support is to maintain voltage levels on the electric system by providing or absorbing reactive power or through the use of voltage tap changers that mechanically adjust voltage. The provision and absorption of reactive power is an application for which distributed storage may be especially attractive, because reactive power cannot be transmitted efficaciously over long distances. Notably, many major power outages are at least partially attributable to problems related to transmitting reactive power to load centers. So, distributed storage – located within load centers where need for reactive power is greatest – can be especially helpful in managing voltage.[13]
>
> "

Unfortunately, not all energy markets will allow energy storage to bid for these services. New business models and market rules will be needed to reward these services and outcomes. Rate and pricing reforms, like time of use rates, are needed to enable grid innovation.

Power to X

When our energy systems begin to merge electricity and thermal energy management, they can become far more efficient and versatile. In Germany, for example, "Power to *X*" refers to the idea of converting excess electricity produced by wind and sun to another useful, storable energy product (for example, fuel for your vehicle).[14]

The University of Minnesota Morris has created a similar program. Its West Central Research and Outreach Center constructed a "wind to hydrogen to ammonia plant," effectively storing excess wind energy as hydrogen. By converting wind energy to hydrogen and to nutrient-rich ammonia, the plant envisions a system in which farmers capture wind energy and simultaneously fertilize their crops.[15] Thus, energy storage

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[12] Spinning reserve: on-line generation capacity that can respond within ten minutes to electricity shortages. Non-spinning reserve: generation capacity that is off-line but can be brought on-line within ten minutes.

[13] Sky Stanfield & Amanda Vanega, Interstate Renewable Energy Council, Deploying Distributed Energy Storage: Near-Term Regulatory Considerations to Maximize Benefits 16 (Feb. 2015), used with permission.

[14] Daniel Fürstenwerth & Lars Waldmann, Agora Energiewende, *Electricity Storage in the German Energy Transition* (Dec. 2014).

[15] West Central Research & Outreach Center, *Renewable Energy Program* (2013), https://wcroc.cfans.umn.edu/sites/wcroc.cfans.umn.edu/files/Renewable%20Hydrogen%20and%20Ammonia%20Pilot%20FINAL%207-9-13.pdf.

may have implications not only for the electric grid, but also for farming.

Renewable Integration

While energy storage can add value to renewable energy generation, the transmission grid does not necessarily need additional storage to accommodate near-term growth of renewables. Solar and wind tend to have a complementary relationship, and the distribution of renewable sources geographically reduces the impact of localized weather disturbances on overall generation. A recent engineering study published by the Minnesota Department of Commerce concludes that Minnesota's current power system, with transmission upgrades, could handle up to forty percent wind and solar without impacting reliability – even if no additional storage is added.[16] Rather, the growth of energy storage could help to push beyond these limits to very high renewable energy levels, accelerate decarbonization of the grid, maintain the stability and affordability of the electric grid, and enable the growth of innovative community-based solutions like microgrids.[17] [18]

Microgrids

Microgrids are miniature local grids that can be disconnected from the larger electric grid in times of emergency or system outages while using their own generating capacities to continue to serve local loads. Their ability to operate autonomously improves grid resilience. Additionally, since microgrids often serve only their local loads, they can help minimize energy losses resulting from long-range transmission. Similarly, due to their short-range nature, microgrids allow for faster system response times, yet another efficiency improvement.

One of the main benefits of microgrids is the added resiliency that they provide. Resiliency benefits can be difficult to quantify, so one way of examining potential resiliency benefits is by looking at costs of power outages in the grid. One use-case analysis presented in Massachusetts' State of Charge report estimates the total cost of a city-wide power outage in Boston. This analysis finds that the costs of outages can be exceptionally high, especially for small commercial and industrial customers, a group that is unlikely to have access to backup power sources on site. In particular, the analysis finds that the citywide cost of an hour-long power outage in Boston may exceed $86 million.[19] This demonstrates how devastatingly costly blackouts can be and emphasizes the potential benefit that resilient microgrids can provide.

