Mobile Energy Storage Study

Emergency Response and Demand Reduction

Massachusetts Department of Energy Resources

February 1, 2020

Acknowledgments

On August 9, 2018 Governor Baker signed *An Act to Advance Clean Energy* (the Act) into law. Section 22 of the Act directed the Department of Energy Resources (DOER) to study the feasibility of mobile battery storage systems to respond to extreme weather events or power outages and provide emergency relief.

DOER Commissioner Patrick Woodcock would like to acknowledge the following people for their assistance in the analysis and drafting of this report.

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EXECUTIVE SUMMARY

Strategic electrification of transportation and thermal loads is necessary to achieve the State's emissions goals; however, they increase our dependence on constant access to electricity. As a result, the impacts of outages increase with electrification and at a time when the effects of climate change increase the likelihood of major disruption events driving a need for further energy resilience.

Methods to increase the resilience of our electric system and enhance our emergency response capabilities is a core adaptation strategy to align with our electrification strategies. Energy storage is widely recognized for its ability to enhance energy resilience. Battery energy storage systems (BESS) increase resilience by providing local electric service through an outage, extending the run-time of emergency generators by increasing efficiency and reducing fuel consumption, and enabling renewable generators to produce power through outages.

Most BESS solutions are stationary, interconnected with permanent infrastructure and designed to serve localized loads. BESS have a long history of serving this role in the form of Uninterruptable Power Supplies (UPS), often found in data centers and locations negatively impacted by even short duration power disruptions. Resilient BESS solutions have recently expanded in adoption, often providing backup power paired with renewable generation in residential applications. This report is designed to analyze an alternative, in which energy storage solutions are mobile and can be physically dispatched to prioritized locations based upon evolving emergency response needs and thereby expanding the resilience of a broader range of facilities.

Study Overview

On August 9, 2018 Governor Baker signed An Act to Advance Clean Energy (the Act) into law. Section 22 of the Act directed the Department of Energy Resources (DOER) to study the feasibility of mobile battery storage systems to respond to extreme weather events or power outages and provide emergency relief.

Further, on September 16, 2016 Governor Baker Signed Executive Order No. 569: Establishing an Integrated Climate Change Strategy for the Commonwealth.[1] In 2018 Massachusetts became the first state in the nation to integrate climate change impacts and adaptation strategies into its hazard mitigation planning through the Statewide Hazard Mitigation and Climate Adaptation Plan.[2]

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[1] Executive Order No. 569: Establishing an Integrated Climate Change Strategy for the Commonwealth available at https://www.mass.gov/executive-orders/no-569-establishing-an-integrated-climate-change-strategy-for-the-commonwealth

[2] Statewide Hazard Mitigation and Climate Adaptation Plan available at www.resilientma.org

Massachusetts is developing data-driven strategies to mitigate, prepare for, and adapt to the impacts of climate change. Climate change is already exacerbating natural hazards and extreme weather events, as well as leading to new impacts that will affect the Commonwealth.

The 2016 Massachusetts Energy Storage Initiative Study, known as the *State of Charge* report, found that:

> "Storage provides energy resilience allowing critical facilities and other loads within the microgrid to ride through prolonged grid outages, maximally leverage renewable resources (such as solar PV), and/or extend limited liquid fossil fuel supplies."[3]

Mobile energy storage systems (mobile ESS) may be uniquely capable of enhancing energy resilience in response to severe weather events and associated outage conditions. Mobile ESS can be self-mobile electric vehicles (light-duty vehicles, vans, or buses) or towable (towable or transportable via semi-trailer truck). This study provides a comprehensive assessment of Mobile ESS, their use in emergency relief operations, and their use on typical (non-outage) days. Specifically, this report addresses four fundamental questions; state-of-the-art, usage on typical days, opportunities and challenges to deploy in response to outages, and potential advantages over stationary BESS.

Key Findings and Takeaways

State-of-the-art

- **Mobile ESS products can be categorized into self-mobile such as electric vehicles (EVs) and towable such as shipping containers**

Self-mobile ESS ranges from light duty vehicles to transit buses, with an anticipated future inclusion of heavy-duty trucks. Towable mobile ESS are often containerized solutions ranging from human-portable to standard 53' shipping container sizes.

- **Mobile ESS can provide valuable emergency relief services, and offset procurement costs with operations on typical days**

The ability for mobile ESS to provide service on typical days enables a return-on-investment, which is atypical in the realm of emergency response equipment. Additionally, mobile ESS can improve emergency response services and capabilities beyond traditional emergency response equipment such as diesel generators.

- **Self-mobile ESS adoption is accelerating to meet transportation needs, however the batteries are currently under-utilized when parked and in emergency situations**

Light duty EV adoption is increasing exponentially. To-date, the batteries of light duty EVs have been solely used for transportation needs. Pilot projects have demonstrated vehicle-to-grid opportunities,

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[3] Massachusetts Department of Energy Resources and Mass Clean Energy Center. 2016. State of Charge: for a study of Energy Storage uses in Massachusetts Energy Storage Initiative, Page 131. Available at https://www.mass.gov/media/6441/download

and in recent broad outage conditions EV owners have leveraged their EV battery to power their home by driving beyond the extent of the outage, charging, then returning home to power onsite load.[4]

- **Self-mobile ESS may provide customers energy distribution services**

EVs have substantial flexibility in the time of charging, as many vehicles have around 200 miles of range but drive an average of less than 35 miles per day. The substantial oversize of onboard energy capabilities compared to typical daily use means the battery could be leveraged to wirelessly distribute energy over-road to serve customer load. For example, if a residence has stationary storage, the EV could potentially charge the household battery, reducing or mitigating the customers' reliance on local distribution service in both typical days as well as through outage conditions. This pathway further opens as buildings become more efficient, workplaces increase the offering of EV charging as an employee benefit, retail sites offer EV charging as a customer benefit, retail package delivery and transportation service providers independently move to electrify their fleets, and solar canopy deployment continues. Depending on the cost of charging off-site, the pathway also provides further customer incentives to electrify transportation and thermal loads.

- **Self-mobile ESS may open substantial renewable energy transition pathways**

Self-mobile energy storage may enable the deployment of renewable generation which is not interconnected with the grid. As distributed generation increases, the system increasingly requires substantial expensive infrastructure upgrades to host more renewable generation. Solar PV deployment has traditionally relied on export to the grid (e.g. Net Metering) to make sense financially and this may not continue to be possible without infrastructure upgrades. To resolve this, on-site stationary storage would need to be substantially oversized in order to island and store renewable generation for later consumption, a potentially inefficient investment. Self-mobile energy storage in the form of EVs may provide an opportunity to charge from otherwise excess renewable generation and enable the deployment of renewable generation that is not dependent on export to the grid, thereby mitigating the costs associated with interconnection upgrades. Further, since the typical daily transportation needs of an EV are low compared to the onboard storage capacity, the EV can provide transportation without charging every day, enabling charging to align with renewable production, reducing or skipping recharging on cloudy or overcast days. This would shift demand to align with available generation.

- **Autonomous self-mobile ESS opens additional business models**

Autonomous self-mobile ESS opens the opportunity to merge the concepts of transportation as a service (TaaS) with energy as a service (EaaS) into a bundled subscription and delivery of utilities provided by a single physical fleet. A fleet operator would leverage the EV fleet to provide transportation services, while also distributing electricity over roadways to recharge stationary energy storage systems at customer sites. This service would make the energy transition seamless and invisible to the customer,

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[4] 'With Blackouts, California's Electric Car Owners Are Finding New Ways To Charge Up.' Vanessa Romo, NPR, December 11, 2019. https://www.npr.org/2019/11/08/777752175/with-blackouts-californias-electric-car-owners-are-finding-new-ways-to-charge-up

reducing friction points to adoption. The fleet is also flexible on charge location, so may mitigate constraints and leverage daily and seasonal variations in renewable generation, for example driving to points with access to excess solar generation in spring and to points with access to excess hydro or wind during other periods. Finally, the bundling of TaaS with EaaS provides a substantial increase in addressable market for EV fleets, increasing business opportunities without increasing capital costs, potentially accelerating the electrification of transportation while also enabling novel emergency response approaches and capabilities.

- **Towable mobile ESS is being adopted, but at a slower rate than self-mobile ESS**

Towable mobile ESS has been adopted to-a-degree in the consumer arena in the form of battery backups for laptops and mobile devices. Towable mobile ESS has also been leveraged by remote energy intensive operations (such as mining and military operations) to reduce generator fuel consumption to relieve associated logistics and costs.[5]

Typical day use cases

- **Self-mobile ESS initially operates primarily to provide transportation service on typical days (current use)**

Today, most self-mobile ESS provide only transportation services on typical days. There is currently relatively limited deployment (as compared to traditional fuel-based vehicles), but with ongoing cost declines, EVs are anticipated to be cost competitive on a transportation only basis in the next few years. This will allow for rapid, wide-spread deployment.

- **Self-mobile ESS could provide transportation and distribution on typical days (in the near-term future)**

In this case, the EV provides the owner with both transportation and electric distribution services daily. One operational form of this would be: the EV is driven to work, charged at the workplace (residential stationary storage with or without on-site renewables serve electric load of household while unoccupied), driven home, then discharges to power the home for the evening and overnight and charges the stationary storage (if it wasn't charged by onsite renewables). Depending on the cost to charge the EV, this model may substantially increase customer cost effectiveness of transitioning to an EV. This model would also increase the cost effectiveness of electrifying the customers' thermal loads, as the electricity is subsidized by either work or retail market competition.

- **Self-mobile ESS may operate to provide TaaS and EaaS if full autonomy is realized (in the future)**

[5] 'Decarbonization Takes Center Stage in Mining as Renewables-Plus-Storage Become Cost-Competitive.' GTM CREATIVE STRATEGIES, GreenTech Media, December 30,2019. https://www.greentechmedia.com/articles/read/decarbonization-takes-center-stage-in-mining

The EV is owned and operated by a third-party fleet manager and provides transportation and energy (and potentially package delivery) as subscription services. The EV operates like the above, however the EV may leave when the residence has sufficient onsite charge and the EV would provide better value being elsewhere either charging, providing transportation, or discharging and providing energy services for other subscribers. The transportation and energy service package could be further bundled with retail package delivery given the prevalence of vehicles and fleets currently providing that service and overlap of delivery needs under this model with current delivery behavior.

- **Towable mobile ESS operates to reduce demand charges and local grid constraints**

Typical day use of towable mobile ESS matches typical current stationary storage use cases, with the increased benefit of flexibility to change location based upon seasonal needs or changing grid or customer conditions. Use cases are typically categorized into front-of-the-meter (FTM) grid services and behind-the-meter (BTM) applications. The revenue potential or value streams that energy storage provides generally fall into three broad categories: wholesale, utility, and host customer.[6,7] Wholesale and utility value streams are typically derived from FTM applications, although aggregated BTM systems can also provide these services.

Emergency response use cases

- **Self-mobile ESS currently operate primarily to minimize use of limited fuel supplies and supplement traditional fuel-based generators**

Today, self-mobile ESS can provide transportation and supply delivery services during emergency response outage conditions without using traditional fuel which may be limited in supply and/or re-fueling. With ongoing deployment of V2G infrastructure, self-mobile ESS can more readily participate in emergency response as a back-up energy source operating on its own or in conjunction with traditional fuel-based generators.

- **Self-mobile and towable ESS could harvest energy from stranded distributed sources of generation**

Both self-mobile and towable ESS could be used to transport energy from an available energy resource to an area of an outage. Mobile ESS can move outside of an outage area, charge, and then travel back into an outage area and deliver energy to a facility or provide for transportation needs of personnel or supplies. Energy generation assets that might otherwise be stranded due to downed wires or damaged electric distribution infrastructure can be incorporated into emergency response plans and utilized through an outage.

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[6] Rocky Mountain Institute (RMI). *The Economics of Battery Energy Storage*. October 2015. Available at: https://rmi.org/wp-content/uploads/2017/03/RMI-TheEconomicsOfBatteryEnergyStorage-FullReport-FINAL.pdf.

[7] Lazard. Levelized Cost of Storage Analysis – Version 5.0. November 2019. Available at: https://www.lazard.com/media/451087/lazards-levelized-cost-of-storage-version-50-vf.pdf.

- **Self-mobile and towable ESS could be deployed to form microgrids reducing the impact of long-term outages across a region**

Both self-mobile and towable ESS could be used to form a microgrid at a facility or set of facilities with required infrastructure in place. For example, an emergency shelter could have V2G infrastructure[8] installed in preparation of receiving power from a mobile ESS during an outage. The mobile ESS could connect to and charge stationary ESS and supplement on-site renewable or other generation. If the appropriate wiring and infrastructure were installed to connect that shelter to a neighboring medical or public safety (police or firehouse, for example) facility, that set of buildings could separately island from the grid, provide necessary power to support emergency response needs and serve a broad set of people and their needs through an outage.

Opportunities and Challenges

Mobile ESS provides the opportunity to;

- relieve emergency responders of delivered fuels logistics challenges in emergencies
- enable otherwise stranded generation to produce power
- enable emergency response equipment to provide typical day services
- diversify transportation fuels
- reduce single point of failure reliance on local electric distribution, and
- increase adoption of and dependence on intermittent renewable generation

The adoption of mobile ESS faces several challenges, including;

- operational considerations of disconnecting from typical day usage
- deployment logistical challenges
- interconnection processes including timelines and costs
- interoperability with site generators and loads
- emergency responder training on setup and operations, and
- necessary planning and matching system capability with emergency needs

Advantages over stationary storage

The primary advantage of mobile ESS is the flexibility they provide when deployed in both typical day use and outage conditions. During typical day use conditions, mobile ESS can serve many of the same applications served today by stationary systems. The flexibility offered by mobile ESS provides advantages due to the ability to relocate the mobile ESS as conditions on the grid change over time.

The flexibility of mobile ESS is also an advantage during outage conditions. The nature of many outage conditions—such as those caused by unplanned equipment failure, natural disasters, or terrorism events—is that they cannot be anticipated. Mobile ESS can be deployed to the exact location of the need for emergency power. Paired with traditional, fuel-based generators, mobile ESS can improve the efficacy

[8] This technology is currently available: https://www.mobilityhouse.com/int_en/vehicle-to-grid; https://wallbox.com/en_us/quasar-dc-charger

of generators used for emergency response operations and reduce the cost and frequency of refueling. Furthermore, mobile ESS can harvest energy from stranded distributed sources of generation, including wind farms and rooftop solar. During a prolonged grid outage, this creates a significant advantage through the continued supply of power to critical loads using the grid-forming capabilities that mobile ESS offer.

Mobile ESS create an additional advantage by providing mobility during outage conditions when there is risk of disruption to diesel and gasoline supply. Grid outages during emergency events can lead to downed power lines, which can often be restored quickly. However, disruptions to conventional gasoline and diesel fuel supplies can take longer to restore. Having access to transportation that doesn't rely on conventional fuels can be a valuable asset to disaster relief crews by increasing their flexibility and ability to respond in different situations.[9] The ability to transport personnel and supplies during outage conditions can be critical. As mentioned above, mobile ESS used to harvest energy from stranded DG sources could potentially offer continued mobility services during prolonged outage conditions.

Finally, mobile ESS offer economic advantages over stationary ESS. Emergency response planning includes investments in equipment infrequently used, except during outage conditions. The ability to create value during typical day use conditions serves to offset the initial capital investment. In addition, the capital cost of mobile ESS is largely justified by the mobility services provided during typical day use conditions. A municipal agency that purchases vehicles might consider buying an electric vehicle with V2G capabilities, thus offering the option to deploy the vehicle during outage conditions as part of an overall emergency response plan. The California investor-owned utility Pacific Gas & Electric purchased purpose-built plug-in hybrid trucks that are equipped and designed with the capability to export power. The utility deployed these trucks in October 2015 to power an emergency shelter during a power outage caused by wildfires.[10] In 2011, EVs played an important role when gasoline supplies for conventional vehicles were disrupted; they delivered critical supplies to regions in northeastern Japan ravaged by a tsunami.[11]

[9] The National Association of State Energy Officials. June 2016. Electric Vehicles and Emergency Response. Available at https://naseo.org/data/sites/1/documents/publications/iREV%20EV%20Case%20Study.pdf.

[10] ibid

[11] After Disaster Hit Japan, Electric Cars Stepped Up. May 6, 2011. New York Times. Available at https://www.nytimes.com/2011/05/08/automobiles/08JAPAN.html.

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1. INTRODUCTION

The energy landscape is in a period of rapid transformation, with energy storage poised to play a major role in both the electric grid and transportation systems. Bloomberg New Energy Finance projects in its latest forecast that global stationary battery storage deployments will expand from 9 gigawatts (GW) as of 2018 to 1,095 GW by 2040. Bloomberg further projects that this growth in stationary energy storage will require $662 billion in new investments.[12] At the same time, analysts are projecting exponential growth in battery electric vehicle (EV) adoption. In 2018, the global EV fleet totaled 5 million and is expected to grow 25 times larger by 2030.[13]

The State of Massachusetts recognizes the important role that energy storage and electric vehicles will play in meeting the State's clean energy goals and offers supportive programs and policies.

The Energy Storage Initiative (ESI) launched in May 2015 included $20 million to fund 26 advanced energy storage demonstration projects across the state. The Massachusetts Department of Energy Resources (DOER) established a storage target in 2017 of 200 megawatt-hours (MWh) by January 1, 2020. The 2018 Act to Advance Clean Energy replaced the 2017 target with a 1,000 MWh by 2025 target.[14] Furthermore, Massachusetts became the first state to incentivize investments in customer-sited (behind-the-meter or BTM) energy storage systems. A January 2019 Order issued by the Massachusetts Department of Public Utilities allowed utility companies to pay customers who agree to rely upon their energy storage systems and dispatch the energy during peak events. To spur electric vehicle (EV) adoption in the Commonwealth, DOER has provided over $30 million for its Massachusetts Offers Rebates for EVs (MOR-EV) consumer rebate program to incentivize the purchases of EVs. In January 2018, Governor Baker signed Executive Order 579 establishing the Commission on the Future of Transportation to further explore emerging clean transportation solutions.

Like many other jurisdictions, Massachusetts seeks to prepare for more intense and frequent weather storms driven by climate change. The 2016 Massachusetts Energy Storage Initiative Study, entitled *State of Charge,* notes the pivotal role energy storage can have in preparing for these events through creating more resilient energy systems.

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[12] Bloomberg New Energy Finance. July 2019. Energy Storage Investments Boom as Battery Costs Halve in the Next Decade. Available at https://about.bnef.com/blog/energy-storage-investments-boom-battery-costs-halve-next-decade/.

[13] International Energy Agency. May 2019. Global EV Outlook. Available at https://www.iea.org/publications/reports/globalevoutlook2019/.

[14] The 191st General Court of the Commonwealth of Massachusetts. Chapter 227. AN ACT TO ADVANCE CLEAN ENERGY. Section 20. Available at https://malegislature.gov/Laws/SessionLaws/Acts/2018/Chapter227.

> "Storage provides energy resilience allowing critical facilities and other loads within the microgrid to ride through prolonged grid outages, maximally leverage renewable resources (such as solar PV), and/or extend limited liquid fossil fuel supplies."[15]

Mobile energy storage systems (mobile ESS) and their use in emergency relief operations could be a key piece of the Commonwealth's energy resilience and energy storage strategies. Mobile ESS can be self-mobile electric vehicles such as light-duty vehicles, vans, or buses, or towable resources such as those transported via semi-trailer truck). In Massachusetts' 2018 Act to Advance Clean Energy Section 22, DOER was tasked with providing a study of the feasibility of such systems to provide emergency relief during power outages or extreme weather events. [16]

This study provides a comprehensive assessment of mobile energy storage systems and their use in emergency relief operations. In keeping with the emerging resiliency literature, we use the term blue sky conditions interchangeably with typical days to refer to times when emergency response equipment would ordinarily be idle and not deployed for emergency relief operations. In contrast to blue sky conditions, outage conditions are those periods when the mobile energy storage systems are deployed for emergency relief operations. This report addresses four fundamental questions:

1. What is the state-of-the-art in mobile battery storage systems available today or in the near future for use in emergency relief operations?
2. How can mobile energy storage systems be used to shave the peak demand for energy, lower distribution costs and provide additional value to the electric grid and host customers when not in use for emergency response purposes?
3. What are the opportunities and challenges associated with deploying mobile energy resources to serve during emergency relief operations?
4. Do mobile energy systems offer advantages over stationary systems when evaluated both under normal conditions and during emergency response events?

Section 2 of this report explores the landscape of available mobile energy storage systems, which are roughly divided into towable units and self-mobile systems in the forms of various EV platforms. Section 3 provides a detailed assessment of deployment logistics for mobile energy storage systems. Section 4 evaluates the use of mobile energy storage systems during normal conditions when not in use in emergency relief operations. Section 5 presents an assessment of mobile energy storage systems for use in a variety of emergency response scenarios. Section 6 provides a comparison between mobile energy storage systems and stationary systems in terms of the various applications and cost-effectiveness. And

[15] Massachusetts Department of Energy Resources, Mass Clean Energy Center. 2015. State of Charge: for a study of Energy Storage uses in Massachusetts Energy Storage Initiative, Page 131. Available at https://www.mass.gov/media/6441/download

[16] The 191st General Court of the Commonwealth of Massachusetts. Chapter 227. AN ACT TO ADVANCE CLEAN ENERGY. Section 22. Available at https://malegislature.gov/Laws/SessionLaws/Acts/2018/Chapter227.

finally, Section 7 draws conclusions from the preceding sections and offers recommendations for next steps.

2. Mobile Energy Storage Systems & Use Cases

This section details the various types of mobile ESS currently on the market, those in precommercial development, and the corresponding applications. Mobile ESS can be classified into two types. The first is self-mobile ESS in the form of electric light-duty vehicles (LDV), electric utility vans, electric buses, and in the near future, heavy-duty trucks. We refer to this category throughout the report as electric vehicles (EVs). The second classification of mobile ESS is referred to as towable systems, which include tow-behind ESS trailers and containerized ESS transported via semi-trailer trucks. This section also discusses defining elements for these classifications and logistical as well as system-specific considerations. Within each grouping, we assess currently available products and identify standard technical parameters such as output power and energy capacity, which are common considerations for all types of energy storage systems. In addition, we explore the capability of mobile ESS to pair with both traditional and renewable existing distributed generation (DG) systems. We also discuss whether mobile ESS can be interchangeable in part or in whole with those generation systems. This section serves as the reference base for the rest of the report with respect to technologies and applications considered.

2.1. Mobile Energy Storage System Categories

The primary mobile energy storage system configurations considered in this study include the following:

- Vehicle to Grid (V2G) Electric vehicles:
    - V2G LDV/utility van: According to the Federal Highway Administration, these include vehicles transporting passengers or cargo with a Gross Vehicle Weight Rating (GVWR) less than or equal to 10,000 lb.[17]
    - V2G Bus: Any motor vehicle operating on a public way in any city or town for the transport of passengers.
- Towable systems:
    - Tow-behind ESS trailer: Trailers with integrated ESS that can be towed by vehicles with the necessary towing capacity.

[17] Federal Highway Administration. Figure 21. Law Enforcement Vehicle Identification Guide. Accessed 12 December 2019: https://ops.fhwa.dot.gov/publications/fhwahop10014/long_f21.htm

- Semi-trailer truck containerized batteries: Semi-trailer trucks can vary in lengths, some up to 53 feet, and will be utilized for the purpose of transporting containerized ESS.

Major global manufacturers of EVs include Tesla, Nissan, and Chevrolet. All EVs sold in the United States are equipped with lithium-ion (Li-ion) batteries.[18] During charge and discharge cycles, Li-ion batteries undergo electrochemical reactions involving exchange of lithium ions between the electrodes. Historically, Li-ion batteries have been used in consumer electronics and are currently the primary technology used for stationary battery energy storage installations. The most common chemical compositions used for EV batteries include lithium nickel manganese cobalt oxide (NMC), lithium iron phosphate (LFP), lithium manganese oxide (LMO), and lithium nickel cobalt aluminum oxide (NCA). Tesla models, Nissan Leaf, and BMW i3 use NCA, LMO, and NMC batteries, respectively.

Example EV products along with their major manufacturers, charging power ratings, and energy capacity are provided in Table 1. The energy capacities of electric car batteries range from approximately 40 kWh–100 kWh, across a spectrum of various manufacturers. Charging power is typically over 5 kW.

[18] D. Coffin and J. Horowitz, The Supply Chain for Electric Vehicle Batteries, United States International Trade Commission, Journal of International Commerce and Economics, December 2018. https://www.usitc.gov/publications/332/journals/the_supply_chain_for_electric_vehicle_batteries.pdf

Table 1. State-of-the-art self-mobile (EV) energy storage systems

Mobile ESS		Battery	
Type	**Manufacturer/EV Model**	**Charging Power (kW)**	**Energy Capacity (kWh)**
LDV Passenger Vehicle / Utility Vans	Nissan Leaf[19]	5	40 and 62
	Chevrolet Bolt[20]	6	60
	Tesla (Model S/ Model 3/ Model X)[21] CYBRTRCK (announced)	Maximum onboard charging = 11.5, Maximum supercharging = 200 and 250	65 to 100 200+
	Rivian R1S / R1T (announced)[22]	Onboard = 11 DCFC = 160	Up to 180
	Zenith Motors[23]	6	51.8, 62.1, and 70 or 100
Electric Bus	The Lion Electric Company[24]	19.2	88, 132, 176 and 220
	Proterra (Catalyst 40-ft bus)[25]	72 and 132	220, 440, and 660

Electric buses are typically equipped with Li-ion batteries with energy capacity ranging from 88–660 kWh and a charging power over 19 kW.

