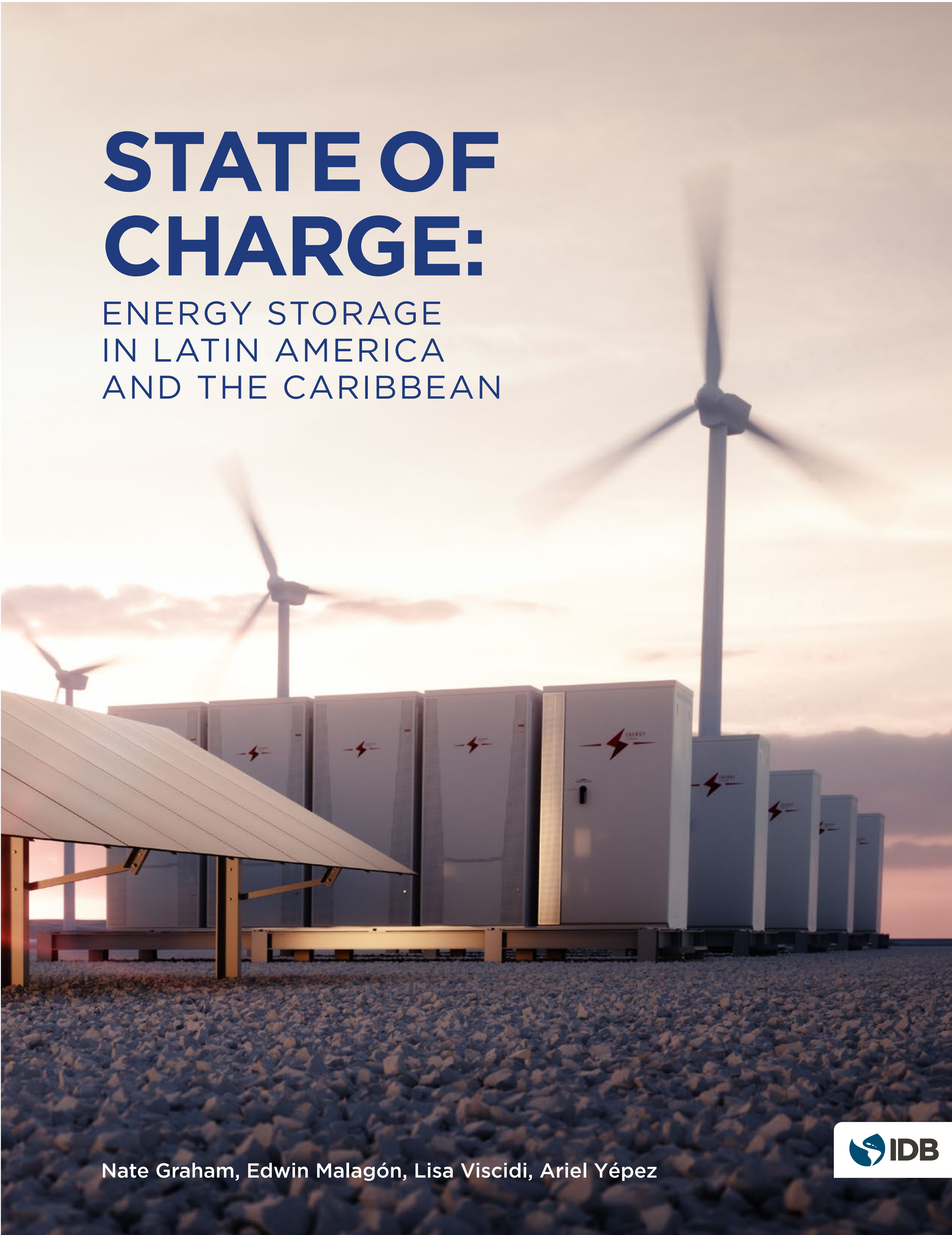
STATE OF CHARGE:

ENERGY STORAGE IN LATIN AMERICA AND THE CARIBBEAN



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I. INTRODUCTION

a. Global Decarbonization and the Role of Energy Storage

Electricity storage could play an instrumental role in decarbonization of the energy sector in order to reduce greenhouse gas emissions. Even if countries meet all of their current unconditional pledges under the Paris Agreement—which in 2015 declared the goal of keeping the rise in global temperature to well below 2 degrees Celsius above pre-industrial levels—global temperatures may rise by 3.2 degrees Celsius, according to the United Nations Environment Programme (UNEP).[1]

The decarbonization of the energy sector is a crucial component of climate change mitigation strategies. To achieve change on the scale that is required, an integrated approach to energy decarbonization must include great strides in energy efficiency; electrification of transport, heating, and other energy applications currently provided by fossil fuels; decentralization of the grid; and a massive transition to power generation from renewable sources.

Electricity storage can bring many benefits to electricity systems, including enhancing grid reliability, efficiency, and flexibility and facilitating decarbonization through renewable energy expansion. The shift to renewable power is a critical element of energy decarbonization, not only because of the enormous current contribution of the power sector to greenhouse gas emissions, but also since the share of the power sector in the global energy mix will grow as other sectors such as transport and heating are electrified in order to decarbonize. The importance of renewable power in mitigating climate change is underscored by the Intergovernmental Panel on Climate Change's statement that "virtually full" decarbonization of the power sector by 2050 will be needed to meet the 2-degree target set under the Paris Agreement.[2]

Unfortunately, current growth in renewable power is not on pace to rise to this challenge, despite large gains. Renewable energy's share in the global electricity matrix has increased in recent years, reaching 28% of global electricity generation in Q1 2020,[3] up from 20% in 2015 and 17% in 2010.[4] Solar and wind capacity increased by 20% and 10% respectively over the decade. However, in order to meet the International Energy Agency (IEA)'s Sustainable Development Scenario (SDS),[5] which "holds the temperature rise to below 1.8 °C with a 66% probability without reliance on global net-negative CO_2 emissions," renewables must account for 49% of power generation by 2030.[6]

1. "Cut global emissions by 7.6 percent every year for next decade to meet 1.5°C Paris target - UN report." UN Environment Programme, November 26, 2019. https://www.unenvironment.org/news-and-stories/press-release/cut-global-emissions-76-percent-every-year-next-decade-meet-15degc
2. "What is "decarbonisation" of the power sector? Why do we need to decarbonise the power sector in the UK?" Grantham Research Institute on Climate Change and the Environment, January 29, 2020. https://www.lse.ac.uk/granthaminstitute/explainers/what-is-decarbonisation-of-the-power-sector-why-do-we-need-to-decarbonise-the-power-sector-in-the-uk/
3. International Energy Agency. "Global Energy Review 2020." April 2020. https://www.iea.org/reports/global-energy-review-2020/renewables.
4. "Data & Statistics." IEA. Accessed August 14, 2020. https://www.iea.org/data-and-statistics?country=WORLD&fuel=Energy%20transition%20indicators&indicator=Share%20of%20renewables%2C%20low-carbon%20sources%20and%20fossil%20fuels%20in%20power%20generation.
5. IEA. "Sustainable Development Scenario – World Energy Model". Accessed July 28, 2020. https://www.iea.org/reports/world-energy-model/sustainable-development-scenario
6.Bahar, Heymi. "Renewable Power – Analysis." IEA, June 1, 2020. https://www.iea.org/reports/renewable-power.

How can renewable deployment reach such levels? The greatest potential for growth lies in wind and solar, which together accounted for 90% of renewable capacity additions in 2019 and reached a 9% share of global power generation in Q1 2020.[7 8] The SDS is heavily dependent on growth from these technologies,[9] banking on a 5.6-fold increase in solar generation between 2018 and 2030 and a 3.4-fold increase in wind generation. These technologies together would account for almost 90% of the renewable power capacity additions between 2019 and 2024.[10]

Rapidly declining costs have driven this trend. According to Bloomberg New Energy Finance (BNEF), the levelized cost of electricity (LCOE) since the second half of 2009 has fallen 86% for fixed-axis solar PV and 60% for onshore wind. This means solar PV and onshore wind "are now the cheapest sources of new-build generation for at least two-thirds of the global population."[11] However, the perennial question is how a grid can be fully decarbonized when these sources of energy, often referred to as "variable renewable energy" (VRE) are not available during all times of the day. For now, baseload generation sources, such as hydropower, natural gas or diesel are necessary to ensure security of supply.

Thus, deployment of energy storage will be a key enabler of the mass transition to VRE required for significant climate change mitigation and ensuring the security and reliability of these VRE-based grids. Through energy storage, excess VRE produced during low-demand periods can be stored to serve the grid when there is high demand. This prevents VRE curtailment and maximizes the quantity that can be sold, thereby minimizing the fossil-fuel generation needed to meet demand and increasing VRE revenues. It also allows VRE to serve as firm capacity. Energy storage technologies also offer a host of other services to make power grids more secure, resilient, efficient, and cost-effective. For conventional power sources, energy storage can provide spinning reserve and allow plants to immediately deliver power to the system, reducing the need to quickly ramp up power and permitting the plants to operate steadily at the most efficient levels, increasing life extension.

In 2018, more than 3 GW of energy storage were added to the grid globally, up from less than 2 GW added in 2017.[12] New storage capacity was down slightly in 2019 but still brought global installed storage capacity above 10 GW. By 2030, the SDS calls for 200 GW of cumulative capacity, meaning "installations need to continue multiplying at the strong 2018 rate for the next ten years." Energy storage will also have to expand to new markets – most growth to date has been concentrated in the United States, Europe, and East Asia (see Figure 1). According to the IEA, an average annual investment of $37 billion is required in energy storage to 2050.[13] Fortunately, major technological improvements and cost decreases are driving adoption. For instance, the LCOE of battery storage has fallen by about half in just the last two years to $150/MWh for systems with a four-hour duration.[14] Still, awareness of energy storage technology and its benefits will have to increase significantly in untapped markets.

7. "Uptick for renewable electricity generation in 2019." UN Environment Programme, April 20, 2020. https://www.unenvironment.org/news-and-stories/story/uptick-renewable-electricity-generation-2019

8. International Energy Agency. "Global Energy Review 2020." April 2020. https://www.iea.org/reports/global-energy-review-2020/renewables.

9. Bahar, Heymi. "Renewable Power – Analysis." IEA, June 1, 2020. https://www.iea.org/reports/renewable-power.

10. IEA. "Renewables 2019 - Market analysis and forecast from 2019 to 2024." October 2019. https://www.iea.org/reports/renewables-2019

11. BloombergNEF. "Scale-up of Solar and Wind Puts Existing Coal, Gas at Risk." April 28, 2020. https://about.bnef.com/blog/scale-up-of-solar-and-wind-puts-existing-coal-gas-at-risk/

12. Munuera, Luis, and Claudia Pavarini. "Energy Storage – Analysis." IEA, June 2020. https://www.iea.org/reports/energy-storage.

13. IEA. "Sustainable Development Scenario – World Energy Model". Accessed July 28, 2020. https://www.iea.org/reports/world-energy-model/sustainable-development-scenario.

14. BloombergNEF. "Scale-up of Solar and Wind Puts Existing Coal, Gas at Risk." April 28, 2020. https://about.bnef.com/blog/scale-up-of-solar-and-wind-puts-existing-coal-gas-at-risk/

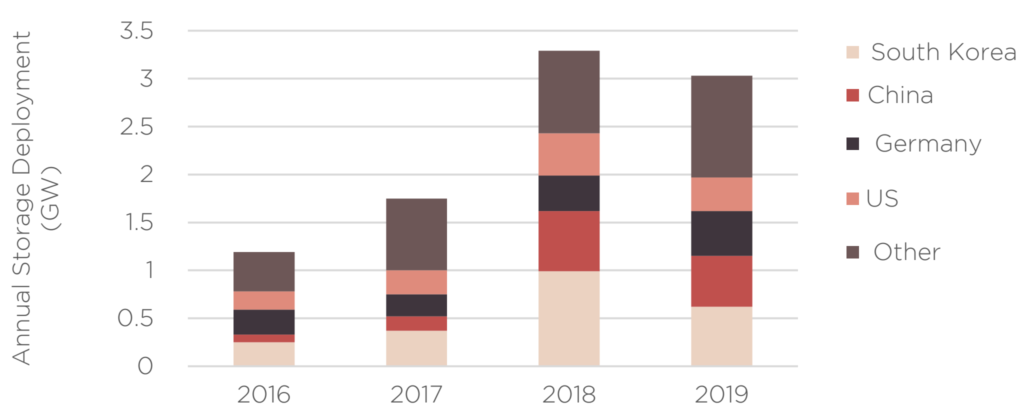
b. Report Objectives

This report's objectives are to describe the primary energy storage technologies being used internationally, including what services they can provide to power grids, and characterize the state of the most prominent energy storage technologies in Latin America and the Caribbean, highlighting emblematic projects. The report also seeks to identify the most promising potential applications of each of these technologies in different LAC contexts and provide general recommendations on the regulatory and policy changes that would be required to facilitate greater energy storage uptake in the region. A heightened understanding of energy storage and its applications in LAC will serve as a first step for governments to consider their options as they seek to decarbonize and improve the performance of their grids. This knowledge will also be important for the development of regulation that facilitates the uptake of energy storage in the region.

The report's first section provides an overview of the most prevalent energy storage technologies being developed and deployed across the world, the services they can provide to grids, and the regulatory challenges they face. The second section analyzes the current energy storage landscape in LAC, the regulatory environment and potential for growth.

The report finds that pairing energy storage with mini-grids appears to be the most technically and economically viable energy storage application in the region at the moment, and that lithium-ion batteries hold the most near-term potential for both off-grid mini-grids and many interconnected applications. Pumped hydro energy storage also holds potential for large-scale applications, especially considering the extensive existing hydroelectric infrastructure in many countries. Other technologies, such as molten salt thermal energy storage paired with concentrated solar power generation, or compressed air energy storage, could be deployed in specific contexts. Hydrogen storage is likely poised for a larger role down the line as the technology matures.

Figure 1: Annual Energy Storage Deployment, 2016-2019 (GW)



Source: IEA[15]

15. Munuera, Luis, and Claudia Pavarini. "Energy Storage – Analysis." IEA, June 2020. https://www.iea.org/reports/energy-storage.

II. GLOBAL ENERGY STORAGE CONTEXT

a. Multiple Services Provided by Energy Storage and its Role in Flexible Power Systems

Greater participation of VRE in power generation has increased the need for more flexibility in power systems to ensure their safe, reliable, and efficient operation. Flexible systems can respond to variability and uncertainty of supply and demand in a reliable and cost-effective way in different time scales.[16] [17] The capacity of energy storage systems to absorb and release electricity on demand, as well as the multiple services these systems can provide, make them one of the more versatile tools to provide flexibility to power systems. Continuous cost declines also make energy storage an increasingly cost-effective solution compared to other solutions that increase system flexibility, such as adding generation capacity or transmission infrastructure.

Energy storage can deliver multiple services that span the whole chain of electricity provision, from generation to transmission and distribution, benefiting utilities, network operators and customers. Table 1 (at the end of section II.a.) shows the summary of a number of services energy storage systems can provide. In the case of power generation, energy storage is key for solar and wind integration and can provide services such as capacity firming, power output smoothing and time shifting, avoiding curtailment, and increasing the value of renewable energy generation. In general, at high VRE penetration levels energy storage can reduce the need to build additional reserve generation capacity.[18] Energy storage systems also offer multiple services and benefits for conventional power generation. For instance, for combustion turbine plants energy storage can provide spinning reserve and allow natural gas turbines to immediately deliver power to the system, reducing ramp-up efforts and allowing them to operate steadily at the most efficient production levels, increasing life extension.[19] [20] Figure 2 shows common applications of peak shaving and load leveling.