In Duluth, MN, the Hartley Nature Center (HNC) decided to install an energy storage system as part of an energy system upgrade to increase their building's resilience. Shortly before deciding to install the energy storage system, the entire City of Duluth lost power for six days after an extreme weather event and HNC

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[16] GE Energy Consulting et al., *Minnesota Renewable Energy Integration and Transmission Study* (Prepared for Minn. Utils. & Transmission Cos. and Minn. Dep't of Commerce, Oct. 2014).

[17] Energy Transition Lab, Modernizing Minnesota's Grid: An Economic Analysis of Energy Storage Opportunities, http://energytransition.umn.edu/wp-content/uploads/2017/07/Workshop-Report-Final.pdf (Jul. 11, 2017).

[18] John Farrell, *supra* note 11.

[19] Massachusetts Department of Energy Resources, *State of Charge: Massachusetts Energy Storage Initiative* (2016), http://www.mass.gov/eea/docs/doer/state-of-charge-report.pdf.

was forced to cancel a week of youth camps, which generate "a large part of their revenue for the year."[20]

Microgrids and energy storage are highly compatible. While disconnected from the larger grid, or operating as an island, microgrids either must rely on their own generating capacities or on previously stored energy. Since energy storage is not dependent on momentary generating ability (this especially includes wind and solar-related weather patterns for renewable sources of energy), storage-based microgrids can often be more reliable, especially over time periods under four hours. However, as storage technology continues to develop, microgrids will likely begin to rely on Long Duration Storage (LDS) technologies, especially on flow batteries.[21]

Policy, Regulatory and Market Drivers

Storage has many intriguing possibilities for improving energy systems, but these vary significantly in cost-effectiveness, and are not all cost-effective strategies.[22] Nevertheless, many are decreasing in cost over time.

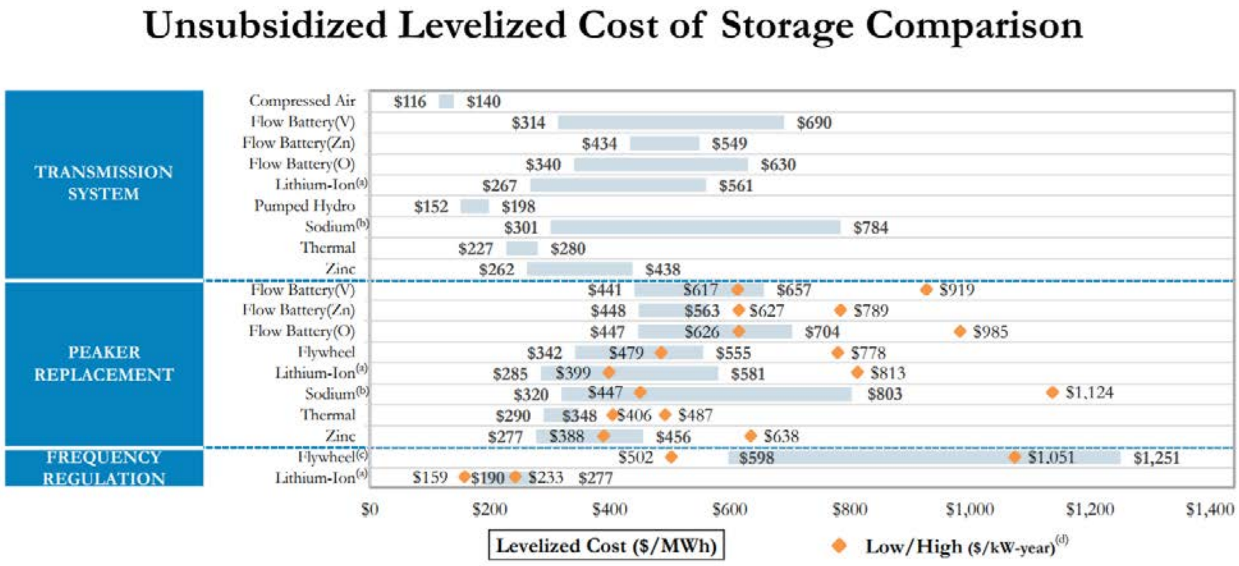

Image source: Lazard, Levelized Cost of Storage Version 2.0 (2016).