Example towable mobile energy storage systems are listed in Table 2.

[19] 2019 Nissan Leaf range, charging and battery: https://www.nissanusa.com/vehicles/electric-cars/leaf/features/range-charging-battery.html

[20] 2019 Chevrolet Bolt EV Specifications: https://media.chevrolet.com/media/us/en/chevrolet/vehicles/bolt-ev/2019.tab1.html

[21] Tesla: https://www.tesla.com/models

[22] Rivian: https://rivian.com/

[23] Zenith Motors: http://www.zenith-motors.com/wp-content/uploads/2013/05/Zenith-Brochure_0518.pdf

[24] The Lion Electric Company: https://thelionelectric.com/documents/en/BrochureLionCang.pdf

[25] Proterra. https://www.proterra.com/wp-content/uploads/2019/06/Proterra-Catalyst-40-ft-Spec-Sheet.pdf

Table 2. State-of-the-art towable mobile ESS

Mobile ESS		Battery		Applications
Type	Manufacturer/ Model/ Owner	Output Power	Energy Capacity	
Tow-Behind Trailer	MOBISUN Mobile Solar Generator[26]	3.7 kW	34 kWh, 68 kWh, and 124 kWh	• Diesel offset • Harvesting PV
	ZeroBase[27]	5-120 kW	9.6 kWh – 83.2 kWh	• Disaster and emergency response • Temporary shelters • Expeditionary power needs • Rapid deployment missions • Mobile command centers • Grid reliability
Semi-Trailer Truck Containerized	Consolidated Edison and NRG Energy[28]	1 MW	4 MWh	• Congestion relief • System upgrade deferral • Frequency regulation and operating reserves when mobile ESS is not deployed
	Power Edison - 40-ft container[29]	1 MW and above	1 MWh and above	• System upgrade deferral • Hybrid capability for pairing with generator • Wide spectrum of electricity-related services
	RES - 40-ft ISO Container[30]	500	1 MWh	• Backup power for critical facilities in storm-prone areas • Meet temporary additional power generation needs for large events • Provide energy storage services on seasonal or short-term contracts • Increase the efficiency of diesel generators
	Aggreko (Y.Cube 30/Y.Cube 60) - 20-ft ISO HC Container[31]	1000 kW/1050 kW	610 kWh/1050 kWh	• Power quality and reliability • Renewable integration
	Posetron	100 kW-1 MW	200 kWh-2 MWh	• Power insurance • Emergency communication • Rescue and relief work • Military command and field exploration

[26] MOBISMART. MOBISUN Mobile Solar Generator: https://mobismart.ca/mobisun-mobile-solar-generator/

[27] ZeroBase Energy to the Edge: https://zerobaseenergy.com/

[28] Utility Dive. ConEd, NRG partner on 4 MWh mobile battery storage demo for REV docket: https://www.utilitydive.com/news/coned-nrg-partner-on-4-mwh-mobile-battery-storage-demo-for-rev-docket/437125/

[29] Power Edison: https://www.poweredison.com/articles

[30] RES Mobile Energy Storage: https://www.res-group.com/media/342353/mobile_energystorage_28319.pdf

[31] Aggreko. Y.Cube – Energy Storage to Go: https://www.aggreko.com/en/products/energy-storage/ycube

Mobile ESS		Battery		Applications
Type	Manufacturer/ Model/ Owner	Output Power	Energy Capacity	
	MOBISMART Containerized Universal Battery (CUB) - 10/20/40-ft Container[32]	30-40 kW, 60-80 kW, and 120-160 kW	120 kWh, 240 kWh, and 480 kWh	• Pairing with off-grid generator enabling the generator to operate less frequently and at optimal power resulting in fuel savings and improved cycle life • Pairing with off-grid PV and backup generator resulting in fuel savings of up to 75% • Grid services including energy arbitrage, VAR support, renewable support and frequency regulation • Backup power with and without grid-tied solar • Telecommunications
		20-22.5 kW, 40-45 kW, and 80-90 kW	180 kWh, 360 kWh, and 720 kWh	

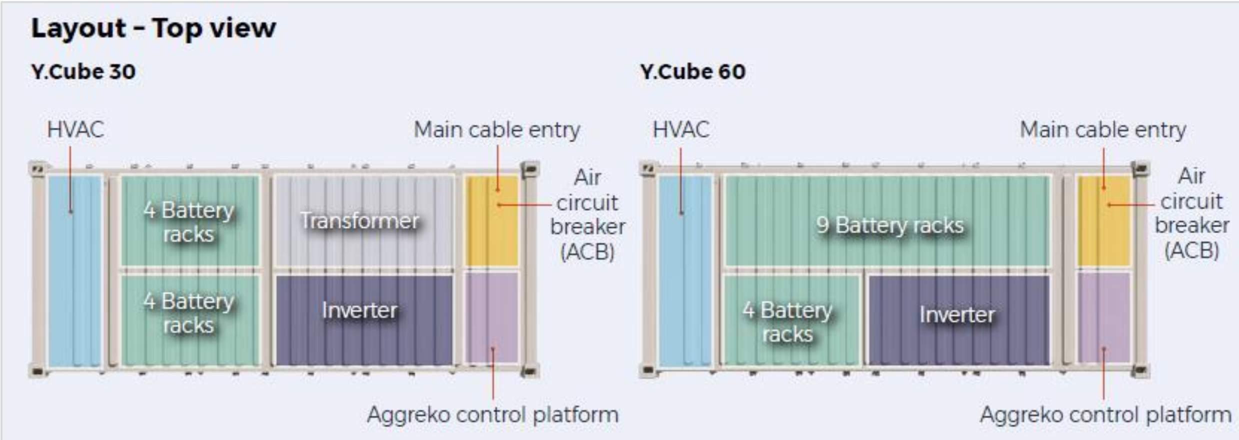
Example containerized mobile ESS are shown in Figure 1-Figure 3. These containerized mobile ESS are typically equipped with battery racks, HVAC systems for thermal management, power conversion systems, and power control systems. Additionally, they may also include other balance-of-system equipment such as transformers. An external view of the Aggreko Y.Cube mobile energy storage system and its layout are presented in Figure 1 and Figure 2.

Figure 1. Aggreko Y.Cube mobile energy storage system

Source: Aggreko Energy Storage Product Guide: https://www.aggreko.com/en-gb/products/energy-storage

[32] MOBISMART Containerized Energy Storage CUB: https://mobismart.ca/cub/

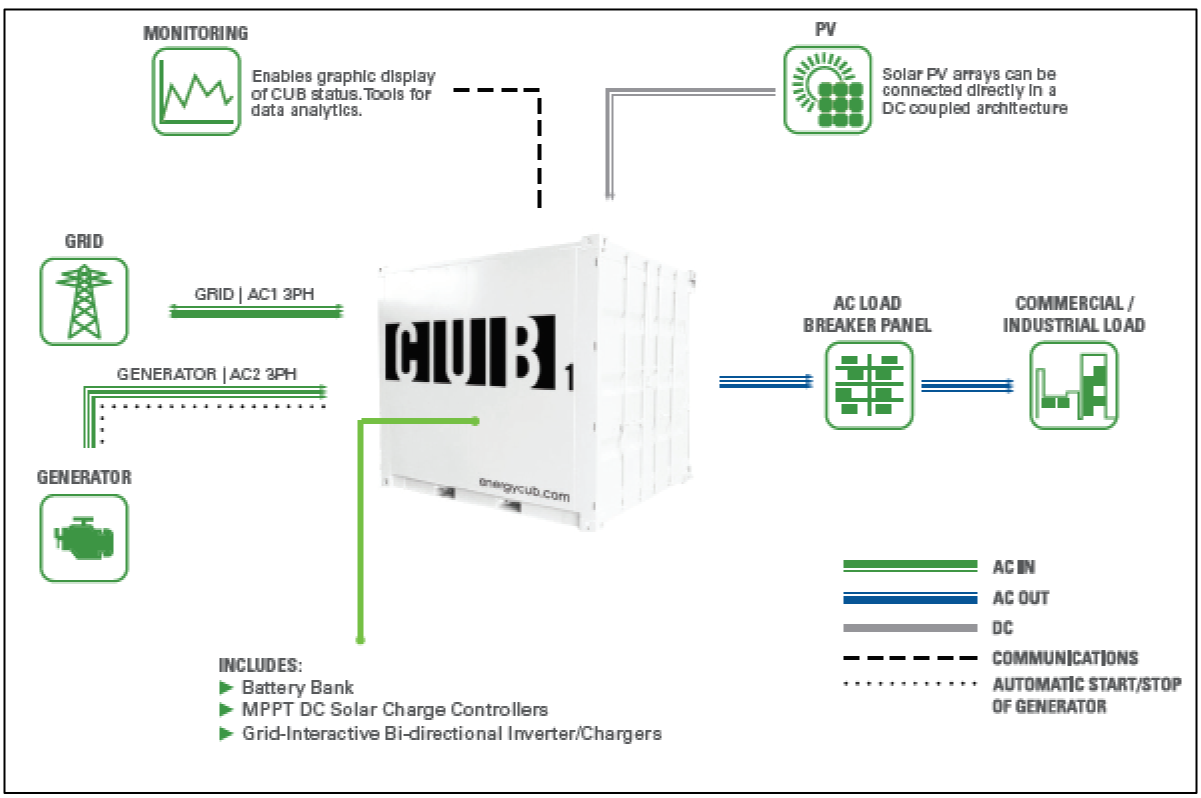
Figure 2. Aggreko Y.Cube layout



Source: Aggreko Energy Storage Product Guide: https://www.aggreko.com/en-gb/products/energy-storage.

MOBISMART's Discover Containerized Universal Battery (CUB) system architecture and interface are shown in Figure 3. The CUB system consists of the battery bank, maximum power point tracking (MPPT) DC solar charge controller, and grid-interactive bi-directional inverter. The CUB system can charge from the grid as well as from a generator and can be DC-coupled with a PV system.

Figure 3. MOBISMART Discover CUB architecture and interface



Source: MOBISMART Containerized Energy Storage CUB: https://mobismart.ca/cub/

Examples of other mobile storage configurations are given in Table 3. These include person mobile energy storage systems and float-in mobile energy storage systems. Person mobile energy storage systems are portable solutions that can be used for on-the-go applications. Types of products include portable renewable energy storage systems and car jump starters. The float-in mobile storage systems listed in Table 3 are conceptual.

Table 3. Other mobile ESS configurations

Mobile ESS		**Battery**	
Type	**Manufacturer/ Model**	**Output Power**	**Energy Capacity**
Person mobile	Bienno Power[33]	100-1000 W	120-1200 Wh
	Elite Power Solutions[34]	1500 W	1200 Wh
Float-in Mobile[35]	Container Ship	1-2 GW	2-4 GWh
	Barge Boat	200-500 MW	200-500 MWh
	Tanker	200-500 MW	0.8-2 GWh
	Ferry	0.5-1 GW	1-2 GWh

Additional forms of mobile storage were identified but not included for full analysis in this study included battery electric locomotives, electric ships and ferries, electric heavy-duty trucks, and person mobile thermal. Specific considerations for these which may be worth future investigation include:

- Rail rights of way often pass electrical substation infrastructure and electrified locomotives may support blackstart and microgrid substations.
- Electric ships and ferries may support land-based infrastructure across existing shore-power connection points
- Heavy-duty trucks (semi-tractor-trailer truck) are anticipated to have large onboard storage capabilities. They will likely utilize the majority of their onboard capability on a daily basis and may not be available for inclusion in emergency response operations.
- Person mobile thermal storage (propane tanks) can provide a lot of energy storage in a standardized distributed tank format. Battery electric propane heaters (forced air and

[33] Bioenno Power: https://www.bioennopower.com/

[34] Elite Power Solutions. Portable Solar Energy Storage System. Accessed on: https://www.elitepowersolutions.com/portable-solar-energy-storage-system

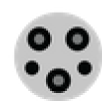
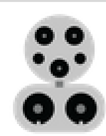
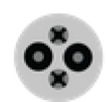
[35] DNV GL - Floating energy storage for grid and maritime applications: https://blogs.dnvgl.com/energy/floating-energy-storage-for-grid-and-maritime-applications

radiant) may provide deployable thermal capabilities in outages. Outages in winter are often of top concern due to life safety conditions when heat is lost. If households could remain warm with battery electric heaters, fewer households would strain emergency response teams hosting displaced residents. The equipment is low capital cost, and may make sense for both private ownership as well as emergency responder deployment.

Typical output interfaces

Currently, there are three charging options available for electric LDVs, utility vans, and buses; AC Level 1 Charging, AC Level 2 Charging, and DC Fast Charging. Level 1 Charging is the slowest with an hour of charging resulting in 2-5 miles of range.[36] An hour of Level 2 and DC Fast Charging adds 10-20 miles and 60-80 miles of range, respectively. The charge ports compatible with these charging options are provided in Table 4.

Table 4. EV charging options and interfaces

Charge Type	Input	Charge Port
AC Level 1 Charging	120 V AC input from wall outlet (NEMA 5-15)	 J1772 charge port
AC Level 2 Charging	240 V AC residential input (NEMA 6-20, NEMA 6-50, NEMA 14-50) or 208 V commercial input	
DC Fast Charging	208/480 V AC three-phase input	 J1772 combo  CHAdeMO  Tesla combo

The Society of Automotive Engineers' (SAE) J1772 connector is the standard for single-phase AC charging. It can be used for both Level 1 and 2 charging while the J1772 Combo connector can be used for all charging methods. The CHAdeMO and the Tesla Combo are intended for DC Fast Charging. The combined charging system (CCS) connector (J1772 Combo) is capable of a charging power over 350 kW.[37] Charging powers of CHAdeMO chargers range from 6-400 kW while the Tesla Supercharger is capable of a charging power up to 250 kW.[38] An AC Level 1 charging cord is equipped with a J1772 plug on one end and a NEMA

[36] U.S. DOE, Energy Efficiency and Renewable Energy, Alternative Fuels Data Center - Developing Infrastructure to Charge Plug-In Electric Vehicles: https://afdc.energy.gov/fuels/electricity_infrastructure.html

[37] CharIN: https://www.charinev.org/index.php?id=170

[38] CHAdeMO: https://www.chademo.com/about-us/what-is-fast-charging/ ; Tesla. Introducing V3 Supercharging: https://www.tesla.com/blog/introducing-v3-supercharging

5-15 plug, which is a three-prong household plug. The NEMA 5-15 plug connects with a NEMA 5-15 receptacle which is a two-pole, three-wire grounding receptacle with maximum voltage and current ratings of 125 V and 15 A, respectively.[39] The input of an AC Level 2 charging cord is equipped with a NEMA 6-20, NEMA 6-50, or NEMA 14-50 plug. In addition to the charging pins, EV charging connectors include pins for data transfer between the EV and the charging station for proper monitoring of the battery. The J1772, J1772 combo, and CHAdeMO connectors include 2 data pins; one for communication and another to detect that the connector has been plugged into the socket.[40] The Tesla Supercharger has two communication pins and a connection detection pin.[41]

When using EVs for V2G applications, the electric vehicle service equipment (EVSE) provides the necessary link between the EV and the grid. The charging connectors are compatible with bi-directional power flow. However, the power conversion requirements differ from AC EVSE to DC EVSE. Specifically, when using AC EVSE, the DC output from the EV battery is converted to AC by the onboard inverter, so that the output from the EV is AC. Conversely, when using DC EVSE, the output from the EV itself is DC and is converted to AC by the inverter in the EVSE.[42] In 2019 CharIN, the organization responsible for establishing the ccs charger standards (which is a required standard for EVs in Europe), announced their roadmap to include bi-directional vehicle to grid (V2G) and vehicle to home (V2H) support by 2025.[43]

While there is no standard for other mobile energy storage technologies, these mobile ESS presently subscribe to the same standard electrical connectors as any other device based on its current and voltage ratings. Figure 4 shows several standard AC connectors used in North America.

[39] Schneider Electric. NEMA 5-15 receptacle description: https://www.se.com/us/en/faqs/FA156527/

[40] Hydro-Québec, Electric Vehicle Charging Station - Technical Installation Guide, 2nd Edition, August 2015: http://www.hydroquebec.com/data/electrification-transport/pdf/technical-guide.pdf

[41] Tesla. Introducing V3 Supercharging: https://www.tesla.com/blog/introducing-v3-supercharging

[42] A. Briones, J. Francfort, P. Heitmann, M. Schey, S. Schey and J. Smart, Vehicle-to-Grid (V2G) Power Flow Regulations and Building Codes Review by the AVTA, Idaho National Laboratory, September 2012: https://www.energy.gov/sites/prod/files/2014/02/f8/v2g_power_flow_rpt.pdf

[43] CharIN Announcement in press; https://insideevs.com/news/342354/charin-ccs-combo-standard-to-offer-v2g-by-2025/

Figure 4. Standard North American AC power connectors

Size / type	Straight-blade connector	Twist-lock connector	Comments
208 Volt 15 Amp	 NEMA 6-15P	 NEMA L6-15P	2496 VA equipment load
208 Volt 20 Amp	 NEMA 6-20P	 NEMA L6-20P	3328 VA equipment load
208 Volt 30 Amp	None	 NEMA L6-30P	4992 VA equipment load
125 Volt 3-phase 30 Amp	None	 NEMA L14-30P	8640 VA equipment load

Source: J. Spitaels, Revision 2, The Different Types of AC Power Connectors in North America: https://download.schneider-electric.com/files?p_File_Name=SADE-5TNRML_R2_EN.pdf&p_Doc_Ref=SPD_SADE-5TNRML_EN.

System monitoring equipment

An effective monitoring and control system is necessary for detecting anomalies by continuously monitoring system variables such as voltage, current, state-of-charge (SOC), and temperature by the battery management system (BMS). Communication of the battery management system can ensure that appropriate corrective actions are taken using supporting systems inherent to mobile ESS. These systems include electrical protection devices and a heating, ventilation and air conditioning (HVAC) system for thermal management. Communication with site-based control systems can ensure supporting equipment systems (e.g. fire detection, fire suppression, space ventilation) respond to any system anomalies.

2.2. Mobile Energy Storage Use Cases

Mobile ESS can be used for a wide variety of applications by independent system operators (ISOs), utilities, commercial and industrial (C&I), and residential host customers, similar to stationary energy storage. These applications can generate revenue for mobile ESS owners by providing various grid services and providing value to host-customers when used to manage the timing of grid energy consumption to reduce electric bills.[44] These applications are discussed further in Section 4.

One of the primary use cases of mobile ESS is providing resiliency and backup power under emergency conditions. In addition to participating in revenue generating applications and electric bill management under normal operating conditions, the modular nature of these systems enables fast deployment to the location where emergency response is needed. Mobile ESS can also support the grid during network repairs.[45] Table 5 presents the four primary use cases and one secondary use case for mobile energy storage systems considered in this study. The emergency response events associated with these use cases are discussed in Section 5.

Table 5. Mobile energy storage use cases

Primary Use Cases	**Description**
Off-grid power	Mobile ESS that can provide power for emergency response front-line operations separate from a power grid
Building or campus microgrid	Mobile ESS that can be dispatched to a building or campus to meet critical loads in the event of an outage
Distribution-level minigrid	Mobile ESS dispatched to create a minigrid in the case of a grid outage
Grid-forming for harvesting stranded DG	Mobile ESS paired with renewable generation sources such as PV systems or wind farms, or off-grid conventional generators to provide black start[46]
Secondary Use Case	**Description**
Fossil fuel generator fuel optimization	Any energy storage system can be paired with fossil fuel generation to optimize fuel usage and extend and optimize capability

Mobile ESS are designed to be plug-and-play solutions requiring minimal reconfiguration once on site. Off-grid mobile ESS provide power without being connected to the grid. EVs are capable of providing off-grid power. For example, electric vans or trucks with standard AC outlets could be deployed to front-line operations fighting fires or other situations far from a power grid. Communications equipment and other electronic devices could be recharged to serve front-line personnel. In the case of microgrids, the mobile storage system will interconnect to the main electrical distribution panel for the building or campus to feed critical loads. EVs, tow-behind trailers, and semi-trailer trucks are appropriate for this application. However, measures must be in place to prevent back-feeding onto the distribution system while the distribution system is not powered. Interconnection of mobile energy storage with larger minigrid systems can occur at the distribution substation or anywhere along the feeder. All four primary mobile system

44 National Renewable Energy Laboratory (NREL), Batteries 101 Series: Use Cases and Value Streams for Energy Storage: https://www.nrel.gov/state-local-tribal/blog/posts/batteries-101-series-use-cases-and-value-streams-for-energy-storage.html

45 New Jersey Energy Storage Analysis (ESA) - Final Report: https://www.bpu.state.nj.us/bpu/pdf/commercial/New%20Jersey%20ESA%20Final%20Report%2005-23-2019.pdf

46 A black start is the process of restoring an electric power station or a part of an electric grid to operation without relying on the external electric power transmission network to recover from a total or partial shutdown.

configurations considered in this study are appropriate for this application. A fleet of EVs and semi-trailer trucks with containerized ESS can provide black start to stranded DG in order to harvest energy.[47] As in the case of microgrids, back-feeding onto an unpowered distribution system must be prevented.

The text below explores the current range of costs of mobile ESS, which are summarized in Table 6. Some costs scale with the amount of energy stored in the system (expressed in kWh), while others scale with the amount of power that can instantaneously flow into and out of the ESS (expressed in kW). The battery system equipment cost in $/kWh includes batteries, racking and enclosure, charge controllers, and battery management system (BMS) while the cost in $/kW represents the inverter cost. The site balance of system (BOS) cost in $/kW includes foundation, system enclosure, microgrid controllers, fire suppression, transformer, electrical service panel, switchgear, surge protection, and electrical disconnects. Installation labor, permitting, inspection, interconnection, engineering, commissioning, and sales tax are accounted for under soft costs.

The battery system equipment costs for V2G applications were calculated considering the cost of the EV and EVSE, energy capacity of a typical EV battery, and the charging power of an EV. The battery system cost in $/kWh for the V2G application represents the unit cost of the EV battery, although the purchaser must incur the total cost of the EV. To account for this, we computed the battery system equipment cost by dividing the cost of the EV by the energy capacity of the EV battery. On the other hand, the $/kW (inverter) component of the battery system equipment cost corresponds to the EVSE costs associated with V2G applications and was computed by dividing the total cost of the EV charging station by the charging power of the EV battery.

[47] Sources of DG shut down when the larger grid is in outage conditions as a safety precaution to protect line workers. The inverters isolate the source of generation, which can only be restored if the inverters sense voltage, which mobile ESS can provide to begin to harvest the stranded DG energy.

Table 6. Mobile energy storage system costs based on use case

Use Case	Battery system technologies	System installation parameters				
		Battery system equipment cost		Site BOS cost	Soft cost	
		$/kW	$/kWh	$/kW	$/kW	$/kWh
Off-grid	Stationary battery	350 - 550	520 - 700	50 - 80	330 - 420	15 - 20
	Tow-behind trailer	350 - 550	500 - 550	50 - 80	320 - 500	15 - 20
	V2G-light vehicles/van	80 – 100	480 - 650	30 - 50	20 -500	5 - 85
	V2G-bus	80 – 350	2250 - 4150	30 - 50	10 - 200	2 - 35
Microgrid	Stationary battery	100 - 120	350 - 420	50 - 80	330 - 420	15 - 20
	Tow-behind trailer	100 - 120	500 - 550	50 - 80	320 - 500	15 - 20
	V2G-light vehicles/van	80 – 100	480 - 650	30 - 50	20 -500	5 - 85
	V2G-bus	80 – 350	2250 - 4150	30 - 50	10 - 200	2 - 35
Minigrid	Stationary battery	60 – 70	290 - 370	50 - 80	370 - 550	20 - 25
	Tractor trailer	60 – 70	550 - 600	50 - 80	350 - 550	15 - 20
	V2G-light vehicles/van	80 – 100	480 - 650	30 - 50	20 -500	5 - 85
	V2G-bus	80 – 350	2250 - 4150	30 - 50	10 - 200	2 - 35
Grid-forming	Stationary battery	67 – 77	290 - 370	50 - 80	370 - 550	20 - 25
	Tractor trailer	67 – 77	550 - 600	50 - 80	350 - 550	15 - 20
	V2G-light vehicles/van	80 – 100	480 - 650	30 - 50	20 -500	5 - 85
	V2G-bus	80 – 350	2250 - 4150	30 - 50	10 - 200	2 - 35

As with stationary energy storage, mobile battery energy storage system equipment costs will likely decrease with scale. Therefore, the battery system equipment cost in $/kWh for the off-grid and microgrid use cases are considered to be higher than that of the minigrid and grid-forming use cases. A diesel generator rated at 15 kW for use in off-grid or microgrid applications can cost approximately $727/kW while a 30 kW-diesel generator can cost approximately $477/kW.[48] Based on Table 6, a 15 kW/30 kWh tow-behind trailer mobile energy storage system for off-grid applications can result in a storage equipment cost of approximately $1,000-$1,100/kW. One of the main differences between mobile energy storage and stationary energy storage is the additional ruggedization required to make the mobile storage

[48] Home Depot -Generac Protector Series 15,000-Watt Liquid Cooled Automatic Standby Diesel Generator, Accessed 15 January 2020: https://www.homedepot.com/p/Generac-Protector-Series-15-000-Watt-Liquid-Cooled-Automatic-Standby-Diesel-Generator-RD01523ADAE/205506794?MERCH=REC-_-PLP_Search-_-205506809;205506810;205506808;-_-205506794-_-N; Home Depot - Protector Series 30,000-Watt Liquid Cooled Standby Diesel Generator 120-Volt/240-Volt Single-Phase, Accessed 15 January 2020: https://www.homedepot.com/p/Generac-Protector-Series-30-000-Watt-Liquid-Cooled-Standby-Diesel-Generator-120-Volt-240-Volt-Single-Phase-RD03022ADAE/304985394

architecture robust enough to withstand transportation.[49] While these requirements increase the battery system equipment costs, ultimately, the total installed cost of mobile energy storage is comparable to and in certain instances cheaper than stationary energy storage due to the reduced engineering, procurement, and construction (EPC) costs.