16. Milligan, Michael, Bethany Frew, Ella Zhou, and Douglas J. Arent. Advancing System Flexibility for High Penetration Renewable Integration. Golden, CO: National Renewable Energy Laboratory, 2015. https://www.nrel.gov/docs/fy16osti/64864.pdf

17. IEA. "Status of Power System Transformation 2019: Power System Flexibility." IEA, May 2019. https://www.iea.org/reports/status-of-power-system-transformation-2019

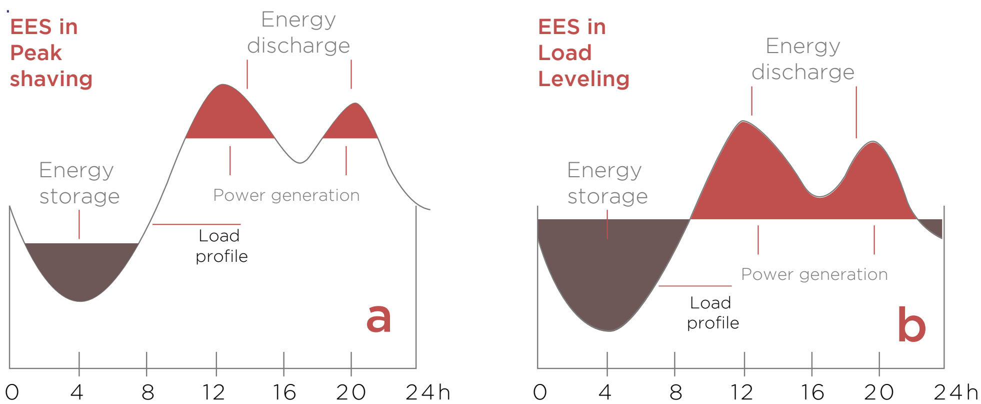
Denholm, Paul, Jennie Jorgenson, Marissa Hummon, David Palchak, Brendan Kirby, Ookie Ma, and Mark O'Malley. The Impact of Wind and Solar on the Value of Energy Storage. Golden, CO: National Renewable Energy Laboratory, 2013. https://www.nrel.gov/docs/fy14osti/60568.pdf

18. Denholm, Paul, Jennie Jorgenson, Marissa Hummon, David Palchak, Brendan Kirby, Ookie Ma, and Mark O'Malley. The Impact of Wind and Solar on the Value of Energy Storage. Golden, CO: National Renewable Energy Laboratory, 2013. https://www.nrel.gov/docs/fy14osti/60568.pdf

19. Power Engineering International. "Gas Turbines and Batteries: A Perfect Pairing." Power Engineering International, July 13, 2020. https://www.powerengineeringint.com/news/gas-turbines-and-batteries-a-perfect-pairing/

20. "Energy Storage Proves Key to Delivering Natural Gas Advantages." Black & Veatch, October 14, 2018. https://www.bv.com/perspectives/energy-storage-proves-key-delivering-natural-gas-advantages

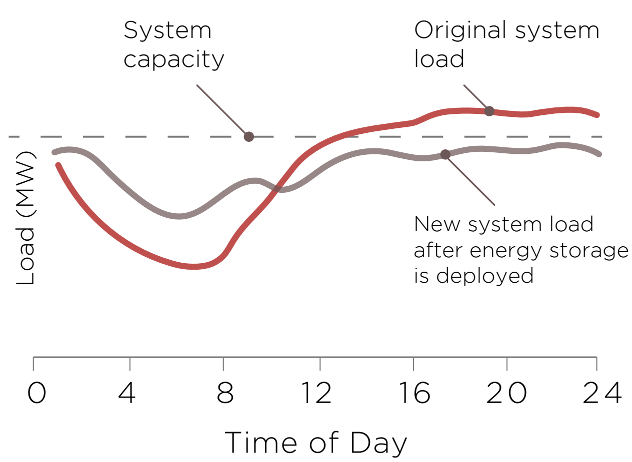
Figure 2: Load Profile of a Large-scale Electrical Energy Storage System (EES) - (a) EES in Peak Shaving, (b) EES in Load Leveling



Source: Chen, Haisheng, Thang Cong, Chunqing Tan, Yongliang Li, Yulong Ding, and Wei Yang. "Progress in Electrical Energy Storage Systems: a Critical Review." Progress in Natural Science 19 (March 2009). https://doi.org/10.1016/j.pnsc.2008.07.014

In power transmission and distribution, energy storage systems can defer utilities' investments in grid upgrades, reducing peak demand and the need to invest in new infrastructure because of expected demand growth. Figure 3 shows how with energy storage the system load profile remains below the system capacity limit, allowing the utility to postpone additional investments.[21]

Figure 3: System Load Profile Before and After Using Energy Storage for Distribution Deferra

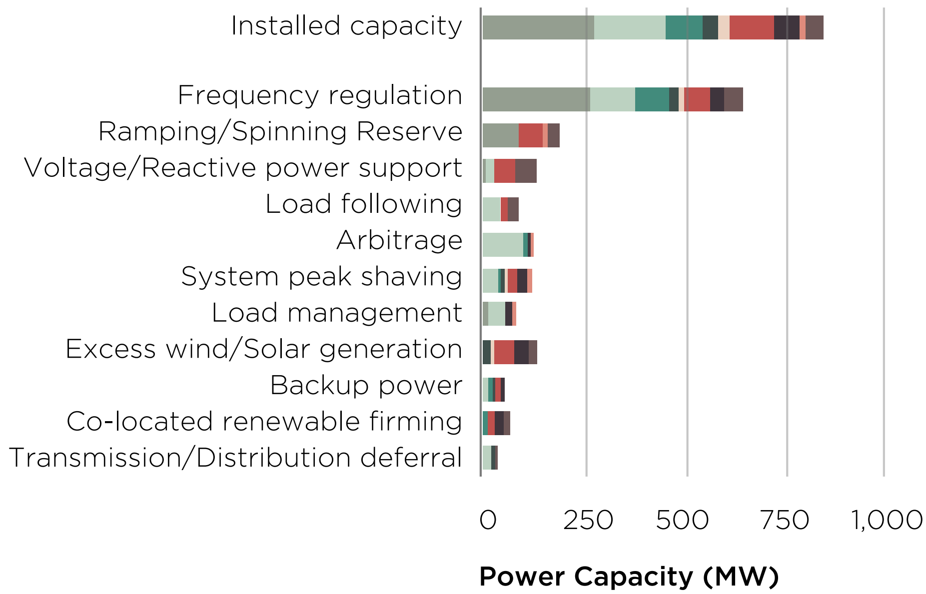


Source: Fitzgerald, Garrett, James Mandel, Jesse Morris, and Herve Touati. The Economics of Battery Energy Storage: How Multi-Use, Customer-Sited Batteries Deliver the Most Services and Value to Customers and the Grid. Boulder, CO: Rocky Mountain Institute, September 2015.http://www.rmi.org/electricity_battery_value

21. Mallapragada, Dharik S., Nestor A. Sepulveda, and Jesse D. Jenkins. "Long-Run System Value of Battery Energy Storage in Future Grids with Increasing Wind and Solar Generation." Applied Energy 275 (October 1, 2020). https://doi.org/10.1016/j.apenergy.2020.115390

For network operation, ancillary services are the most common application of energy storage. According to the US Energy Information Administration, in 2018 75% of battery storage facilities in the US provided frequency regulation services, followed by ramping and spinning reserve[22] (see Figure 4).

Figure 4: Applications Served by Large-scale Battery Storage in the US (2018)



Source: Battery Storage in the United States: An Update on Market Trends. Washington, DC: U.S. Energy Information Administration, 2020. https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf

Power systems can also benefit from energy storage at the customer level. Energy storage can deliver multiple services not only for the customer's installation but also for power systems. According to a 2015 study by the Rocky Mountain Institute[23], energy storage deployed as a primary service for commercial customer demand-charge management (aiming to reduce peak demand charges and billing costs) could also provide secondary services such as arbitrage, frequency regulation, spinning reserve, and resource adequacy.

Capturing the full value of energy storage requires a clear understanding of these multiple services. Some energy storage services can be delivered by the same storage facility, if the provider has the opportunity to stack multiple value streams. However, the regulatory framework must enable and/or incentivize energy storage and allow providers to monetize its benefits. In addition, regulators need a sound understanding of service requirements and characteristics to facilitate storage technology selection.

22. Battery Storage in the United States: An Update on Market Trends. Washington, DC: U.S. Energy Information Administration, 2020. https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf

23. Fitzgerald, Garrett, James Mandel, Jesse Morris, and Herve Touati. The Economics of Battery Energy Storage: How Multi-Use, Customer-Sited Batteries Deliver the Most Services and Value to Customers and the Grid. Boulder, CO: Rocky Mountain Institute, September 2015.http://www.rmi.org/electricity_battery_value

Table 1: Services Provided by Energy Storage Systems[24 25]

Service	Description	Duration of the Service	Response Time
Bulk energy services or energy management (relating to the large-scale production, storage, and consumption of energy according to supply and demand).			
Electric energy time-shift	Storage can absorb excess supply produced during off-peak periods for use during high-demand periods, reducing the need for new generation capacity and allowing for more constant generation from sources for which this is more efficient or for which generation is variable (such as solar and wind). By storing excess energy generated when prices are low and re-selling it when prices are higher (arbitrage), generators can also increase revenues.	**1-8 hours**	**Minutes**
Peak shaving	By storing energy generated during higher supply or lower demand periods, and releasing the energy during peak times, the need for expensive and inefficient plants running only to meet peak demand is reduced.	**1-8 hours**	**Minutes**
Electric supply capacity	The installation of energy storage systems could avoid the installation of new generation capacity.	**1-6 hours**	**Minutes**
Ancillary services (services related to the maintenance of grid reliability)			
Frequency regulation	Frequency regulation is required to ensure the perfect balance between load and generation on a moment-by-moment basis. Energy storage can have a very fast response, charging or discharging to maintain that balance and keep the frequency of the system within the acceptable range.	**15 min to 1 hour**	**Immediate**

24. Akhil, Abbas A., Georgianne Huff, Aileen B. Currier, Benjamin C. Kaun, Dan M. Rastler, Stella Bingqing Chen, Andrew L. Cotter, Dale T. Bradshaw, and William D. Gauntlett. DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA. Albuquerque, NM: Sandia National Laboratories, 2013. https://www.energy.gov/sites/prod/files/2013/08/f2/ElecStorageHndbk2013.pdf.
25. Bowen, Thomas, Chernyakhovskiy, Ilya and Denholm, Paul. "Grid Scale Battery Storage FAQ" NREL, September 2019. https://www.nrel.gov/docs/fy19osti/74426.pdf

Spinning, non-spinning, and supplemental reserves	Storage capacity can serve as backup capacity in the event of a generation or transmission outage. The term "spinning reserves" refers to reserves that are online but unloaded and available to respond within 10 minutes.[26] Non-spinning reserves may be offline and used after all spinning reserves have been deployed.	**15 min to 1 hour**	**30 seconds**
Black start:	Energy storage units can be brought online to restart the system after a blackout.	**Hours**	**< 30 seconds**
Load following/ Ramping up	Energy storage can provide a rapid supply response to changes in demand, compensating for the slower response of generation assets.	**15-30 min to hours**	**Minutes**

Transmission infrastructure services

Transmission upgrade deferral	Storage installations can relieve bottlenecks of the transmission system where its peak load is being constrained by its thermal performance, thus deferring the need for upgrades.	**1-6 hours**	**Minutes**
Transmission congestion relief	Through decentralization, storage can reduce congestion at high-use components of the transmission system.	**1-6 hours**	**Minutes**

Distribution infrastructure services

Distribution upgrade deferral:	Storage installations can relieve bottlenecks of the distribution system where its peak load is being constrained by its thermal performance, thus deferring the need for upgrades.	**2-6 hours**	**Minutes**
Voltage support:	Energy storage can provide or absorb reactive power and help maintain a specific voltage on the grid. This is needed for equipment to operate properly, to prevent overheating that can cause damage to connected generators, to facilitate energy transfers, and to mitigate transmission losses.[27] Voltage support can also be used as ancillary services.		

26."Spinning Reserve." Energy Storage Association, March 24, 2013. https://energystorage.org/spinning-reserve/

27. "Harnessing the Potential Of Energy Storage: Storage Technologies, Services, and Policy Recommendations." Edison Electric Institute, May 2017. https://www.eei.org/issuesandpolicy/generation/Documents/EEI_HarnessingStorage_Final.pdf

b. Regulatory Challenges for Energy Storage

Energy storage comprises a diverse set of technologies that are not always well understood and are in some cases fairly nascent. Furthermore, the number of distinct services offered by energy storage, as described in the previous section, is a central feature of these technologies and creates a challenge to regulating energy storage systems and assessing and compensating their value. This has produced obstacles, including high barriers to entry, restrictions on the use of storage across multiple value streams, a lack of acknowledgement by regulators and markets of the quality and quantity of services provided by energy storage, and a general lack of an adequate price environment and long-term market signals—all of which can be addressed by policy.

An absence of regulation specifically tailored to energy storage can lead to an inability for providers to capitalize on the benefits that these technologies offer and can even serve as a disincentive to energy storage. One of the first barriers faced by regulators is therefore the need to define storage, the asset class or participant type in the market. This includes what the activity entails and what entities can perform it. Existing frameworks designed to regulate generation can create barriers to entry for energy storage.[28] For example, the regulatory framework in some markets includes performance penalties that penalize storage for failing to provide some services while charging. Additionally, in some markets, regulators require ancillary services to have an energy schedule, meaning systems must already be online and running when they are called on for ancillary services, a regulation that does not acknowledge the ability of energy storage technologies to ramp up much faster than conventional technologies and presents an unnecessary restriction.

Restrictions or uncertainty regarding the use of storage across multiple value streams (generation, transmission, and distribution) present another hurdle.[29] As described above, storage provides a range of services spanning multiple parts of the power sector and often multiple markets. As an example, frequency regulation may be compensated in a wholesale market, whereas investment deferrals in transmission or distribution systems may be classified as a cost of service paid by the utility or system operator. Due to concern about "double compensation" for services, receiving compensation for services from multiple sources may even be restricted in some markets, which can make a project uneconomical. The high upfront cost of storage installations often implies that one single value stream is not a sufficient incentive for a project.[30]

Another roadblock related to the appropriate compensation of energy storage systems is the fact that the value of their services and the flexibility they provide is often poorly understood or difficult to quantify.[31] This stymies the formation of a market for energy storage system services. For instance, in the case of frequency regulation, battery systems may be able to provide the service faster and more accurately than conventional technologies, but this may not be reflected in the compensation for battery storage if the added value is not recognized.

28. Condon, Madison, Revesz, Richard and Unel, Burcin. "Managing the Future of Energy Storage." Institute for Police Integrity, April 2018. https://policyintegrity.org/files/publications/Managing_the_Future_of_Energy_Storage.pdf

29. Bowen, Thomas, Chernyakhovskiy, Ilya and Denholm, Paul. "Grid Scale Battery Storage FAQ" NREL, September 2019. https://www.nrel.gov/docs/fy19osti/74426.pdf

30. Condon, Madison, Revesz, Richard and Unel, Burcin. "Managing the Future of Energy Storage." Institute for Police Integrity, April 2018. https://policyintegrity.org/files/publications/Managing_the_Future_of_Energy_Storage.pdf

31. Bowen, Thomas, Chernyakhovskiy, Ilya and Denholm, Paul. "Grid Scale Battery Storage FAQ" NREL, September 2019. https://www.nrel.gov/docs/fy19osti/74426.pdf

In general, the current price environment governing energy storage is insufficient to incentivize its deployment on a large scale.[32] Though the price of lithium-ion batteries, for instance, has fallen precipitously and it is a well-established technology, other technologies are still in development or have significant untapped cost-reduction potential. These emerging technologies may require the expectation of reliable markets in order for their development to be viable. The absence of regulation mandating or even permitting the appropriate compensation of energy storage constitutes a major obstacle to the formation of economical prices for storage.

Another factor contributing to suboptimal pricing for energy storage is that social and environmental externalities are not adequately priced into fossil fuel generation. As previously explained, variable renewable energy technologies hold the greatest potential to drive uptake of energy storage. But although VRE technologies are already competitive with fossil fuel generation in many cases, fossil fuels still benefit from prices that do not capture the cost of their emissions, hindering VRE in some cases and thus dampening demand for storage. Additionally, if charged with fossil fuels, energy storage can even increase greenhouse gas emissions, meaning that in cases where fossil fuels are a more competitive energy source, incentives to charge energy storage with zero-carbon energy may be necessary to capitalize on its positive effects for climate change.

Box 1: New York's "Value Stack" and Multiple Revenue Streams for Storage

Energy storage presents a unique scenario for utilities and regulators by providing services across different value streams within the power sector — generation, transmission, and distribution. However, regulators have put up barriers to compensating energy storage projects for multiple revenue streams because of concerns about double compensation, which has reduced the economic viability of energy storage projects. The US state of New York has tackled this issue through its "value stack" system associated with distributed energy resources, including energy storage installations.[33]

The system was implemented as part of the transition away from net metering for distributed energy resources, which began in March 2017. Designed by the New York State Energy Research and Development Authority (NYSERDA) with feedback from utilities, project developers, and other external stakeholders, the system divides the value provided by distributed energy and storage into five categories and determines the beneficiary of each. The value of each category is calculated by the utility and paid to distributed energy producers and storage operators.

Though calculating these values presents a challenge for utilities and regulators, the case of New York demonstrates a framework for differentiation between the beneficiaries of energy storage services across value streams. In many cases, this exercise will be an important step for regulators seeking to facilitate energy storage expansion.

32. Bowen, Thomas, Chernyakhovskiy, Ilya and Denholm, Paul. "Grid Scale Battery Storage FAQ" NREL, September 2019. https://www.nrel.gov/docs/fy19osti/74426.pdf

33. "The Value Stack Compensation for Distributed Energy Resources." NYSERDA. Accessed August 14, 2020. https://www.nyserda.ny.gov/All-Programs/Programs/NY-Sun/Contractors/Value-of-Distributed-Energy-Resources.

Table 2: Values Calculated Under New York State's "Value Stack" System

Value	Service	Beneficiary
Energy Value	Provides energy	Generation and partially transmission
Installed Capacity Value	Reduces the need for generation capacity expansion	Generation
Environmental Value	Reduces emissions	Society at large
Demand Reduction Value	Reduces the need for distribution-level infrastructure investment	Distribution
Locational System Relief Value	Reduces distribution-level congestion	Distribution

Source: Reproduced from p. 15 of Condon 2018

c. Energy Storage Technologies

The term "energy storage" encompasses a diverse array of technologies that can be used to store and shift the use of electricity and provide other services to the grid, as discussed above and summarized in Table 3. Some of these technologies are well-established, whereas others are still in research or pilot phases. Many are in different stages of adoption in different parts of the world. Later in the paper, each technology's current level of uptake in LAC will be characterized, and its potential for further adoption explored.