Policy goals that could be considered in storage deployment are whether its use:

· Is Cost-effective

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[20] Sarah Galbraith, Clean Energy Group, *Resilient Power Project Case Study: Hartley Nature Center*, http://www.cleanegroup.org/wp-content/uploads/Hartley-Nature-Center-Case-Study.pdf (Aug. 2017).

[21] Energy Storage Systems Inc., *Beyond Four Hours* (2016), http://www.essinc.com/wp-content/uploads/2016/11/Beyond-Four-Hours_ESS-Inc-White-Paper_12_2016_mr.pdf.

[22] Bentham Paulos, GreenTech Media, *Why You Should Question the Value Proposition of Energy Storage*, http://www.greentechmedia.com/articles/read/questioning-the-value-proposition-of-energy-storage (Oct. 17, 2014).

· Reduces Greenhouse Gases

· Adds value to renewable generation (e.g., as an alternative to curtailment, smoothing variable production, making renewable energy dispatchable, extending hours of self-generation)

· Strengthens the grid (ancillary services, etc.)

· Reduces cost of energy to ratepayers

· Allows energy independence (microgrids, off-the-grid systems)

· Increases resiliency (back-up or islanded power for critical infrastructure or vulnerable populations)

· Enables other valuable innovations (e.g., electrification of transportation)

Policy or regulatory incentives should be tailored to meet public policy goals such as these, but should allow for a variety of technology platforms. Policymakers and regulators need to determine the real value of storage, and create market mechanisms to monetize that value, in order to prepare for a rapidly emerging future with very high levels of renewable energy, carbon constraints, and smart technology.

Energy storage is a unique hybrid in that it can both save energy and supply energy, and it can be used at the customer, distribution, or utility scale—so conventional laws and rules may not fit well.[23] Depending on whether a storage resource provides services that act like a generation, transmission, or distribution asset, the governing jurisdiction and cost-recovery rules will vary.[24] State regulators (Public Utilities Commissions) or the Federal Regulatory Energy Commission (FERC) may govern the three levels at which storage is deployed. Regional transmission organizations (RTOs/ISOs) also set market-based rules that determine dispatch order of different resources. Getting the rules right is complicated, and regulations will continue to evolve.

Potential policies that could be used to support the growth of the energy storage industry include tax incentives and energy storage capacity minimums. Energy storage tax incentives would give commercial and residential users of energy storage tax credits for procuring storage, while a capacity minimum would typically mandate that utilities procure at least a specified amount of storage by a given date. However, creating such laws could be complicated, as there are many forms of energy storage, and lawmakers would have to decide what exactly constitutes an energy storage device.[25]

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[23] Penelope Crossley, *Defining the Greatest Legal and Policy Obstacle to 'Energy Storage'*, 2013 Renewable Energy L. & Pol'Y Rev., no. 4, 2014, at 268.

[24] Amy L. Stein, Reconsidering Regulatory Uncertainty: Making a Case for Energy Storage, 41 Fla. St. U. L. Rev. 697 (2014).

[25] Community Choice Aggregations (CCAs) may also encourage energy storage procurement and renewable integration. CCAs allow local governments to aggregate their communities' electricity demands and buy and sometimes develop power which IOUs then distribute to individuals served by the CCA. Since CCAs often are already helping meet renewable energy goals, one possibility is to allow CCAs to have lower minimums for energy storage capacity than utilities; Sean F. Kennedy, *'Greening' the Mix through Community Choice* (2017), https://www.ioes.ucla.edu/wp-content/uploads/Community-Choice-Aggregation_final-June-2017.pdf.

If policies can be developed to support effective deployment of energy storage, then the energy storage sector will boom, supporting thousands of new jobs, especially at the utility level. The American Jobs Report estimates that in Illinois, for example, an expanding energy storage industry may support over 3,150 utility-scale energy storage jobs through 2030.26 Similar results can be expected for other states that have the potential to support an energy storage market. As a side effect, such a job boom would stimulate the economy as earnings from new jobs could be spent within the local economy.