Grid-forming vs. grid-following inverters

Currently, grid-following inverters are more common than grid-forming inverters. A three-phase, grid-following inverter supplies current by creating a current template from the grid voltage waveform, and then delivers current in phase with the line voltage. Converting such an inverter into a grid-forming inverter requires changes in hardware and software, but no significant rebuilding. The grid-following inverter has an inner current control loop, and an outer loop that commands current magnitude. The grid-forming inverter has an inner current control loop that is controlled by an outer voltage control loop, which tries to maintain the voltage waveform under all load conditions. In order for a grid-forming inverter to create the voltage waveform by controlling current, it must create a load. The most common way of creating a load is to increase the capacitance in the output filter to draw sufficient current to allow voltage regulation. This is the only significant hardware change, since the grid-following inverter is already equipped with line voltage sensors and line current transducers. As the grid-following inverter is already line locked and must monitor line voltage as part of IEEE 1547 requirements, the inverter already has the signals it needs to process. The grid-forming inverter serves the load, drawing necessary current from the DC side. If the battery system regulates the DC voltage and supplies current to maintain a DC voltage input to the inverter, then these control internal functions inherently and automatically act to serve the load without any need for external synchronization. Generally, a grid-following inverter is not suited for the applications considered here.

Transportation considerations

The transportation of mobile ESS requires several specific preparations. First, before deployment the systems must undergo necessary testing and receive relevant certifications. The size and configuration of a mobile storage asset will need to be considered during transportation arrangements. This differs from stationary energy storage applications because those battery cells are disconnected and transported separately from the container to meet road weight restrictions. Another key consideration is the state-of-charge (SOC) of the battery energy storage equipment. Typically, energy storage systems are not transported at a fully charged state (SOC of 100 percent) due to safety concerns. For instance, when transported by aircraft, Li-ion cells and batteries must not exceed an SOC of 30 percent. However, in an emergency scenario when the mobile storage asset is needed for immediate use, recommended SOC limits are problematic. (One way around this could be to transport and charge mobile ESS on site ahead of forecasted events.) Authorities with jurisdiction (AHJ) over deployment requirements for mobile energy

[49] Shihab Kuran, Power Edison, 5 December 2019.

storage will need to agree on requirements that can address safety and ensures preparedness at the same time.

Typical pairings with generators

Just as with stationary energy storage, mobile energy storage is designed to pair with a wide variety of generators. Such hybrid systems include the following configurations:

- Stand-by generator + energy storage
- Renewable generator + energy storage
- Stand-by generator + renewable generator + energy storage

In addition to the above, there are likely future configurations which include both stationary energy storage as well as mobile ESS. A diesel or natural gas generator can pair with mobile energy storage, reducing the cycling of the generator and prolonging its life. Specifically, not only can energy storage feed part of the load during peak load events, it can also alleviate the need for the generator to run continuously.[50] This has proven to be valuable during emergencies as fuel can be limited during outages arising from natural disasters or other circumstances. Delivered fuel logistics during outage events is a substantial burden on emergency relief personnel, and mobile ESS can reduce consumption and deliveries of fuel, relieving emergency responders to focus on logistics other than fuel delivery.

A mobile energy storage system can be paired with renewable generation such as wind and solar and can be utilized during periods with low irradiance or low winds resulting in poor solar or wind power production. The two systems described below have been in service for over five years and demonstrate this principle well. While these are stationary storage-based systems, a mobile system would serve the same function.

Stand-by generator + Renewable generator + Energy Storage

Alcatraz Island Microgrid

Alcatraz Island was rendered an islanded grid in the late 1950's when a vessel dragged anchor and broke the submarine cable. This was never repaired or replaced, and the island converted to full-time diesel generator service. By 2008, the National Park Service had taken over the facility, and the island's presence on a top-polluting site list prompted the agency to seek an alternative.

Princeton Power Systems designed a fully off-grid, AC coupled microgrid system which includes:

- 305 kW of Photovoltaic Generation
- 2.0 MWh of Advance Pb acid energy storage

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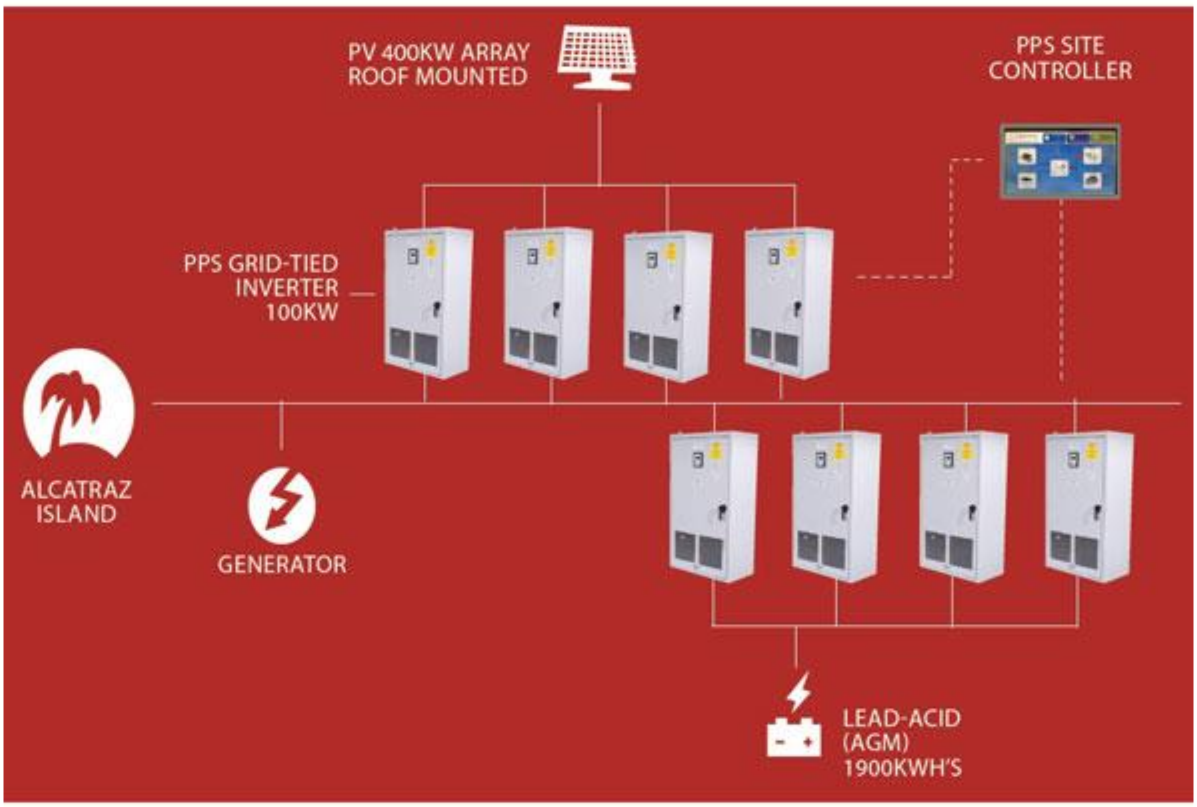
[50] Mark Lucas, ZeroBase Energy, 11 December 2019.

- 800 kW Inverters
    - 2 banks of 4x100 kW
    - One converting PV, One converting ESS
- Site controller software system
- 2 x 250 kW redundant diesel generators

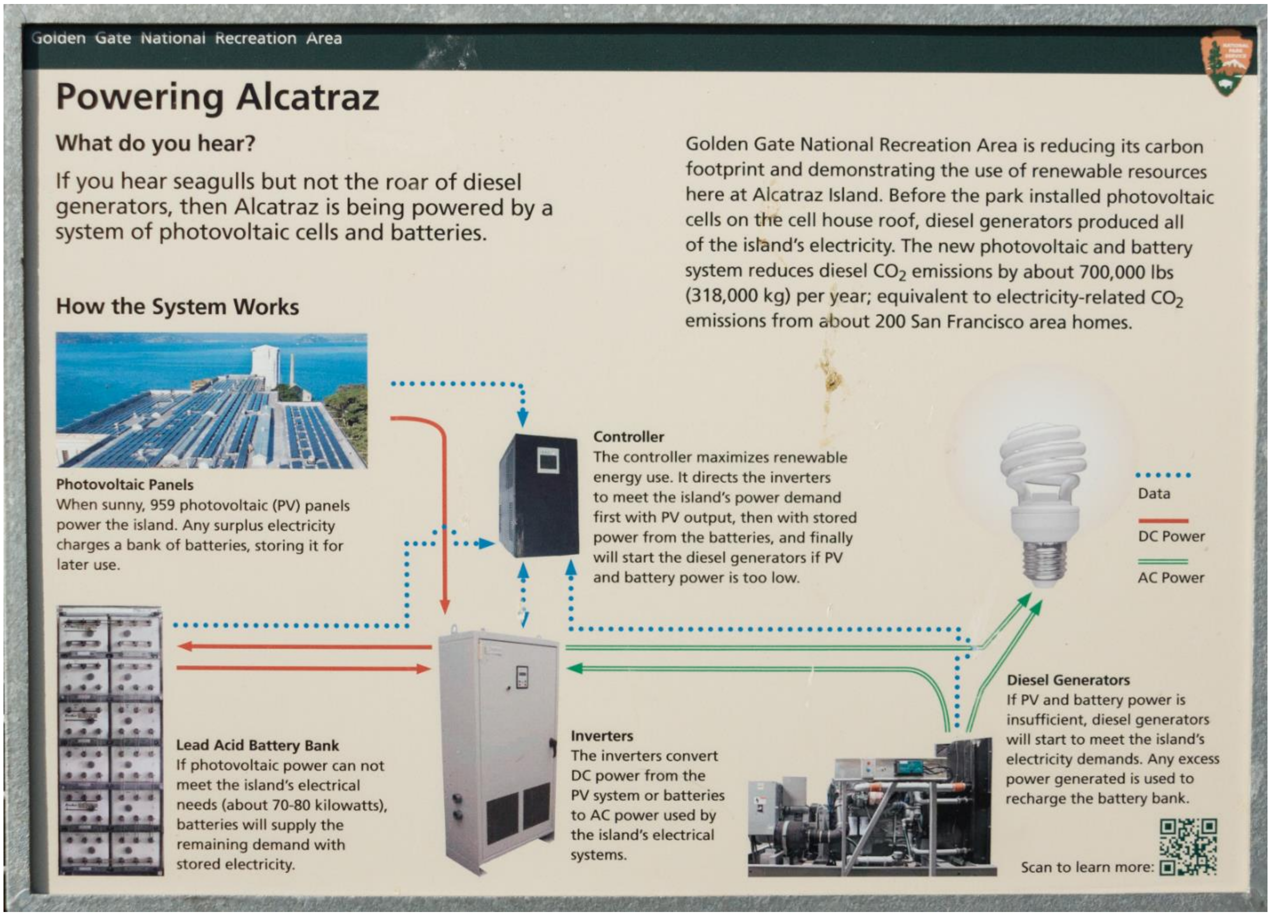
This system lowered emissions by reducing diesel fuel usage by 76 percent (from 1,200 gallons to 280 gallons/week) and reducing generator use time by 60 percent. The system's solar PV system generates energy to meet the island's energy needs (load) and the storage system ensures that energy is available at the right times. The storage system absorbs any excess solar energy generation during the day and provides energy when the PV system is not generating (known as PV smoothing). The diesel generator only turns on once the storage system's SOC reaches 10 percent of rated power.

Figure 5. Schematic of Alcatraz Island Microgrid System



Source: Alcatraz Escapes A Power Crisis Microgrid system provides clean power for Alcatraz and its environment in Power Electronics https://www.powerelectronics.com/markets/energy/article/21863753/alcatraz-escapes-a-power-crisis

Figure 6. Description of Alcatraz Island Microgrid System



Source: https://commons.wikimedia.org/wiki/File:Alcatraz,_Wikiexp_75.jpg

This system has been operational since January of 2012. The savings would have been dramatically increased with the use of current Li-ion energy storage technology from both increased depth of discharge and installed energy capacity. This option was not economically viable at the time for the project.

Stand-by Generator + Energy Storage Only

If no onsite renewable generation is available, a generator and storage combination would produce fewer savings but would enable a smaller emergency mobile generator selection. This type of system will allow for increased efficiency of preexisting generators which were sized to meet peak load, and which, with storage, could be operated to meet only average or minimum load and recharging. If existing backup generation was sized to meet critical load only, mobile energy storage allows for more load centers to be served with its additional energy capacity.

Renewable Generator + Energy Storage

Scripps Ranch Community Center

Many businesses, municipal buildings, and community facilities across the country have added solar power generation (PV) in the last 10 years. These sites present a clear use case for the application of any energy storage system, but mobile storage has an advantage because these sites often have space constraints.

One facility that augmented an existing PV array with stationary storage very early on was the town of Scripps Ranch, CA. This was the first PV+ESS installation in the state and one of the first in the country. The Scripps Ranch Recreation Center near San Diego is a municipal park and building that is used as an emergency command center for the surrounding community. In the face of frequent wildfires and brownouts, the building's existing PV array was augmented with an energy storage system to support its use as an emergency shelter. It installed this system in 2012.

Princeton Power Systems designed a fully off-grid, AC coupled microgrid system which includes:

- 30 kW of existing PV
- 2x 100 kW of inverters (1 for Storage, 1 for PV)
- 100 kWh Lithium ESS
- Weatherproof, ISO 20ft containerized enclosure.

While this system was installed for emergency use, it runs year-round to reduce the facility's utility bills, provide grid services, and mitigate demand charges. The stationary ESS could be readily replaced with a mobile ESS with similar specifications.

Sizing and pairing considerations of mobile ESS with existing generation

Backup power is rated based on the power needs of the application. Generally, cost, space, and load values will determine what power in watts or kilowatts of generation are installed. The capacity of these systems in Wh or kWh is a function of the size of the fuel tank and the ability to replenish, or in the case of a natural gas generator, the amount of disruption of the gas supply, generally perpetual. Mobile energy storage can displace or augment the capacity of the fuel tank. However, the inverters will limit the amount of power that the system can deliver.

Thus, storage systems have a dual sizing component, power and energy. The power will be determined by what the system will need to deliver relative to the on-site needs and is fairly straightforward. The capacity will be the length of time a battery can deliver energy at any given power level. This decision will also be affected by the rate of discharge (C rate) parameters of the energy storage system in question.

For example, a 100kW/200kWh energy storage system can deliver 100kW for 2 hours (technically known as a 0.5C or C/2 discharge) and is termed a 2-hour system. The system can deliver less power for a longer time up to a total energy delivered of 200 kWh (e.g., 50 kW for 4 hours). Note that capacity can vary depending on power output.

A storage system where the capacity (in Wh or kWh) is smaller than the power output (in W or kW) can deliver a greater number of Wh or kWh than rated if the full power is needed, but for less than an hour. For Example, a 200 kW/100 kWh storage system can deliver 200 kW for 30 minutes (technically known as 2C discharge) and is termed a 30-minute system. Capacity can be varied by power output.

The flexibility of these power/capacity configurations allows for greater customization and more granular specification of a system, which can translate to a more cost-effective system. The need for bandwidth of power or capacity will dictate the ratio that is optimal for any facility.

Table 7. C-rate and duration for any given capacity

C-rate	Time
5C	12 min
2C	30 min
1C	**1h**
0.5C or C/2	2h
0.2C or C/5	5h
0.1C or C/10	10h
0.05C or C/20	20h

3. Mobile Energy Storage System Deployment Logistics

Section 3 analyzes the logistical considerations required for proper deployment of the mobile battery storage systems discussed in Section 2 above.

3.1. Guiding Principles

This section explores five key principles which influence the deployment of mobile energy storage systems.

Figure ES- 1. Key Considerations for Mobile ESS Design and Deployment

Resiliency	• Must meet the minimum requirements of broader emergency relief systems, with consideration to system recovery times, reliability of services, and preservation of societal well-being
Reliability	• To maintain power reliability to critical services during emergency events in extreme conditions, mobile ESS may require more durable—and therefore more costly—components than stationary systems
Interoperability	• Standards must ensure that mobile systems are compatible with the equipment at the sites to which they provide power as well as with emergency response infrastructure and protocols
Hazard prevention	• Standards must ensure that the safety of the equipment operators, individuals at the site, utility workers, and the general public is protected, particularly against the risks of thermal runaway and electrical fire
Cost	• Cost will affect the economic feasibility of their use for emergency relief operations as compared to substitute technologies

Resiliency

Serving as a component of a broader emergency relief system, mobile energy storage can improve societal resiliency for responding to events such as extreme weather events or power outages. Design and deployment of mobile energy storage systems must meet minimum requirements for emergency system resiliency, with consideration to system recovery times, reliability of critical and priority services, and preservation of societal well-being.

Reliability

Provision of critical services in the Commonwealth during emergency events requires reliable power to certain facilities and off-grid operations. Historically, stationary energy storage systems and fuel-based generators have played an important role providing backup power to ensure power availability. If mobile ESS are to supplement or replace stationary assets, the mobile systems must be designed and deployed in a manner that meets reliability conditions for specified durations to maintain critical services. Mobile ESS may be exposed to more extreme conditions (e.g. vibrations during transportation) than their stationary counterparts and may require more durable—and thus more costly—components to maintain the same reliability standards.

Interoperability

Mobile energy storage systems must be compatible with the equipment at the sites to which they provide power as well as with emergency response infrastructure and protocols. The requirement for interoperability applies to both physical and communications connections, which may differ across the various sites to which the mobile systems are dispatched.

For example:

- Electrical interconnection ports on mobile systems must match the sites' electrical distribution equipment (i.e. "the plug must fit in the socket");
- Anchors and foundations used to dock mobile systems, where necessary, must be sized for compatibility with the mobile system dimensions and weight; and
- Controls equipment for the energy storage system and the site's building energy management system must use the same communication protocol (i.e. "speak the same language"). Compatibility may also be required with information systems of central agencies such as the Massachusetts Emergency Management Agency, the Massachusetts Department of Public Utilities, and electric companies.

Although not a prerequisite to interoperability, standardization of equipment components and communication protocols can reduce cost and improve the likelihood of compatibility.

Hazard prevention

Mobile ESS must be designed and dispatched in a manner that protects the safety of the equipment operators, individuals at the site, utility workers, and the general public. Adherence to the codes, standards, and protocols that exist at the federal, state, and local levels will help prevent safety hazards. Two hazards of concern for mobile ESS are thermal runaway and electrical fire. **Thermal runaway** occurs when a temperature increase changes the operating conditions in a manner that further increases temperature, which may produce damage. **Electrical fires** are fires involving electrically energized equipment that can cause harm due to temperature, electrical shock, or both. The potential for thermal runaway can contribute to the electrical fire risk. Battery systems and the equipment to which they connect must be designed to prevent thermal runaway and electrical fires which can be associated with chemical reactions, current flow, and power dissipation.

Cost

The feasibility of using mobile ESS in emergency relief operations to respond to emergency events will depend, in part, on the economic value of mobile systems compared to substitute technologies. See Section 6 for discussion of mobile ESS costs and benefits as compared to stationary systems. Steps that may reduce the cost of dispatching mobile ESS include equipment standardization, process automation, and incorporating learning mechanisms to drive adaptative improvements in resource efficiency.

3.2. Site Requirements

This section details the site-relevant constraints and considerations for deploying energy storage systems in a temporary or semi-permanent configuration.

Codes and standards

A number of relevant codes and standards exist for equipment, construction, interconnection, transportation, and permitting of energy storage systems. Table 8 presents a non-exhaustive list and description of these requirements. The extent to which each requirement applies to a particular site may vary by jurisdiction. To ensure all applicable codes and standards are satisfied, projects should undergo engineering design and should be reviewed by relevant authorities.

Table 8. Codes and standards applicable to energy storage systems or components

Codes or Standard		Scope
NFPA 70	National Electric Code	MA state electrical code is based on this standard; Article 706 established standards for ESS
IFC	International Fire Code	Regulations to safeguard life and property from fires and explosion hazards
NFPA 855	Standard for the Installation of Stationary Energy Storage Systems	Provides the minimum requirements for mitigating the hazards associated with energy storage systems
UL1642	Standard for Lithium Batteries	Requirements for lithium batteries for use as power sources in products
UL1973	Standard for Batteries for Use in Light Electric Rail (LER) Applications and Stationary Applications	Equipment requirements for battery systems for use as energy storage for stationary applications
UL9540	Standard for Energy Storage Systems and Equipment	Requirements for energy storage systems that receive, store, and provide electric energy to loads at the site-level up through the utility grid
UL 9540A	Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems	Equipment testing standard to evaluate fire propagation risk to ensure compliance with IFC and NFPA 855 large scale fire and fault testing
UL1741	Standards for Inverters, Converters, Controllers, and Interconnection System Equipment for Use with DERs	Requirements for inverters, converters, charge controllers, and interconnection system equipment used in off-grid applications
IEEE 1547	Standard for Interconnection and Interoperability of Distributed Energy Resources (DER) with Associated Electric Power Systems Interfaces	Specifications for, and testing of, the interconnection and interoperability between utility power systems and DERs. Includes requirements for performance, operation, testing, safety, and maintenance.
UN/DOT 38.3	Transportation Testing for Lithium Batteries	Testing standards for safety of lithium batteries during shipping and transportation
IEC 62619	Safety requirements for secondary lithium cells and batteries, for use in industrial applications	Requirements and tests for the safe operation of secondary lithium cells and batteries used in industrial applications, including stationary applications
IEC 62477	Safety requirements for power electronic converter systems and equipment	Requirements for power electronic converter systems and equipment, their components for electronic power conversion and electronic power switching, including the means for control, protection, monitoring, and measurement
IEC 61000-3-2	Electromagnetic compatibility - Part 3-2: Limits for harmonic current emissions	Requirements and test for harmonic currents injected into the public supply system, inc. limits of harmonic components
Utility interconnection standards		Such standards govern the interconnection requirements for DERs and may vary by electric utility and jurisdiction

Space clearances

There are several space requirements to consider when vetting critical sites for use of mobile energy storage systems:

Equipment clearances surrounding the mobile storage systems must conform to any code requirements and also provide adequate access for operation and maintenance of the systems.

Vehicular driving clearances should be assessed and deemed adequate for any mobile storage system types selected for use at a particular site. Determinants of driving clearance include the width, length, and height of system (both the vehicle and any tow-behind equipment) as well as the vehicular turning radius. The following listing of system configurations is arranged in order of increasing space requirements for onsite transportation, though some variation may occur depending on individual system design: V2G LDVs and utility vans, tow-behind trailers, V2G-buses, and semi-trailer trucks.

Space separation relative to critical buildings, critical equipment, and other battery storage systems is an important factor in hazard mitigation. Adequate separation is necessary (1) to minimize any risks posed by mobile ESS to the site associated with thermal runaway, chemical exposure, or electrical fire; and (2) to minimize damage to the mobile ESS from site operations.

Egress routes for site personnel must not be obstructed by the placement of mobile energy storage systems.

Firefighting access is crucial to protecting the safety of site personnel, the public, and assets at the site. Although mobile ESS should include adequate fire suppression systems, as discussed below, professional firefighters serve as a safety backstop. As such, adequate clearances should be provided to ensure access to the mobiles by firefighting personnel and their equipment.

Site preparation

Sites require preparation to interconnect and safely operate mobile ESS. The requirements, however, may vary by the type of site.

Mobile ESS operating at the **facility level** will typically connect behind-the-meter to the facility's existing electrical distribution system and site preparation will generally need to adhere to commercial and institutional site standards. Massachusetts is a home-rule state, in which each local jurisdiction maintains a list of individual critical infrastructure sites. Representative types of critical facilities are listed below.

• Airports • Boat, ferry, and cruise terminals • Bus garages • Cell towers • Electric utility control centers • Electric utility equipment yards • Emergency operations centers • EMS facilities • Evacuation sites • Fire stations • Fuel storage facilities	• Gas stations • Grocery stores • Hospitals and medical centers • Hotel Internet centers • Microwave transmission facilities • Pharmacies • Points of distribution • Police stations • Public safety answering point facilities • Radio transmission facilities	• Rail yards and stations • Sewer pumps • Sewer treatment plants • Shelters • Water pumps • Water purification • Water storage facilities • Wire centers

Systems which provide services at the **distribution level** are likely to interconnect in front of the meter to electrical grid distribution infrastructure. Site preparation should adhere to standards applicable to power distribution infrastructure sites. Mobile ESS could provide power to a portion of a distribution feeder,[51] a full distribution feeder, or an entire substation. The point of interconnection and the site preparation requirements may vary for each.