Table 3: Energy Storage Technologies and Most Suitable Applications

		PHS	Li-ion	Lead-acid	NaS	Flow	Molten salt TES	Hydrogen	CAES
Bulk Energy Services	Electric Energy Time-Shift	x	x	x	x	x	x	x	x
	Peak Shaving	x	x	x	x	x	x	x	x
	Electric Supply Capacity	x	x	x	x	x	x	x	x
	Long-term/ Large-scale Storage	x							x
Ancillary Services	Frequency Regulation		x	x	x	x			
	Voltage Support		x	x	x	x			
	Operational Reserves	x	x	x	x	x			
	Black Start	x	x	x	x	x	x	x	x
	Load Following	x							x
Transmission and Distribution (T&D) Services	T&D Upgrade Deferral		x	x	x	x		x	x
	Transmission Congestion Relief		x	x	x	x		x	x
	Voltage Support		x	x	x	x			
Microgrid	Microgrid		x	x		x		x	

Sources: IRENA[34] (p 22), IDB[35] (p. 6), University of Michigan,[36] own elaboration
PHS = pumped hydro storage, Li-ion = lithium-ion battery, lead-acid = lead-acid battery, NaS = sodium-sulfur battery, flow = flow battery, TES = thermal energy storage, CAES = compressed air energy storage"

34. IRENA (2020), Electricity Storage Valuation Framework: Assessing system value and ensuring project viability, International Renewable Energy Agency, Abu Dhabi. https://irena.org/-/media/Files/IRENA/Agency/Publication/2020/Mar/IRENA_storage_valuation_2020.pdf

35. IDB (2014) Potential for energy storage in combination with renewable energy in Latin America and the Caribbean / Lenin Balza, Christiaan Gischler, Nils Janson, Sebastian Miller, Gianmarco Servetti. https://publications.iadb.org/publications/english/document/Potential-for-Energy-Storage-in-Combination-with-Renewable-Energy-in-Latin-America-and-the-Caribbean.pdf

36. Centre for Sustainable Systems, University of Michigan (2020), U.S. Grid Energy Storage http://css.umich.edu/factsheets/us-grid-energy-storage-factsheet

i. Pumped hydro energy storage

Hydroelectricity is the world's largest source of renewable electricity and holds great potential to facilitate the introduction of variable renewable energy and provide other grid services, especially when paired with pumped hydro energy storage (PHS).

In 2018, hydroelectricity provided 15.9% of global electricity generation[37], and it is especially widely used in Latin America, where it accounted for 47.4%.[38] At a conventional large hydropower plant, water accumulates in a reservoir created by damming a river, ideally atop a large drop in elevation. When the water is released, it flows downhill through a turbine, which in turn generates electricity. Through the storage of large quantities of water as potential energy with low short-term variability, large hydroelectric dams can serve as a reliable source of firm energy supply to complement variable renewable energy sources, releasing water and generating energy when necessary to provide grid stability and security of supply. However, though independent hydroelectric dams can store potential energy for long periods, they were not considered a form of energy storage in this report since they cannot store electricity produced by other sources.

PHS goes a step further by harnessing the ability of large reservoirs to store energy that has already been generated by another source. A PHS installation requires two water reservoirs at different levels, storing energy generated during periods of high supply or low demand by using it to pump water from the lower reservoir to the upper reservoir. The water can then be released at a later point to flow downhill to the lower reservoir, spinning a turbine to generate power as in a conventional dam. PHS projects can be either open, meaning there is a connection with an outside body of water, or closed, meaning the reservoirs are an isolated system.

PHS projects have a number of advantages, one of which is the fact that they have the largest storage capacity of any technology – the largest current pumped storage project (Bath County, Virginia, USA) has a total capacity of over 3 GW/24,000 MWh, and even larger projects are in the pipeline.[39] PHS projects can also typically generate for up to 12 hours or more,[40] and they have the longest lifespan of any storage technology (60-100 years).[41] Due to their large size, long life, and fairly high efficiency, they are among the most competitively priced storage technologies per unit of power (see Figure 5). The large potential capacity of PHS also makes it a suitable option for multiple grid services: operational reserve capacity, load following, renewable energy arbitrage, and long-term storage, even on the order of weeks in some cases.[42]

37. International Hydropower Association. "Hydropower Status Report 2019." IHA, 2019. https://www.hydropower.org/sites/default/files/publications-docs/2019_hydropower_status_report_0.pdf

38. "Climatescope 2019 – Capacity & Generation." BloombergNEF. Accessed July 30, 2020. http://global-climatescope.org/capacity-generation

39. International Hydropower Association. "The world's water battery: Pumped hydrostorage and the clean energy transition." IHA, December 2018. https://www.hydropower.org/sites/default/files/publications-docs/the_worlds_water_battery_-_pumped_storage_and_the_clean_energy_transition_2.pdf

40. International Hydropower Association. "The world's water battery: Pumped hydrostorage and the clean energy transition." IHA, December 2018. https://www.hydropower.org/sites/default/files/publications-docs/the_worlds_water_battery_-_pumped_storage_and_the_clean_energy_transition_2.pdf

41. International Hydropower Association. "The world's water battery: Pumped hydrostorage and the clean energy transition." IHA, December 2018. https://www.hydropower.org/sites/default/files/publications-docs/the_worlds_water_battery_-_pumped_storage_and_the_clean_energy_transition_2.pdf

42. International Hydropower Association. "The world's water battery: Pumped hydrostorage and the clean energy transition." IHA, December 2018. https://www.hydropower.org/sites/default/files/publications-docs/the_worlds_water_battery_-_pumped_storage_and_the_clean_energy_transition_2.pdf

However, the unique characteristics of PHS also have drawbacks. PHS project are capital-intensive, requiring large upfront investments and a long construction period. They are also space-intensive and site-specific, requiring two large reservoirs at different elevations. The space requirements of PHS mean that they can have a large environmental impact (though this can be mitigated by pairing PHS systems with an existing large hydroelectric installation or designing an off-river closed system, even using underground reservoirs or using the ocean as the lower reservoir).[43] These drawbacks also impose limitations on the services that PHS projects can provide. They cannot usually be deliberately sited to facilitate transmission and distribution (T&D) investment deferrals and are not economical for contexts with storage needs on a smaller scale. The response time of PHS also limits its utility for the provision of ancillary services such as power quality (frequency regulation and voltage support), which require a more rapid response.

PHS is the most mature and widespread form of energy storage, and the basic technology has existed for over a century. In 2019, PHS accounted for 158 GW and 94% of global installed storage capacity, and the International Hydropower Association expects it to continue growing, with 78 GW of additional capacity by 2030.[44] Much of this growth (50 GW) is expected to come from China as it introduces more wind and solar generation.[45] Increased VRE penetration is also driving PHS adoption in Europe. Current PHS capacity is led by China (30.3 GW), Japan (27.6 GW), and the US (22.9 GW), followed by Italy, Germany, Spain, France, Austria, India, and South Korea. The size of the global PHS industry has been estimated at $300 billion and projected to grow to $400 billion by 2026 (see Figure 6).[46]

ii. Lithium-ion batteries

Several battery technologies are well-developed and hold potential for Latin American and Caribbean grids, but lithium-ion is by far the most prevalent and fastest growing. As in all batteries, lithium-ion batteries consist of an anode, a cathode, and an electrolyte. When the battery is discharged, lithium atoms in the anode (made of graphite) are oxidized, releasing electrons and becoming Li^+ ions. The electrons flow to the cathode (common materials include lithium cobalt oxide, lithium manganese oxide, and lithium iron phosphate[47]) in an external circuit, generating an electric current. Meanwhile, Li^+ ions travel to the cathode through the liquid electrolyte and a separator permeable by lithium. When an electric current flows through the battery, the reaction is reversed and the battery is charged.

The popularity of lithium-ion batteries is owed to a number of factors. For one, their cost is lower than other battery technologies and rapidly declining (see Figure 5). According to BNEF, their cost fell by 85% from 2010 to 2018 and is projected to fall by half again by 2030.[48] This

43. International Hydropower Association. "The world's water battery: Pumped hydrostorage and the clean energy transition." IHA, December 2018. https://www.hydropower.org/sites/default/files/publications-docs/the_worlds_water_battery_-_pumped_storage_and_the_clean_energy_transition_2.pdf.

44. International Hydropower Association. "Hydropower Status Report 2020." IHA, 2020. https://www.hydropower.org/sites/default/files/publications-docs/2020_hydropower_status_report.pdf.

45. International Hydropower Association. "The world's water battery: Pumped hydrostorage and the clean energy transition." IHA, December 2018. https://www.hydropower.org/sites/default/files/publications-docs/the_worlds_water_battery_-_pumped_storage_and_the_clean_energy_transition_2.pdf.

46. Gupta, Ankit, and Abhishek Chopra. "Pumped Hydro Storage Market Share Analysis Report 2026." Global Market Insights, Inc., October 2019. https://www.gminsights.com/industry-analysis/pumped-hydro-storage-market.

47. "Lithium-Ion Battery." Clean Energy Institute. University of Washington. Accessed August 17, 2020. https://www.cei.washington.edu/education/science-of-solar/battery-technology/.

48. BloombergNEF. "Energy Storage Investments Boom As Battery Costs Halve in the Next Decade." BNEF, July 31, 2019. https://about.bnef.com/blog/energy-storage-investments-boom-battery-costs-halve-next-decade/.

trend is driven mostly by demand for electric vehicles, but also by stationary storage.[49] A study by the US Department of Energy (DOE) projects price declines of around 23% from 2018 to 2025 (see Figure 5). In Latin America, an Inter-American Development Bank (IDB) study projects capital costs for lithium-ion battery systems to fall 50% between 2019 and 2030 to $700,000/MW.[50] Due to the small size of lithium ions, the power density of these batteries is high, and they also have a high round-trip efficiency (meaning the share of electricity to be stored that is lost during the storage and retrieval process is low). Lithium-ion batteries, like all batteries, have a fast response time, which makes them suitable for the provision of ancillary services like frequency response and voltage support. Their size is also highly customizable – they can be sited strategically to facilitate T&D upgrade deferrals and support mini-grids, but they can also be large enough to provide time-shifting/arbitrage and backup capacity. The world's largest lithium-ion battery, Neoen's Hornsdale Power Reserve in Australia, has capacity of 100 MW/129 MWh,[51] and even larger projects are planned, including a 112-MW project under construction in Chile[52] and planned units with 400-800 MW of capacity elsewhere. There is also a discussion about how the batteries of electric vehicles, once they are deployed on a large scale, could be incentivized to charge and discharge in patterns that allow for renewable energy time-shifting and balancing the grid.

Though the technology is still improving, lithium-ion batteries have their drawbacks, including economic, technical, logistical, and regulatory challenges to recycling them and concerns about safety (they have been known to short-circuit and overheat).[53] Some also continue to question their cost-effectiveness, though as indicated, this is expected to continue seeing significant improvements.

Conventional lithium-ion batteries are currently the most mature battery technology and the fastest-growing energy storage technology. According to the IEA, of more than 3 GW of new grid-scale and behind-the-meter (installed by the electricity customer) energy storage deployed in 2018, lithium-ion batteries made up nearly 85% of the capacity.[54] BNEF projects the annual market for lithium-ion batteries to quadruple from around $30 billion in 2020 to almost $120 billion by 2030 (see Figure 6).[55]

Between 2020 and 2023, lithium-ion storage projects with capacity greater than 100 MW are expected in Australia, the US, China, Japan, the UK, and Ireland, with smaller utility-scale and off-grid projects planned all over the world.

49. Munuera, Luis, and Claudia Pavarini. "Energy Storage – Analysis." IEA, June 2020. https://www.iea.org/reports/energy-storage.

50. García de Fonseca, Leila; Parikh, Manan; Manghani, Ravi. "Evolución futura de costos de las energías renovables y almacenamiento en América Latina." Inter-American Development Bank, December 2019. https://publications.iadb.org/es/evolucion-futura-de-costos-de-las-energias-renovables-y-almacenamiento-en-america-latina

51. "South Australia's Big Battery." Hornsdale Power Reserve. Accessed July 30, 2020. https://hornsdalepowerreserve.com.au/.

52. "AES Gener inicia primer proyecto Solar con Baterías en Chile y consolida su presencia eólica en el sur del país." AES Gener, October 15, 2020. https://www.aesgener.cl/prensa_articulos/aes-gener-inicia-primer-proyecto-solar-con-baterias-en-chile-y-consolida-su-presencia-eolica-en-el-sur-del-pais/

53. Balaraman, Kavya. "Why Is the Utility Industry Less Bullish on Grid-Scale Storage?" Utility Dive, February 13, 2020. https://www.utilitydive.com/news/safety-volatile-market-less-bullish-storage/572013/.

54. Munuera, Luis, and Claudia Pavarini. "Tracking Energy Integration 2019." IEA, May 2019. https://webcache.googleusercontent.com/search?q=cache:affjTUKBjIYJ:https://prod.iea.org/reports/tracking-energy-integration-2019/energy-storage+&cd=5&hl=en&ct=clnk&gl=us.

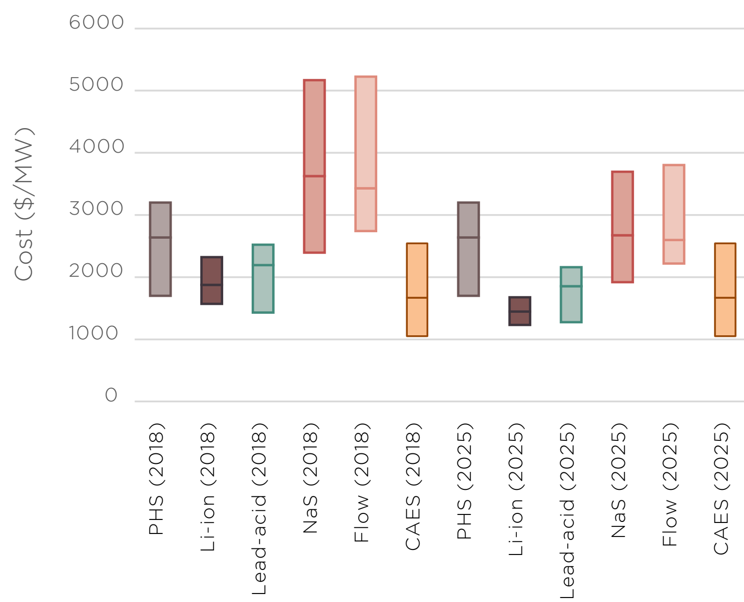
55. "Battery Pack Prices Fall As Market Ramps Up With Market Average At $156/KWh In 2019." BloombergNEF, December 3, 2019. https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/.

Box 2: Solid-state Lithium Batteries

Another emerging battery technology using lithium—solid-state lithium batteries—seeks to improve on the success of the lithium-ion model by replacing the liquid electrolyte with a solid one. This innovation facilitates the use of a lithium anode, which can have an energy density 10 times greater than that of a conventional graphite anode.[56] The use of a solid electrolyte can improve battery safety relative to conventional lithium-ion batteries due to greater mechanical, electrochemical, and thermal stability. Companies claim they could achieve more than double the energy of conventional lithium-ion batteries and significantly improve safety using solid-state technology. However, the diffusion of ions through a solid is much slower than through a liquid and the battery is therefore less conducive. The technology's potential is widely recognized, and research is taking place in North America, Europe, and Asia, at academic institutions such as MIT and companies including Hydro-Québec, Mercedes-Benz, and Samsung.[57 58 59] But due to its limitations, solid-state lithium battery technology is not widely commercially viable, and many scientists do not expect it to be so for years. Still, it will be a technology to watch closely in the coming years.[60]

Figure 5: Declines in Range of Total Project Cost for Various Storage Technologies (2018 – 2025)

a) Capacity



56. Kelly, Taylor. "Exploring Solid-State Lithium Ion Batteries." Intertek, May 21, 2019. https://www.intertek.com/blog/2019-05-21-lion/.

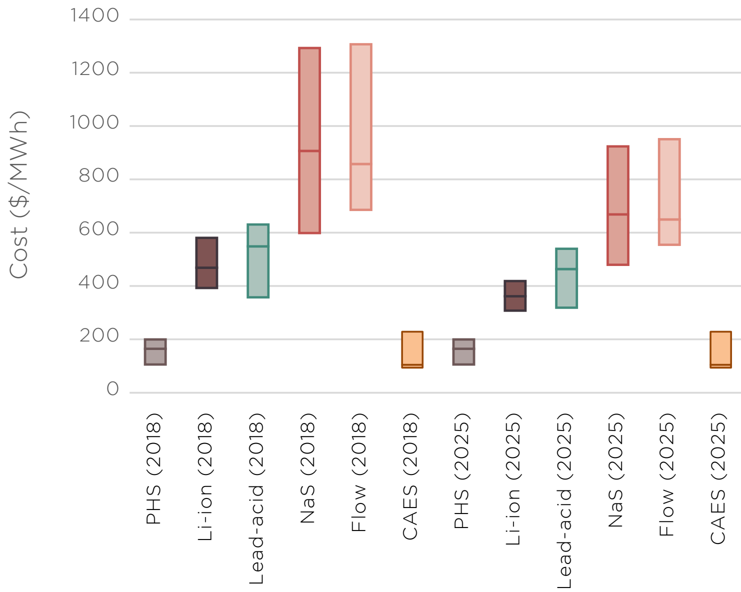
57. Lavars, Nick. "MIT's Solid-State Battery Breakthrough May See Phones Last for Days." New Atlas, February 5, 2020. https://newatlas.com/materials/mits-solid-state-battery-breakthrough/.