State Policies to Procure Storage

California

A number of policies are being constructed and implemented by state legislatures, ISOs and RTOs, and the federal government to address the regulatory and economic issues in energy storage.[27] California has led the nation in energy storage policy and regulatory incentives.[28] Under AB 2514, the California Public Utilities Commission set a utility procurement target of 1.325 gigawatts of cost-effective energy storage systems by 2020.[29] At the distribution level, advanced energy storage projects are eligible for an incentive payment per kWh under the Self-Generation Incentive Program, which supports customer-side generation.[30] Other states are promoting storage with grants and incentives, demonstration and pilot projects, and procurement targets.[31]

Oregon

In 2015, Oregon became the second state after California to pass an energy storage mandate. The mandate stipulates that all electric companies selling energy to 25,000 or more retail consumers in Oregon must

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[26] The American Jobs Project, *The Illinois Jobs Project: A Guide to Creating Jobs in Utility-Scale Batteries* (2017), http://americanjobsproject.us/wp-content/uploads/2017/05/IL-Jobs-Project-Cited-Report.pdf.

[27] Sky Stanfield & Amanda Vanega; Mike Munsell, Green Tech Media, *GTM Research: 5 States Where Energy Storage Could Thrive*, http://www.greentechmedia.com/articles/read/GTM-Research-5-States-Where-Energy-Storage-Could-Thrive (June 3, 2015); Thomas J. Dougherty, National Law Review, *Will 2015 Be 'Just Right' For Energy Storage?* (Jan. 22, 2015); Shelley Welton, Sabin Center for Climate Change Law, Columbia Law School, Climate Law Blog, *California Creates First State Energy Storage Mandate* (Oct. 19, 2013).

[28] California ISO, *Advancing and Maximizing the Value of Energy Storage Technology: A California Roadmap* (Dec. 2014), *available at* http://www.caiso.com/Documents/Advancing-MaximizingValueofEnergyStorageTechnology_CaliforniaRoadmap.pdf.

[29] Melicia Charles, Cal. Pub. Utils. Comm'n, *California's Energy Storage Mandate: Electricity Advisory Committee Meeting* (June 17, 2014), *available at* http://energy.gov/sites/prod/files/2014/06/f17/EACJune2014-3Charles.pdf.

[30] Energy.gov, *Self-Generation Incentive Program*, http://energy.gov/savings/self-generation-incentive-program (last visited August 3, 2017).

[31] Mike Munsell, *supra* note 26.

procure energy storage systems with a capacity of at least 5 MW by the year 2020.[32]

Massachusetts

Massachusetts is another state that is on the forefront of energy storage policy and deployment. Economic modeling done in Massachusetts suggests that the installation of 600 MW of energy storage by 2025 could result in cost savings of $800 million. Furthermore, the modeling shows that a more aggressive target of 1766 MW of storage by 2020 would lead to a total value of storage of $3.4 billion over ten years.[33]

In the Massachusetts modeling, the optimized storage target of 1766 MW results in $2.3 billion in benefits to ratepayers and $1.1 billion in market revenue to resource owners for a total value of storage of $3.4 billion. The $2.3 billion in ratepayer savings is composed of:

Reduced peak demand	$1093 million
T&D cost reduction	$305 million
Energy cost reduction	$275 million
Integrating distributed renewable generation cost reduction	$219 million

The substantial potential net benefits have not been overlooked by Massachusetts' legislators. In 2016, Massachusetts became the third state to enact energy storage legislation. The legislation allows Massachusetts' Department of Energy Resources, or DOER, to determine appropriate energy storage procurement targets for electric companies to meet by 2020.[34] In June of 2017, DOER adopted a target of 200 MWh of energy storage. However, models suggest that DOER could have mandated even more storage than this target without any net negative consequences, and it is likely that Massachusetts will exceed the target without a mandate.

Maryland

Maryland is yet another state whose legislature has taken steps to encourage energy storage deployment. In 2017, Maryland enacted a tax credit incentive for commercial and residential storage.[35] The incentive is the first of its kind, and provides 30% tax credits on the installed costs of storage systems. Credits are capped at $5,000 for residential storage projects and $75,000 for commercial storage projects and may not exceed $750,000 in a year. The program will run through 2022. Maryland hopes that this incentive will both improve grid resiliency, integrate more renewable energy sources, and reduce peak demand.

Minnesota

During Minnesota's 2015 Session, legislation was considered that would create a statewide incentive

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[32] 78th OR Legis. Assemb. Reg. Sess., *House Bill 2193* (2015).