Site selection must consider adequacy of the roadways needed to access the site for transport of mobile ESS. Larger mobile ESS may require roadways with higher loading capacity and greater lane widths. For the system types discussed in this report, roadway adequacy is unlikely to be a constraint for facilities located on highways and major thoroughfares. A roadway adequacy assessment may be necessary for facilities located on paved surface roads or non-paved roads. Critical facilities in difficult-to-access locations may be best served by stationary energy storage systems, particularly when transportation access could be compromised by geologic or atmospheric events.

Water hazard prevention should be considered when selecting sites for mobile ESS and the location of such systems within a site. Specifically, system layout and components should be designed to minimize damage risk to equipment systems and electrical shock safety hazard associated with flooding events. Site elevation is an important consideration.

Pavement strength of surfaces across which mobile energy systems will be transported must be sufficient to support the system weight. Similarly, foundation loading strength for docking mobile energy systems should be designed to support the system weight.

Thermal barriers can provide protection to mobile ESS which must be clustered in higher density. Adding barriers between battery systems serves as an alternative to providing larger space separation, which may otherwise be necessary to prevent damage caused by thermal runaway or fire from one system to

[51] A distribution feeder is a medium voltage power line which carries electricity from a power distribution substation to serve local loads.

another. This approach would be most relevant to applications which use many smaller systems to achieve greater power output or longer energy duration.

Space ventilation safety systems may be a necessary precaution against hazardous gases which are potential byproducts of a battery system failure in certain battery chemistries. This would be most applicable to mobile energy systems deployed in enclosed or partially enclosed spaces (e.g. parking garages). Ventilation safety systems may already exist at locations with existing backup generators, which can pose risks associated with combustible fuels and combustion byproducts.

Security barriers or enclosures such as fencing and bollards may be desirable to protect mobile ESS.

Smoke detection systems are needed to identify thermal runaway or fire hazards so that automated or manual safety protocols can be initiated. Smoke detection can be included in mobile ESS, at the site, or both.

Fire suppression systems are essential to reducing the risk of damage from potential fires associated with mobile ESS. The selection of suppression medium will depend on the battery chemistry in the mobile unit. For example, among Li-ion batteries, the lithium ferrous phosphate chemistry is a relatively safe battery chemistry and can be extinguished with water, carbon dioxide, dry chemical powder, or foam. If used, chemical-based fire suppression systems should be included in mobile system enclosures. If used, water-based fire suppression systems would need to be available onsite, as recommended volumes required would exceed the carrying capacity of mobile units. Portable fire extinguishers should also be provided at mobile ESS.

Interconnection power lines

In circumstances where mobile ESS cannot be located at the same site as the energy loads they will serve, it may be necessary to stage the mobile units offsite and install interconnection power lines between the site and the offsite staging area. Capital expenditures to install such power lines may substantially increase the cost of using mobile storage. Costs will scale with the distance between the site and the staging area.

Electrical interconnection

To provide power to critical loads during an emergency event, mobile ESS will require electrical interconnection to existing electrical distribution infrastructure—either behind the meter or in front of the meter. Several considerations are necessary to ensure the safety and compatibility of these mobile assets.

Electrical safety equipment is necessary to protect personnel, the mobile units, and the site-based infrastructure. The following components will commonly be required:[52]

[52] The provided list is non-exhaustive and may vary by jurisdiction, based on utility and local permitting requirements.

- **Electrical disconnect**: one or more switches that can be used to electrically isolate the mobile energy storage unit from the electrical distribution infrastructure at the site.
- **Ground fault protection**: a device or system intended to protect against hazard against ground fault, which occurs when electrical contact is inadvertently made between an energized electrical system and a person or object that is electrically grounded.
- **Overcurrent protection**: a device or system designed to protect against overcurrent fault, which occurs when an electrical circuit is overloaded with current or is short-circuited.
- **Surge protection**: a device or system designed to protect electrical systems or equipment against voltage spikes, which can be caused by lightning strikes and other electrical disturbances.
- **Islanding safety protection**: anti-islanding technology is typically incorporated into inverter-based DG systems to prevent that system from electrically islanding in the event of a grid outage.[53] In order to provide power to critical loads during an emergency event, the mobile storage energy system and site-based electrical distribution equipment would need to be configured such that the end loads can remain energized during a grid outage—that is, that they *do* island. A system could be designed to automatically detect grid outage and disconnect the critical loads from the rest of the utility grid (configuration will vary depending on if the system is BTM or in front of the meter). Alternatively, a system may be designed with double rectifier hardware or other means of preventing flow of power from the site back to the grid under all circumstances. Such system configurations have not been broadly adopted in practice and would need review for conformity to code requirements. The double-rectifier approach differs from a traditional **net metering** configuration, which allows for export of power back to the grid under blue sky conditions.

Compatibility of the mobile system with the electric equipment and connections at the site should be tested and verified prior to deployment under an outage condition event. Considerations include physical interfaces (i.e. "the plug must fit in the socket") as well electrical compatibility (i.e. matching voltage level and the type and phasing of power). Mobile systems intended to serve various end loads with differing

[53] The following definition and discussion of islanding is taken from Lazar, J. 2016. Electricity Regulation in the US: A Guide. Second Edition. Montpelier, VT: The Regulatory Assistance Project. Retrieved from http://www.raponline.org/wp-content/uploads/2016/07/rap-lazar-electricity-regulation-US-june-2016.pdf.

Islanding is "[p]lacing the electric system into a configuration in which some subpart of it is electrically separated from the rest of the system but remains energized and operative. A system may be islanded to facilitate maintenance or equipment upgrades or in response to a system failure or instability. In the context of distributed generation, a single customer or small group of customers might be islanded during a system outage to be served by one or more distributed generation resources. IEEE 1547.8 governs the conditions under which islanding may occur. Microgrids may also function in an islanded manner in response to system failures or instabilities, or for economic reasons."

physical and electrical characteristics could be designed with onboard equipment that adapts to match the end use (e.g. step-up or step-down transformers).

3.3. Operational Protocols for Deployment of Mobile Systems

Entities responsible for ensuring availability of critical services during an emergency event will need operational protocols to assure that mobile ESS can be dispatched and will operate in a manner that meets or exceeds standards for system resiliency. Protocols should be developed with consideration to the guiding principles discussed in Section 3.1 to system recovery times, reliability of critical and priority services, and preservation of societal well-being.

Operational protocols for mobile ESS should be harmonized to guidelines in existing emergency planning documents. These include, but are not limited to, the following:

- The **Comprehensive Emergency Management Plan** (CEMP) of the Commonwealth of Massachusetts;
- Relevant annexes to the Commonwealth's CEMP and Emergency Support Function, especially **Massachusetts Emergency Support Function 1—TRANSPORTATION** and **Massachusetts Emergency Support Function 12—ENERGY**;[54]
- **Emergency Response Plans** (ERP) of electric companies operating in Massachusetts, which are filed annually with the Massachusetts Department of Public Utilities; and
- The internal **Emergency Management Plans** for relevant State of Massachusetts departments, especially of the Department of Public Utilities and the Department of Energy Resources.

Verification of resource compatibility

Operational protocols should ensure that any mobile ESS dispatched to serve critical loads have been validated for physical and operational compatibility with the existing site infrastructure (e.g. electrical connections). For each site where critical services are provided, operators should test each type of mobile energy storage system which may be used onsite. Testing should be conducted in all relevant operational modes, ideally under simulated outage conditions events. Qualified personnel should verify and document the adequacy of existing safety systems (e.g. fire suppression, electrical safety) and space clearances for each site and each mobile storage technology.

Critical load sizing and prioritization

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[54] Other annexes may be relevant on a site-by-site basis, depending on the type of critical services provided (e.g. Massachusetts Emergency Support Function 2—*COMMUNICATIONS* will be relevant to sites providing critical communications services).

A key consideration when developing operational plans for deployment of mobile ESS is the adequacy of mobile systems for meeting critical loads. The power and energy capacity of the dispatched systems should be based on a thorough assessment of the critical loads, ideally using historical data. System deployment decisions should attempt to “right-size” the dispatched unit to avoid overcapacity. This approach may reduce cost and ensure sufficient mobile storage resources are available for use at other sites during outage conditions events. This dispatch optimization can be accomplished through software tools and trained emergency operations personnel. While right-sizing is an ideal case, mobile ESS may be deployed in a similar manner to existing emergency backup generators, which is to deploy in standardized sizes and deploy a system expected to be slightly oversized to the need.

Given finite resources, operational protocols should include a prioritization of loads to ensure the most critical services are provided reliably throughout an emergency event. A sample prioritization scheme could identify each site according to its relative importance: Critical, uninterruptible; Critical, interruptible; Priority; and Non-Priority. The designation “uninterruptible” should be used for end loads which cannot tolerate even temporary power outages. Such loads may be best served by stationary ESS or a combination of mobile and stationary to assure continuous availability of power.

Site-specific protocols

Protocols should be in place to ensure sites are prepared to receive mobile ESS. Before deployment of the mobile storage asset, site personnel should receive supplier-approved training for operating as well as performing maintenance on the energy storage system.[55] A service manual providing maintenance and safety instructions should be made available to site personnel. Additionally, appropriate signage must be placed on site, identifying electrochemical equipment, emergency stop buttons, and contact information for a subject matter expert (SME). To ensure safe operation of the mobile energy storage system upon deployment, site-specific measures must be in place to identify and respond to any issues.

Emergency event deployment logistics

At the time when an emergency event is declared, it will be necessary to assess the feasibility of deploying mobile resources. Differing types of events (e.g. meteorological, tectonic, hydrologic, industrial hazard, infrastructure hazard, terrorism) may pose a variety of logistical challenges to transporting or interconnecting energy storage systems. For example, road conditions may produce a hindrance to deployment under circumstances with severe ice, snow, flooding, stranded vehicles, or damaged roadways. Further, it may be necessary to clear sites of obstructions to access points of electrical interconnection. To the extent that some emergency events can be forecasted (e.g. meteorological) it may be advisable to deploy the types of mobile systems considered in this report in the days, hours, or minutes prior to outage conditions, due to sensitivity to road conditions.

[55] DNV GL. Recommended Practice - Safety, operation and performance of grid-connected energy storage systems: https://www.dnvgl.com/services/gridstor-recommended-practice-for-grid-connected-energy-storage-52177.

Operational schedules

During an outage conditions event, emergency management personnel will need to manage the operational schedules of mobile resources. This will include monitoring the depth of discharge of the batteries and forecasting the remaining duration over which site load requirements can be met. Less-severe events may allow periodic recharging of the mobile units using existing grid connections at the site, for example under rolling brownout conditions. Mobile storage systems afford the benefit of "resource swapping," meaning that a system at or near full charge can replace a low-charge unit and the low-charge unit can then be transported to a recharging station. Given the time duration needed to disconnect one mobile storage unit and interconnect another, such activities should be scheduled during times when an interruption of services is tolerable. For services which cannot tolerate a scheduled outage, infrastructure redundancy may be necessary.[56] Where mobile resources are inadequate to meet the full load of all sites, emergency planners may consider dispatching units in a revolving schedule across several sites, ideally in a manner that the rolling outages can be managed systematically. For example, a single unit could conceivably be shared between a gas station (daytime-only refueling) and a water tower (nighttime-only pumping to refill).

Communications

Emergency planning protocols should account for communication requirements among energy storage equipment, critical facilities, and operations personnel. Communication infrastructure will exist at multiple levels of the societal emergency response system, and key types of equipment systems are listed below:

- Battery management system: Battery systems, whether stationary or mobile, will include a number of devices responsible for control of battery cells and other system components. These will typically include a system display and communications device, a communication manager device, a system DC monitor, and controls integrator.
- Energy management system: Commercial and institutional facilities are likely to have a system which tracks and controls a variety of energy-using equipment systems at the site. The energy management system should be capable of sending and receiving signals from the battery management systems, possibly including scheduling of charging and discharging.
- Distribution-level control system: Electric utility companies use control systems to manage the functionality of distribution-level infrastructure, including substations, points of common coupling, switchgear, and more.
- Microgrid control system: Microgrids with DERs use a system of controllers to balance supply and demand for power over a geographically limited area, including managing the flow of power to loads and production of power from dispatchable resources.

[56] Examples include combined stationary and mobile systems, equipping sites with interconnection points for more than one mobile system (in parallel), or equipping mobile systems to connect to each other (in series).

- Emergency personnel communication equipment: During a grid outage or other emergency event, telecommunication and internet/data connectivity will be necessary for coordination among emergency operations dispatchers, mobile transport teams, system operators, and site personnel. Further, such personnel will interface with the above-mentioned controls equipment, which may require means of remote communication.

During an outage conditions event, central communication infrastructure (e.g. cellular, radio, microwave) may be compromised due to grid outage or other disturbances. Mobile ESS can help maintain or restore communication and data connectivity by powering local wireless communication equipment.

Standardization of communication protocols across equipment for the ESS and the sites' building energy management systems will facilitate interoperability of systems (i.e. ensure the systems "speak the same language"). Compatibility may also be required with information systems of central agencies such as the Massachusetts Emergency Management Agency, the Massachusetts Department of Public Utilities, and electric companies. Ideally all systems would use the same native communication protocol. However, given the multitude of sites to be served and the variety of mobile system types and manufacturers, differing communication protocols will exist. Substantial resources may be required to integrate equipment with different protocols. Non-proprietary, open protocol systems should be used in mobile ESS where possible.

Development and testing of communication protocols among personnel and equipment systems will help ensure preparedness for outage conditions. Such protocols should include the above-mentioned equipment systems and a range of responsible personnel: emergency operations dispatchers, mobile transport teams, system operators, and site personnel. Protocols may include the following:

- Monitoring of location and availability of mobile ESS
- Notification of an outage condition event, whether forecasted or underway
- Assignment of mobile energy storage resources to sites
- Dispatch and transportation of mobile energy storage resources
- Validation of mobile energy storage system interconnection and operability
- Ongoing monitoring of system operation throughout the event
- Notification that the outage conditions event has ended
- Validation of mobile energy storage system disconnect
- Dispatch of mobile energy storage resources to blue sky operation
- Other protocols identified in emergency management plans

3.4. Operational Guidelines

When an emergency event is declared, relevant agencies must take a series of steps to deploy mobile ESS. Below is a representative list of these actions, with consideration given to different mobile system types and site-infrastructure:

Before Deployment	Communicate the decision to dispatch a mobile system to the system operators.
	Validate system operability, ensuring that the mobile storage system is functionally capable of operation in intended use.
	Discontinue normal operations.
	Remove any connections to infrastructure at the current site of the system, including physical anchoring, electrical interconnection, and communications pairing.
	For towable systems, load battery systems onto trailers (if not already there), anchor system to trailer, and connect trailer to towing vehicle.
	Validate that system is prepared for transportation to site. This may include double checking that the state-of-charge is safe for transport, that system is prepared to handle in-transit vibrations, and similar safety checks.
	Transport the system to the site. Route planning should account for any event-related hazards that may impact if roads are passable.

Once on Site	Maneuver the system to its interconnection point at the site. Operations personnel may require access codes or keys to gain entry through security or physical barriers such as fencing and bollards.
	Dock the system at its interconnection point. This may include a combination of tasks such as unloading containerized systems, disconnecting trailers from the towing vehicle, blocking the vehicles' wheels, and/or anchoring systems to the pavement or foundation.
	Validate that the system has not been damaged in the course of transportation and docking.
	Validate the adequacy of the site-based infrastructure, such as electrical safety equipment and fire suppression systems. This step may be performed prior to the decision to deploy the mobile system.
	Validate the interoperability of the mobile storage system with the site-based infrastructure. This step may be performed prior to the decision to deploy the mobile system.

Connecting

Electrically interconnect the system to the site-based infrastructure *without* enabling *power flow.*

Pair storage system with site-based communications equipment to enable monitoring and control.

Initiate any battery system startup safety tests.

Perform manual switching and enable any automatic switching needed to allow power flow between the mobile system and the site-based infrastructure. Examples include safety switches, disconnect switches, and points of common coupling.

AC interconnections will be common, but DC interconnections are possible as well. For example, where DC systems exist at the site, there may be benefits from interconnecting behind the inverter of other DC systems. Examples include generators, PV systems, and other batteries.

A number of possible configurations exist depending on the use case, the mobile storage system type, and existing site-based infrastructure. Examples include:

- Standalone connection to the electrical distribution equipment at the site.
- Connection in series between existing site-based generation and the electrical distribution equipment at the site.
- Connection in series to an existing site-based energy storage system that is already interconnected to electrical distribution equipment at the site.
- Connection to the electrical distribution equipment at the site in parallel with other existing site-based generation.

Begin Operating

Enable operating mode applicable to the intended use. This is likely an input parameter within the battery controller.

Ensure storage system monitoring is operational for key parameters, such as state-of-charge.

Validate system operation and communicate results to relevant emergency management personnel.

This list of steps is presented sequentially, however, the ordering of these steps may vary based on a variety of conditions, including system type, use case, and existing site-specific infrastructure. In accordance with operational protocols and emergency planning documents, additional actions may be needed, or some actions may be omitted.

3.5. Regulatory Oversight of Energy Storage Systems

There are three domains of regulation pertaining to the design of mobile ESS and their deployment at a site.

A. Permitting, inspection, and interconnection processes that govern DERs: These regulatory processes govern the installation of permanent fixtures and equipment that interconnect directly to the grid or grid-tied facilities.

B. Safety standards testing and certification for manufactured vehicles: Manufactured vehicles intended for operation on public roadways must be tested to prove conformity to automotive standards.

C. Safety standards testing and certification for manufactured battery equipment: Manufactured components of battery systems must be tested to prove conformity to equipment standards.

The commercial availability of mobile systems with the capability to discharge power to the grid are a relatively new and evolving phenomenon. To our knowledge, there is no domain of regulation that fully covers some of the mobile systems discussed in this report, and regulatory gaps exist. A number of technologies reviewed in this report are factory-built tested and certified equipment, but there is no certification standard or regulatory permitting for the composite system. This stands in contrast to stationary systems, in which systems are (similarly) built of tested and certified equipment, and then a permitting and inspection process reviews the system for interconnection. Thus, the process of making physical changes to prepare a site to receive a mobile energy storage unit (e.g. installing electrical interconnection and safety equipment) must be permitted and inspected. However, to the knowledge of Synapse and DNV GL, there is no regulatory oversight over the temporary interconnection of mobile ESS to a site. Entities intending to use such technologies should seek guidance from their electric utility, local permitting authority, and professional engineers. Traditional backup generation behind an automatic transfer switch (ATS) which breaks connection with the grid before making connection to the generator does not require electric utility notification or interconnection processes. Sites with existing backup generation and ATS in place are thus good target sites for the deployment of mobile ESS.

4. Evaluation of Mobile Energy Storage System Use: Blue Sky Conditions

Section 2, above, presented several mobile energy system configurations and described the technical characteristics and performance capabilities for state-of-the art available mobile ESS. There are two broad categories of mobile storage systems. The first is self-mobile energy systems in the form of different EV platforms with vehicle-to-grid (V2G) capabilities.[57] The second category of mobile ESS is referred to as towable systems. These are generally larger battery packs that are packaged in a tow-behind ESS trailer or containerized ESS transported to locations where emergency relief operations are occurring. In this section we explore the use of these mobile energy systems during normal conditions. The use of these assets during normal operations can create value well beyond the value they provide during emergency relief operations.

As discussed below, mobile storage systems (both self-mobile and towable) can provide many of the same services provided today by stationary battery storage systems. It is important to note that self-mobile energy sources in the form of EVs provide valuable mobility services during blue sky conditions. Furthermore, mobility services during outage conditions could also be highly valued particularly if shortages of traditional fuels limit the use of conventional vehicles.

This section explores the services that mobile ESS could provide during blue sky conditions. The potential value that mobile ESS can provide during normal operations is additive to the value they provide as emergency response assets. Understanding the combined value is important to identifying cost-effective investments in assets that are necessary to meet emergency preparedness goals. We first discuss the use of mobile energy systems during blue sky conditions relative to the services currently being provided today by stationary energy storage systems. Next, we discuss specifically the self-mobile category of mobile energy systems with the goal of establishing a value framework for mobility services during blue sky conditions.

4.1. Services Provided by Stationary Battery Systems

Stationary energy storage is becoming an increasingly important resource in both front-of-the-meter (FTM) grid services and BTM applications. The revenue potential or value streams that energy storage can provide generally fall into three broad categories: wholesale, utility, and host customer.[58,59] Wholesale and utility value streams are typically derived from FTM applications, although aggregated BTM systems can also provide these services. Customer value is derived from BTM applications. FTM refers to energy storage systems connected at either the distribution or transmission levels. These are systems that are

[57] The various EV platforms discussed in Section 2 do not necessary currently come equipped with V2G capabilities, but there is a growing interest in accessing vehicle batteries for emergency power and grid services. Furthermore, numerous V2G demonstrations have taken place and commercially available vehicle-to-home products are appearing in some markets outside the United States.

[58] Rocky Mountain Institute (RMI). *The Economics of Battery Energy Storage*. October 2015. Available at: https://rmi.org/wp-content/uploads/2017/03/RMI-TheEconomicsOfBatteryEnergyStorage-FullReport-FINAL.pdf

[59] Lazard. Levelized Cost of Storage Analysis – Version 5.0.November 2019. Available at: https://www.lazard.com/media/451087/lazards-levelized-cost-of-storage-version-50-vf.pdf

typically operated by a utility company or other merchant plant operator. BTM storage systems are connected at the service panel of the host customer and are typically owned and operated by the host customer. Increasingly, storage is being paired with solar in both FTM and BTM applications to increase the value of solar-generated electricity.

FTM stationary energy storage systems are finding new and expanding market opportunities providing transmission and distribution investment deferrals, energy and capacity services in wholesale markets, reliability services, and transmission congestion relief, among others. BTM stationary energy storage is being installed at an increasing rate to provide back-up power, help customers manage energy use to reduce electric bills, and increase solar self-consumption. BTM energy storage systems can participate in demand response programs. In these programs, customers receive compensation for allowing the utility to manage the timing of charging and discharging in response to conditions on the grid.[60] It is possible for BTM systems to access wholesale and utility value streams through aggregation of individual storage systems by a utility or a third-party aggregator.[61] Increasing levels of renewable generation and the growth of strategic electrification for the transportation and thermal sectors create additional important and potentially valuable applications for energy storage systems going forward.

Appropriate mobile energy storage systems

While stationary storage has proven its ability to provide the services discussed above, it is conceivable that mobile storage systems can provide some or all of these services while also being available to provide additive mobility services and resilience benefits during outage conditions. Table 9 identifies the appropriate mobile ESS for each application and service considered.

[60] US Department of Energy. 2016. Demand Response and Energy Storage Integration Study Storage for Demand Response. Available at https://www.energy.gov/sites/prod/files/2016/03/f30/DOE-EE-1282.pdf

[61] https://rmi.org/wp-content/uploads/2017/03/RMI-TheEconomicsOfBatteryEnergyStorage-FullReport-FINAL.pdf

Table 9. Mobile energy storage applications during blue sky days

Application	Service	Description	Mobile ESS / Notes
BTM (residential & commercial)	Peak demand savings	Shave peak to reduce utility peak demand charges	V2G—Light-duty V2G—Bus Trailer
	Energy arbitrage (TOU rates)	Buy low and sell high	V2G—Light-duty V2G—Bus Trailer
	Emergency back-up power	Serve critical loads during grid outage (planned or forced)	V2G—Light-duty V2G—Bus Tow-Behind Trailer
	Power quality	Improve power quality from the grid	V2G—Light-duty V2G—Bus Trailer
	Demand response	Generate revenue as grid resource	V2G—Light-duty V2G—Bus Tow-Behind Trailer
	Solar self-consumption	Storage can be used to increase the self-consumption of onsite solar	V2G—Light-duty V2G—Bus Trailer
Grid System (wholesale market & utility)	Capacity RA value	Provide a capacity resource for the bulk transmission system	V2G—Light-duty V2G—Bus Trailer Container
	Ancillary services	• frequency response regulation • reserve (spin and non-spin) • voltage support • black start	V2G—Light-duty V2G—Bus Trailer Container
	Renewables integration	Managing variability, avoiding curtailment, etc.	V2G—Light-duty V2G—Bus Trailer Container
	Transmission and Distribution (T&D) Deferral	• can defer investments in T&D infrastructure when strategically sited • can be readily moved to a new location when the T&D constraint is relieved, or a T&D investment becomes necessary	V2G—Light-duty V2G—Bus Trailer Container
	Wholesale Energy Arbitrage	Buy low, sell high	V2G—Light-duty V2G—Bus Trailer Container

Behind-the-meter services

BTM services are provided on the host customer's side of the meter. For grid operators and utilities, BTM energy storage systems only appear as changes in demand similar to how BTM solar changes a customer's load profile. These BTM energy storage systems provide several benefits to host customers as described below. As an example, a fire station or other emergency response facility could use mobile ESS during blue sky conditions to reduce overall energy bills and potentially generate revenue by participating in a utility demand response program. Here we discuss each BTM service that mobile ESS could potentially provide.