58. Berman, Bradley. "Work on Goodenough's Breakthrough Solid-State EV Battery Moves Forward." Electrek, April 24, 2020. https://electrek.co/2020/04/23/work-on-goodenoughs-breakthrough-solid-state-ev-battery-moves-forward/.

59 "Samsung Presents Groundbreaking All-Solid-State Battery Technology to 'Nature Energy'." Samsung Global Newsroom, March 10, 2020. https://news.samsung.com/global/samsung-presents-groundbreaking-all-solid-state-battery-technology-to-nature-energy.

60. Collins, Bryony. "Innolith Battery Strikes at 'Flammable' Lithium-Ion: Q&A." BloombergNEF, May 13, 2019. https://about.bnef.com/blog/innolith-battery-strikes-flammable-lithium-ion-qa/.

b) Energy



Source: DOE 2019 [61]

Notes: PHS = pumped hydro storage, Li-ion = lithium-ion battery, lead-acid = lead-acid battery, NaS = sodium-sulfur battery, flow = flow battery, CAES = compressed air energy storage

iii. Lead-acid batteries

One of the earliest rechargeable battery technologies, lead-acid batteries use lead plates as the two electrodes and an electrolyte that is a mix of water and sulfuric acid.[62] In its charged state, the battery's anode consists of lead dioxide and the cathode of lead. To discharge the battery, the anode is oxidized and converted to lead sulfate, and the cathode is reduced and also converted to lead sulfate. The sulfuric acid in the electrolyte has reacted with the electrodes, leaving water as the sole substance in the electrolyte. To charge the battery, this reaction is reversed.

Lead-acid batteries share some of the benefits of other batteries, namely that they can be small and flexibly sited and they have a rapid response time, making them suitable for T&D investment deferrals and ancillary services. They can also be as large as 100 MW but have not typically been deployed on the same scale as lithium-ion batteries (the largest lead-acid installations generally range from a few megawatts of capacity up to 20 MW, large enough to provide bulk energy services such as time-shift and backup capacity for small and medium renewable energy installations). Other advantages of lead-acid batteries are that they do not require rare minerals, their water-based electrolyte makes them safe to use, and they are easier to recycle than lithium-ion batteries, with an established industry for doing so.

61. Mongird, K, V Fotedar, V Viswanathan, V Koritarov, P Balducci, B Hadjerioua, and J Alam. "Energy Storage Technology and Cost Characterization Report." Department of Energy, July 2019. https://www.energy.gov/sites/prod/files/2019/07/f65/Storage%20Cost%20and%20Performance%20Characterization%20Report_Final.pdf.

62. Balza, Lenin, Gischler, Christiaan, Janson, Nils, Miller, Sebastian and Servetti, Gianmarco. "Potential for energy storage in combination with renewable energy in Latin America and the Caribbean." Inter-American Development Bank, 2014. https://publications.iadb.org/publications/english/document/Potential-for-Energy-Storage-in-Combination-with-Renewable-Energy-in-Latin-America-and-the-Caribbean.pdf

However, lead-acid batteries have a number of drawbacks, especially compared to lithium-ion batteries. They have a shorter lifespan, a much lower power density, a lower round-trip efficiency, and a low depth of discharge. An IDB project in Suriname found that they functioned best if kept at least 60% charged, and another in Bolivia found that they were space-intensive relative to their lithium-ion counterparts. These limitations increase the costs associated with lead-acid batteries and reduce their convenience.

Due to its limitations and despite its head start, lead-acid battery technology is in limited and declining commercial use for energy storage.[63] Its price is not declining as fast as that of lithium-ion, either. The DOE has projected a drop of about 15% for lead-acid battery projects between 2018 and 2025 (see Figure 5). Among projects identified by the DOE by 2018, only 75 MW of lead-acid battery capacity were in use, compared to 1,629 MW of lithium-ion batteries. According to the IEA, though the share of lead-acid batteries in non-PHS storage installations was 36% in 2011, by 2016 they accounted for just 5% of this mix as they were outpaced by lithium-ion.[64] Once commonly used in electric vehicles, they have largely been replaced by lithium-ion batteries in that market as well. Still, the 2019 lead-acid battery market has been estimated at close to $60 billion, with the Asia-Pacific region (particularly China) holding the largest share.[65] Stationary applications are expected to provide only a small share of the market's growth in coming years, but one segment of the stationary market, the uninterruptible power source (UPS, a form of near-instantaneous emergency power supply) market, has been projected to grow the fastest of any lead-acid battery application—a compound annual growth rate of 6.8% from 2020 to 2027. It accounted for 9.41% of the total lead-acid battery market in 2019.

iv. Sodium-sulfur batteries

Sodium-sulfur (NaS) batteries are the most mature sodium-based battery technology, having existed since the 1960s.[66] NaS batteries consist of an anode of molten sodium and a cathode of molten sulfur. The electrolyte is a solid beta alumina. When the battery is discharged, sodium atoms in the anode are oxidized to Na^+ ions, which flow to the cathode to form sodium polysulfide (Na^2S^x). When the battery is charged, this reaction is reversed.

NaS batteries benefit from a rapid response time that makes them an option for the provision of ancillary services. They also have a long lifetime for a battery. They can be used for T&D investment deferral and are usually large, making them suitable for bulk energy services. However, they have several downsides. They require high temperatures (300-350 degrees Celsius) to operate, which can raise problems for intermittent operation.[67] The chemicals involved are also dangerous. These are issues for smaller installations without constant maintenance support, meaning that NaS battery projects are typically very large.[68] They have a significantly lower power density than lithium-ion batteries and a much higher cost.

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

64. "Technology Mix in Storage Installations Excluding Pumped Hydro, 2011-2016 – Charts – Data & Statistics." IEA. Accessed July 30, 2020. https://www.iea.org/data-and-statistics/charts/technology-mix-in-storage-installations-excluding-pumped-hydro-2011-2016.

65. "Lead Acid Battery Market Size, Share: Industry Trend Report 2027." Grand View Research, 2019. https://www.grandviewresearch.com/industry-analysis/lead-acid-battery-market.

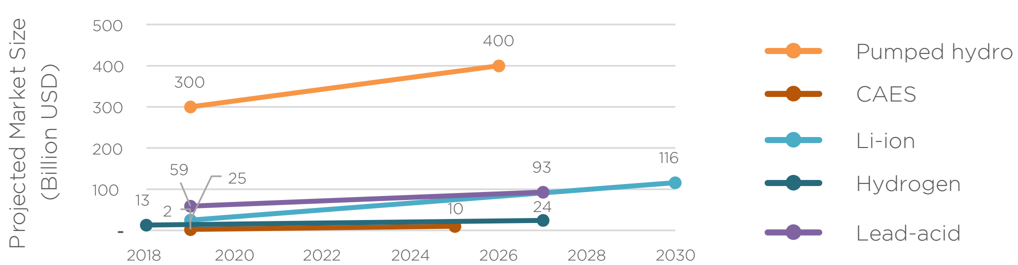
66. "Sodium Sulfur (NaS) Batteries." Energy Storage Association. Accessed July 30, 2020. https://energystorage.org/why-energy-storage/technologies/sodium-sulfur-nas-batteries/.

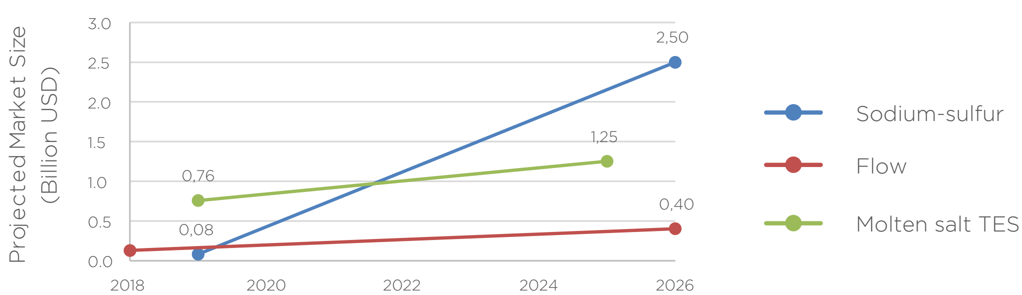
67. "Sodium Sulfur (NaS) Batteries." Energy Storage Association. Accessed July 30, 2020. https://energystorage.org/why-energy-storage/technologies/sodium-sulfur-nas-batteries/.

68. Balza, Lenin, Gischler, Christiaan, Janson, Nils, Miller, Sebastian and Servetti, Gianmarco. "Potential for energy storage in combination with renewable energy in Latin America and the Caribbean." Inter-American Development Bank, 2014. https://publications.iadb.org/publications/english/document/Potential-for-Energy-Storage-in-Combination-with-Renewable-Energy-in-Latin-America-and-the-Caribbean.pdf

Like lead-acid batteries, NaS batteries have lost significant market share to lithium-ion and are in limited commercial use. According to the IEA, their market share in storage installations excluding pumped hydro in 2014 was 19%, but by 2016 it was just 4%. [69] The DOE has counted 189 MW of deployed sodium-sulfur storage to 2018.[70] However, it also projects a fairly robust price decrease of about 26% between 2018 and 2025 (see Figure 5), and given burgeoning global demand for energy storage, one market research firm expects a compound annual growth rate of 61.9% during the period of 2020-2026 (see Figure 6), mostly in stationary applications (due to the high operating temperature and corrosive nature).[71] Many of the largest NaS installations are in Japan, which is home to NGK, the primary manufacturer of the technology.[72] According to Mordor Intelligence, North America is the largest market and Asia-Pacific is the fastest growing.[73] There are also several fairly large projects in Italy and the United Arab Emirates.

Figure 6: Current and Projected Market Sizes for Energy Storage Technologies (Billion USD)





Note: Lithium-ion and lead-acid battery figures include all uses, as do sodium-sulfur battery figures, though stationary storage is the predominant application in that case.

Sources: Global Market Insights, BNEF, Grand View Research, Market Research Engine, Stratistics Market Research Consulting, Industry Research, Allied Market Research, GlobalInfoResearch

69. "Technology Mix in Storage Installations Excluding Pumped Hydro, 2011-2016 – Charts – Data & Statistics." IEA. Accessed July 30, 2020. https://www.iea.org/data-and-statistics/charts/technology-mix-in-storage-installations-excluding-pumped-hydro-2011-2016.
70. Mongird, K, V Fotedar, V Viswanathan, V Koritarov, P Balducci, B Hadjerioua, and J Alam. "Energy Storage Technology and Cost Characterization Report." Department of Energy, July 2019. https://www.energy.gov/sites/prod/files/2019/07/f65/Storage%20Cost%20and%20Performance%20Characterization%20Report_Final.pdf.
71. "Global Sodium-Sulfur Battery Market Size, Manufacturers, Supply Chain, Sales Channel and Clients, 2020-2026." Industry Research, July 16, 2020. https://www.industryresearch.co/global-sodium-sulfur-battery-market-15935218.
72. "Sodium Sulfur (NaS) Batteries." Energy Storage Association. Accessed July 30, 2020. https://energystorage.org/why-energy-storage/technologies/sodium-sulfur-nas-batteries/.
73. "Sodium Sulfur Battery Market: Growth, Trends, and Forecast (2020 - 2025)." Mordor Intelligence, 2019. https://www.mordorintelligence.com/industry-reports/sodium-sulfur-battery-market.

v. Flow batteries

Flow batteries encompass several different chemistries and function differently than other battery technologies.[74] A flow battery consists of two tanks, one containing a positive electrolyte and the other a negative electrolyte. The tanks are connected by a cell stack containing an anode and a cathode, which are separated by an ion-selective membrane. When the battery is discharged, a chemical reaction takes place in which the negative electrolyte is oxidized and electrons flow to the positive electrolyte, which is reduced. Ions travel through the membrane so that the reaction reaches equilibrium. The battery is charged using the reverse reaction. Chemistries for flow batteries include vanadium redox, iron-chromium, and zinc-bromine.

One of the major benefits of flow batteries is their low degradation and their lifetime, which is longer than the other batteries considered here. Because the storage capacity is a function of the size of the electrolyte tanks, the battery is straightforward to customize to fit a variety of contexts. Thus, like other batteries, they can be used for ancillary services such as power quality and for T&D upgrade deferral, and they can also be very large, providing energy management services and backup capacity. However, flow batteries have by far the lowest power density of the batteries in this study, so they are space intensive.

Flow batteries make up only a small share of the battery market, less than 5%, and 2019 yielded few major deployments or announcements despite past excitement surrounding the technology.[75] Though they are commercially available, their wider use may depend on the materialization of demand for the large-scale, long-duration battery storage that they could provide.[76] The 2026 flow battery market has been estimated at $403 million,[77] compared to a lithium-ion battery market of more than $100 billion (see Figure 6). Even so, the price of flow batteries continues to fall—the DOE projects a 24% decrease between 2018 and 2025 (see Figure 5)—and in many cases they are less expensive than lithium-ion batteries. Projects in the pipeline include a 200-MW (800 MWh) vanadium redox flow battery being built in Dalian, China, which was originally expected in 2020.[78] Multiple major projects have also been announced or built in China, Australia, the US, Germany, Japan, and Canada, among a variety of other smaller markets. A 3-GWh flow battery is reportedly being developed in Saudi Arabia.[79]

74. Balza, Lenin, Gischler, Christiaan, Janson, Nils, Miller, Sebastian and Servetti, Gianmarco. "Potential for energy storage in combination with renewable energy in Latin America and the Caribbean." Inter-American Development Bank, 2014. https://publications.iadb.org/publications/english/document/Potential-for-Energy-Storage-in-Combination-with-Renewable-Energy-in-Latin-America-and-the-Caribbean.pdf

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

76. Deign, Jason. "Flow Batteries Struggle in 2019 as Lithium-Ion Marches On." Greentech Media, November 6, 2019. https://www.greentechmedia.com/articles/read/flow-batteries-struggle-in-2019-as-lithium-ion-marches-on.

77. Prasad, Eswara, and Krunal Yeware. "Redox Flow Battery Market Size, Share, Growth, Trend ..." Allied Market Research, March 2020. https://www.alliedmarketresearch.com/redox-flow-battery-market.

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

79. Munuera, Luis, and Claudia Pavarini. "Energy Storage – Analysis." IEA, June 2020. https://www.iea.org/reports/energy-storage.

vi. Molten salt thermal energy storage

Thermal energy storage (TES) is technology that, by heating or cooling a storage medium, saves energy for later use, whether for heating and cooling applications or for power generation.[80] Molten salt TES (in which molten salt is the storage medium) is the most common form for electricity applications, accounting for 75% of deployed capacity in mid-2017.[81] Other types of thermal energy storage for power generation include pumped heat electrical storage and liquid air energy storage.[82] The most prevalent use for any TES technology for power generation is using molten salt storage to provide backup capacity and energy management for concentrated solar power (CSP) plants. CSP plants use mirrors called heliostats to concentrate the sun's energy to a power tower, where the energy heats a transfer fluid to over 1,000 degrees Fahrenheit (or 540 degrees Celsius). This process produces steam that is used to run a central power generator.[83] In the case of CSP paired with molten salt TES, molten salt stores the thermal energy reflected and concentrated by the mirrors. Later, the stored heat is transferred from the molten salt to boil water and produce steam, thereby facilitating electricity generation when the sun is not available, smoothing power output and extending power production for one to ten hours.

Molten salt TES has the advantages of high efficiency and a long lifetime, but the site requirements for CSP plants present hurdles. Naturally, CSP plants must be located in areas with high direct solar radiation, but they also require ample space (they are most efficient and cost-effective when greater than 100 MW in size[84]) and access to water for cooling. The response time of molten salt TES, on the order of minutes, does not make it suitable for the provision of ancillary services like frequency regulation and voltage support.

This technology is in limited but growing commercial use, with projects largely concentrated in a few countries that include Spain, South Africa, China, and Chile. One market research firm expects the molten salt TES market to grow by 660 MW to 2023, with a 39% share of this growth from the Americas.[85] Another firm expects the market to grow at 13.4% annually to 2025, reaching a value of $1.3 billion (see Figure 6).[86] High demand for CSP is expected to drive demand for molten salt TES in the Middle East and Africa,[87] and China has announced a plan to construct 6,000 MW of CSP with storage.[88]

80. "Thermal Energy Storage." International Renewable Energy Agency, January 2013. https://www.irena.org/publications/2013/Jan/Thermal-energy-storage.

81. Deign, Jason. "Will Molten Salt Outdo Batteries for Grid-Tied Storage?" Greentech Media, October 25, 2017. https://www.greentechmedia.com/articles/read/will-molten-salt-outdo-batteries-for-grid-tied-storage.

82. "Thermal Energy Storage Technology." Energy Storage Association. Accessed July 30, 2020. https://energystorage.org/why-energy-storage/technologies/thermal-energy-storage/.

83. "Concentrating Solar Power." Solar Energy Industries Association. Accessed July 30, 2020. https://www.seia.org/initiatives/concentrating-solar-power.

84. "Concentrating Solar Power." Solar Energy Industries Association. Accessed July 30, 2020. https://www.seia.org/initiatives/concentrating-solar-power.