[33] Massachusetts DOER, *supra* note 19.

[34] MA Bill, M. H. 4568, "An Act to Promote Energy Diversity" (Mass. 2016).

[35] MD Bill, *Senate Bill 758* (2017).

program for energy storage.[36] The bill called for a rebate for utility-controlled, customer-sited energy storage equipment if manufactured in Minnesota. This approach was based in part on a White Paper mandated by 2013 legislation to be commissioned by the Minnesota Department of Commerce to evaluate costs and benefits of different storage use cases.[37] The 2015 bill enjoyed bipartisan support, but died in conference committee. Nevertheless, energy storage has established a presence in the minds of Minnesota lawmakers, regulators, and utilities, and may soon become an essential part of Minnesota's resource mix.

A 2017 report published by the Energy Transition Lab estimates how soon energy storage will be selected as an economic resource in MISO, in Minnesota's footprint. By varying initial input variables, the study examines 176 different scenarios, and finds that storage is always selected as an economic resource by 2050, but in scenarios optimal for storage integration, storage is found to be an economic resource in the present day. Furthermore, though MISO is able to reduce greenhouse gas emissions by 80% by 2050, scenarios including energy storage were able to reduce both the amount of fossil fuel generation required and also the levelized cost of electricity across the MISO region.[38]

Storage Today and Tomorrow

Energy storage can already be deployed to improve resiliency. In 2015, a massive natural gas leak at the Aliso Canyon Underground Storage Facility caused approximately 100,000 tons of methane and over 7,000 tons of ethane to leak.[39] Not only did this gas leak have severe environmental effects by significantly increasing methane levels in the atmosphere, but it also threatened to induce an energy shortage and blackouts across Southern California. In response to the crisis, the California Public Utilities Commission approved 104.5 MW of battery-based energy storage in 2016.[40] Within six months of the project's approval, more than 70 MW of storage had been deployed in the region, greatly improving resiliency and helping meet Southern California's energy needs.

Though California has taken the lead, energy storage may soon begin to play a prominent role in Minnesota's resource mix. The Hartley Nature Center project in Duluth, which was discussed earlier, is one example of the multiple benefits of energy storage that can be utilized in Minnesota today. HNC installed a 14.2 kWh Li-ion battery that can be used during outages of less than four hours to keep Hartley running as a normal business or for longer periods of time to keep Hartley running in a low-power emergency mode. It is also expected to result in energy cost savings of $1,500 per year, with possible additional savings if the

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[36] H.F. 1320/S.F. 1178, 89th Leg (Minn. 2015).

[37] Strategen Consulting, et al., *White Paper Analysis of Utility-Managed On-Site Energy Storage in Minnesota* (Prepared for Minn. Dep't of Commerce, Dec. 2013), *available at* http://mn.gov/commerce-stat/pdfs/utility-managed-storge-study.pdf.

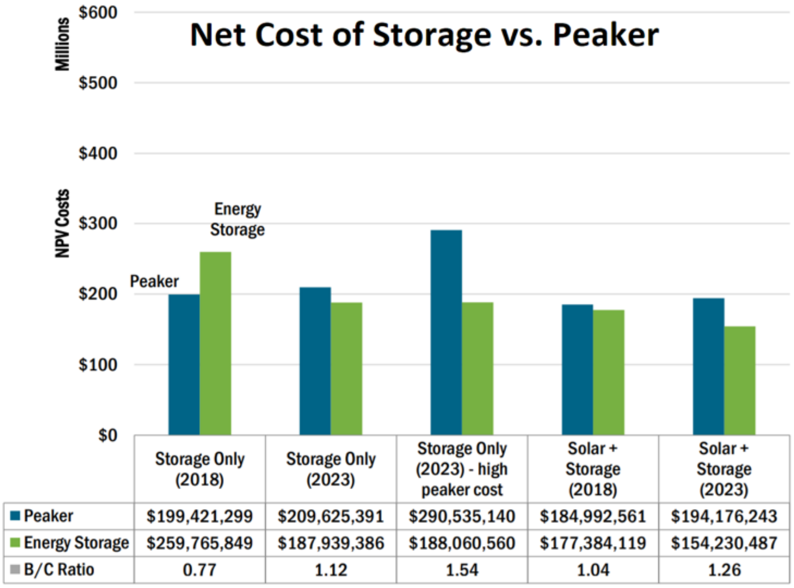
[38] Energy Transition Lab, *supra* note 17).