Peak Shaving for demand charge savings

Commercial and industrial electric rates often include a demand charge component. Demand charges are applied to a facility's monthly peak demand. These demand charges often represent a substantial portion of a customer's overall energy bill. Using energy storage at the facility or household level, customers can charge their energy storage from the grid when their local demand is low and discharge the storage locally to reduce their peak demand (see Figure 7). The economic benefit to the customer is the reduced demand charges on their electric bill resulting from the storage system's peak shaving function. Utility energy bill management is the leading application for BTM storage systems today given the significant value this application provides to host customers.[62]

A 2015 study by the National Renewable Energy Laboratory (NREL) found that small, short-duration batteries represent a cost-effective approach to reducing short load spikes on the order of 2.5 percent of peak demand.[63] While this benefits the customer by reducing their energy bill, peak shaving behind-the-meter also benefits the system operator by creating a smoother demand curve. Mobile ESS could provide peak shaving for facilities as a service, allowing the system to be available to provide critical resiliency services during outage conditions.

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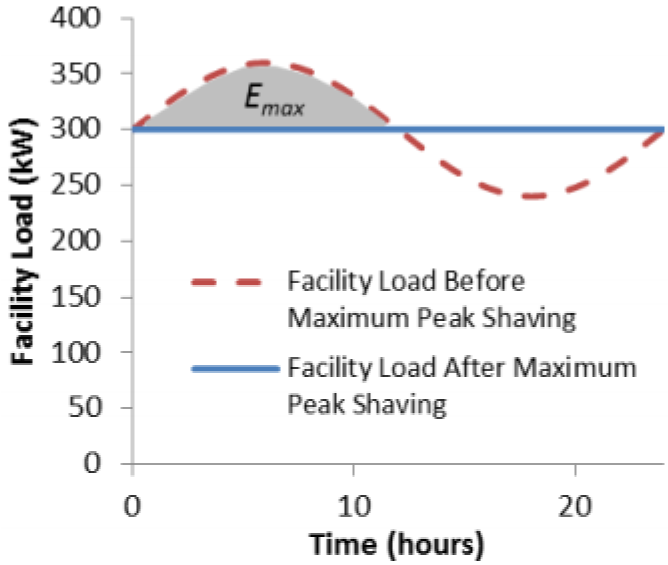
[62] Lazard. Levelized Cost of Storage Analysis – Version 5.0. November 2019. Available at: https://www.lazard.com/media/451087/lazards-levelized-cost-of-storage-version-50-vf.pdf

[63] National Renewable Energy Laboratories (NREL). *Deployment of Behind-The-Meter Energy Storage for Demand Charge Reduction.* January 2015. Available at: https://www.nrel.gov/docs/fy15osti/63162.pdf

Figure 7. Illustration of peak shaving at the facility level



Source: National Renewable Energy Laboratories (NREL). Deployment of Behind-The-Meter Energy Storage for Demand Charge Reduction. January 2015.

Energy arbitrage under TOU rates

Similar to peak shaving to reduce the demand charges component of utility bills, customers under time-of-use (TOU) rate structures can benefit by charging their system from the grid when prices are low and discharging to reduce utility purchases when prices are high. TOU rates vary the price of energy by time of day and sometimes by season. These rates serve as price signals to customers about when energy prices and system demand is high and when energy prices and system demand is low. This is similar to peak shaving in that it is moving energy demand from one time to another. However, under TOU rate structure, the customer is responding to utility rate structures that provide price signals to encourage off-peak usage. Many jurisdictions have TOU rates in place and use them to encourage off-peak charging of EVs. Time-variant pricing is a term that includes TOU rates and other kinds of rate structures. Other types of time-variant pricing include real-time pricing, variable peak pricing, critical peak pricing, and critical peak rebate.[64] All of these rates structures are pricing mechanisms that allow for customers to respond to energy price signals. The ultimate result is more efficient use of energy during specific times. Energy storage systems offer host customers greater control of the timing of energy use and thus create value under these time-varying rate structures.

[64] Environmental Defense Fund (EDF). *A Primer on Time-Variant Electricity Pricing*. 2015. Available at: https://www.edf.org/sites/default/files/a_primer_on_time-variant_pricing.pdf

TOU rates are not widely available in Massachusetts,[65] but the Clean Peak Energy Credits (CPECs) associated with the Clean Peak Standard (CPS) could serve as price incentives for BTM energy arbitrage. Under the proposed CPS, energy storage can receive CPECs for charging and discharging within pre-defined times for each season. This incentive will serve as a new revenue stream for BTM energy storage owners and help grid operators create smoother demand curves.

Emergency back-up power (planned and forced)

Many facilities currently have emergency power systems to serve critical loads during a local power outage that is ether planned for maintenance or forced due to unforeseen impacts on grid infrastructure. A local power outage is not necessarily the same as an outage conditions event that leads to a broader regional power outage. Back-up generators in place today tend to rely on nonrenewable fuels including diesel and gasoline. The proposed Clean Peak Standard would allow the resilience benefit energy storage adds to become monetizable with the specific adder for resiliency within the proposed legislation. The standard categorizes systems that can island from the grid as systems that provide a resilience benefit. This is the first standard in Massachusetts to incorporate a value for resiliency.[66]

Power quality enhancement

Poor power quality coming from the grid can impose costs on customers in facilities with sensitive electrical equipment. Poor power quality is related to electricity that does not have the necessary characteristics—such as voltage and frequency stability—that is needed for electricity-using equipment to function correctly.[67] Issues in power quality can become critical for facilities and require additional support from the utility or require investment in onsite devices to address the problem.

Energy storage located at the facility level can improve power quality locally.[68] Facilities that require good power quality often install capacitors or pay a multiplier on their bill to ensure stable quality of power for their energy intensive units (which often imbalance the power phase). BTM energy storage can replace the need for capacitors or reduce the additional costs on the facility's bill related to power quality issues. Mobile storage could provide this as a service to a facility during blue sky conditions and provide emergency services elsewhere during outage conditions.

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[65] Time-of-Use rates are available for commercial customers and may be available through some competitive energy supply options provided by suppliers.

[66] Department of Massachusetts Energy Resources (DOER). *Clean Peak Standard Straw Proposal*. April 2019. Available at: https://www.mass.gov/files/documents/2019/04/02/Clean%20Peak%20Straw%20Proposal%203.29.19%20.pdf

[67] The ESA Blog. *Uninterruptible Power Systems.* Energy Storage Association (ESA). May 2013. Available at: https://energystorage.org/uninterruptible-power-systems/

[68] ABB. *Power Quality.* Available at: https://new.abb.com/distributed-energy-microgrids/applications/energy-storage-applications/power-quality

Demand response

Electric utilities use demand response to provide capacity, energy, or reliability to the grid. By reducing demand during a small number of peak demand hours per year, utilities can have more control over the demand curve, allowing them to reduce demand instead of buying more energy when energy prices are high due to overall high regional demand. Demand response may also be used to provide capacity in constrained local areas of the grid, thereby avoiding transmission or distribution upgrades. Demand response resources are typically deployed when the reserve margin is below those established for grid reliability. To give an example, it can help avoid brownouts, blackouts, or operating more expensive emergency generation during a power plant forced outage.

Demand response is the opportunity for customers to respond to requests from grid operators to reduce or shift demand to assist operators in grid peak management. Grid operators can use demand response to reduce peak for the entire grid during specific hours or they can use it at strategic locations to reduce transmission and distribution constraints during certain times. Utilities deploy demand response requests as a resource to help maintain reliable and lower cost grid operation.[69] Demand response programs can be a cost-effective alternative to traditional investments in capacity, generation, or T&D infrastructure.

Under a demand response program, customers can use energy storage to respond to calls by the utility to lower demand during certain grid conditions. Eversource has a demand response program that allows residential customers to receive bill credits if they allow the utility to control their smart thermostat as a demand response resource.[70] Since a recent Order by the Department of Public Utilities, an expanded demand response program now allows customers to establish revenue streams for participating in demand response signals by reducing their demand using stationary or mobile energy storage, such as a V2G-capable EV.

Increase solar self-consumption

Facilities with solar PV and no storage are only able to self-consume their locally generated solar power when energy demand coincides with solar production. If these do not coincide, grid-tied solar is exported to the grid under a net metering arrangement. However, if the PV is connected to an energy storage system, the battery can store energy when the local solar production exceeds the local energy demanded and discharge when the local energy demand exceeds the local solar production. The energy storage then allows the facilities to self-consume their locally produced solar energy.

Mobile ESS, in the form of an EV or ESS trailer, can provide solar self-supply services in the proper configuration. For EVs, however, this is only the case if an EV is plugged in at the facility's charging station most of the time. Mobile ESS can potentially support self-consumption of solar, if the mobile storage unit

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[69] Synapse Energy Economics. Best Practices in Utility Demand Response Programs. March 2017. Available at: https://www.synapse-energy.com/sites/default/files/Utility-DR-17-010.pdf

[70] Eversource. *Demand Response.* Available at: https://www.eversource.com/content/general/business/save-money-energy/manage-energy-costs-usage/demand-response

is connected most of the day and if the owner can create additional value by having the potential to relocate the energy storage system in the future.

Grid services (wholesale and utility)

Capacity (resource adequacy)

The Federal Energy Regulatory Committee (FERC) governs wholesale energy markets and has recently focused its attention on the role of energy storage in wholesale power markets. In April of 2019, the FERC approved a revision to ISO New England's Market Rule 1, which governs the operation of New England's wholesale electricity markets and includes detailed information on pricing, scheduling, offering, bidding, settlement, and other procedures related to the purchase and sale of electricity.[71] The approved revision allows energy storage to participate in the real-time energy markets.[72] This revision follows FERC Order No. 841 issued February 18, 2018 requiring the removal of market barriers for electric storage in the capacity, energy, and ancillary service markets.[73] Any sizable stationary storage system is able to participate in the real-time energy market, provided the system has been approved through the ISO's interconnection process.

Resource adequacy is a term used in the electric industry that refers to the amount of installed capacity that is needed to meet the anticipated peak demand and the required reserve margin for electricity on a regional grid. In most regions with wholesale energy markets, capacity markets have been created to achieve resource adequacy goals.

In New England, generators can bid into the Forward Capacity Market[74] to be compensated for providing capacity in the region managed by the regional grid operator ISO New England (Independent System Operator of New England).[75] Mobile energy storage could be a critical resource in providing system, local, and flexible capacity for the ISO New England grid. The mobility component of mobile energy storage can allow the grid operators to request capacity assistance in specific areas within the network as a regular grid operation function, which could be targeted to address potential congestion and other constraints within the network.

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[71] ISO New England. *Market Rule 1.* Available at: https://www.iso-ne.com/participate/rules-procedures/tariff/market-rule-1

[72] Utility Dive. *FERC allows storage to access New England real-time energy markets*. March 2019. Available at: https://www.utilitydive.com/news/ferc-allows-storage-to-access-new-england-real-time-energy-markets/549436/

[73] Federal Energy Regulatory Commission (FERC). *Electric Storage Participation in Markets Operated by Regional Transmission Organizations and Independent System Operators*. Feb 15 2018. Available at: https://www.ferc.gov/whats-new/comm-meet/2018/021518/E-1.pdf

[74] The Forward Capacity Market is a market used by ISO-New England to forecast capacity need 3 years into the future conduct and auction for existing or potential resources to bid into what they will be able to provide the ISO capacity for in 3 years' time and be compensated based on market clearing price.

[75] ISO-New England (ISO-NO). *Forward Capacity Market.* Available at: https://www.iso-ne.com/markets-operations/markets/forward-capacity-market

While stationary energy storage is gaining clarity on how to participate in wholesale energy markets, mobile energy storage has yet to break ground. If the ISO can establish a clear process for how to interconnect mobile storage systems to the bulk transmission system, this will allow these systems to participate in the real-time energy markets and the Forward Capacity Market. There is no obvious reason for limiting mobile ESS's participation in these revenue-generating opportunities. One challenge, however, would be balancing the participation in markets with the need to be ready and available for deployment during outage conditions.

Ancillary services

Ancillary services are critical services required by grid operators to ensure the grid operates within the standards established by the regional reliability authority. In New England, ISO New England is tasked with controlling and operating the electric power system for the entire region. In addition, ISO New England operates wholesale energy markets, including markets for several ancillary services.

Frequency Response Regulation

ISO New England defines regulation services as "the capability of specially equipped generators and other energy sources to increase or decrease output or consumption every four seconds."[76] Generators that participate in this market allow for their assets to be automatically controlled by the ISO and instantaneously responsive to automated signals to balance variations in demand and system frequency. Generators providing this service have historically received payments ranging from $28 to $204 per kilowatt per year in compensation through wholesale ancillary services markets.[77] The frequency response regulation market has been the most important market for grid-scale battery application. According to the U.S. Energy Information Administration (EIA) 88 percent of installed storage capacity in the United States was providing frequency regulation in 2016.[78] If given a process to interconnect with the necessary telemetry to participate in wholesale energy markets, mobile storage would be able to provide the balancing authority frequency response regulation during blue sky conditions just as stationary ESS do today.

Reserves

Reserves serve as insurance for grid operators in the case of an unexpected forced outage of a power plant or transmission facility. The reserve market in ISO New England is broken into two segments: the forward reserve market and real-time reserve pricing.[79] The forward reserve market has two auctions,

[76] ISO New England (ISO-NO). *Regulation Market.* Available at:https://www.iso-ne.com/markets-operations/markets/regulation-market

[77] Rocky Mountain Institute (RMI). Technical Appendix A. Available at: https://rmi.org/wp-content/uploads/2017/05/RMI_Document_Repository_Public-Reprts_RMI-TheEconomicsOfBatteryEnergyStorage-Appendices.pdf

[78] U.S. Energy Information Administration (EIA). *U.S. Battery Storage Market Trends*. May 2018. Available at: https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf

[79] ISO-New England (ISO-NO). *Forward Reserve Market and Real-Time Reserve Pricing.* Available at: https://www.iso-ne.com/markets-operations/markets/reserves

one for the summer and one for the winter. In the forward reserve market, the ISO is ensuring it has assets committed to providing insurance for grid operation and uses an auction to compensate generators for this service. The clearing price for the ISO New England Summer Forward Reserve Auction for 2019 was $1,899/MW-Month[80] and the ISO New England Winter Forward Reserve Auction for 2019–2020 was $799/MW-Month.[81] This means that generators that cleared in this market will be compensated per MW for the capacity they have committed to reserves on a monthly basis for the duration of the season. The generator then bids into the real-time energy market but can only bid at the pre-determined real-time reserve price for the capacity the generator has committed to the reserve market. It is possible for stationary storage systems to participate in this market; however, it is unlikely that mobile storage systems will be able to provide this service to grid operators because the operators need to know exactly when and where the reserves will provide energy at all times. Furthermore, ISO New England's current energy security proposal would restructure how this market works, potentially getting rid of the forward reserve market.[82]

Voltage Support

Transmission and distribution lines require power support to enable electricity to continuously flow through the lines.[83] Voltage support takes the form of generators dispatching reactive power to the grid to ensure the voltage always stays within an acceptable range. When a generator dispatches reactive power, they cannot dispatch the same amount of real power into the energy market. Because the generator could lose money by providing the ISO with voltage support, they are contracted and compensated for the service provided. Mobile storage may be able to provide these services at the distribution level, but the transmission system may require larger generators to provide voltage support.

Black Start

Generators that provide black start services are tasked with the critical ability to restore power to the grid in a partial or complete outage of the system.[84] The ISO contracts and compensates generators with the ability to provide this service at strategic locations on the transmission and distribution system to help restore power. In order to participate in providing the ISO with black start services, generators must be able to dispatch power to the grid at the correct grid voltage with no assistance from the grid itself. Generators that meet this standard are contracted individually by the ISO to provide this service.[85] Black start generators are often fossil fuel resources, but battery storage also has the capability to provide this

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[80] ISO New England. *Forward Auction Summary.* Available at:https://www.iso-ne.com/static-assets/documents/2019/04/fr_auction_sum2019.pdf

[81] ISO New England. *Forward Auction Summary.* Available at: https://www.iso-ne.com/static-assets/documents/2019/08/fr_auction_winter2019-20.pdf

[82] ISO New England. *Energy-Security Improvements Key Project.* Available at: https://www.iso-ne.com/committees/key-projects/energy-security-improvements/

[83] ISO New England. *Voltage Support.* Available at: https://www.iso-ne.com/markets-operations/markets/voltage-support

[84] ISO New England. *Blackstart Service.* Available at: https://www.iso-ne.com/markets-operations/markets/black-start-service

[85] ISO-New England. *Billing, Settlements, and Tariff Reports.* Available at: https://www.iso-ne.com/isoexpress/web/reports/billing/-/tree/schedule-16---blackstart-standard-rate-report

service to the grid with the correct configuration. Mobile storage is able to provide black start services to stranded assets when the grid goes down as well as provide this same service at the minigrid and microgrid levels.

Transmission & distribution investment deferral

There is growing interest in using DERs as alternatives to upgrading T&D infrastructure, so called non-wires alternatives (NWAs) to traditional T&D investments. T&D investments can be extremely expensive and energy storage has been identified as an important technology for NWA to defer such investments.

Stationary storage has already been proven to be effective in deferring T&D upgrades.[86] However, mobile storage may potentially be more effective in deferring these investments. Currently, stationary storage can be strategically installed at substations or other locations on the grid to alleviate constraints that would ordinarily require significant capital investments. However, mobile storage can provide this benefit to a grid operator when called upon while also providing other benefits when not in use for this specific service. T&D constraints often occur for only a few hours each year, which can be predicted based on historical load conditions. Mobile energy storage units could be deployed to specific problematic locations during the peak hours each year and then relocated during the non-peak hours to provide services elsewhere on the grid. For example, the same mobile storage system can alleviate pressure on a winter-peaking circuit and summer-peaking circuit located in a different area. That same system could also be available to meet temporary needs during the shoulder months. V2G resources could be managed to address T&D constraints during peak hours, while providing valuable mobility services during the remaining hours. As discussed below, the ability to stack multiple values is a key to improving the economics of investments in energy storage systems.

Wholesale energy arbitrage

Energy storage can participate in energy arbitrage at wholesale level. Wholesale energy arbitrage involves the purchase of wholesale electricity at times and locations where the locational marginal price (LMP) of energy is low (typically during nighttime hours) and sale of electricity back to the wholesale market when and where LMPs are highest.[87] Mobile storage systems offer the opportunity to charge at one location and time where prices may be low and deliver that energy to locations where and when prices are high. If the mobile system is charging with otherwise curtailed energy from a wind or solar generation source, energy costs will be very low or zero, and the mobile storage provider will only need to charge enough for energy to make up for the cost of mobility, round trip efficiency losses, and any overhead.

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[86] Perter Maloney. *Storage for T&D deferral works, Arizona Public Service finds in Tonto National Forest*. Utility Dive. November 2017. Available at: https://www.utilitydive.com/news/storage-for-td-deferral-works-arizona-public-service-finds-in-tonto-natio/511485/

[87] RMI Storage Economics.https://rmi.org/wp-content/uploads/2017/03/RMI-TheEconomicsOfBatteryEnergyStorage-FullReport-FINAL.pdf

Wholesale energy arbitrage may become a more valuable service in wholesale energy markets as more zero marginal cost resources are added to the grid. The Commonwealth of Massachusetts has a Renewable Portfolio Standard (RPS) of 15 percent of electricity sales in the year 2020, increasing 1 percent yearly. The SMART program aims to add 1.6 gigawatts of in-state solar to the grid, beyond that supported by earlier programs. Additionally, Massachusetts is anticipating around 1.6 gigawatts of offshore wind, to be coming by 2027.[88] This influx of solar and wind power will likely impact wholesale prices and increase curtailment for reliability. Mobile storage systems can be used for targeted application of absorbing renewable energy produced that would otherwise be curtailed. This mobility component allows the energy to be mobile beyond what T&D lines allow for today.

Mana Innovation and Power Energy Vans

Mana Innovation and Power, located in the sunny state of Hawaii, is implementing a unique business model for mobile energy storage. Hawaii's electric grid is unlike most in the United States because it (a) is an island, (b) has very high renewable penetration, and (c) has very high electricity prices. These three factors have allowed Mana Innovation and Power to thrive. Mana works by contracting with facilities looking to reduce their energy bill and with renewable energy generators that are being ordered to regularly curtail their solar or wind energy output by the local utility. Mana then installs stationary storage behind the meter at their customers' facilities and uses electric vans with on-board energy storage systems to absorb otherwise curtailed energy from renewable generators on the island. Mana drives this energy from the renewable energy generation site to their customers' facilities and dispatches this energy into the BTM storage system. Mana provides the energy as a service at a lower cost than the local utility and also compensates the renewable generators for energy they would otherwise not be paid for, generating a profit from the margin between the price they pay and the price they receive from customers. The company has not faced any regulatory barriers thus far given that their entire operation is behind the meter.[89]

The value of grid storage

Estimates of the value added to the grid by ESS vary widely depending on many factors. These include the location, use case, and key modeling assumptions such as fossil fuel prices and battery efficiency. A variety of studies estimate the value of ESS providing many of the services discussed above. Figure 8 illustrates estimates of the annual value of ESS providing wholesale, utility, and host customer services from a variety of recent studies. The figure illustrates the wide range of values depending on the end-use served.

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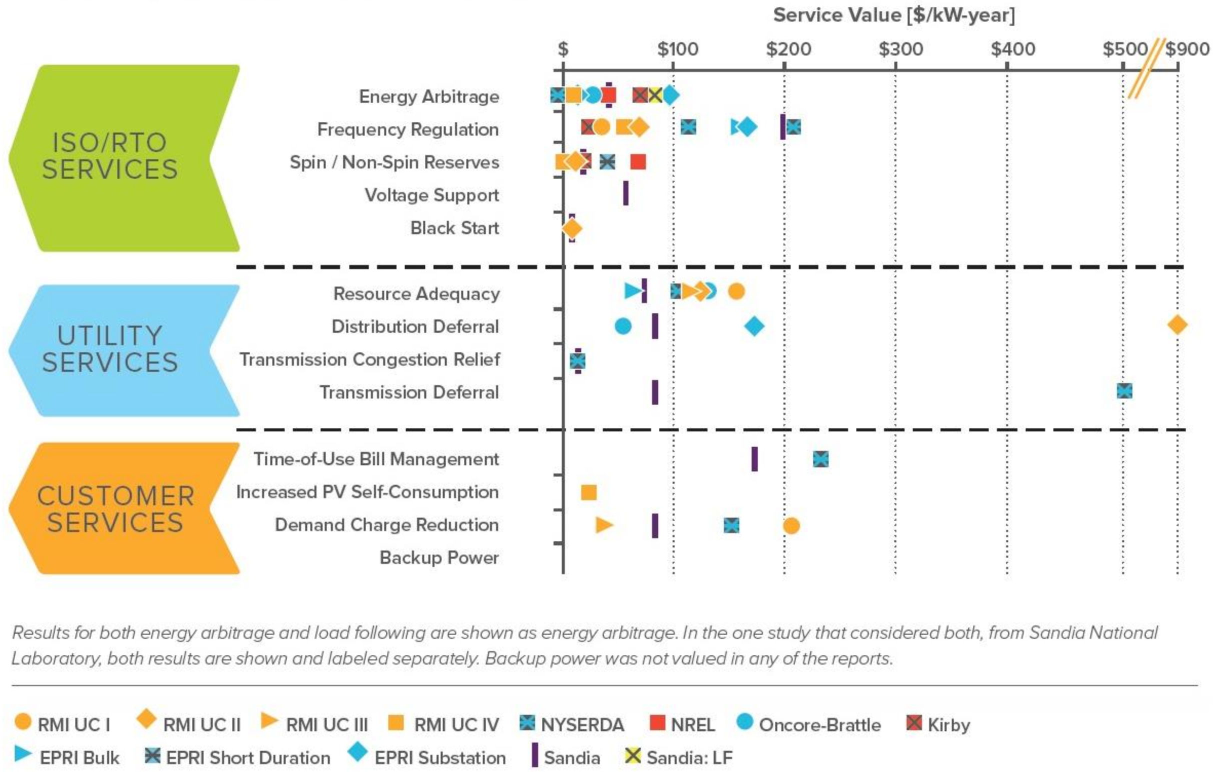
[88] Massachusetts Renewable Energy Division. *Offshore Wind*. Available at: https://www.mass.gov/service-details/offshore-wind

[89] Ka'Ainoa Ravey, founder and CEO of Mana Innovation and Power on a phone interview on October 31, 2019. More information on Mana Innovation and Power can be found at: https://www.manasecurityandpower.com/about-us

Figure 8. Estimates of ESS value providing grid services



Source: Rocky Mountain Institute (RMI). The Economics of Battery Energy Storage. October 2015.

A 2016 study for the State of Massachusetts on stationary energy storage involved modeling to evaluate and quantify the potential benefits that energy storage distributed across Massachusetts' electric grid can provide ratepayers. This included:

- The optimal amount of advanced storage in MW and MWh to be added over the next 5 years—through 2020—that will add maximum benefit to ratepayers;
- The distribution of energy storage locations across Massachusetts where adding storage will achieve maximum benefits to the ratepayers; and
- A quantification of the reduction in GHG emissions that can be achieved with the optimum level of energy storage deployments across the state.[90]

[90] Massachusetts Department of Energy Resources and Mass Clean Energy Center. 2015. State of Charge:for a study of Energy Storage uses in Massachusetts Energy Storage Initiative. Available at https://www.mass.gov/media/6441/download

The study found that up to 1,766 MW of new advanced energy storage would maximize Massachusetts' ratepayer benefits resulting in a $2.3 billion benefit. The benefit was derived from a variety of sources including:

- Reducing the price paid for electricity
- Lowering peak demand by nearly 10 percent
- Deferring T&D investments
- Reducing GHG emissions (reducing the effective cost of compliance)
- Reducing the cost to integrate renewable generation
- Deferring capital investments in new capacity
- Increasing the grid's overall flexibility, reliability, and resiliency[91]

This optimized amount of storage identified in the study was estimated to cost $970 million to $1.35 billion. When compared to the gross benefit of $2.3 billion, results show a net benefit to ratepayers of between $1.33 billion and $950 million dollars.[92] Some portion of this net benefit could be realized using the mobile ESS discussed in this report. The net cost to ratepayers could be significantly less, as these mobile ESS offer the opportunity to generate value providing services during emergency relief events.