85. "Molten Salt Thermal Energy Storage Market 2019-2023: Evolving Opportunities with Abengoa and Acciona, S.A.: Technavio." Business Wire, October 23, 2019. https://www.businesswire.com/news/home/20191023005291/en/Molten-Salt-Thermal-Energy-Storage-Market-2019-2023.

86. "Global Molten Salt Thermal Energy Storage (TES) Market 2020 by Manufacturers, Regions, Type and Application, Forecast to 2025." Market Study Report, June 28, 2020. https://www.marketstudyreport.com/reports/global-molten-salt-thermal-energy-storage-tes-market-2020-by-manufacturers-regions-type-and-application-forecast-to-2025?utm_source=Marketwatchtm.

87. "Thermal Energy Storage Market." Markets and Markets. Accessed July 30, 2020. https://www.marketsandmarkets.com/Market-Reports/thermal-energy-storage-market-61500371.html.

88. Dieterich, Robert. "24-Hour Solar Energy: Molten Salt Makes It Possible, and Prices Are Falling Fast." InsideClimate News, April 10, 2019. https://insideclimatenews.org/news/16012018/csp-concentrated-solar-molten-salt-storage-24-hour-renewable-energy-crescent-dunes-nevada.

vii. Compressed air energy storage

This emerging technology stores energy by using it to compress ambient air or another gas in an underground cavern or container, later heating the pressurized air and causing it to expand in a turbine when electricity is needed.[89] Historically, compressed air energy storage (CAES) has been used in conjunction with natural gas turbines, lowering their emissions. There are three main methods of CAES: diabatic, adiabatic, and isothermal, each with a different level of efficiency.

The advantages of CAES include the fact that it is relatively inexpensive and can be used to store very large amounts of energy, making it useful for large-scale energy management and backup capacity, including for large-scale renewable installations in large grids. The project lifetime of CAES is also much longer than for batteries. On the other hand, CAES projects have a relatively high rate of energy loss, low power density, and a response time that does not facilitate the provision of ancillary services. They require a large amount of space and are somewhat site-specific, ideally located in artificially constructed salt caverns in deep salt formations because of the high flexibility of these spaces, the lack of pressure losses, and the lack of a reaction between oxygen in the air and the salt host rock.[90] Natural aquifers may also be used in some cases, and depleted natural gas fields have been proposed as another possible alternative.

CAES is in a phase of limited commercial use, with the main markets in Germany, the United States, and Canada. The first two commercial-scale CAES plants were constructed in Huntorf, Germany, in 1978, and in McIntosh, Alabama, in 1991, with combined capacity of around 400 MW.[91] However, in the last decade a number of other projects have proliferated, including projects much smaller than the original two. In 2019, six new CAES projects were announced in China.[92] As a relatively mature technology with a long development timeline, CAES is not expected to see a significant decrease in prices to 2025, according to the DOE (see Figure 5). Still, one market research firm has projected the CAES market to grow by 27% per year to reach $10.1 billion in 2025 (see Figure 6).[93]

89. “Mechanical Electricity Storage Technology.” Energy Storage Association. Accessed July 30, 2020. https://energystorage.org/why-energy-storage/technologies/mechanical-energy-storage/.

90. “Mechanical Electricity Storage Technology.” Energy Storage Association. Accessed July 30, 2020. https://energystorage.org/why-energy-storage/technologies/mechanical-energy-storage/.

91. “Compressed Air Energy Storage (CAES) Market - Segmented by Type and Geography - Growth, Trends, and Forecast (2019 - 2024).” Mordor Intelligence, August 2019. https://www.reportlinker.com/p05815044/Compressed-Air-Energy-Storage-CAES-Market-Segmented-by-Type-and-Geography-Growth-Trends-and-Forecast.html?utm_source=PRN.

92. Munuera, Luis, and Claudia Pavarini. “Energy Storage – Analysis.” IEA, June 2020. https://www.iea.org/reports/energy-storage.

93. “Compressed Air Energy Storage Market By Application Type (Renewable Energy Integration, Grid Optimization, T&D Deferral) and by Regional Analysis - Global Forecast by 2020 - 2025.” Marketresearch, January 2020. https://www.marketresearchengine.com/compressed-air-energy-storage-market.

viii. Hydrogen energy storage

Hydrogen is a promising technology for a wide range of applications, including stationary power storage. Through electrolysis, electricity from renewable resources can be used to split water into oxygen and a product referred to as "green" hydrogen. This hydrogen can then be stored until electricity is needed, at which point it can generate power via a hydrogen-powered combustion engine or a fuel cell. Hydrogen can also be produced through steam methane reformation ("gray" hydrogen) or gasification of coal or lignite ("brown" hydrogen), and in tandem with carbon capture and storage ("blue" hydrogen). About 71% of current production is "gray" hydrogen, with "brown" accounting for most of the rest.[94] Because of its focus on decarbonization, this study is interested in "green" hydrogen, despite the fact that it is currently a miniscule share of the market.

Green hydrogen has multiple advantages for stationary power storage. It can be used to store small or very large amounts of energy for long durations (on the order of days), making it fit for both deferring T&D upgrades and large-scale energy management. It is transportable (it can travel in natural gas pipelines, for instance), and can be used for heating or transport, meaning it is potentially an important link in decarbonizing non-electric components of the energy sector using renewable power. Hydrogen storage projects also have a long lifetime. On the other hand, storage in the form of hydrogen is relatively inefficient and expensive (one reason is that fuel cells require platinum), and on a very large-scale, underground salt caverns are required for its storage. Its response time is also not fast enough to provide power quality in the way that batteries can. However, hydrogen technology is improving and its costs are falling – according to IHS Markit, green hydrogen costs have decreased by 50% since 2015 and could fall 30% further by 2025, becoming cost-competitive with the methods currently prevalent by 2030 due to economies of scale, more standardized manufacturing, and falling renewable costs.[95] Wood Mackenzie estimates green hydrogen costs could fall by 64% to 2040, and BNEF estimates that the range of costs for producing green hydrogen could fall from $2.50-$5.00/kg today to $0.70-$1.60/kg by 2050.

For now, hydrogen's commercial use is limited, estimated at around $13 billion in 2018,[96] even though it has been touted as a potentially transformative technology since at least the 1970s.[97] Deployment of hydrogen storage projects is fairly concentrated in Europe (especially Germany) and Japan, and most projects are no larger than a few megawatts. However, some countries have major long-term plans for development of hydrogen technology and deployment of hydrogen storage (for instance, a leaked draft of the European Union's post-Covid-19 stimulus plan reportedly includes a 2030 goal of 40 GW of green hydrogen capacity).[98] Los Angeles, California, has plans for the world's first green hydrogen power plant, which would store up to 100,000 MWh of hydrogen in over 100 enormous salt caverns.[99] Though the timeline for its development depends on numerous factors, hydrogen is ultimately likely to be a key component of decarbonization. IHS Markit analysis postulates

94. Flowers, Simon. "Green Hydrogen: A Pillar Of Decarbonization?" Wood Mackenzie Contribution. Forbes Magazine, January 31, 2020. http://www.forbes.com/sites/woodmackenzie/2020/01/31/green-hydrogen-a-pillar-of-decarbonization/.

95. "IHS Markit: Production of Carbon-Free 'Green' Hydrogen Could Be Cost Competitive by 2030." IHS Markit Online Newsroom, July 14, 2020. https://news.ihsmarkit.com/prviewer/release_only/slug/bizwire-2020-7-15-ihs-markit-production-of-carbon-free-green-hydrogen-could-be-cost-competitive-by-2030.

96. "Hydrogen Energy Storage - Global Market Outlook (2018-2027)." Research and Markets - Market Research Reports - Welcome, February 2020. https://www.researchandmarkets.com/reports/5008299/hydrogen-energy-storage-global-market-outlook?utm_source=dynamic.

97. "After Many False Starts, Hydrogen Power Might Now Bear Fruit." The Economist, July 4, 2020. https://www.economist.com/science-and-technology/2020/07/04/after-many-false-starts-hydrogen-power-might-now-bear-fruit.

98. "After Many False Starts, Hydrogen Power Might Now Bear Fruit." The Economist, July 4, 2020. https://www.economist.com/science-and-technology/2020/07/04/after-many-false-starts-hydrogen-power-might-now-bear-fruit.

99. "Energy Storage Updater." Norton Rose Fulbright, June 2020. https://www.nortonrosefulbright.com/en/knowledge/publications/518825d1/energy-storage-updater-june-2020.

that in a fully decarbonized Europe, hydrogen could represent for up to one third of the energy mix.[100]

Technical characteristics of the eight energy storage technologies described above are summarized in Table 4.

Table 4: Technical Characteristics of Energy Storage Technologies

Technology	Power Rating (MW)	Storage Duration	Depth-of -Discharge	Life (Full Equivalent Cycles)	Energy Density (Wh/L)	Efficiency	Response Time
PHS	100-1000	4-12 hrs	90%	20000	0.2-2	70-85%	sec-min
Lithium-ion	0.1-100	1 min - 8 hrs	90%*	3500*	200-400	85-98%	10-20 ms
Lead-acid	0.001-100	1 min - 8 hrs	50%**	500**	50-80	80-90%	<sec
NaS	10-100	1 min - 8 hrs	100%	5000	150-300	70-90%	10-20 ms
Flow	1-100	2-10 hrs	100%***	10000***	20-70	60-85%	10-20 ms
Molten salt TES	1-150	hours	X	10000	70-210	80-90%	min
Hydrogen	0.01-1000	minutes - weeks	83%†	Electrolyzer: 50000 hrs Fuel cell: 15000 hrs	600 (200 bar)	25-45%	sec-min
CAES	10-1000	2-30 hrs	40%	20000	2-6	40-75%	sec-min

*lithium iron phosphate or lithium nickel manganese cobalt **valve-regulated lead-acid ***vanadium redox †for "electrolyzer + tank H2 storage + PEM fuel cell"

Sources: World Energy Council[101], IRENA[102] (p. 39), Clean Horizon Consulting (hydrogen life),[103] Solar Thermal World (molten salt TES life), NREL[104] (hydrogen depth-of-discharge)

100. "IHS Markit: Production of Carbon-Free 'Green' Hydrogen Could Be Cost Competitive by 2030." IHS Markit Online Newsroom, July 14, 2020. https://news.ihsmarkit.com/prviewer/release_only/slug/bizwire-2020-7-15-ihs-markit-production-of-carbon-free-green-hydrogen-could-be-cost-competitive-by-2030.

101. "Energy Storage Monitor, Latest Trends in Energy Storage 2019." World Energy Council, 2019. https://www.worldenergy.org/assets/downloads/ESM_Final_Report_05-Nov-2019.pdf

102. IRENA. "Electricity Storage Valuation Framework: Assessing system value and ensuring project viability." International Renewable Energy Agency, 2020. https://irena.org/-/media/Files/IRENA/Agency/Publication/2020/Mar/IRENA_storage_valuation_2020.pdf

103. Epp, Baerbel. "Molten Salt Storage 33 Times Cheaper than Lithium-Ion Batteries." Solarthermalworld, October 18, 2019. https://www.solarthermalworld.org/news/molten-salt-storage-33-times-cheaper-lithium-ion-batteries.

104. Hunter, Chad and Penev, Michael. "Energy Storage Analysis." NREL, April 30, 2019. https://www.hydrogen.energy.gov/pdfs/review19/sa173_penev_2019_p.pdf

III. ENERGY STORAGE IN LAC

a. Introduction to Energy Storage in LAC

i. Decarbonization in LAC and the Role of Energy Storage

Electricity storage offers great opportunities for LAC for a variety of reasons. Many countries in the region have ambitious climate change mitigation targets[105] the energy sector is a major contributor to CO^2 emissions, and the region has vast VRE potential. Furthermore, as economic development, population growth, and electrification progress, power demand is poised to grow, increasing the need for enhanced grid services.

In 2017, electricity and heat accounted for 26.5% of greenhouse gas emissions in LAC,[106] despite the fact that the region has a relatively clean power matrix by global standards. Renewable energy, including hydropower, represented a share of almost 60% of power capacity in LAC in 2018, with large hydro alone accounting for about 43%.[107] However, though hydropower provides a significant supply of firm energy in many countries across the region (around 70% of generation or more on average in Brazil, Colombia, and Costa Rica[108]), hydropower capacity is becoming less predictable in some countries as climate change alters rainfall patterns, and in some regions, reservoirs are being depleted by drought. The impetus to build new hydropower capacity is also stymied by concerns over its detrimental environmental and social impacts and high costs. Building hydroelectric dams involves flooding large areas, dramatically altering both terrestrial and aquatic ecosystems and sometimes displacing entire human communities. These dams are often built in anticipation of future demand, and if demand growth in that particular market is slower than anticipated, it can take a long time to recover the large upfront investments.

Meanwhile, as large hydro potential has stagnated over the last decade, solar and wind energy have accelerated (see Figure 7). In recent years, government-led auctions in LAC have awarded many solar and wind generation contracts at prices competitive with fossil fuel generation.[109] [110] According to BNEF, in the first half of 2020, onshore wind was the cheapest source of new bulk generation in Brazil, Argentina, Peru, and Panama, and solar in Colombia, Uruguay, Ecuador, Chile, and Guatemala.[111] MIT expects solar and wind generation in Latin America to grow by 550% between 2015 and 2030,[112] and the IDB has projected that the participation of solar and wind in the regional power matrix will grow from 5.1% to 18.9%

105. Morillo Carrillo, Jose, David Lopez , Monica Espinosa , Angela Cadena, and Michelle Carvalho . Alineamiento de las políticas energéticas y los compromisos climáticos de los países en Latinoamérica: Una comparación entre las NDC y las trayectorias de emisiones de la generación eléctrica. Inter-American Development Bank, November 22, 2019. https://publications.iadb.org/es/alineamiento-de-las-politicas-energeticas-y-los-compromisos-climaticos-de-los-paises-en.

106. "Data & Statistics." IEA, August 1, 2020. https://www.iea.org/data-and-statistics.

107. "Climatescope 2019 – Capacity & Generation." BloombergNEF. Accessed July 30, 2020. http://global-climatescope.org/capacity-generation

108. "Climatescope 2019 – Capacity & Generation." BloombergNEF. Accessed July 30, 2020. http://global-climatescope.org/capacity-generation

109. Viscidi, Lisa and Yepez, Ariel. "Clean Energy Auctions in Latin America." Inter-American Development Bank, January 14, 2020. https://www.thedialogue.org/analysis/clean-energy-auctions-in-latin-america/

110. Lopez, David, Alexandre Mejdalani, Adelaida Nogales, Michelle Carvalho, and Mauricio Tolmasquim. "Advancing the Policy Design and Regulatory Framework for Renewable Energies in Latin America and the Caribbean for Grid-Scale and Distributed Generation." Inter-American Development Bank, December 2019. https://publications.iadb.org/en/advancing-policy-design-and-regulatory-framework-renewable-energies-latin-america-and-caribbean.

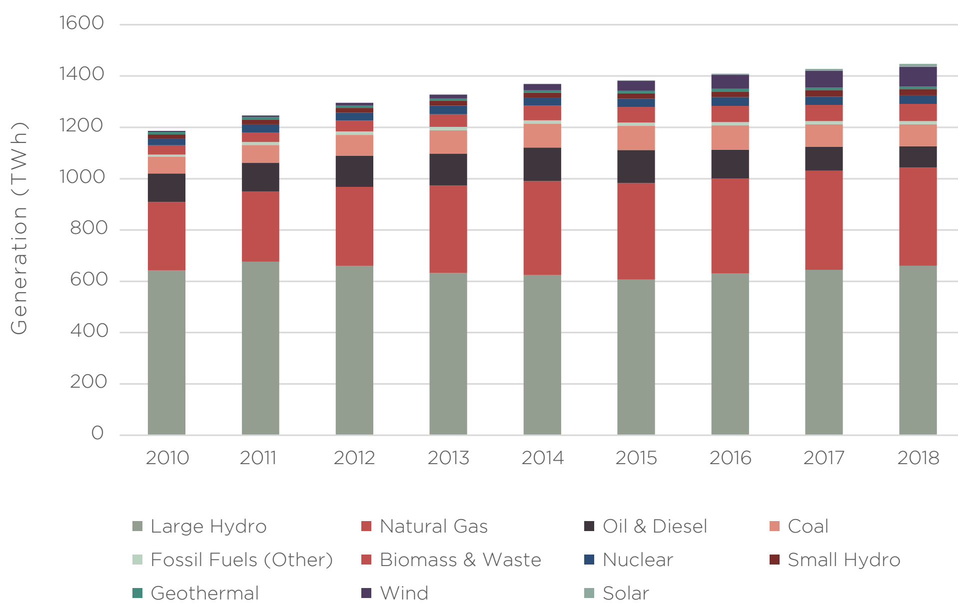
111. BloombergNEF. "Scale-up of Solar and Wind Puts Existing Coal, Gas at Risk." April 28, 2020. https://about.bnef.com/blog/scale-up-of-solar-and-wind-puts-existing-coal-gas-at-risk/

112. Paltsev, S., M. Mehling, N. Winchester, J. Morris and K. Ledvina. "Pathways to Paris: Latin America." MIT Joint Program Special Report, 2018. http://globalchange.mit.edu/publication/17161

between 2016 and 2030 in a base scenario, even as demand increases by 72%.[113] The region is endowed with vast solar and wind resources – enough to meet present power demand 37 and 16 times over, respectively.[114]

Despite the impressive growth rates of VRE in LAC, the share of these energy sources in the total matrix is starting from a very low base. Solar and wind accounted for just 1.9% and 6.5%, respectively, of LAC power capacity in 2018, and would need to grow at a much faster pace to meet incremental demand and allow for full decarbonization of the energy system over the longer term. Electricity demand in the region is already projected to double by 2040,[115] and the electrification of transport and heating to decarbonize these sectors will drive it up further still. Full decarbonization will thus require VRE to be deployed on a much larger scale, perhaps demanding cumulative investments of $800 billion by 2050, according to UNEP.[116] Energy storage will be a crucial element in order to integrate all of this VRE and develop clean and reliable grids.