[39] S. Conley, et al. "Methane Emissions from the 2015 Aliso Canyon Blowout in Los Angeles, CA." *Science*, vol. 351, no. 6279, 18 Mar. 2016, pp. 1317-1320., doi:10.1126/science.aaf2348.

[40] Julia Pyper, Greentech Media, *Tesla, Greensmith, AES Deploy Aliso Canyon Battery Storage in Record Time*, https://www.greentechmedia.com/articles/read/aliso-canyon-emergency-batteries-officially-up-and-running-from-tesla-green (Jan. 31, 2017).

battery system can reduce electric consumption and peak demand.[41]

The Energy Transition Lab's report suggests that energy storage will become a cost-effective resource in the near future in Minnesota, especially when coupled with solar PV. The analysis compares energy storage to natural gas-fired peaking plants. Such peakers are only used during peak energy demand times for a total of just a few hours each year, but can be quite costly, both in terms of operating costs and in terms of carbon emissions. In fact Massachusetts found that the top 1% most expensive hours accounted for 8%, or $680 million of ratepayers' annual electricity costs.[42] Until now, energy storage has not been an economically viable alternative to peaking plants in Minnesota. However, the ETL report finds if environmental benefits are included, solar + storage is a cost-effective alternative to peakers beginning in 2018, and standalone storage will be a cost-effective alternative as soon as 2023.[43]



	Storage Only (2018)	Storage Only (2023)	Storage Only (2023) - high peaker cost	Solar + Storage (2018)	Solar + Storage (2023)
■ Peaker	$199,421,299	$209,625,391	$290,535,140	$184,992,561	$194,176,243
■ Energy Storage	$259,765,849	$187,939,386	$188,060,560	$177,384,119	$154,230,487
■ B/C Ratio	0.77	1.12	1.54	1.04	1.26

Image source: Energy Transition Lab, Modernizing Minnesota's Grid: An Economic Analysis of Energy Storage Opportunities (2017), prepared by Strategen Consulting.

Clearly, energy storage is a resource that is becoming more and more viable. As various storage technologies develop, the cost of storage will continue to fall. Additionally, if energy storage can help reduce the need for natural gas peakers which emit large amounts of carbon, strong environmental benefits can be realized. However, natural gas and energy storage do not have to be mutually exclusive resources. General Electric has been developing hybrid storage-generation plants, and can now integrate energy storage with any of its power plants.[44]

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[41] Sarah Galbraith, *supra* note 20).

[42] *State of Charge, Massachusetts Energy Storage Initiative*, http://www.mass.gov/eea/docs/doer/state-of-charge-executive-summary.pdf

[43] Energy Transition Lab, *supra* note 17.

[44] Stephen Lacey, Greentech Media, *GE Can Now Put Battery Storage on Any of Its Power Plants*, https://www.greentechmedia.com/articles/read/ge-can-now-put-battery-storage-on-any-power-plant

The costs of renewable resources like wind and solar have been continually falling, and this trend is expected to continue.