4.2. Electric Vehicle Fleet V2G Resource Analysis and the Value of Mobility

Transportation electrification is widely recognized as a key strategy to achieve regional greenhouse gas emissions targets. A commitment to transportation electrification is featured in the Massachusetts's 2018 Comprehensive Energy Plan.[93] The state has a variety of policies with the goal to reduce emissions and fuel costs in the transportation sector. The policies to promote EV adoption currently in place in Massachusetts include the following:

- Massachusetts Offers Rebates for Electric Vehicles (MOR-EV) program offers residents rebate towards the purchase of an electric vehicle (EV).;
- The Mass Drive Clean program provides opportunities for the public to test drive EV models to help increase consumer awareness about electric vehicles.;
- As part of the Massachusetts Clean Cities Coalition (MCCC), the Commonwealth is investing in EV charging stations across the state;

[91] Massachusetts Department of Energy Resources (DOER). *Massachusetts Comprehensive Energy Plan*. December 2018. Available at: https://www.mass.gov/files/documents/2019/01/10/CEP%20Report-%20Final%2001102019.pdf

[92] Massachusetts DOER. *Massachusetts Comprehensive Energy Plan*. December 2018. Available at: https://www.mass.gov/files/documents/2019/01/10/CEP%20Report-%20Final%2001102019.pdf

[93] Massachusetts DOER. *Massachusetts Comprehensive Energy Plan*. December 2018. Available at: https://www.mass.gov/files/documents/2019/01/10/CEP%20Report-%20Final%2001102019.pdf

- The Vehicle-to-Grid Electric School Bus pilot program provides grants to Massachusetts schools to purchase electric school buses.; and

- Massachusetts Electric Vehicle Incentive Program (MassEVIP) for Fleets is administered by MassDEP and provides incentives to municipalities, state agencies, and public colleges and universities that operate vehicle fleets to acquire EVs and the associated charging infrastructure.[94]

In this section we assess the size of the V2G resource for a given fleet of EVs. Specifically, we explore the energy and capacity value for a fleet of 100 light-duty EVs and 100 electric busses. Next, we present a framework for measuring the value of mobility services during blue sky conditions. This is an important component to understanding the cost-effectiveness of V2G resources serving outage conditions applications during emergency relief operations. Finally, we consider the possibility of self-mobiles ESS to take facilities and distributed renewable generation off the grid.

EV fleet as a V2G resource

In this section, we explore the potential size of the V2G resource based on a fleet of 1,000 light-duty EVs or 10 electric buses. The purpose is to demonstrate the size of the V2G resource that is available as a grid resource during the hours when the vehicles are not in use providing mobility—its primary function—or serving various needs during emergency relief events.

There are several key factors that influence the potential size of the V2G resource for a given fleet of EVs beyond the number vehicles in the fleet. Key parameters include the average size of the battery pack per EV. The available power capacity is a function of the reverse flow capability of the V2G-enabled EVSE and the number of vehicles plugged in to bi-directional EVSE. The total energy capacity available is a function of the number of vehicles connected to a bi-directional EVSE and the average state of charge or usable energy of the onboard battery pack. Table 10 below lists the assumptions used to assess the potential size of the V2G resource for a hypothetical fleet of 1,000 light-duty EVs or 10 electric buses. These assumptions were selected to present the range of possible power and energy capacities that a fleet of 1,000 light-duty EVs and 10 electric buses could potentially provide.

[94] Massachusetts DOER. Massachusetts Comprehensive Energy Plan. December 2018. Available at: https://www.mass.gov/files/documents/2019/01/10/CEP%20Report-%20Final%2001102019.pdf.

Table 10. Assumptions used in EV fleet V2G resource analysis

Parameter	Light-Duty		Buses	
	Low	High	Low	High
Energy Storage Capacity per EV (kWh)	40[95]	100[96]	220[97]	440[98]
V2G EVSE Power Rating (kW)	7.5[99]	19[100]	19[101]	132[102]
EV Fleet Connected to EVSE (percent)	40%	80%	40%	80%
Average Useable Energy per EV (percent)	30%	60%	30%	60%

Table 11 below presents the estimated energy storage capacity potential of two fleet types (1,000 light-duty EVs and 10 electric buses) as V2G resources. Table 11 presents estimates of the available power capacity potential of the V2G resource for the same fleet types. The values presented are meant to be illustrative of the energy storage and power capacity potential of EV fleets based on a range of key input assumptions.

The energy storage capacity potential is a function of how many vehicles are connected to a bi-directional EVSE, the size of the onboard battery storage pack, and the amount of useable energy in the EV's battery pack. Depending on these assumptions, the low end of the estimated available energy capacity is about 4,800 kWh for a fleet of light-duty EVs with 40 percent of vehicles connected to a bi-directional EVSE with an average of 30 percent of usable energy. The resource increases to 48,000 kWh for a fleet of 1,000 light-duty EVs assuming higher values for vehicles connected to a bi-directional EVSE and average available usable energy. For a fleet of 10 electric buses, the energy storage capacity ranges from 264 kWh to 2,112 kWh based on the low and high connection and usable energy scenarios. To place these values in context, a typical residence in Massachusetts uses 583 kWh per month.[103] The energy storage capacity of a fleet of EVs, either light-duty or buses, represents a considerable energy storage resource.

Table 11. Estimated fleet of 1,000 light-duty EVs and 10 electric buses as V2G resource-energy storage capacity (kWh)

	1,000 Light-Duty	10 Buses
	EV Storage Capacity	EV Storage Capacity

95 Based on a 2019 Nissan Leaf with 150 mile range. Details at: https://www.nissanusa.com/vehicles/electric-cars/leaf/features/range-charging-battery.html

96 Based on Tesla's Model S. Details at: https://en.wikipedia.org/wiki/Tesla_Model_S#Battery

97 Based on the Lion C electric school bus with a 155 mile range. Details at: https://thelionelectric.com/en/products/electric

98 Based on the specifications for the Protera Catalyst Model 35 ft. E2 Model with Max Plug-in Charge Rate at 200A (https://www.proterra.com/wp-content/uploads/2019/06/Proterra-Catalyst-35-ft-spec-sheet-2019.pdf)

99 Based on Clipper Creek EVSE 20 - 32A (4.8 - 7.7kW) Details at: https://store.clippercreek.com/level2/level2-20-to-32

100 Based on Clipper Creek EVSE 40 - 80A (9.6 - 19.2kW+). Details at: https://store.clippercreek.com/level2/level2-40-to-80

101 Based on the Lion C electric school bus with a 19.2 kW onboard charger. Details at: https://thelionelectric.com/en/products/electric

102 Based on the specifications for the Protera Catalyst Model 35 ft. E2 Model. Details at: https://www.proterra.com/wp-content/uploads/2019/06/Proterra-Catalyst-35-ft-spec-sheet-2019.pdf

103 Provider Power. *Average Electric Bill, Rates and Consumption in Massachusetts*. Available at: https://providerpower.com/power-to-help/average-electric-bill-rates-consumption-massachusetts/

	Low	High	Low	High
Low EV Fleet Connected / Low Usable Energy	4,800	12,000	264	528
High EV Fleet Connected / High Usable Energy	19,200	48,000	1,056	2,112

The power capacity of a V2G enabled fleet is a function of the number of vehicles connected to an EVSE and its reverse flow power capabilities.[104] For the reverse flow power capabilities, we assume the same rate of reverse flow as the rate of charging. Again, we assume high and low scenarios for EVs connected to a V2G-ready EVSE. Table 12 provides projections of the estimated V2G resource based on power capacity for two EV fleet types: light-duty EVs and electric buses. The values vary depending on how many EVs are connected to EVSE and the assumed reverse power flow capability. For a fleet of 1,000 light-duty EVs, the aggregate power rating of the V2G resource ranges from 3,000 kW to approximately 15 MW (15,000 kW). For a fleet of 10 electric buses, the power capacity ranges from 760kW to 1.05 MW. To place these values in context, a typical home solar installation in Massachusetts is 7.4 kW.[105]

Table 12. Estimated power capacity (kW) of fleets of 1,000 light-duty EVs and 10 electric buses as a V2G resource

	1,000 Light-Duty		**10 Buses**	
	V2G EVSE Power Rating		**V2G EVSE Power Rating**	
	Low	High	Low	High
Low EV Fleet Connected	3,000	7,600	76	528
High EV Fleet Connected	6,000	15,200	152	1,056

Even a relatively small fleet of EVs represents a significant V2G resource, both in terms of energy storage capacity and power capacity. Numerous studies have been conducted to assess the technical opportunity and economic potential of V2G.[106] The literature includes an assessment of V2G-enabled EVs providing many of the same services discussed above that both stationary and towable battery storage systems can

[104] Today, commercially available electric vehicle supply equipment generally does not provide reverse flow capabilities. One company NUVVE does market a V2G charger (see details here: https://nuvve.com/wp-content/uploads/2019/07/nuvve-powerport-spec-sheet-us-ul-certified_v3.0pdf.pdf).

[105] Solar Cost Calculator for Massachusetts. Power to the People. Last Updated July 2019. Available at: https://solar-to-the-people.com/solar-panel-cost/ma-massachusetts-cost-of-solar-panels/

[106] Kempton, Willett and Steven Letendre, 1997. "Electric Vehicles as a New Source of Power for Electric Utilities", Transportation Research 2(3): 157-175.

provide in both BTM and in FTM applications.[107] The grid services opportunities would require aggregation of individual EVs to form MW blocks that could potentially participate in wholesale energy markets. In 2013 the University of Delaware was operating a fleet of electric Mini Coopers with V2G capabilities that generated revenue by providing grid services to the regional grid operator PJM.[108]A V2G demonstration project at the Los Angeles Airforce Base involved aggregating a 29 EV demonstration fleet, consisting of mixed-purpose and duty vehicles such as sedans, pickups, vans, and medium-duty trucks, to provide grid services to the California Independent System Operator.[109] These demonstrations and others, show the potential to use EV fleets during blue sky conditions to create a second value stream beyond mobility services.

Synapse and DNV GL are not aware of any analysis of V2G resources serving in emergency relief operations. Reports have surfaced from recent natural disasters, including the rash of fires in California and the associated power outages in California, of EV owners hacking their EVs to access the stored energy to power their homes during the power outage.[110] In addition, global EV automaker Nissan currently offers a vehicle-to-home package[111] for sale in Japan and has developed promotional materials on EVs serving as emergency response assets.[112] EVs of all different platforms offer a versatile form of mobile storage that could provide many services during dark sky events. During a prolonged outage, EVs could continue to provide mobility services by charging at a DG source such as a community solar installation with a grid-forming inverter. In addition, the energy they harvest from these stranded DG assets could be delivered to locations under blackout conditions to meet critical loads.

The incremental cost and value of electric mobility with V2G

EVs in a variety of platforms represent a sizable source of mobile energy storage capacity. Given the necessary infrastructure investments, these V2G resources could ultimately serve a valuable role during outage conditions. However, EVs primarily create value through the mobility services they provide during

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107 Kempton, Willett, Victor Udo, Ken Huber, Kevin Komara, Steven Letendre, Scott Baker, Doug Brunner, & Nathaniel Pearre, 2008, "A Test of Vehicle-to-Grid (V2G) for Energy Storage and Frequency Regulation in the PJM System". Available at https://www1.udel.edu/V2G/resources/test-v2g-in-pjm-jan09.pdf

108 Wald, Matthew L. "*In Two-Way Charging, Electric Cars Begin to Earn Money From the Grid*". The New York Times. April 2013. Available at: https://www.nytimes.com/2013/04/26/business/energy-environment/electric-vehicles-begin-to-earn-money-from-the-grid.html

109 California Energy Commission. *Los Angeles Air Force Base Vehicle-to-Grid Demonstration*. October 2018. Available at: https://ww2.energy.ca.gov/2018publications/CEC-500-2018-025/CEC-500-2018-025.pdf

110 Romo, Vanessa. "With Blackouts, California's Electric Car Owners Are Finding New Ways To Charge Up". NPR. November 2019. Available at: https://www.npr.org/2019/11/08/777752175/with-blackouts-californias-electric-car-owners-are-finding-new-ways-to-charge-up

111 Nissan Motor Corporation. "'Vehicle to Home' Electricity Supply Stream". Available at: https://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/vehicle_to_home.html

112 Huang, Echo. "Japan wants to boost the use of electric vehicles as a power source during natural disasters". Quartz. February 2019. Available at: https://qz.com/1555710/japan-to-harness-power-of-electric-vehicle-batteries-in-natural-disasters/

blue sky conditions. The capital investment in EVs and the associated charging infrastructure is largely justified by the mobility services provided during blue sky conditions. The incremental costs to enable EVs to provide V2G services must be justified by the value created providing service other than mobility: grid services during blue sky conditions and serving as mobile energy systems during emergency relief operations.

A 2017 report by NREL identified three primary physical elements to enable EVs to serve as V2G resources:

- EVs equipped with battery-management software and hardware that allow two-way flow of electricity
- Communication technologies mediating between vehicles and grid operators
- EVSE or alternative technologies connecting vehicles to the grid[113]

The full potential of V2G would require an expanded network of EVSE in both private and public locations allowing EVs to be plugged in for more hours of the day. Currently, most of the time that EVs are plugged in is at the owner's place of residence.[114] The incremental costs to facilitate the use of EV fleets as V2G resources must be justified by the value they provide as grid resources. This report considers another value stream associated with EVs providing distributed energy and mobility services during outage conditions.[115]

There is no standard method to value mobility services. This is necessary to account for the portion of the capital investment to determine the net incremental cost of an EV serving as a mobile energy resource. Individual households and businesses place a high value on mobility services. We assume that the "avoided cost" of buying an EV that can serve as a grid resource and mobile energy unit is the cost of a comparable gasoline or diesel fueled vehicle.

Here we look at a representative cargo delivery van assuming a 10-year life with 15,000 miles driven per year. We calculate the net present value cost of ownership over 10 years—including the initial capital cost and annual fuel and maintenance cost—to arrive at the avoided mobility value. This is used to determine the net lifetime cost of owning and operating an electric cargo van that is capable of serving as a grid resource and a mobile energy storage asset for emergency relief operations. In this simple example, we estimate $57,500 for the avoided mobility cost for a cargo delivery van with 530 cubic feet of cargo space.

Figure 9 illustrates conceptually how the "avoided cost" of mobility can be used to determine the incremental cost of an electric cargo van that must be justified based on the value of the grid and outage conditions mobile storage services provided over the life of the vehicle. Here the column on the left represents the life-time present value cost of a conventional gasoline cargo van. The column on the right represents the all-in cost of an electric cargo van including the allocation of the three cost categories to

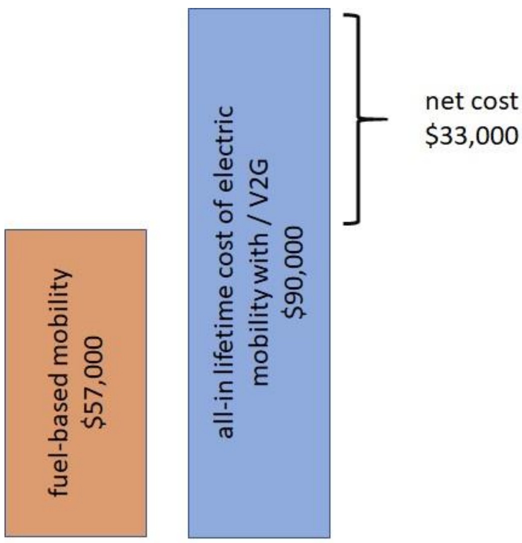
[113] Steward, D. Critical Elements of Vehicle-to-Grid (V2G) Economics. 2017. National Renewable Energy Laboratory. Available at https://www.nrel.gov/docs/fy17osti/69017.pdf

[114] *Ibid.*

[115] Devices can be directly plugged into EVs that offer AC outlets in off-grid applications to support emergency relief operations.

enable V2G services described above to the vehicle.[116] The net cost of $33,000 represents the portion of the life-time costs that must be justified based on the life-time income generated from providing V2G grid services and the value attributed to have the EV as mobile energy storage system dispatched to provide emergency relief services when needed. We note that some portion of the net cost can be justified based on an organization's goal to pursue low carbon transportation solutions that yield no direct revenues.

Figure 9. Illustration of the incremental cost of electric mobility with V2G



Source: Synapse Energy Economics Inc.

The use of EVs as grid resources through a V2G network raises several concerns about viability. These concerns include the potential increase in battery cycling—leading to accelerated degradation of the battery pack—privacy and security concerns, and consumer acceptance.[117] The use of EVs as mobile ESS during outage conditions could offer an initial high-value market opportunity that could evolve overtime as infrastructure costs decline and lessons are learned leading to broader market acceptance of V2G.

EVs as a Distribution Service

The onboard energy capacity of EVs is continuing to grow annually in response to perceived range anxiety as a current barrier to broad EV adoption and with battery technology and cost improvements. At the same time new construction is being built with improved envelop performance, reducing onsite energy

[116] Note, that the all-in cost of the EVs are meant to be illustrative and do not represent a full accounting of vehicle costs and V2G infrastructure costs.

[117] Steward, D. Critical Elements of Vehicle-to-Grid (V2G) Economics. 2017. National Renewable Energy Laboratory. Available at https://www.nrel.gov/docs/fy17osti/69017.pdf

needs for heating and cooling. A detailed assessment of the technical feasibility and pathways for EVs to provide distribution services are beyond the scope of the study, however the following high-level analysis reveals the concept has technical potential.

Feasibility

EVs are currently available with 100+ kWh of onboard energy, and future vehicles are anticipated to be available with substantially more energy. The average passenger vehicle travels an average 33 miles per day.[118] Current EV consumption is approximately 260 kWh per 100 miles (0.26 kWh/mi).[119] At 0.26 kWh/mile, those 33 miles consume approximately 9 kWh of energy per day. So, on average, an EV with 100kWh of onboard storage will use less than 10% of its available capacity (before considering available intra-day recharging) per day.

If an average single-family home in Massachusetts fully electrified its thermal needs (via air source heat pump and heat pump water heater), it would consume an average of approximately 966 kWh per month or an average of 32 kWh per day.[120] Adding the single-family residential electric and thermal needs with their transportation needs results in about 41 kWh of average daily energy consumption. This is still substantially less than half of the 100kWh EV. New and future construction are anticipated to have improved envelope performance with increased insulation and air-tightness, further reducing the average consumption of customers, where increasingly popular passive house designs reduce heating and cooling requirements by 75%-95% over code construction. Making buildings very efficient, such as passive house, also makes building consumption patterns align with solar production profiles, resolving seasonal storage challenges and enabling an increased dependence on distributed solar generation and a potentially increased comfort with EV supplied energy.[121]

In addition, the average household in Massachusetts has two passenger vehicles.[122] A typical existing household which fully electrified their energy needs with two 100kWh EVs would be using on average less than one quarter of the energy storage capability of their EV if they charged once per day. Many winter and summer days will consume substantially more energy than the annual average. Even if some days of substantial residential load do exceed the EV capability, the EVs could be charged offsite to meet those increased loads. Additionally, sites with sufficient space and orientation for solar may further mitigate the household reliance on the EV supplied energy from an offsite charge. For the site to be completely

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[118] National average of 12,177 VMT per LDV, 12,177/365 days = 33.3 miles/day : https://www.bts.gov/archive/publications/bts_fact_sheets/oct_2015/table_02
[119] EPA Data on Tesla Model 3: https://www.fueleconomy.gov/feg/Find.do?action=sbs&id=41189
[120] DOER 2018 Comprehensive Energy Plan: https://www.mass.gov/files/documents/2019/01/10/CEP%20Report-%20Final%2001102019.pdf
[121] 'Investigations of 6-pane glazing: Properties and possibilities.' Aleš Kralj, Marija Drev, Matjaž Žnidaršič, Boštjan Černe, Jože Hafner, Bjørn Petter Jelle; Energy and Buildings Volume 190, 1 May 2019, Pages 61-68 https://www.sciencedirect.com/science/article/pii/S0378778818331554?via%3Dihub
[122] https://datausa.io/profile/geo/massachusetts

self-sufficient , it would require stationary storage in addition to the EV. The stationary storage would serve onsite load during periods when the EV is not at home.

Many consumers would likely be unwilling to make the leap directly from receiving electricity and or natural gas to an EV-only energy supply. As such, an initial roll-out of this framework would likely depend on customers maintaining their grid services as backup to their EV supply. EV charging infrastructure does not traditionally need to follow the interconnection process. If an EV were to operate in parallel with the electric distribution system, the charger would need to follow an interconnection process. If, in the alternative, the EV along with supplemental onsite storage were islanded from the grid it would not follow the interconnection process. If customers were to transition to an EV energy supply over time, customers may opt to double-convert all grid sourced power from AC to DC, then back from DC to AC in one-way rectifier and inverters in order to prevent paralleling the grid and avoid the interconnection process.[123] This would be similar in practice to existing one-way conversions such as Online Uninterruptable Power Supplies. This ability to draw from the grid as a transition period may increase customer acceptance of transitioning to reliance on an EV for electricity by mitigating the leap-of-faith required to disconnect from the grid and self-island in one fell swoop.

Business Case

The case of EV energy self-reliance may be enhanced by a customer's access to free workplace charging or access to subsidized charging at retail shopping centers. Many employers are starting to offer free workplace charging as an employment perk, and retailers are offering reduced EV charging rates in order to draw customers and increase dwell and shopping times. As the DOER's 2018 Comprehensive Energy Plan found, it is difficult to find an economic means to drive consumer fuel switching from natural gas to electricity. EVs as a replacement to distribution service may be one mechanism which would accelerate the rate of electrification.

The customer cost benefit of leveraging an EV to replace distribution may drive this business case. As envisioned, there would be limited additional capital costs and the entire cost of the EV could be justified as a transportation service, so the entire electric cost savings are pure benefit from a customer finance perspective. This operational model could be adopted with today's technologies, would require upfront capital investment in an EV and residential storage, and is dependent on customer access to public or workplace EV charging and the consumers specific energy consumption patterns.

Few customers today are fully electrified.[124] Electrification represents substantial capital costs. EV provision of distribution may support accelerated electrification because it:

- Makes the consumer consider electrification on a typical day basis

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[123] Double Conversion On-Line UPS: https://www.sweetwater.com/insync/double-conversion-line-ups/
[124] DOER 2018 CEP: https://www.mass.gov/files/documents/2019/01/10/CEP%20Report-%20Final%2001102019.pdf

- The 2018 CEP recognized that appliance replacement normally occurs at failure. The customer only wants to resolve their immediate issue of access to heat/hot water. Replacement at failure and the associated long-term fuel lock-in is a major barrier to electrification, which EV as distribution may resolve because now the customer is thinking about electrifying and considering purchasing options well in advance of failure. This gives the customer time to fully consider their options and investigate available programs.

- Enables the consumer to put savings toward incremental appliance electrification until fully electrified
    - There isn't a capital cost cliff where the customer must purchase all at once to reap benefits. The customer can electrify at their own pace, each time increasing their monthly savings and ability to save for the next appliance replacement.

Accelerated efficiency and electrification were identified as key measures to cost effective emissions reductions and enhanced fuel security in the CEP, and the EV replacement of distribution may resolve the primary barriers to adoption.

EV distribution service likely increases customer resilience and mitigates the impact of outages. Most customer outages are relatively localized. The customer would not be impacted by a local outage at the residence and is only impacted if the workplace or other local public charging equipment is impacted. The EV likely enables the customer to drive beyond the effect of most outage conditions to recharge.[125] In the case of broader regional outages, the EVs would be well suited to drive to stranded DG sites as addressed in Section 5, which are enabled to continue to produce by deployment of emergency response mobile ESS equipment. EVs may also seek to charge at sites supported by backup generators, which the performance of may be enhanced by mobile-ESS as identified in Section 2.

Emissions

EV distribution enables customers to act on the majority (transportation, residential, electricity) of their direct CO_2 emissions. The Department of Environmental Protection's (DEP's) business-as-usual projections show these sectors as our predominant contributions to climate change.