Figure 7: Generation (TWh) by Technology, LAC



113. Paredes, Juan Roberto. "Red del futuro: desarrollo de una red eléctrica limpia y sostenible para América Latina." Banco Interamericano de Desarrollo Paredes, 2017. https://publications.iadb.org/es/publicacion/14076/la-red-del-futuro-desarrollo-de-una-red-electrica-limpia-y-sostenible-para.

114. Paredes, Juan Roberto. "Red del futuro: desarrollo de una red eléctrica limpia y sostenible para América Latina." Banco Interamericano de Desarrollo Paredes, 2017. https://publications.iadb.org/es/publicacion/14076/la-red-del-futuro-desarrollo-de-una-red-electrica-limpia-y-sostenible-para.

115. Yepez, Ariel, Yi Ji, Michelle Carvalho , and David Lopez . "The Energy Path of Latin America and the Caribbean." Inter-American Development Bank, December 28, 2018. https://publications.iadb.org/en/energy-path-latin-america-and-caribbean.

116. "Latin America and the Caribbean could save US$ 621 billion by 2050 through the decarbonization of energy, transport sectors." UN Environment Programme, December 12, 2019. https://www.unenvironment.org/news-and-stories/press-release/latin-america-and-caribbean-could-save-us-621-billion-2050-through

ii. LAC Regulatory Context

As in much of the world, regulation pertaining to energy storage is in an early stage in Latin America and the Caribbean. However, some countries have begun to remove barriers to energy storage that exist because of regulation that is not tailored to storage, and to create explicit mechanisms for compensation of services provided by energy storage and collection of revenue from multiple sources. Ambitious renewable energy goals also create the expectation of increasing demand for storage, and some countries have even begun to hold specific tenders for storage.

Rules governing energy storage have begun cropping up across the region. In Chile, the 2016 general law of electric services explicitly addressed energy storage, facilitating its participation in the country's power markets and reducing the need to interpret regulations that are not tailored to these technologies, which had caused much uncertainty for energy storage developers.[117] Colombia's government followed suit in 2019, taking an active role in energy storage deployment with Resolution 098, which creates a competitive process and designates responsibilities for the installation and operation of battery systems.[118] Poor grid reliability, especially on the country's Caribbean coast,[119] was a driving force behind this regulation, which should facilitate T&D deferrals.[120] El Salvador has also begun the process of developing energy storage regulation as the share of VRE in the national grid increases.[121]

Some countries have also begun to undertake the challenge of assigning values to the benefits of energy storage. This requires a robust understanding of the grid services provided by various energy storage technologies and can be facilitated by regulators through close collaboration with companies. For example, in Chile, a pilot project implemented by AES Gener, a private company, was evaluated with regulators so that regulations could be adjusted in order to provide additional compensation for capacity services.[122] Colombia's regulator prepared a regulation permitting storage to be compensated as a transmission asset in cases where it can be used in place of transmission upgrades.[123] In 2019, Mexico's energy regulator approved regulations to define payment for and prioritization of various services provided by energy storage to the transmission and distribution system, with the aim of making storage installations profitable by recognizing and compensating their multiple functions.[124] These regulations have not entered into effect as their formal publication is still pending approval from the federal government national official registry.

117. Riego, Cristobal. "What Can Regulators Do to Accelerate the Adoption of Energy Storage?" BNamericas, June 25, 2020. https://app.bnamericas.com/article/section/all/content/x6asq6icc-que-pueden-hacer-los-reguladores-para-acelerar-la-penetracion-del-almacenamiento-de-energia.

118. "Reglamentan Uso De Baterías Para Guardar Energía Renovable." Portafolio, November 6, 2019. https://www.portafolio.co/economia/reglamentan-uso-de-baterias-para-guardar-energia-renovable-535337.

119. Place, Michael. " Colombia to Launch Battery Storage Tender." BNamericas, June 24, 2020. https://app.bnamericas.com/article/section/all/content/xfqiofecm-colombia-to-launch-battery-storage-tender.

120. Place, Michael. "The Future of Energy Storage in Latin America." BNamericas, June 18, 2020. https://app.bnamericas.com/article/section/all/content/xqfhapdf9-the-rise-of-energy-storage-in-latin-america.

121. Casallas, David. "El Salvador Preparing Energy Storage Regulation." BNamericas, June 15, 2020. https://app.bnamericas.com/article/section/all/content/xyumbv9mn-el-salvador-preparing-energy-storage-regulation.

122. Riego, Cristobal. "What Can Regulators Do to Accelerate the Adoption of Energy Storage?" BNamericas, June 25, 2020. https://app.bnamericas.com/article/section/all/content/x6asq6icc-que-pueden-hacer-los-reguladores-para-acelerar-la-penetracion-del-almacenamiento-de-energia.

123. Riego, Cristobal. "Fluence: Storage as Transmission 'Is Winning a Lot of Ground' in Chile," July 28, 2020. https://app.bnamericas.com/article/section/all/content/xaymwwamq-for-tuesday-fluence-storage-as-transmission-is-winning-a-lot-of-ground-in-chile.

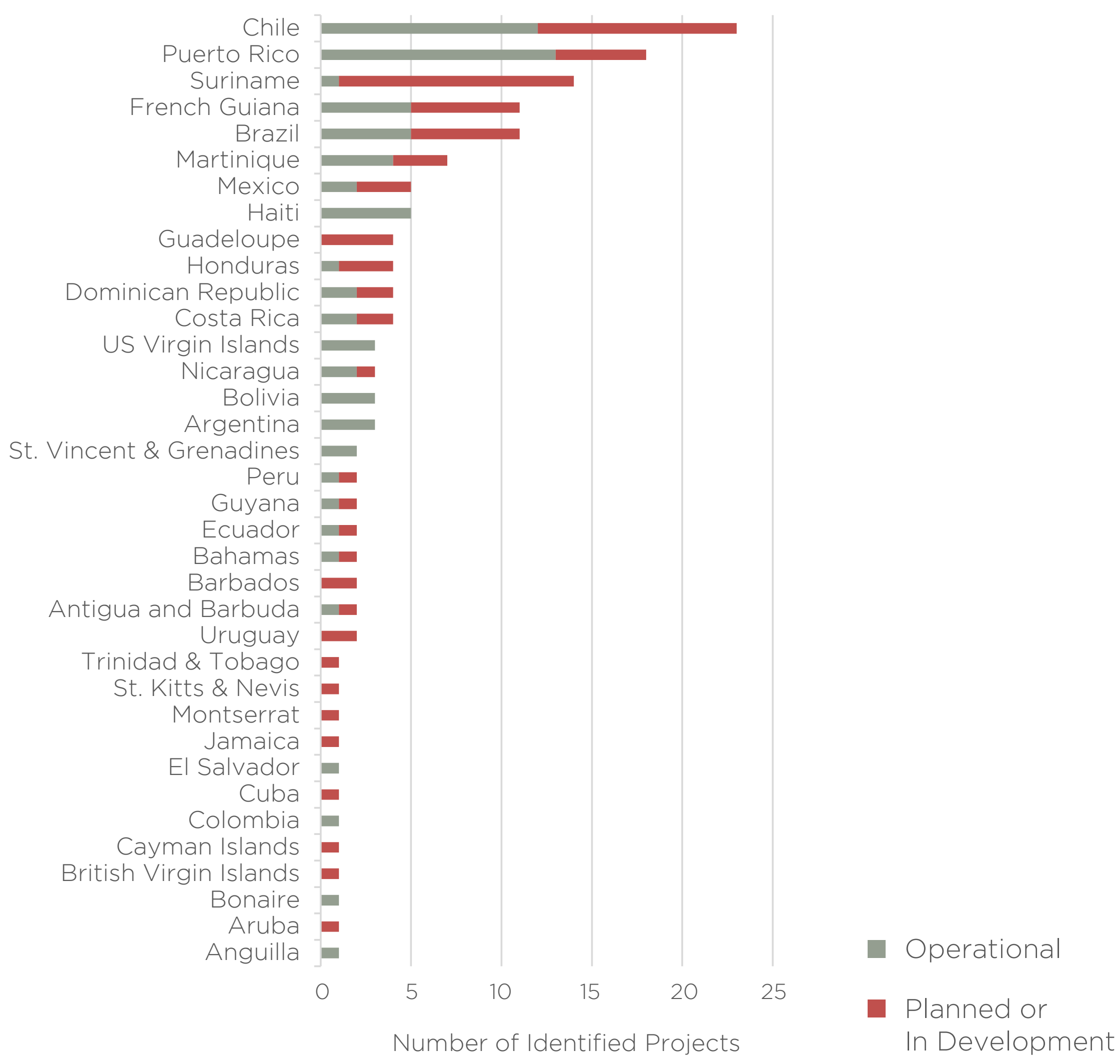
124. "Prepara CRE Disposiciones En Materia De Almacenamiento De Energía." Energia a Debate, February 13, 2019. http://energiaadebate.com/regulacion/prepara-cre-disposiciones-en-materia-de-almacenamiento-de-energia/.

Finally, in terms of creating a reliable market with competitive terms for energy storage, many countries in the region have already taken promising steps through long-term renewable energy goals, incentives for renewable energy, and renewable energy auctions. These steps all send a signal that the value of cleaner and more resilient grids is recognized in the region and that demand for VRE, and inevitably storage, is poised to expand. Colombia is even holding its first tender for energy storage, targeted at congestion problems near Barranquilla, in 2021.[125]

iii. Overview of Current Energy Storage Deployment in LAC

Our research identified 150 energy storage projects in 36 countries and territories in LAC, with the greatest number in Chile (see Figure 8).

Figure 8: Number of Identified Energy Storage Projects by Geography, LAC



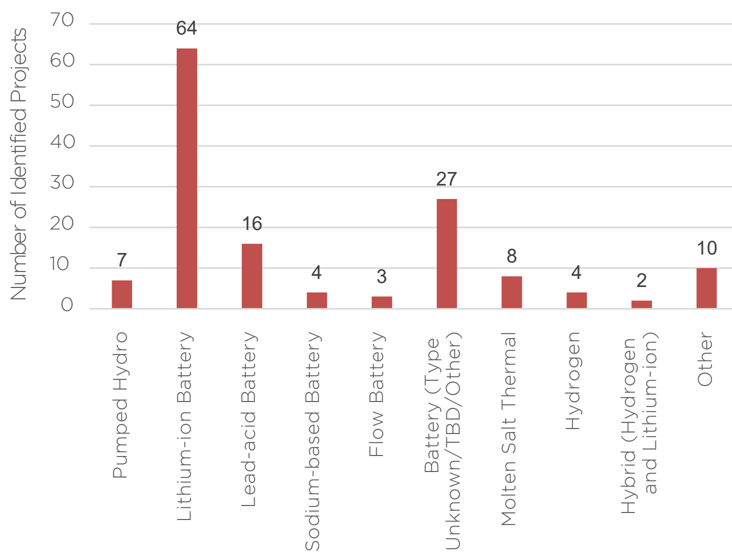
Sources: Authors' calculations based on GlobalData, DOE[126], IDB, BNamericas, news reports

125. Place, Michael. "Colombia to launch energy storage tender in 2021." BNamericas, October 6, 2020. https://app.bnamericas.com/article/section/all/content/xrzlkem4w-colombia-postpones-energy-storage-auction

126. "DOE Global Energy Storage Database." US Department of Energy. Accessed July 30, 2020. https://www.sandia.gov/ess-ssl/global-energy-storage-database/

Although our list is not comprehensive, it demonstrates that a wide range of electricity storage projects are operating or planned all over the region. Lithium-ion batteries were the dominant technology (see Figure 9), accounting for nearly half of projects, while batteries of other types, or whose type is unknown or to-be determined, accounted for a further 35%. We also identified several molten salt thermal energy storage and pumped hydro storage projects.

Figure 9: Number of Identified Energy Storage Projects by Technology Type, LAC

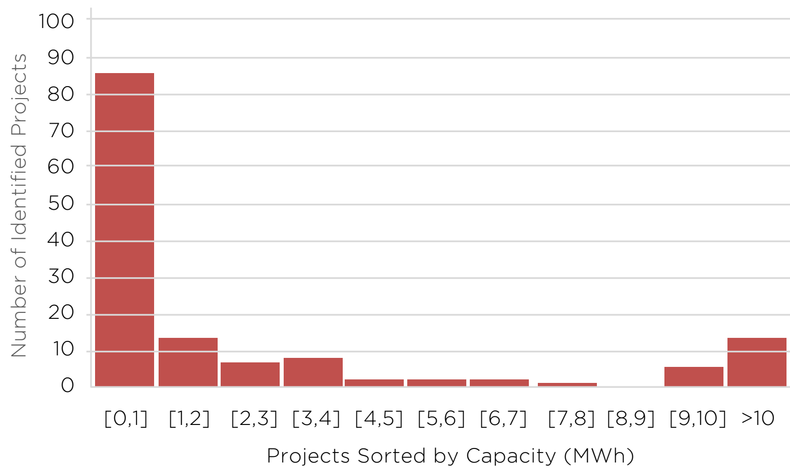


Sources: Authors' calculations based on GlobalData, DOE[127], IDB, BNamericas, news reports

127. "DOE Global Energy Storage Database." US Department of Energy. Accessed July 30, 2020. https://www.sandia.gov/ess-ssl/global-energy-storage-database/

The vast majority of projects are very small, under 1 MWh, and deployed in mini-grids (see Figure 10).

Figure 10: Number of Identified Energy Storage Projects Sorted by Storage Capacity (MWh), LAC



Sources: Authors' calculations based on GlobalData, DOE[128], IDB, BNamericas, news reports
Note: Not all 150 identified projects are visualized in this figure due to missing data.

While some storage installations have been deployed in order to integrate renewable energy, they have also served other purposes, including providing frequency regulation, reserve capacity, and on-site power, and enabling mini-grids. Clean Horizon Consulting, meanwhile, finds that operational energy storage capacity in the region has reached 111 MW, and another 87 MW of capacity has been announced. In Chile, the region's leader, there are more than 54 MW of operational systems, followed by 22.5 MW in Mexico and close to 20 MW in the Dominican Republic. Frequency regulation has been the dominant application so far, followed by integration of renewable energy. Clean Horizon also states that more than 20 GW of energy storage capacity is announced, operational, or under construction worldwide. However, although LAC is behind the curve, the following section will demonstrate that energy storage is gaining traction in numerous markets and has myriad untapped applications in the region.

128. "DOE Global Energy Storage Database." US Department of Energy. Accessed July 30, 2020. https://www.sandia.gov/ess-ssl/global-energy-storage-database/

b. Current and Potential Uses of Energy Storage in LAC by Technology

i. Pumped hydro energy storage

In LAC, we identified four PHS projects currently in use, and three more on the horizon. The Los Reyunos and Río Grande projects in Argentina, with combined capacity of almost 1 GW, have been operating since the 1980s (see Box 3).[129] Two smaller projects (30.8 MW and 20 MW) are also operational in Chile and Brazil. In Chile, the 300-MW Espejo de Tarapacá project plans to pump seawater to store energy produced by solar energy in the Atacama Desert,[130] and two projects with combined capacity of more than 1.4 GW are being permitted in Brazil. Finally, in 2015 a 50-MW seawater pumped storage project was proposed to facilitate greater VRE penetration in Guadaloupe, but we found no evidence that the project was completed.[131] Jamaica is also reportedly considering a pumped hydro system of up to 200 MWh that would pump water from an aquifer and then release it to the lower-lying parts of the island around Kingston, which suffers from water shortages.[132] Honduras is considering a pumped storage system as part of the modernization of its 300-MW Francisco Morazán hydroelectric complex.

Though its applications are limited for the reasons outlined above, and as a mature technology it is no longer witnessing significant cost declines like some other storage technologies (see Figure 5), PHS could have a place in the development of more secure and VRE-dependent power systems in LAC. The region is one of the most hydro-dependent in the world – Brazil is home to the second-most installed hydro capacity of any country (109 GW), and Venezuela, Mexico, and Colombia also rank in the top 20.[133] Incorporating PHS with existing hydroelectric dams could provide an economically competitive solution with lower added environmental impact. A research study proposed that in Brazil PHS be coupled with existing reservoirs to balance seasonal variations, which have been increasing in magnitude with climate change, even reducing spillage or evaporation and thereby improving efficiency in addition to other benefits of storage.[134] In 2018, Brazil's Energy Research Office (EPE) identified 15 possible sites for PHS plants totaling 21.1 GW in Rio de Janeiro state alone, but the lack of a regulatory framework for PHS complicates capitalizing on this potential.[135] Projects using seawater could be explored in coastal areas, though they are very site-specific and only a small number of these projects currently exist globally.

129. Barrow, Deanne and Borda-Olarte Monica. "Energy Storage in Latin America and the Caribbean." Norton Rose Fulbright, February 20, 2018. https://www.projectfinance.law/publications/energy-storage-in-latin-america-and-the-caribbean.