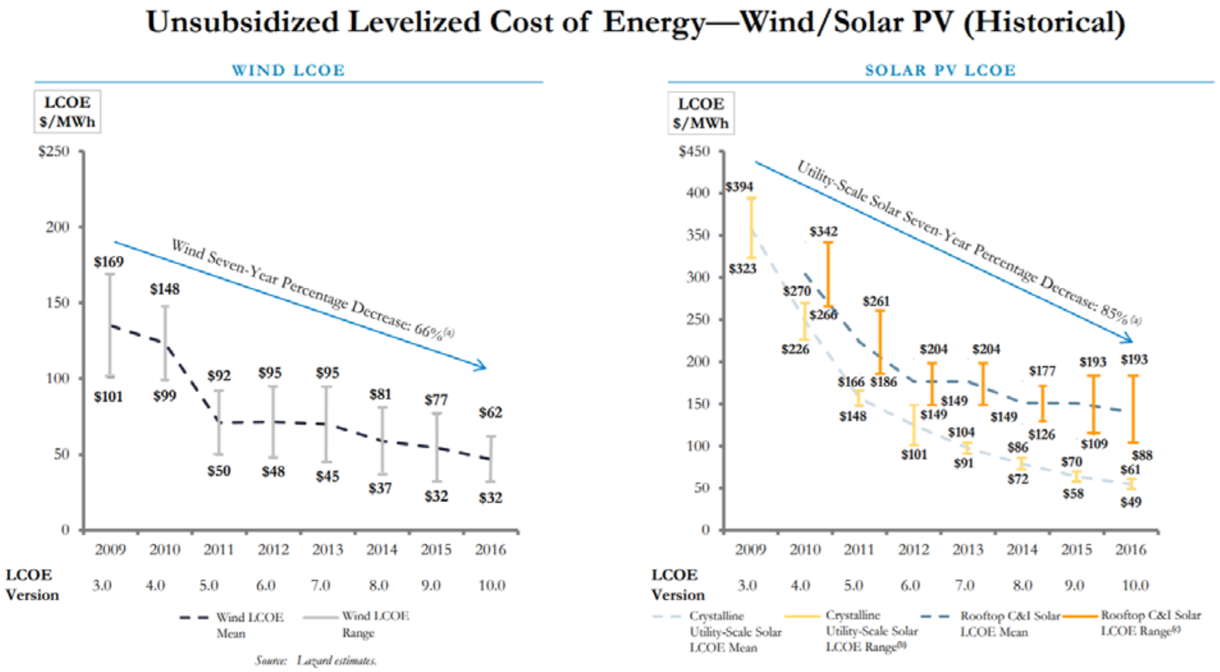

Image source: Lazard, Levelized Cost of Energy Version 10.0 (2016).

As wind and solar become more and more economic, the grid can be expected to continue to increase its reliance on renewables. As grids move to very high levels of renewable energy - 60-90% - storage would help compensate for fluctuations in demand and weather patterns, and help avoid curtailment and spiking energy prices during times of peak demand. If renewables were integrated into the grid in combination with energy storage, grid resiliency would likely improve, carbon emissions would fall, and energy price fluctuations would be diminished.

National and global energy storage trends show sustained future growth. As we experienced with wind and solar energy, deployment is going up and costs down, at a rapid pace. [45]

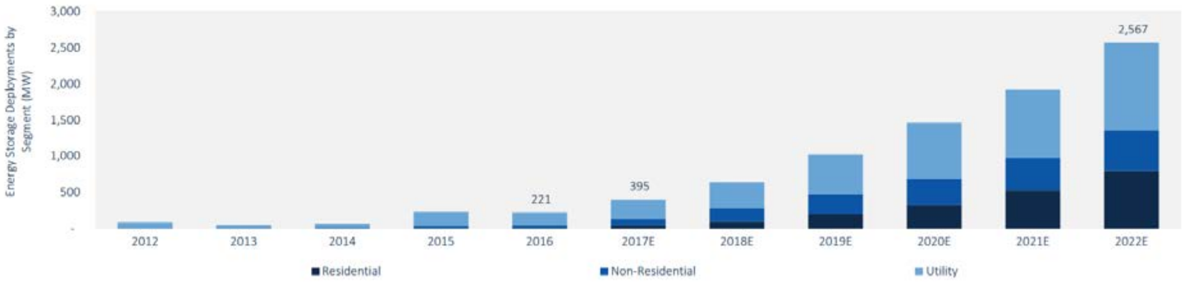

Image source: GTM Research/ESA, U.S. Energy Storage Monitor Q2 (2017).

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[45] Dougherty, *supra* note 24.