[125] 'With Blackouts, California's Electric Car Owners Are Finding New Ways To Charge Up.' Vanessa Romo, NPR, December 11, 2019. https://www.npr.org/2019/11/08/777752175/with-blackouts-californias-electric-car-owners-are-finding-new-ways-to-charge-up

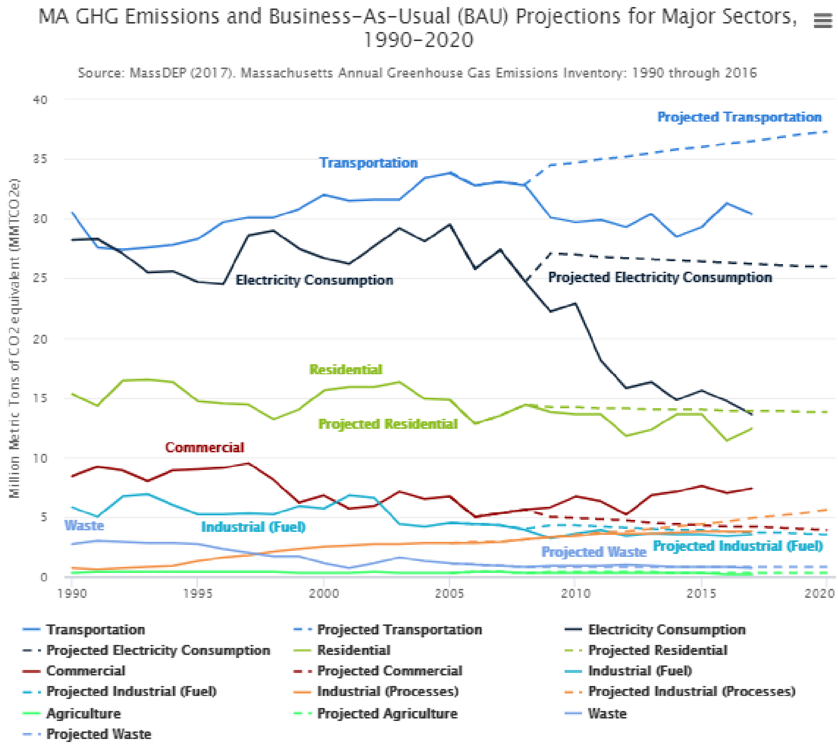

Figure 10 MA GHG Emissions by Sector[126]

Empowering individuals to impact these emissions directly will be critical to achieving greenhouse gas emission reduction targets laid out by the Global Warming Solutions Act.

Charging with Renewables

EVs may also enable future deployment of distributed renewable generation which is unable to export to the grid. Massachusetts is facing substantial interconnection costs and timelines associated with the challenge of increasingly connecting distributed generation to the grid.[127] Solar PV deployment has traditionally relied on export to the grid (e.g. Net Metering). Storage would need to be substantially oversized in order to island and store renewable generation for later consumption instead of curtailing available production. EVs may provide an opportunity to charge from otherwise excess renewable generation, and enable the deployment of renewable generation that is not dependent on export to the grid, thereby mitigating the costs associated with interconnection upgrades. Further, since the typical daily transportation needs of an EV are so low compared to the onboard capability, the EV can readily continue to provide transportation without charging every day, enabling charging to align with renewable production, reducing or skipping recharging on cloudy or overcast days. This would shift demand to align

126 GHG Emissions and Mitigation Policies. https://www.mass.gov/info-details/ghg-emissions-and-mitigation-policies

127 https://www.greentechmedia.com/articles/read/massachusetts-grid-study-disrupts-1gw-distributed-solar-pipeline

with available generation, which is the flip side of classic energy storage which is to shift generation to align with demand. Sites with such systems may transition following a similar path as the double conversion of grid power identified above. While historically double conversion systems have been avoided due to the inefficiency involved, this scenario aims to reduce grid consumption to zero, mitigating the inefficiency concern. For example, a retail site may install onsite rooftop solar and or carport solar which is substantially oversized to their coincident load. It may double convert grid service, and feed that double converted power to an onsite stationary energy storage system. The energy storage system would then accept charge from the renewables and serve all onsite load. The retail site may then offer excess solar production, which by configuration cannot export and which may exceed the stationary storage capabilities, to customers for a reduced cost (or free). This would both draw customers to the site to shop and leverage the EVs as the oversized storage to prevent curtailing solar generation without needing to export to the grid. This configuration would also open the potential to leverage vehicles to import power from vehicles charged elsewhere if a EV distribution service were an end goal.

Automation

The potential future adoption of autonomous vehicles may simplify customer adoption of the above EV distribution. Autonomous self-mobile ESS opens the opportunity to merge the concepts of transportation as a service (TaaS) with Energy as a service (EaaS) into bundled services provided by a single physical fleet. A fleet operator would leverage the EV fleet to provide transportation services, while also distributing electricity over roadways to recharge stationary energy storage systems at customer sites. This service would make the energy transition seamless and invisible to the customer, reducing friction points to adoption. The fleet is also flexible on charge location, so may mitigate constraints and leverage daily and seasonal variations in renewable generation, for example driving to points with access to excess solar generation in spring and to points with access to excess hydro or wind in other periods. The autonomous fleet may also be able to distribute electricity to larger facilities which adopt the above islanded deployment of distributed renewables but still face likely periods with insufficient onsite generation to meet demand. Such operations could be included in the EaaS, where the fleet has access to parking spaces and free charging for the majority of the year, but must import energy to the facility in times of relative low renewable generation.

Seamless autonomous EV TaaS + EaaS would depend on an automated plug-in process. Wireless EV chargers, such as those developed in Massachusetts by WiTricity, may enable the autonomous vehicle plug-in capability.[128]

Fleet operators of TaaS + EaaS would likely provide additional transportation services, such as package delivery. Package delivery back-end logistics software may be similar to the required planning and dispatch modeling required to provide TaaS + EaaS. This would further increase available revenue streams on a similar capital outlay.

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[128] Massachusetts based WiTricity: https://witricity.com/

Finally, the bundling of TaaS with EaaS provides a substantial increase in addressable market for EV fleets, increasing business opportunities without increasing capital costs, potentially accelerating the electrification of transportation while enabling new novel emergency response capabilities. Depending on the business model of autonomous fleet operators, there may be zero up front cost to subscribe and the leveraging of the fleet to address both transportation and energy may enable pricing low enough to enable low income customer adoption, addressing the common equity challenges associated with new technology roll-out.

5. EVALUATION OF MOBILE ENERGY STORAGE SYSTEM USE: OUTAGE CONDITIONS

Mobile ESS are deployed for emergency relief operations during outage conditions. The purpose of this section is to outline responsibilities and best practices regarding emergency operation of mobilized energy storage. Building from the data and analysis in Sections 2-4, this section assesses the anticipated emergency relief applications, as well as the requirements for each group for utilization in such conditions. We then provide details of on-site requirements for deployment and prime user classes, load qualification, events which will result in an emergency, and the parameters of the transition from blue sky to outage conditions operation. In addition, we discuss the personnel requirements for proper and safe engagement of the mobile system.

5.1. Emergency Response Service Scenarios

There are four types of emergency response service scenarios considered in this study: planned utility outages, power outages, natural disasters, and acts of terrorism. Each of these scenarios can result in the mobile energy storage use cases outlined above. However, the personnel roles are different and are discussed in detail below.

Planned utility outages

Planned utility outages are scheduled in advance by a service provider to perform planned maintenance, repairs, or other services that require safe de-energization of the distribution system. These events, however, may not be considered emergencies, but planned outages impose inconveniences and costs on customers. Advanced notice allows those affected areas to plan accordingly in advance of the outage. In addition, there is typically some indication of the length of the outage. Mobile energy storage systems can be deployed in these situations to minimize the disruption to customers. In the event of a foreseeable, planned power outage, mobile energy storage can be deployed prior to de-energization to ensure that there are no interruptions in service. This requires planning, as proper interconnection requirements need to be met, which are dependent on the anticipated load to be served during the outage and its expected duration.

Three of the use cases presented in Section 2 are applicable to this scenario. Mobile ESS could be deployed to support both microgrid and minigrid applications. In addition, mobile energy systems could create grid-forming benefits during a planned outage. Mobile energy storage with grid-forming capabilities would allow for the use of stranded DG energy, which would be particularly helpful for longer duration planned outages. Grid-forming using mobile energy storage is discussed in further detail below.

Power outages

A power outage is defined as a short- or long-term outage in a specific geographic area that is caused by numerous potential factors impacting the grid's infrastructure. Outages are often a result of faulted power lines or issues with a distribution sub-station. In contrast to a planned outage, these outages occur without warning for an unknown duration. Depending on the extent of the damage, it can affect a single household, a neighborhood, or an entire city. This is the primary driver for the back-up power supply equipment market. The use cases applicable for this scenario are microgrid, minigrid, and grid-forming.

Natural Disasters

Natural disasters are natural events that endanger lives, property, and other assets. The natural hazards relevant for Massachusetts identified by the 2018 State Hazard Mitigation and Climate Adaptation Plan (SHMCAP) are categorized as follows.[129]

- Changes in precipitation: Inland flooding, drought, and landslide
- Sea level rise: Coastal flooding, coastal erosion, and tsunami
- Rising temperatures: Average/extreme temperatures, wildfires, and invasive species
- Extreme weather: Hurricanes/tropical storms, severe winter storm/Nor'easter, tornadoes, and other severe weather such as strong wind and extreme precipitation
- Non-climate-influenced hazards: Earthquake

These disasters can cause disruptions in emergency services necessary for essential activities and preservation of life. Utility ERPs outline types of emergency events and the procedures that need to be followed in such situations. For example, the ERP of Unitil MA Electric Operations identifies the following event types.[130]

- Type 1 – Full-scale Catastrophic Alert: Considered to be Catastrophic Impact Events which occur less than once per 10 years; severe to catastrophic weather threat conditions such as Nor'easter, strong tropical storm, Category 1-5 tropical cyclone, and earthquake.

[129] Massachusetts State Hazard Mitigation and Climate Adaptation Plan, September 2018: https://www.mass.gov/files/documents/2018/10/26/SHMCAP-September2018-Full-Plan-web.pdf

[130] Unitil Emergency Response Plan. Version 14, May 2019.

- Type 2 – Serious Weather Alert: Considered to be Severe Impact Events which occur less than once per year; severe weather threat conditions such as severe thunderstorms with intense lightning, tropical storm or Category 1 tropical cyclone, strong sustained gusts and sustained winds, and heavy, wet snow or ice.
- Type 3 – Heightened Alert: Considered to be Serious Impact Events which occur less than 3 times per year; moderate to serious weather threat conditions such as strong thunderstorms with frequent lightning, strong frequent gusts and sustained winds, and heavy, wet snow or ice.
- Type 4 – Upgraded Alert: Considered to be Moderate Impact Events which occur less than 10 times per year; e.g. moderate weather threat conditions such as weak thunderstorms with infrequent lightning, frequent wind gusts, and moderate, wet snow.
- Type 5 – Normal Operations: Considered to be Minor Impact Events which occur less than 200 times per year; e.g. normal weather conditions or minor weather threat conditions such as isolated wind gust. These are non-emergency events such as isolated wind gust.

A recent example of this event type is Hurricane Maria, which destroyed Puerto Rico's power grid and left 3.4 million residents without electricity and caused over 3,000 fatalities. It took several months to restore energy to much of Puerto Rico, with some customers facing nearly a year or more for restored electricity. In the aftermath of this hurricane, some of the more remote areas of the island were told by the Puerto Rico Electric Power Authority (PREPA), that they could pursue grid defection via the implementation of Distributed Energy Resource System/Microgrid (DER/MG), as PREPA would not be running new T&D lines to replace those which were lost. This placed a spotlight on energy storage-based systems in all conceivable forms. The off-grid, microgrid, minigrid, and grid-forming use cases are applicable for this extreme emergency scenario.

Terrorism

Physical attacks to the power grid by acts of well-informed terrorists can result in an emergency. Transmission lines spanning hundreds of miles are often left unguarded and many key facilities lack security. These facilities are thus potential targets by terrorists. Key components to these facilities are often large, costly, and difficult to procure which would result in an extended outage.

Automation plays a significant part on how energy is being operated and dispatched. An emergency can result if an unauthorized user were to gain access to disable protective systems, manipulating SCADA systems, computer systems, energy management systems, send false signals to operators or equipment, and disrupt communications. Similar to natural disasters, the off-grid, microgrid, minigrid, and grid-forming use cases are applicable for this emergency scenario. The applicable use cases for each emergency scenario are tabulated in Table 13. They are further discussed below.

Table 13. Applicable use cases for emergency response scenarios

Emergency Response Scenario	Applicable Use Cases
Planned utility outage	Microgrid, minigrid, grid-forming
Power outage	Microgrid, minigrid, grid-forming

Natural disasters	Off-grid, microgrid, minigrid, and grid-forming
Terrorism	Off-grid, microgrid, minigrid, and grid-forming

5.2. Use of Mobile Energy Storage in Off-grid Systems for Emergency Response

Steps to deploy

Emergency command centers identifies the location and off-grid power needs

Emergency command centers dispatches mobile energy units to locations with the energy and power capacity needs to power devices being used in front-line emergency response theatres

In this case, the systems being used to deliver front-line emergency response services will be fully functional

System Operation

A storage-enabled off-grid system will generally be sited at a specific location where front-line personnel are active.

- The deployment of mobile ESS would only be necessary when front-line operations are unable to access grid power due to distance of physical limitations.
- In all cases, sizing of the elements is critical for optimized function and operation.

Several firms have endeavored to produce mobile combination PV and storage systems: BoxPower, JLM Energy, etc.

Other configurations

- Transition time/UPS capability to genset only off-grid systems
- Load peak shaving to optimize the genset operation
- With sufficient scale of each element, a PV and storage only configuration can be utilized for nearly perpetual power and energy provision
- If paired with a diesel generator or renewable generator, the controls will need to be designed to shunt production of the generation asset when the mobile storage system is in a fully charged state

Benefits

- The capability to respond to various locations where front-line operations are taking place
- Maintaining resiliency capability to front-line emergency responders

Challenges

- Finite system capacity could limit scope of operation to the original loads being served and usage profile

Personnel Requirements

- Trained personnel to deliver and operate the mobile ESS to front-line operations (should be no different than any other use case)
- Any additional or specialized personnel that are mandated by virtue of the nature of the system being an energy storage modality (should be no different than any other site-situated generation power grid)

5.3. Use of Mobile Energy Storage in Microgrids for Emergency Response

Steps to deploy

The steps for this use are the same as for the off-grid system above, except that the system will be grid-connected with islanding capability.

Emergency command centers identifies the location and off-grid power needs

Emergency command centers dispatches mobile energy units to locations with the energy and power capacity needs to power devices being used in front-line emergency response theatres

In this case, the systems being used to deliver front-line emergency response services will be fully functional

Key elements of deployment are described in the interconnection considerations explicated earlier in this document. Namely there can be no possibility for feedback to the grid until grid restoration occurs, proper lock out, and tag out structures, etc.

System Operation

- The mobile energy storage use case for islanded microgrid systems would operate in a nearly identical fashion as any other islanded generation-load scenario, e.g., use case 5.2.
- The mobile storage asset would need to be sized adequately to enhance any pre-existing storage capability and/or further optimize the system for extended outage operation.

Benefits

- Maintaining resiliency capability in the face of alternating grid availability
- Generally located in less remote locations and urban and suburban centers where deployment of energy storage assets is not complicated or compromised—allows for the capability to redeploy electrons to another area of the grid for immediate or nearer term grid services revenue, as well as provision of resilience services to other areas of a generation compromised grid

Challenges

- Finite system capacity could limit scope of operation to the original loads being served and usage profile
- These systems are not common at present
- These systems need more regular attention to maintenance, as they are in grid-connected state most of the time (out of sight, out of mind, or the backup generator syndrome)
- Off-grid and microgrid systems do not possess the robust frequency fluctuation ride-through capability of grid-connected systems and equipment (adherence to system specifications and a robust load management system are key to successful off-grid operation)
- Insufficient or improper pre-existing site electrical infrastructure: Microgrid systems that do not have needed improvements or augmentations for the insinuation of an energy storage system.

Metrics of Success and Reliability

- These are essentially the same as use case 5.2

Personnel Requirements

- This should be no different than any other use case: Any additional or specialized personnel that are mandated by virtue of the nature of the system being an energy storage modality should be no different than any other grid-scale energy storage use case.

Caveats

As with all energy storage systems:

- The AHJ, Utility and local first responders, should be consulted *a priori* the execution of this or any other devised energy storage use case, mobile or otherwise.
- Risk management and liability implications are key as well but may be superseded by the gravity of any of the use cases' necessity of use.

5.4. Use of Mobile Energy Storage in Distribution-Level Minigrids for Emergency Response

Steps to deploy

Steps to deploy will revolve around coordination with the utility of record

No possibility for feedback to the grid until grid restoration occurs, proper lock out and tag out structures, etc.

Generally sub-station situated, abetting their deployment by limiting the interconnection points to several key locations and thus contributing to a more rapid targeting of installations

System Operation

The distribution-level minigrid will operate much like legacy deployable power generation at the distribution level.

- Deployed large-scale gensets and turbine systems that can interconnect at the substation
- Would need to be sized to adequately serve the section of the distribution grid targeted for its use
  - Will need to be deployed for a specific period of time in a distribution-level setting, as there will be no grid-based recharging possible
  - Combination PV and storage systems are intuitively attractive to mitigate this shortcoming, but the power density is not generally sufficient for distribution-level power needs and requirements

Benefits

Benefits of distribution-level energy storage for emergency response are limited by the nature and scale of the application.

- In the absence of better emergency solutions, mobile energy storage represents a good, Method of Last Resort (MOLR)
- Their greatest benefits arise far more in a grid connected, T&D asset deferral scenario

Challenges

- Lack of generation limits the storage to a short-term solution to a potentially long-term problem
- Distributed systems at the load center level mitigate the need of storage at the distribution level
- The repeated short-term movement and discharge profile will contribute to the accelerated degradation of the storage asset.
- Regulatory and electrical standards uncertainty which can translate to risk management uncertainty
- Insufficient or improper pre-existing site electrical infrastructure—legacy sites without any possible needed improvements or augmentations for the insinuation of an energy storage system

Metrics of Success and Reliability

- Given the limited applicability of storage in a distribution-level support role, the metrics of success are still nonspecific
- If deployed, providing power and energy for the narrowly specified capacity of the storage system without issue would function as success

Personnel Requirements

- This should be no different than any other use case. Any additional or specialized personnel that are mandated by virtue of the nature of the system being an energy storage modality should be no different than any other grid-scale energy storage use case.

Caveats

As with all energy storage systems:

- The AHJ, Utility, and local first responders, should be consulted *a priori* the execution of this or any other devised energy storage use case, mobile or otherwise.
- Risk management and liability implications are key as well but may be superseded by the gravity of any of the use cases' necessity of use.

5.5. Grid-forming to harvest stranded distributed generation

Stranded DG energy, non-islandable PV, wind, and any grid-connected generation asset whose production is lost due to compliance with IEEE 1547 anti-islanding mandates, is energy that is unavailable during outage conditions. Mobile energy storage can be deployed to service stranded assets during an emergency scenario. The technologies discussed in this report can provide voltage to existing assets that have become stranded, allowing them to begin delivering energy. Ensuring that ERPs are up-to-date to address site requirements that are essential to safe deployment, such as physical limitations and interconnection requirements referenced by IEEE 1547, is necessary. ERPs will also address the proper steps to deploy, system operation, personnel requirements, and benefits and challenges for each use case.

Once all testing and interconnection requirements have been met, the deployment requirements are not different from any other grid-connected stationary assets or legacy deployable power generation equipment. Prior to mobilization, it is important to be mindful of the energy requirements of the existing asset, as the mobile storage would need to be sized to adequately to capture the volume of energy lost or projected to be lost.

When paired with existing assets such as solar, mobile ESS have the ability to harvest stranded DG energy until utility services are restored.

Mobile energy storage may be used to recoup the lost production for use later at the interconnection point of the prime mover generation asset. That production could also be deferred temporally and by location for use at a different time and/or a different location. If the lost DG production is located at a load center of some ilk, the mobile energy storage can provide a microgrid-enabling function to redirect that lost production to the load center. A key example of where this might well have been executed is in the State of New Jersey in the aftermath of Hurricane Sandy.

Steps to deploy

Similar to other connections to grid-connected stationary assets or legacy deployable power generation equipment	Must be no possibility for feedback to the grid until grid restoration occurs, proper lock out and tag out structures, etc.	As a Service (aaS) model renders many of these considerations the responsibility of the asset owner, not the end user. A strong case could be made for this model for a governmental entity

System Operation

The mobile energy storage use case for outage lost, energy production would operate in a nearly identical fashion as any other islanded generation-load modality (in this case the electron tank that is the storage).

- Storage asset would need to be sized to adequately capture volume of energy lost or projected to be lost
- Controls will need to be designed to shunt the production of the generation asset subsequent to the fully charged state of the storage asset
- At such time as the mobile storage asset reaches full charge, the plan for its use and/or redeployment will need to be enacted, or additional storage assets added to continue harvesting of lost distributed energy production
- In the event that there is a load center attached or proximate to the stranded generation, the storage asset could be used to execute a microgrid operation until the grid is reformed.

Benefits	Challenges
• Solar +mobile energy storage with islanding capabilities can be used in an emergency • Reduced downtime if deployed prior to forecasted severe weather event • Harvesting lost contracted energy revenue • Maintaining resiliency capability to DG-based load centers • Financial disaster mitigation • Capability to redeploy those historically lost electrons to another area of the grid for immediate or nearer term grid services revenue, as well as provision of resilience services to other areas of a generation compromised grid	• Additional equipment may need to be installed onsite such as switches, critical load panels, and appropriate controls • Added costs with equipment associated with a grid-connected system the ability to island • The cost of such a system of a capacity sufficient to meet the needs of the generation asset owner or load center may potentially exceed the loss incurred, based on the duration of the outage. • Regulatory and electrical standards uncertainty can translate to risk management uncertainty • Insufficient or improper pre-existing site electrical infrastructure—legacy generation sites without any possible needed improvements or augmentations for the insinuation of an energy storage system

Metrics of Success and Reliability
• This is a byproduct of the scope and composition of the benefits and challenges. Ultimately, the system must save the deployer more than it costs, unless its nature renders a utilitarian benefit beyond the financial considerations, e.g. life and limb v. monetary benefit.
Personnel Requirements
• This should be no different than any other use case. Any additional or specialized personnel that are mandated by virtue of the nature of the system being an energy storage modality should be no different than any other grid-scale energy storage use case.
Caveats
As with all energy storage systems: • The AHJ, Utility and local first responders, should be consulted a priori the execution of this or any other devised energy storage use case, mobile or otherwise. • Risk management and liability implications are key as well but may be superseded by the gravity of any of the use cases' necessity of use.

5.6. Assessment of the Types of Loads

This section focuses on the process of determining which types of loads have priority during outage conditions. Mobile ESS can be deployed during emergency events to provide emergency power for critical loads that are essential to preserving the health, quality of work life, and safety of employees. Mobile ESS can service prioritized critical loads, which can change depending on the type of disaster, season, and severity. In a severe flooding emergency, priority to mobile energy storage will likely be critical pumps and pumping stations to avoid further damage caused by significant flooding. Examples of critical loads include, but are not limited to, water pumps, hospitals, clinics, shelters, fuel stations, and schools.

Massachusetts Emergency Support Function 12 (MAESF-12)

This document goes into details regarding energy coordination across Massachusetts State agencies and implementation of emergency procedures, policies, and emergency response measures. MAESF-12 will coordinate emergency energy storage to support immediate response operations as well as the restoration of the normal supply of power. MAESF-12 will work closely with local, state, and federal agencies, energy offices, suppliers, generators, transmitters, and distributers to determine which loads are the most critical to support in an emergency scenario.

Federal Emergency Management Agency (FEMA)

The FEMA document "Critical Infrastructure and Key Resources Support Annex" describes policies, roles and responsibilities, and the concept of operations for assessing, prioritizing, protecting, and restoring critical infrastructure and key resources. The document defines critical infrastructure assets, systems, networks, and functions so vital that their destruction would have an impact on health and safety. Examples includes safety buildings, hospitals, nursing homes, emergency shelters, and schools as they are essential to public safety. The document goes into detail on how owners and operators can clearly establish priorities for prevention, protection, and recovery.

Mobile energy storage can enhance distribution system resilience against extreme weather events. Dispatching mobile energy storage prior to a severe weather event and positioning it to service critical loads is essential to minimize downtime. Positioning a mobile energy storage solution to pair with standby power prior to the severe weather will decrease the interruptions of critical loads. Having access to nearby mobile battery storage in the aftermath of a disaster can drastically minimize damages, severe economic loss, and disruptions in service.

Power outages due to unexpected events are much more difficult to deal with, as transporting energy storage can be difficult during times of disasters. Integrating mobile energy storage into critical infrastructure will require advanced planning, as these facilities use a variety of systems consisting of alternate sources of backup power, switching equipment, controls, and distribution equipment.

Critical loads can utilize mobile energy storage in emergency scenarios by pairing it with generators to extend the life of the generator. Generators (such as diesel, gas, propane, etc.) have a finite lifespan and prolonged outages bring the risk of depleted fuel. Creating a hybrid battery- turbine system results in improved up-time and better reliability than a single backup generator source.

5.7. Other Considerations for Emergency Operation

This section provides details on factors apart from load types to consider when deploying mobile energy storage for emergency response. These include the following.

- Time for and cost of transitioning from normal operations to emergency operations
- Interconnection requirements
- Additional site requirements
- Roles and responsibilities of parties involved in mobile storage operation

Transition time and cost

The manner of switching the mode of operation of the mobile energy storage system from blue sky operations to outage conditions is dependent on whether the storage system will be deployed at the host site or at a different location. A mobile energy storage system that is pre-positioned and correctly connected at the host site and operational when the emergency event occurs can switch to emergency operations within a matter of seconds—most mobile energy storage systems will have a controller governing operation. However, this would not be the case if the mobile storage system had to be deployed at a different site. Setup and testing times vary widely depending on the site parameters and the mobile storage technology. Approximate amount of time required for setup and testing are as follows.