130. Valhalla. "Espejo de Tarapacá." Accessed on July 30, 2020. http://valhalla.cl/espejo-de-tarapaca/

131. Pierre Brun, Bernard Mahiou and Michel Ayoub. "La STEP marine de petit canal en Guadeloupe : une solution de stockage pour l'insertion des ENR intermittentes." La Houille Blanche, March 2015. https://www.shf-lhb.org/articles/lhb/abs/2015/01/lhb2015001/lhb2015001.html

132. Casallas, David. "Pumped Storage Hydropower on Jamaica Radar." BNamericas, March 23, 2020. https://app.bnamericas.com/article/section/all/content/xruzj3zwc-pumped-storage-hydropower-on-jamaica-radar.

133. International Hydropower Association. "Hydropower Status Report 2020." IHA, 2020. https://www.hydropower.org/sites/default/files/publications-docs/2020_hydropower_status_report.pdf

134. International Hydropower Association. "The world's water battery: Pumped hydrostorage and the clean energy transition." IHA, December 2018. https://www.hydropower.org/sites/default/files/publications-docs/the_worlds_water_battery_-_pumped_storage_and_the_clean_energy_transition_2.pdf

135. Ruddy, Gabriela. "Batteries, Pumped Hydro and Gas Storage Could Gain Ground in Brazil." BNamericas, August 29, 2019. https://app.bnamericas.com/article/section/all/content/xogowswli-batteries-pumped-hydro-and-gas-storage-could-gain-space-in-brazils-energy-market.

Box 3: Pumped Hydro in Argentina

Pumped hydro is the most widespread form of energy storage worldwide, but despite the abundance of hydroelectric power in use in Latin America, this technology has not been deployed in most of the region. Argentina is an exception, home to two pumped hydro storage facilities with combined capacity of almost 1 GW since the 1980s.

The larger of these plants, the Río Grande complex, has rated power of 750 MW and is located in Córdoba Province's Calamuchita Valley. The $1 billion project, inaugurated in 1986 following four years of research and 12 years of construction,[136] comprises two reservoirs — one 12 kilometers downstream of the other and 185 meters lower in elevation. The plant has four sets of turbine-pumps, each with a capacity of 187.5 MW, which can be used to generate electricity, to pump water from the lower to the upper reservoir, and to provide reactive power to the system. By using power during periods of low demand to pump water to the upper reservoir, the plant increases the amount of potential power available for generation during high-demand periods. In fact, the Río Grande only provides 15% of the flow that is necessary for the complex to generate. The remaining 85% is provided by pumping water to the upper reservoir during low-demand periods.[137]

Given the relative lack of experience with pumped hydro in the region, the 34-year case study of the Río Grande complex could be a useful tool for energy policy planners and utilities that are considering pumped hydro as an option. There is also a wealth of experience with this well-established technology in the 158 GW of projects operating worldwide.

ii. Lithium-ion batteries

Due to their many advantages, lithium-ion batteries are the fastest growing energy storage technology worldwide, and Latin America and the Caribbean are part of the trend, with lithium-ion battery projects of many different sizes already operational and many more planned. We identified 64 planned or operational projects in Mexico, St. Kitts and Nevis, Ecuador, the Dominican Republic, French Guiana, Martinique, Guadeloupe, El Salvador, Chile, Brazil, Costa Rica, St. Vincent and the Grenadines, Antigua and Barbuda, the US Virgin Islands, the Bahamas, Haiti, Puerto Rico, Guyana, Suriname, Bolivia, and Anguilla. Many of these projects facilitate renewable energy integration, including through capacity firming, time-shift, and arbitrage, as well as providing services (see Box 4) including reserve capacity, frequency regulation, and enabling mini-grids.

For example, the Basseterre Valley Solar PV Park in St. Kitts and Nevis is expected to have one of the region's largest batteries, with a 14.8-MW / 45.7-MWh lithium-ion system. Construction began on the project in December 2020 and it is expected to be operational in 18 months.[138] Ecuador is tendering a 14.8-MW solar farm on the Galápagos island of Santa Cruz, with 40.9 MWh of storage.[139] AES Gener recently broke ground on the Andes Solar II B solar park, which will have five hours of 112-MW lithium-ion battery storage

136. "Central Río Grande, Un Orgullo Para Los Cordobeses." La Voz del Interior, November 2, 2017. https://www.lavoz.com.ar/espacio-de-marca/central-rio-grande-un-orgullo-para-los-cordobeses.
137. "Central Río Grande." EPEC. Accessed August 14, 2020. https://web.epec.com.ar/generacion_central_h_rio-grande.html.
138. Leclanché. "Government of St. Kitts and Nevis, SKELEC and Leclanché Commence Construction of Caribbean's Largest Solar Generation and Storage System." PR Newswire. Cision, December 11, 2020. https://www.prnewswire.com/news-releases/government-of-st-kitts-and-nevis-skelec-and-leclanche-commence-construction-of-caribbeans-largest-solar-generation-and-storage-system-301190418.html.
139. Bellini, Emiliano. "Tender Launched for 14.8 MW/40.9 MWh of Solar+Storage in Ecuador." PV magazine International, June 18, 2020. https://www.pv-magazine.com/2020/06/18/tender-launched-for-14-8-mw-40-9-mwh-of-solarstorage-in-ecuador/.

capacity, making it Latin America's largest lithium-ion battery storage system.[140] The Albireo Power Reserve in El Salvador, with capacity of 3.3 MW/2.2 MWh, recently came online as the largest storage project to date in Central America, accompanying a solar park.[141] The IDB is financing a solar mini-grid with 1 MWh of lithium-ion battery storage in Godo Olo, Suriname, and has also financed a 624-kWh battery accompanying a small solar plant in Puerto Villazón, Bolivia.

Box 4: Grid-Scale Services Provided by Lithium-ion Batteries in Mexico

While energy storage is an indispensable asset for high levels of VRE penetration, it also offers a number of other services that improve grid performance and reliability. An example comes from a Kia manufacturing plant near Monterrey, Mexico, where a 12-MW/12-MWh lithium iron phosphate battery system provides frequency regulation, voltage support, and spinning reserves to ensure continuous power supply to the plant's operations.[142]

This large manufacturing facility, with capacity to produce up to 400,000 small cars per year, relies on seven 18-MW natural gas generators to circumvent interconnection to the Mexican grid. In the event that one of these generators fails or the load spikes, the lithium battery system can respond nearly instantaneously to maintain supply. According to the battery provider, the system can respond to an engine failure in 100 milliseconds and stabilize frequency in 500 milliseconds. The system, operational in October 2018, not only serves as insurance against an outage, but also provides daily power quality[143].

Even though it is a behind-the-meter project, as one of Mexico's first large-scale batteries, this system illustrates the services beyond the integration of VRE that batteries can provide to the grid on a large scale.

Due to their scalability and low cost, lithium-ion batteries will likely be the most competitive energy storage technology for the foreseeable future for projects seeking to expand electricity access through mini-grids in the region's many off-grid areas (see Box 6). In off-grid applications, energy storage combined with small wind or solar projects is often cheaper than the common alternative, diesel powered-generators. Similarly, the interconnected grid systems in Caribbean islands often rely on expensive fuel oil and diesel imports for power generation. For instance, in Jamaica, which generated 88% of its power from oil, diesel, and natural gas in 2018,[144] residential power prices are around twice the global average.[145] Lithium-ion batteries may in many such cases be more competitive than conventional fuels when paired with wind and solar generation.[146] Thus, overall, many lithium-ion projects in the region have focused on off-grid and island contexts. In contrast, utility-scale applications for large interconnected systems, such as facilitating VRE integration and providing ancillary and T&D services, are generally less economically viable because they cannot compete on price with firm generation sources such as natural gas.

140. AES Gener. "AES Gener Begins Construction of Chile's First Solar plus Storage Project and Consolidates Wind Presence in Southern Chile." BNamericas, October 15, 2020. https://app.bnamericas.com/article/section/all/content/xqshlhwt5-aes-gener-begins-construction-of-chiles-first-solar-plus-storage-project-and-consolidates-wind-presence-in-southern---
141. "El Salvador: Planta Solar Neoen Instala La Batería De Litio Más Grande De La Región." Revista Estrategia & Negocios, February 27, 2020. https://www.estrategiaynegocios.net/empresasymanagement/1359861-330/el-salvador-planta-solar-neoen-instala-la-bater%C3%ADa-de-litio-m%C3%A1s-grande.
142. "Mexico Microgrid Project." Powin Energy. Accessed August 13, 2020. http://www.powinenergy.com/project/mexico-microgrid-project
143. Spector, Julian. "Mexico Gets Its First Grid-Scale Battery—at a Car Factory." Greentech Media, December 17, 2018. https://www.greentechmedia.com/articles/read/mexico-gets-its-first-grid-scale-battery-and-its-at-a-car-factory#gs.jrc20f.
144. "Climatescope 2019 – Capacity & Generation." BloombergNEF. Accessed July 30, 2020. http://global-climatescope.org/capacity-generation
145. "Electricity Prices around the World." GlobalPetrolPrices.com. Accessed August 14, 2020. https://www.globalpetrolprices.com/electricity_prices/.
146. Viscidi, Lisa, Nate Graham, Marcelino Madrigal, Malaika Masson, Veronica Prado, and Juan Cruz Monticelli. "Electrified Islands: The Road to E-Mobility in the Caribbean." The Inter American Dialogue, February 11, 2020. https://www.thedialogue.org/analysis/electrified-islands-the-road-to-e-mobility-in-the-caribbean/

Box 5: South America's "Lithium Triangle" and Potential for Battery Manufacturing

In addition to the benefits of lithium-ion batteries for power systems, the lithium-ion battery supply chain may represent a commercial opportunity for South America's "Lithium Triangle." Chile, Argentina, and Bolivia hold almost 60% of the world's identified lithium resources and manufacturing of batteries using locally-sourced lithium could create jobs and economic diversification.[147] The government of Chile (home to the largest share of reserves) has accepted bids for the development of the Chilean Clean Energy Institute in the lithium-rich (and solar-rich) region of Antofagasta. The institute, among other objectives, will seek to promote advanced lithium technology development. It will receive investment of up to US$193 million over 10 years, funded partly by the government and partly by the private sector as part of a lithium-extraction agreement.[148] Past efforts in Chile to make production contracts contingent on the development of a local battery supply chain have not produced the results that were hoped for, and plans for a battery plant in Bolivia also fell through in 2019.[149] However, the growth of the Latin American energy storage market could improve the economics of battery manufacturing in the Lithium Triangle in the coming decade.[150] Furthermore, in 2018 a large amount of lithium was discovered in Peru, and recent discoveries in Mexico could also place its reserves among the world's largest. Mexico also has the added benefit of being a global auto manufacturing hub already, making the step from lithium production to battery production much smaller. According to Bloomberg New Energy Finance, by 2025, the lithium-ion battery supply chains of Brazil, Chile, Argentina, and Mexico will all rank in the top 16 in the world.[151]

iii. Lead-acid batteries

Though lithium-ion batteries are by far the dominant battery technology for energy storage in LAC, this study identified seven planned or operational lead-acid battery projects. Six of these are mini-grid projects paired with solar PV, located in Guyana, Chile, Costa Rica, and Colombia, as well as IDB projects in Bolivia and Suriname. A cinema in the US Virgin Islands also uses a behind-the-meter solar PV and lead-acid battery system for on-site generation and reduction of peak electricity cost. Lead-acid batteries may continue to provide an option for off-grid applications in some contexts, especially as renewable mini-grids increase in popularity, though its role will be increasingly limited as lithium-ion battery prices continue to fall and perform better for the same applications.

147. U.S. Geological Survey. "Mineral Commodity Summaries." USGS, January 2020. https://pubs.usgs.gov/periodicals/mcs2020/mcs2020-lithium.pdf

148. "Corfo Recibe Cuatro Postulaciones Para Desarrollar El Instituto Chileno De Tecnologías Limpias En Antofagasta." Electricidad Revista, April 8, 2020. https://www.revistaei.cl/2020/04/08/corfo-recibe-cuatro-postulaciones-para-desarrollar-el-instituto-chileno-de-tecnologias-limpias-en-antofagasta/.

149. "Bolivia Scraps Joint Lithium Project with German Company." DW.COM. Accessed August 14, 2020. https://www.dw.com/en/bolivia-scraps-joint-lithium-project-with-german-company/a-51100873.

150. Sherwood, Dave. "How Lithium-Rich Chile Botched a Plan to Attract Battery Makers." Reuters. Thomson Reuters, July 17, 2019. https://www.reuters.com/article/us-chile-lithium-focus/how-lithium-rich-chile-botched-a-plan-to-attract-battery-makers-idUSKCN1UC0C8.

151. "China Dominates the Lithium-Ion Battery Supply Chain, but Europe Is on the Rise." BloombergNEF, September 16, 2020. https://about.bnef.com/blog/china-dominates-the-lithium-ion-battery-supply-chain-but-europe-is-on-the-rise/

Box 6: Energy Storage for Mini-grids in LAC

Though energy storage holds potential for many grid-scale applications, it is also a promising tool for rural electrification. Indeed, the vast majority of energy storage applications in LAC to date have been in the form of mini-grids. The IDB has implemented or is implementing a number of these projects, one of which was inaugurated in July 2019 as the largest hybrid solar-thermal island generation system in the region.[152] The Caribbean Pride project, with 2.1 MW of solar capacity and 2.4 MW (2.22 MWh[153]) of lithium-ion battery storage capacity, is located on Corn Island in Nicaragua and is a pioneer for the use of battery storage in the region.

The $5.9-million project co-financed by the IDB and the Nicaraguan government[154] is expected to provide clean and reliable electricity to around 2,000 homes and more than 7,000 residents of the island that previously depended on diesel. The project's 6,372 solar panels, accompanied by battery storage that mitigates the variability of the power they supply, is expected to lower generation costs and increase energy autonomy by reducing diesel consumption by 67%, or 30,000 gallons per month. The project is also projected to reduce CO^2 emissions by 3.3 million metric tons per year. According to the developer, the project took 60 days to construct and the investment will be recovered over four years. [155]

Table 5: IDB-Financed Mini-grid Projects in LAC

Project Name	Country	Beneficiaries	Generation Technology	Generation Capacity	Storage Technology	Storage Capacity	Status
San Juan Microgrid	Nicaragua	1,300 inhabitants	Solar PV, diesel	300 kw, 420 kw	Lithium-ion battery	300 kW/ 769 kWh	In operation
Corn Island Microgrid	Nicaragua	7,656 inhabitants	Solar PV, diesel	2.1 MW 1.8 MW	Lithium-ion battery	1.65 MW / 2.2 MWh	In operation
Brus Laguna Microgrid	Honduras	1,000 families	Solar PV	0.6 MW	Battery	400 kW / 1.6 MWh	Planned/in development
Guanaja Microgrid	Honduras	1,195 families	Solar PV	0.75 MW	Lithium-ion battery	1 MW / 4MWh	Planned/in development
Remanso Solar Hybrid Plant	Bolivia	175 families	Solar PV	166.5	Lead-acid battery	548 kWh	In operation

152. Alonso, Judit. "Nicaragua Se Une a La Carrera Del Desarrollo De La Energía Solar En América Latina." DW.COM, July 20, 2019. https://www.dw.com/es/nicaragua-se-une-a-la-carrera-del-desarrollo-de-la-energ%C3%ADa-solar-en-am%C3%A9rica-latina/a-49658007.
153. "Vatios Con Propósito: Corn Island." Solartia, July 15, 2019. http://solartia.com/2019/07/18/vatios-con-proposito-corn-island/.
154. Bellini, Emiliano. "Inaugurada Central Solar De 2.1 MW En Nicaragua." pv magazine Latin America, July 15, 2019. https://www.pv-magazine-latam.com/2019/07/15/inaugurada-central-solar-de-2-1-mw-en-nicaragua/.
155. "Vatios Con Propósito: Corn Island." Solartia, July 15, 2019. http://solartia.com/2019/07/18/vatios-con-proposito-corn-island/.

Table 5: IDB-Financed Mini-grid Projects in LAC (cont.)

Project Name	Country	Beneficiaries	Generation Technology	Generation Capacity	Storage Technology	Storage Capacity	Status
Puerto Villazón Solar Hybrid Plant	Bolivia	100 families and 160 members of the military	Solar PV	156 kWp	Lithium-ion battery	624 kWh	In operation
Isolated Solar Mini-grid in Pokigron/Atjoni	Suriname	400 households, primary and secondary school, medical center, several businesses	Solar PV	500 kW	Lead-acid battery	1,800 kWh	In operation
Isolated Solar Mini-grid in Godo Olo	Suriname	350 households, primary school, medical center, several businesses and communal facilities	Solar PV	250 kW	Lithium-ion battery	1,000 kWh	Planned/in development
Solar Mini-grids in Isolated Upper Suriname	Suriname	12 villages (952 households, 58 businesses)	Solar PV	2,058 kW	Lead-acid and lithium-ion batteries	11,095 kWh	Planned/in development
Solar Interconnected Mini-grid in Brownsweg	Suriname	5,000 inhabitants	Solar PV	500 kW	TBD	250 kW / 500 kWh	Planned/in development
Solar Interconnected Mini-grid in Alliance	Suriname	2,000 inhabitants	Solar PV	200 kW	TBD	150 kW / 300 kWh	Planned/in development

Source: Inter-American Development Bank

Building on these promising results, the IDB is also financing mini-grids with solar generation and battery storage in several other countries, including Honduras, Bolivia, and Suriname (see Table 5). With 3% of the region's population still lacking electricity, largely in rural areas (and up to 10% in countries including Guatemala and Honduras[156]) the coming years could witness a proliferation of such projects at a faster rate than grid-scale storage projects, which are less familiar and whose results are less proven in the region.