Glossary

Ancillary Services – Services necessary to support the transmission of energy from resources to loads, while maintaining reliable operation of the grid; such services include scheduling, dispatch, reactive power-voltage control, frequency response, and operating reserves.[46]

Community Choice Aggregation (CCA) – A program in which local governments aggregate electricity demand for their local communities and buy electricity which is then distributed by to customers by IOUs.[47]

Curtailment – A reduction in energy delivery because energy demand exceeds capacity; usually happens during times of high demand.[48]

Cogeneration (sometimes co-gen)/Combined Heat and Power (CHP) – A system which generates electricity and useful thermal energy in a single, integrated system, most often fueled by natural gas or biomass; highly efficient.[49]

Dispatchable Generation/Load – A DER that can be quickly dispatched to meet needs identified by grid operators, either by increasing available supply or reducing current load.

Distributed Energy Resource (DER) – Electricity source connected to the grid which:

Generates electricity (from any source);

Stores energy and can supply that energy to the grid; OR

Involves load changes by end users in response to price signals or other policy incentives.[50]

Energy density – The amount of energy per unit volume of an energy storage device.[51]

Flow battery – A type of battery in which energy is stored within the electrolytes in external tanks instead of in the electrodes; advantages include long lifetimes, easy recharging, can be scaled up to store more energy, unlikely to cause fires.[52]

Flywheel – A heavy, cylindrical body that rotates rapidly around a central axis, storing energy as motion; advantages include very fast ramping and outstanding ability to weather frequent charge-discharge cycles;

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[46] FERC, *Market Oversight Glossary,* http://www.ferc.gov/market-oversight/guide/glossary.asp.

[47] Kennedy, *supra* note 24.

[48] ESA, *supra* note 2.

[49] American Council for an Energy-Efficient Economy, aceee.org.

[50] EPRI, The Integrated Grid: A Benefit-Cost Framework.

[51] ESA, *supra* note 2.

[52] ESA, *supra* note 2.

best for high-power, low-energy applications such as frequency response.[53]

Frequency Response – The ability to stabilize grid operating frequency immediately following the sudden loss of generation or load.[54]

Investor-Owned Utility (IOU) – An energy provider that is typically owned by stockholders; alternative is a public energy provider owned by the government.[55]

Levelized Cost of Energy – Method of standardizing cost per unit for generation alternatives given a standardized time period; used to compare costs of generation systems.[56]

Microgrid – A localized electric grid that can either operate in tandem with the larger grid or disconnect and operate autonomously; can improve grid resiliency.[57]

Ramping – The rate at which energy generation increases or decreases over time.[iv]

Reserve (Operating) – Spinning reserve plus additional generation that can respond within up to 30 minutes of request; generally sufficient to offset the capacity of the largest single generator on the grid.[58]

Reserve (Spinning) – Generation capacity connected to the grid that can respond within 10 minutes of request; compensates for temporary, unexpected outages in the system.[iv]

Thermal Storage – Energy stored as heat; methods include:

Heating or cooling a storage medium (water, molten salt, ceramics, sand molten salt);

Phase changes (ice to water, water to steam, etc.); and

Chemical reactions (adsorption to silica gel, etc.). [59]

Variable Generation – Electricity source that depends on fluctuating factors and thus is not continuously available and cannot be dispatched at will; includes renewables such as wind and solar.

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[53] ESA, *supra* note 2.

[54] MISO, http://www.misoenergy.org.

[55] Energy.gov, https://energy.gov/eere/energybasics/articles/glossary-energy-related-terms (2013).

[56] Lazard, Levelized Cost of Energy Version 10.0 (2016).

[57] Energy Storage Systems Inc., *supra* note 20.

[58] NREL, *Glossary of Transmission Grid Integration Terms*, http://www.nrel.gov/electricity/transmission/glossary.html.

[59] International Renewable Energy Agency, *Thermal Energy Storage: Technology Brief* (Jan. 2013).

Thank you to Matthew Prorok, Great Plains Institute, for valuable advice on this document.

About the Energy Transition Lab

A strategic initiative of the University's Institute on the Environment, the Energy Transition Lab (ETL) brings together leaders in government, business and nonprofit organizations to develop new energy policy pathways, institutions, and regulations. ETL leverages University expertise in building collaborations with these leaders to create innovative solutions for our future energy system.

The 2nd Edition (2017) was prepared by Ellen Anderson, Director, Energy Transition Lab, and Max Foster, Intern, Carleton College. The 2015 version was created with the assistance of Erin Sikkink, Jennifer Purdes, Megan Butler, and Laura Burrington.

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