156. Yepez, Ariel, Yi Ji, Michelle Carvalho , and David Lopez . "The Energy Path of Latin America and the Caribbean." Inter-American Development Bank, December 28, 2018. https://publications.iadb.org/en/energy-path-latin-america-and-caribbean.

iv. Sodium-sulfur batteries

Sodium-based batteries are generally in limited use in LAC, and we have not identified any projects to date using sodium-sulfur technology. A massive project in Mexico, announced in 2010, never materialized.[157] There are several projects using sodium-nickel-chloride chemistry, a less mature technology which requires similarly high temperatures.[158] The largest of these is located at the Toucan Solar PV Park in French Guiana and has storage capacity of 4.5 MWh. There are also smaller projects in Chile and Martinique, and a sodium-based battery in Puerto Rico for which we have not identified the specific chemistry. All four of these projects are associated with renewable energy and used for time-shift. The project in Martinique also provided distribution upgrade deferral, microgrid capacity, and voltage support. Nonetheless, sodium-sulfur batteries could yet be viable in large installations in LAC at which pumped hydro is not an option.[159]

v. Flow batteries

There are few examples of flow battery projects in LAC. One of the only flow battery projects constructed to date in the region is a vanadium-redox battery accompanying a 3-MW solar PV installation that supplies most of the demand of Antigua's V.C. Bird International Airport.[160] In 2018 a 400-kWh pilot project was announced to store solar energy in Brazil,[161] and in 2017 an 800-kWh project using zinc-iron technology was announced in Nicaragua.[162] The results of pilot projects will be important in determining the use of this relatively unknown technology in the region. Yet because their advantage lies in their size, flow batteries have the greatest potential in applications where large-scale, long-duration storage is needed and pumped hydro is not feasible.

vi. Molten salt thermal energy storage

Thanks to its high degree of solar radiation, Chile's Atacama Desert is home to a large number of planned CSP projects with molten salt TES. Seven CSP plants with combined capacity of almost 2 GW and molten salt storage have been announced, including Cerro Dominador, the region's first CSP plant, which was expected to begin operating in April 2021 at the time of writing. The billion-dollar project comprises 10,600 heliostats covering more than 700 hectares and a central tower 820 feet high.[163] It has capacity of 110 MW with 17.5 hours of molten salt storage. Although CSP plants with molten salt TES are site-specific and offer a more limited range of applications, they may be viable in other countries in the region with abundant and remote solar irradiation, like Mexico.

157. Wesoff, Eric. "Rubenius, 1 GW of Energy Storage, Revisited." Greentech Media, February 2, 2012. https://www.greentechmedia.com/articles/read/rubenius-1-gw-of-energy-storage-revisited.

158. "Sodium-Nickel-Chloride Battery." European Association for Storage of Energy, 2016. https://ease-storage.eu/wp-content/uploads/2016/07/EASE_TD_Electrochemical_NaNiCl2.pdf

159. Balza, Lenin, Gischler, Christiaan, Janson, Nils, Miller, Sebastian and Servetti, Gianmarco. "Potential for energy storage in combination with renewable energy in Latin America and the Caribbean." Inter-American Development Bank, 2014. https://publications.iadb.org/publications/english/document/Potential-for-Energy-Storage-in-Combination-with-Renewable-Energy-in-Latin-America-and-the-Caribbean.pdf

160. "DOE Global Energy Storage Database." US Department of Energy. Accessed July 30, 2020. https://www.sandia.gov/ess-ssl/global-energy-storage-database/.

161. "ESS Inc. Enters Latin American Market, Signs Contract with Pacto GD to Deploy Long-Duration Energy Storage + Solar PV System." ESS, Inc, May 22, 2018. https://www.essinc.com/2018/05/22/ess-inc-enters-latin-american-market-signs-contract-with-pacto-gd-to-deploy-long-duration-energy-storage-solar-pv-system/.

162. "ViZn Energy Systems Selected to Provide Commercial-Scale Flow Battery in Central America." ViZn Energy, May 12, 2017. https://www.viznenergy.com/vizn-energy-systems-selected-to-provide-commercial-scale-flow-battery-in-central-america/

163. "CSP Plant Cerro Dominador." Cerro Dominador. Accessed July 30, 2020. https://cerrodominador.com/en/proyectos-en/?proyectos-en-desarrollo.

Table 6: Sample of Noteworthy Energy Storage Projects in LAC

Project Name	Location	Technology	Storage Capacity*	Characteristics
Cerro Dominador CSP Plant	María Elena, Antofagasta Region, Chile	CSP with molten salt TES	17.5 hours	Latin America's first CSP plant, with generation capacity of 110 MW. 10,600 heliostats covering >700 hectares reflect sunlight to a central tower, where molten salt stores large quantities of solar energy for hours in the form of heat, reducing intermittency. Expected to begin operation in April 2021 at the time of writing.
AES Gener Run-of-River Hydro Plant Alfalfal ("Virtual Dam")	San José de Maipo, Metropolitan Region, Chile	Run-of-river hydro plant with battery storage	10 MW / 50 MWh	"Virtual dam"— will store hydroelectric energy (generated by the flow of a river through turbines) without the impact of a large reservoir. Provides firm power, peaking capacity, frequency regulation. Project developer Fluence estimates a 500-MW market for virtual dams in Chile alone.
Aura Solar III	La Paz, Baja California Sur, Mexico	Solar PV with lithium-ion battery storage	10 MW / 5.5 MWh	Mexico's first utility-scale solar plus storage park. Serves the isolated grid of Baja California Sur. Mainly provides primary frequency regulation (up to 8x grid requirements), and ramp-rate control. Has capacity to perform secondary frequency control, fast frequency response, voltage control. In operation since October 2018.
Río Grande Hydroelectric Complex	Santa Rosa de Calamuchita, Córdoba Province, Argentina	Large hydro reservoir with pumped hydro storage	-	750-MW hydroelectric complex operating since 1986. 85% of flow is generated by water that is pumped from a lower to an upper reservoir during periods of low power demand.
French Western Guiana Power Plant	Mana, Saint-Laurent-du-Maroni, French Guiana	Solar PV with hydrogen (long-term) and battery (short-term) storage	130 MWh	The plant, which claims to be the world's largest to use hydrogen to store VRE, has generation capacity of 10 MW during the day and 3 MW at night. Electricity produced by solar energy electrolyzes water to produce hydrogen, which is stored in large quantities for long periods. A fuel cell generates electricity with this hydrogen when it is needed. The project, with a 2020 start date according to the project's website, will power 10,000 homes.
V.C. Bird International Airport of Antigua Solar/ Energy Storage Project	St. John's, Antigua and Barbuda	Solar PV with flow battery storage	4 hours	The 3-MW project, completed in 2015, supplies most of the energy of Antigua's largest airport. A vanadium redox flow battery system stores solar energy and provides renewable capacity firming.

Project Name	Location	Technology	Storage Capacity*	Characteristics
Toucan Solar PV Park	Montsinery-Tonnegrande, Cayenne, French Guiana	Solar PV with sodium-nickel-chloride battery storage	4.5 MWh	This 5-MWp solar power plant, commissioned in 2015, has a sodium-nickel-chloride battery system with 4.5 MWh of storage capacity, facilitating renewable energy time shift.

Sources: Cerro Dominador,[164] Fluence,[165] Gauss Energía,[166] Empresa Provincial de Energía de Córdoba,[167] HDF,[168] [169] DOE [170]. *Units vary based on availability of information.

vii. Compressed air energy storage

CAES has yet to be deployed in LAC. A project announced by Canadian firm Hydrostor in 2013 for underwater CAES at a wind park in Aruba does not seem to have materialized.[171] The same company's website states that it has near- and medium-term development opportunities in Chile, but does not provide further details.[172] CAES may be most suitable for large-scale grid applications or hybrid plants that store energy from VRE and use CAES to improve the efficiency of natural gas plants. The challenges of siting CAES have historically made it a less attractive option for smaller and off-grid installations, but technological innovations including specially constructed tanks have facilitated the construction of smaller projects and made CAES siting more flexible.[173] Even so, appropriate geological formations may exist naturally in some regions such as salt-rich Chile, and in even more areas if natural gas fields and natural aquifers prove suitable locations, as has been proposed.

164. "CSP Plant Cerro Dominador." Cerro Dominador. Accessed July 30, 2020. https://cerrodominador.com/en/proyectos-en/?proyectos-en-desarrollo.
165. Boll, Rebecca. "Energy Storage in LatAm." FLUENCE, a Siemens and AES company, October 2020. https://www.thedialogue.org/wp-content/uploads/2020/10/Rebecca-Boll-PP-Slides-Panel-Two.pptx
166. Olea, Hector. "Aura Solar III – Mexico's First BESS." Electrical Energy Storage, October 8, 2020. https://www.electrical-energy-storage.events/en/news-press/news/articles?tx_news_pi1%5Bnews%5D=4159
167. "Central Río Grande." EPEC. Accessed August 14, 2020. https://web.epec.com.ar/generacion_central_h_rio-grande.html.
168. "The Project." CEOG Project. HDF Energy. Accessed December 21, 2020. https://en.ceog.fr/theproject.
169. "Operating Principles." CEOG Project. HDF Energy. Accessed August 19, 2020. http://www.ceog.fr/operatingprinciples.
170. "DOE Global Energy Storage Database." US Department of Energy. Accessed July 30, 2020. https://www.sandia.gov/ess-ssl/global-energy-storage-database/.
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172. Hydrostor. Accessed July 30, 2020. https://www.hydrostor.ca/projects/.
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viii. Hydrogen energy storage

The use of hydrogen electricity storage for stationary applications in LAC is in its very early stages. This report only identified six such storage projects in the region, five of which store power from renewable sources. Four of these projects are developed by France-based HDF Energy. In Martinique, a 1-MW fuel cell system uses by-product hydrogen from a refinery to supply electricity to the grid. A project to use green hydrogen to decarbonize petrochemical production in Trinidad & Tobago is in its early phases.[174] With 130 MWh of storage, the French Western Guiana Power Plant claims it will be the largest power plant in the world using hydrogen to store VRE.[175] HDF Energy is developing a similar project in Barbados. There are also two microgrids in Chile (one planned and one operational) which combine a hybrid of hydrogen and lithium-ion battery storage.

The lack of operational projects does not imply a lack of interest in hydrogen technology, though. Efforts are underway by both public and private actors. For now, they have been concentrated in the use of hydrogen to decarbonize transport. Such initiatives exist in Chile, Uruguay, Argentina, Costa Rica, and Paraguay, where the IDB is helping develop a hydrogen roadmap.[176] Several countries also see an opportunity for the production of green hydrogen using the region's abundant renewable energy resources. Uruguay hopes to produce green hydrogen for export,[177] as does Chile, which has released a national strategy to do so at low cost and on a large scale by 2040.[178] By 2050, the Chilean government projects a $9 billion annual domestic market and $24 billion in exports. Colombia is now laying the groundwork to emulate this strategy in partnership with Chile and with the help of the IDB.[179] Private companies also see opportunity, including Engie in Chile and Grupo Energía Bogotá in Colombia, which are both increasing their focus on green hydrogen.[180] [181] In Costa Rica, a private-sector alliance has longer-term plans to develop hydrogen for stationary and back-up power.[182] Overall, the development of the hydrogen industry is best envisioned with a long-term view. In Chile, authorities expect hydrogen to become cost-competitive by 2030.[183]

For the time being, hydrogen's role may be limited to industrial pilot projects and transportation initiatives. However, in the long-term, hydrogen could potentially be studied as a way to electrify heating using existing natural gas infrastructure, as fuel for natural gas turbines that would otherwise be retired, or in small or large-scale systems accompanying VRE projects.

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IV. CONCLUSIONS

Thanks in large part to the region's hydroelectric resources, LAC has one of the cleanest power matrices of any region. However, widespread VRE integration using energy storage will be essential to reach full decarbonization. As power demand increases, sectors like transport and heating are electrified, and hydropower capacity stalls, Latin American and Caribbean countries must turn to their vast wind and solar resources. Doing so will enable them to meet climate change mitigation goals, improve the reliability, security, and cost of power systems, meet rising demand, and eventually reach full decarbonization.

Energy planners, regulators, and policymakers should begin exploring options to facilitate the adoption of energy storage facilities. In many cases, massive deployment of energy storage could significantly contribute to the VRE integration needed for full decarbonization. Energy storage technology is in an early but critical phase in Latin America and the Caribbean. The technologies discussed in this paper may hold the key to unlocking the region's renewable energy potential and modernizing its grids through the services they provide. These services can improve the reliability, accessibility, and affordability of the grid. However, steps must be taken to begin implementing this set of technologies on a significant scale.

Energy storage is a class of technologies that is diverse, complex, and rapidly evolving. Policymakers will need to acquire a strong grasp of the technical characteristics and benefits of these technologies, the services they can provide, and the most relevant regional and power market applications for each technology.

The diversity of Latin America and Caribbean power systems demands a variety of technical and economic solutions to store energy. Energy policy planners and regulators must have an open view to these options. LAC has a wide variety of power systems with different characteristics in terms of their size, interconnectedness, available energy sources, demand expectations, and needs. Taking a more in-depth look at these relatively unfamiliar technologies, as well as others, and evaluating how each might complement the characteristics and needs of a given power system, will be an important exercise for energy policy planners and regulators.

Energy storage technologies are rapidly improving and their costs falling. These trends will affect the dynamics for adoption of these technologies and how regulators should facilitate their introduction into energy systems and their incorporation into tariffs. Energy planners should consider the options available and immense cost reductions for energy storage technologies when determining which electricity generation and storage assets to add to the grid and how to integrate them.

At present, pairing energy storage with mini-grids appears to be the most technically and economically viable applications of these technologies in LAC. Energy storage has played a key role in expanding rural electricity access through mini-grids, and this application has thus become the one with the most accumulated experience in the region. Due to their scalability and low cost, lithium-ion batteries will likely be the most competitive energy storage technology for the foreseeable future for projects seeking to expand electricity access through mini-grids in LAC's many off-grid areas. **However, even in some interconnected grid systems, particularly in Caribbean islands, lithium-ion batteries are in many cases more competitive than conventional fuels when paired with wind and solar generation.**

Pumped hydro, despite its limited current use in the region, also holds significant potential for large-scale grid systems due to the vast hydroelectric infrastructure that already exists in many countries and the fact that is a mature and cost-effective technology. It is by far the most widely used energy storage technology worldwide, and its environmental impacts and costs could be mitigated by capitalizing on the region's existing infrastructure. It also plays a different role than lithium-ion batteries do, providing different grid services and low-cost storage on a much larger scale. Other technologies, such as molten salt TES paired with CSP, or CAES, could be deployed in more niche contexts. Still others, particularly hydrogen, may play a larger role down the line as the technology develops. Other battery technologies like lead-acid and sodium-sulfur are less likely to grow in use in LAC because of their drawbacks such as lower power density.

Regulations must be designed to compensate energy storage installations for the ways in which they improve grid performance and facilitate greater VRE penetration and its associated social and environmental benefits. Policymakers need to consider the multiple benefits and economic value of energy storage services in designing related regulations and policies. As explained in the final section of the paper, the regulatory framework for energy storage is underdeveloped in the region, as in many parts of the world, but is a key prerequisite to the introduction of greater energy storage capacity. An expectation of future market opportunities and reliable revenue streams is also crucial to continue incentivizing the research that is driving down costs for a number of technologies.

Regulations must eliminate market rules that discriminate against storage due to its unique characteristics, allow energy storage projects to be compensated for multiple services, and accurately reflect the project's value. To capitalize on the full value of storage, regulators could mandate that storage be considered in power sector planning processes using a standardized, least-cost methodology that accounts for the value of services and innovative applications such as storage as transmission. Government-led storage auctions are also a good way to promote uptake. Regulators can draw upon examples from more developed storage markets such as the United States, Europe, and East Asia. Given that regulation is still evolving even in these more mature markets, participation in spaces dedicated to sharing lessons learned should be emphasized.

Pilot projects and partnerships between government, public utilities, industry could help prove the viability of grid-scale projects, which so far have been limited, and inform regulations. Most energy storage projects in LAC to date have been small-scale, with a focus on mini-grids. For many energy storage technologies, grid-scale applications are unproven and unfamiliar in the region, which makes them a potentially risky investment and presents a barrier to the development of regulation that is necessary for their use. In situations where there are not comparable case studies, partnerships on pilot projects for these technologies (some of which have already been seen) could help private companies, utilities, and governments share risk, learn about the costs, benefits, and technical capabilities of different technologies, and determine whether projects should be scaled up. Engagement with private companies and industry groups could also help utilities, regulators, and governments stay abreast of the many energy storage developments and case studies taking place across the world. With respect to pilot projects, vertically integrated utilities, of which there are many in the region, are in a unique position due to the fact that they reap the full benefits of energy storage, simplifying issues of ownership and compensation for storage services across generation, transmission, and distribution.