- At a minimum, 30 minutes to 1 hour for set up.[131]
- In addition to setup time, testing time can range from:
    - 1-3 hours.
    - 3-4 hours[132]
    - 4-6 hours[133]

Interconnection requirements for emergency operation

This section discusses interconnection requirements to determine safe mobile ESS interconnection to the utility grid. IEEE 1547 is the standard that establishes criteria and requirements for interconnection of DERs.[134] The standard is intended to be universally adoptable, technology-neutral, and cover distributed resources. The requirements for interconnection indicate that the energy storage must be capable for actively regulating voltage, ride through abnormal voltages and frequencies, and be able to provide frequency response. In order to meet these requirements, IEEE states that a variety of testing such as abnormal voltages and frequencies, unintentional islanding, Open Phase, proper synchronization is in order prior to interconnection. Detailed in IEEE 1547, Open Phase testing ensures that the V2G can stop energization to the grid if an individual phase is lost.

Additional site requirements for emergency operation

Establishing an ERP prior to outage conditions is recommended to ensure effective implementation and coordination to ensure electricity providers are prepared to restore power; ensuring that emergency

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[131] Shihab Kuran, Power Edison, 5 December 2019.

[132] Mark Lucas, ZeroBase Energy, 11 December 2019.

[133] Troy Miller, GE Renewable Energy, 13 December 2019.

[134] IEEE Standards. Bulk System Opportunities from New Distributed Energy Resource Interconnection and Interoperability Standards: https://www.nerc.com/comm/PC/System%20Planning%20Impacts%20from%20Distributed%20Energy%20Re/IEEE%20SCC21_1547_Overview_NERC_SPIDERWG_01072019.pdf

personnel are prepared to respond to an emergency is essential. The Department of Public Utilities requires Electric and Gas companies within Massachusetts submit an ERP annually to the Department of Public Utilities by May 15 for review and approval.

Providing training in a controlled atmosphere to prepare an effective response to an emergency is crucial. It allows personnel to review response plans, prepare for emergency coordination, and uncover weaknesses and gaps in the response plan. A benefit of these exercises allows personnel to review for planning emergency responses and obtaining emergency resources to test prior to implementation.

Physical requirements of mobile energy storage are comparable to stationary battery systems. However, due to the physical size and weight of containerized batteries, additional site requirements are needed for emergency operation. If containerized batteries are intended to be used as long-term solutions and would need to be offloaded from the trailer, a platform designed to withstand heavy loads would need to be installed prior to deployment to ensure safe and effective operation in the event of an emergency.

Mobile energy storage assets such as passenger vehicles or tow-behind trailers are required to be clear of any obstructions that may interfere with safe operation, display clear signage, and have suitable access.

Local subject matter experts should be assigned to sites where mobile energy storage assets are hosted. The subject matter experts should be available to coordinate with first responders in the event of an emergency. If a subject matter expert is unable to be present at the site, a toll-free phone number should be provided to first responders for coordination.

Roles and responsibilities during emergency operation

As protocols are still being developed, standards will require further testing and revisions to create a more reliable communication for switching and operating energy storage in an emergency. It is important that all utilities, owner/operators, and emergency personnel are familiar with existing ERP's so that proper protocols and coordination can be followed.

The owner/operator ensures that the mobile energy storage is available to provide safe and reliable energy. To ensure best practices are met, it is their responsibility to coordinate with the local utility prior to implementing any battery storage, as proper communication is essential to deploying the energy safely and reliably.

Emergency personnel roles for mode switch and operation depend on the type of load that will be serviced by mobile energy storage. Performing mode switching to service an off-grid resource is conditional on the owner requirements, as these resources are isolated from the grid and do not have any external requirements other than those set by the owner.

Providing mobile energy storage for critical infrastructure such as health centers requires advanced planning from emergency personnel prior to outage conditions. Health centers contain complex energy requirements as they have strict rules and regulations for maintaining a safe environment for their patients. It is essential emergency personnel be familiar with existing sources of power, controls, and distribution equipment to ensure mobile energy storage can support emergency power.

In mobile energy storage applications available on the market today, the ability to change modes from a grid-following resource to a grid-forming resource—which would enable the resource to switch modes instantaneously—can be utilized for utility applications.

5.8. Impact on Blue Sky Operations

This section explores the lost revenue or value of transportation services when deployed for emergency response. For example, a mobile ESS participating in ancillary services prior to deployment for emergency response, can resume these services once the recovery period is over if the mobile system is in the same transmission zone.[135] Typically, mobile storage systems would not be moved outside of the original transmission zone even when deployed at a different site. But, if it were necessary, mobile storage assets can and likely would be deployed across transmission zones depending on the severity of the emergency power need.

The cost of deploying mobile energy storage would be dependent upon, but not limited to, the following:

- Amount of time the mobile storage asset is deployed for emergency operation
- Blue Sky Revenue streams dependent upon the mobile asset
- Distance the mobile asset must be transported before interconnection/use
- Labor required for loading and off-loading the mobile system, setup at the site, and testing

The design of a deployable energy storage asset which will also be servicing blue sky needs and applications will need to consider the risk of accelerated degradation, if the asset will likely or by plan be deployed in repeated emergency black sky use. If this is not accounted for, the primary detrimental effect on blue sky operations would be accelerated degradation of the deployable asset's energy capacity.

The risk of damage to mobile storage asset should be considered in both its design and the decision to deploy. As would stand to reason, the decision to use a mobile unit during blue sky conditions depends on whether or not the potential harm and damages the system can avert outweigh risk of damage and degradation to the unit.

[135] Shihab Kuran, Power Edison. 5 December 2019.

6. Comparing Mobile vs. Stationary Battery Storage Systems

Today, large battery packs (10 kWh to 100 MWh+) are designed and engineered to meet two distinct applications: mobile or stationary. Advanced rechargeable batteries using Li-ion chemistry dominate the market for battery packs used in both applications.[136] Analysts predict that Li-ion batteries will continue to be the chemistry of choice for advanced battery packs in the foreseeable future in EVs and stationary energy storage applications.[137] Accordingly, we focus our discussion and analysis in this section on Li-ion battery packs. Today, roughly 85 percent of advanced Li-ion battery manufacturing capacity is concentrated in China, Japan, and South Korea.[138]

Most of the manufactured battery energy storage capacity today is used for EVs, with a small fraction deployed in stationary grid applications. According to *Inside EVs*, automakers sold over 361,000 EVs and plug-in hybrid vehicles[139] in 2018 in the United States.[140] This represents an 80 percent increase in EV sales over 2017. EV sales as a percent of new vehicle sales inched higher in 2018 to slightly over 2 percent in the United States. The top 10 plug-in vehicle models accounted for 85 percent of vehicles sold (see Table 14 below). Approximately 74 percent of EV sales in 2018 were all-electric models and 26 percent were plug-in hybrid vehicles.

The market for stationary batteries is diverse. It ranges from home-scale battery storage systems such as Tesla's Power Wall (13.5 kWh) to grid-scale multi-MWh systems designed to provide a variety of services in wholesale energy markets. As discussed in Section 4 above, these systems are deployed in numerous applications serving a variety of markets. Also noted above, stationary battery markets are segmented between BTM and in FTM applications.

According to Wood McKenzie's *U.S. Energy Storage Monitor*, a total of 148 MW of storage was installed in the first quarter (Q1) of 2019, with 46 percent in BTM applications. Based on energy storage capacity, the first quarter of stationary battery system installations totaled 231 MWh with approximately 160 MWh of the total in BTM applications.[141] On a MWh basis, BTM applications represent approximately 70 percent

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[136] Tsiropoulos I., Tarvydas. D., & Lebedeva N. 2018. Li-ion batteries for mobility and stationary storage applications: Scenarios for costs and market growth. European Commission. JSC Science for Policy Report. Available at https://insideevs.com/news/373812/ev-sales-scorecard-september-2019/.https://publications.jrc.ec.europa.eu/repository/bitstream/JRC113360/kjna29440enn.pdf.

[137] Lithium-ion batteries for mobility and stationary storage applications. SCENARIOS FOR COSTS AND MARKET GROWTH. European Commission. JSC Science for Policy Report. Available at https://ec.europa.eu/jrc/sites/jrcsh/files/jrc114616_li-ion_batteries_two-pager_final.pdf

[138] Energy Systems Network. 2017. Energy Storage Roadmap Report. Available at http://energysystemsnetwork.com/wp-content/uploads/2019/04/ESN_EnergyStorageRoadmap_Web.pdf

[139] For simplicity, we refer to battery electric vehicles and plug-in hybrids as EVs throughout.

[140] InsideEVs. Monthly Plug-In EV Sales Scorecard: September 2019. Available at

[141] Wood Mackenzie Power & Renewables/Energy Storage Association. September 2019. *U.S. Energy storage monitor*, Q3 2019 executive summary.

of total installations in Q1 of 2019. This suggests that FTM applications are higher power output for shorter duration relative to BTM applications.

The battery storage capacity of EVs sold in 2018 was equivalent to approximately 6.7 times the cumulative installed battery storage for all stationary applications at the end of 2018. According to the Smart Electric Power Alliance, at the end of 2018 there were approximately 2 GWh of cumulative installed grid batteries in the United States.[142] This pales in comparison to the approximately 13.5 GWh of battery storage in EVs sold in 2018 alone (see Table 14).

Table 14. Top 10 electric vehicle models 2018

Ranking	Car Make	Model	EV/PHEV	2018 Sales^	Storage Low (kWh)	Storage High (kWh)	Total Storage Low (MWh)
1	Tesla	3	EV	139,782	50.0	75	6,989
2	Toyota	Prius Prime	PHEV	27,595	8.8	n/a	243
3	Tesla	X	EV	26,100	75.0	100	1,958
4	Tesla	S	EV	25,745	75.0	100	1,931
5	Honda	Clarity	PHEV	18,602	17.0	n/a	316
6	GM Chevy	Volt	PHEV	18,306	18.4	n/a	337
7	GM Chevy	Bolt	EV	18,019	60.0	n/a	1,081
8	Nissan	Leaf	EV	14,715	40.0	n/a	589
9	BMW	530e	PHEV	8,664	9.2	n/a	80
10	Ford	Fusion Energi	PHEV	8,074	7.6	n/a	61
TOTAL				305,602			13,584

Source: FINAL UPDATE: Quarterly Plug-In EV Sales Scorecard, Insideevs.com.

This section begins with a qualitative assessment of the emergency response applications best suited for stationary and mobile storage systems for each of the use cases identified in Section 2 above. This section continues with an exploration of energy storage cost trends for stationary battery packs relative to mobile systems. This information is used to evaluate the cost-effectiveness of stationary versus mobile ESS, including an assessment of the impact that energy storage cost trends might have relative to the case for mobile energy storage compared to stationary storage. This section concludes with a discussion of potential sources of funding for mobile ESS for use in emergency response applications.

6.1. Applications Best Suited for Stationary vs. Mobile Systems

Table 15 presents a qualitative assessment of the suitability of stationary versus mobile energy storage system by use case. This assessment includes the potential for combination systems, systems that include both a stationary component and a mobile component, to serve the use case under consideration.

[142] Smart Electric Power Alliance. 2019. 2019 Utility Energy Storage Market Snapshot. Available at https://sepapower.org/resource/2019-utility-energy-storage-market-snapshot/

Table 15. Assessment of stationary vs. mobile energy storage by use case

Num.	Use Case	Stationary (S) / Mobile (M) / Combination (C)
1	Off-grid power	M
2	Building or campus microgrid applications	S / M / C
3	Distribution-level minigrid applications	S / C
4	Grid-forming for harvesting stranded DG energy production (variant of #2 and #3)	S / M / C

The off-grid power use case entails meeting the energy requirements for emergency response, front-line operations. A variety of communications and first-responder equipment is powered using electricity. Energy storage represents an alternative to traditional fuel-based generators to provide off-grid power for this purpose. Mobile storage systems are well-suited for meeting off-grid energy requirements. As the location of these operations are unknown in advance of an emergency event, stationary storage systems are not viable. Mobile ESS for off-grid applications can be integrated with a DG source. As noted earlier, one vender provides a tow-behind battery trailer with an integrated PV array. A traditional, fuel-based generator could also serve to recharge a mobile energy storage system serving off-grid loads. This offers potential disadvantages in terms of the timing and availability of refueling.

Stationary, mobile, and combination energy storage systems represent viable solutions to providing emergency power to a single building or campus during an emergency event leading to a power outage. The power output and energy necessary to serve critical loads is likely within the capabilities of both stationary and mobile energy storage systems as discussed in Section 2 above. In addition, a combination system would work well if designed with an optimized blend of stationary and mobile energy storage systems, including V2G resources.

Given the power output and energy storage capacity requirements for distribution-level minigrids, stationary battery storage systems are better suited for these applications. While containerized mobile ESS could technically serve this application, it will likely cost more: The incremental cost of mobile versus stationary storage systems tends to increase with system size. However, a combination system that includes a mobile energy storage component (including the potential of V2G resources) to augment a stationary energy storage system is a viable option. In cases with no DG located within the minigrid, the mobile component of the combination energy storage system could capture stranded DG energy production from a nearby solar array and deliver that energy to the minigrid in the event of a prolonged grid outage.

Use Case 4 is a variant of Cases 2 and 3 whereby storage can provide grid-forming capabilities to harvest stranded DG energy during a larger grid failure. For stationary systems to serve this end use, they must be sited and connected with a local source of DG within a minigrid. Similarly, mobile storage systems sited at a building or campus in a microgrid application with DG can provide grid-forming capabilities and thus harvest the stranded DG energy to serve critical loads. Mobile ESS offer the additional advantage of having the ability to be relocated to charge from stranded DG energy production, and then deliver the energy to where it is needed at a microgrid or minigrid to serve critical loads.

The EV replacement of distribution service case in Section 4 highlighted the opportunity for mobile storage and stationary storage to be combined to enable entire new use cases. As such, the decision is not just whether to select stationary or mobile storage for an application, but instead how much of each would best provide the desired service.

6.2. Current and Projected Cost of Energy Storage: Mobile vs. Stationary

This section provides a review of the literature on energy storage system costs as a supplement to the cost data shared in Table 6 **Error! Reference source not found.**based on industry intelligence. The literature on both stationary battery system costs and EV battery packs leads to the conclusion that mobile ESS costs are unlikely to diverge significantly from stationary ESS costs. The incremental cost is largely due to the personnel and fuel costs associated with delivering the mobile ESS to where it is needed during both blue sky and outage conditions periods. Furthermore, as explored below, future price declines are expected for all components of an ESS leading to growing market opportunities. For the self-mobile ESS category, the fact that the capital cost is largely justified by the mobility services may create a strong cost advantage for the use of EVs as mobile energy sources for emergency relief operations.

The cost of a fully functioning battery ESS is complex and based on various factors, most notably the nameplate duration of the ESS and the application it is designed to serve. For stationary battery systems, the nameplate duration in hours is determined by dividing the energy storage capacity by the nameplate power capacity of the system. There are three general categories based on ESS duration: short-duration (< 0.5 hours); medium-duration (0.5–2 hours); and long-duration (> 2 hours).[143] All things remaining equal, short storage duration batteries cost less on a unit cost per power capacity ($/kW) basis but cost more on a unit cost per energy capacity ($/kWh) basis relative to longer energy duration ESS.[144]

The nameplate duration is not typically used when discussing an EV battery pack. EVs are largely characterized by the range, which is a function of the energy storage capacity of the battery pack and the efficiency of the vehicle in miles per kWh. For example, an EV with a 60-kWh battery pack and an efficiency of 3 miles per kWh, would have a range of 180 miles.

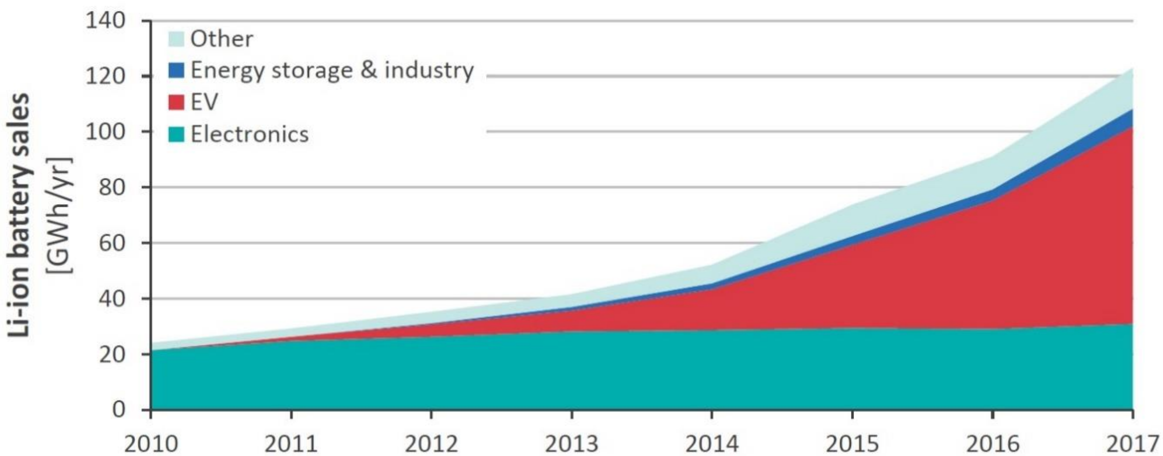
The capital cost of an ESS includes the capital cost of the battery pack stated in $/kWh and the balance of system (BOS) stated in $/kW. The BOS for a stationary ESS includes the containers, climate control, power

[143] U.S. Energy Information Administration. May 2018. U.S. Battery Storage Market Trends. Available at https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf

[144] U.S. Energy Information Administration. May 2018. Battery Storage Market Trends. Available at https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf

management system, fire suppression system, and related components.[145] There is a third cost category for stationary ESS referred to as engineering, procurement, and construction (EPC) often presented in $/kWh. As the market for energy storage has expanded in recent years (see Figure 11), costs in all components of a stationary battery system have declined (see Figure 12). As seen in Figure 11, the market for Li-ion batteries is dominated by the EV market. Figure 12 presents data on the significant cost declines for a 1 MWh utility-scale stationary batteries from 2012–2017.

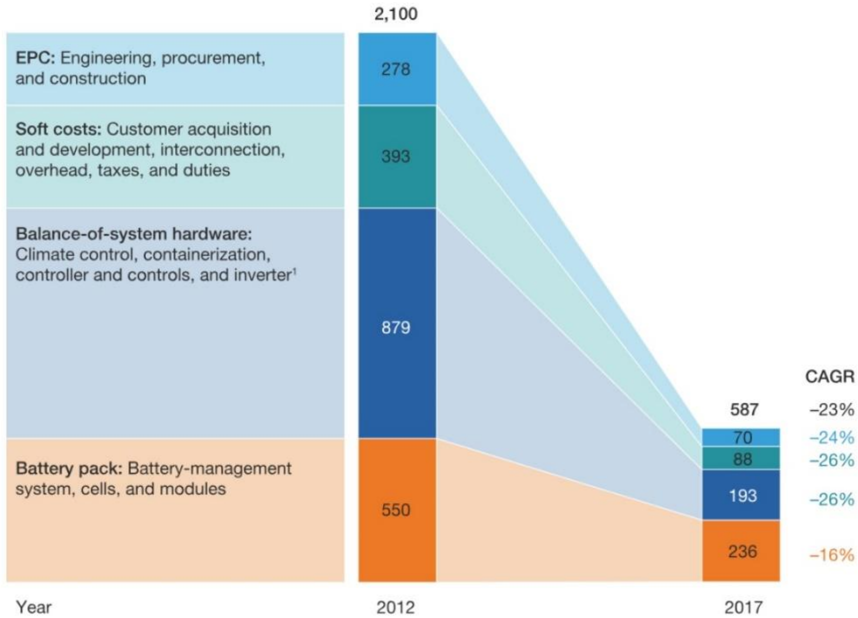
Figure 11. Global historical annual growth Li-ion batteries in main market segments



Source: Tsiropoulos, I. Tarvydas. D., and Lebedeva N. 2018. Li-ion batteries for mobility and stationary storage applications: Scenarios for costs and market growth. European Commission, JRC Science for Policy Report. Authors note: "Data include sales and stock. Electronics *includes mainly portable electronics,* EV *includes BEV, PHEV and electric buses,* Energy Storage & Industry *includes stationary storage, UPS, telecom, and applications in industry,* Other *includes medical devices, power tools, electric bikes and gardening tools."*

[145] National Rural Electric Cooperative Association. April 2019. Business & Technology Report: Battery Energy Storage Overview. Available at https://www.cooperative.com/programs-services/bts/Documents/Reports/Battery-Energy-Storage-Overview-Report-Update-April-2019.pdf

Figure 12. Cost breakdown of a 1 MWh ESS (2017 $/kWh)



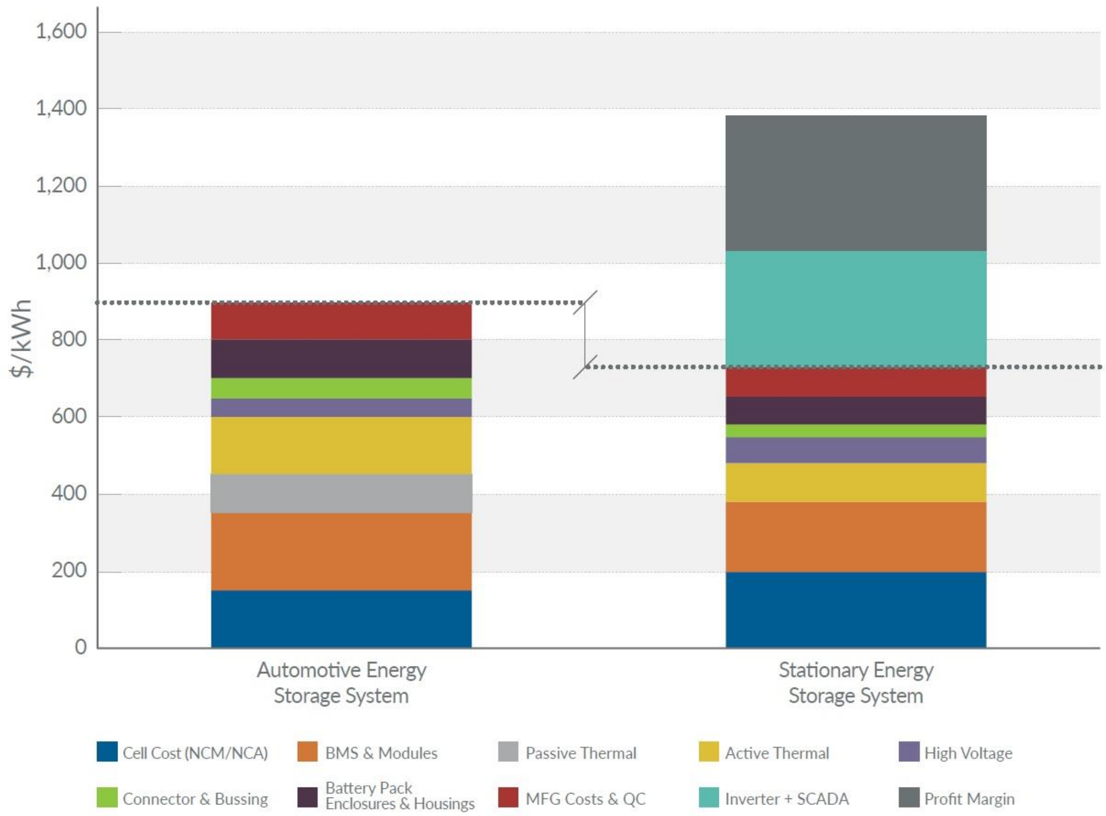
Source: National Rural Electric Cooperative Association. April 2019. Business & Technology Report: Battery Energy

Cost declines for stationary batteries are driven in part due to the growing demand for EVs, which is the dominant factor lowering the price of lithium-ion batteries due to economies of scale in manufacturing.[146] Based on Bloomberg New Energy Finance's ninth Battery Price Survey, the volume weighted average EV battery pack fell 85 percent from 2010 to 2018 reaching an average of $176/kWh.[147] It is rare to find a side-by-side comparison between battery systems for EVs and for those used in stationary applications. Figure 13, however, provides such a comparison illustrating that the underlying battery storage component for these two applications is similar in cost. The other system components cause the overall system costs to diverge.

[146] Energy Systems Network. 2017. Energy Storage Roadmap Report. Available at http://energysystemsnetwork.com/wp-content/uploads/2019/04/ESN_EnergyStorageRoadmap_Web.pdf

[147] Bloomberg New Energy Finance. March 2019. A Behind the Scenes Take on Lithium-ion Battery Prices. Available at https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

Figure 13. Cost comparison: Automotive vs. stationary battery storage systems 2017



Source: Energy Systems Network. 2017. Energy Storage Roadmap Report.

Referring again to Figure 13 above, the cost of an automotive battery pack is close to that of stationary ESS when the inverter and profit margin are removed from the stationary ESS total cost. For EVs to serve as V2G resources, an inverter is necessary in addition to the interconnection (assumed to occur through the EVSE). V2G requires the DC electricity from the battery to be converted to AC at the correct frequency to match the grid. This DC to AC conversion can be accomplished using an inverter built into the vehicle or the EVSE.[148] Thus, these costs should be included as part of the stacked column for the Automotive Energy Storage System on the left side of Figure 13 for an accurate comparison between EVs as a grid resource and stationary battery systems. With appropriate adjustments to the cost differential between automotive battery systems engineered to provide grid services and stationary battery systems, the price differential becomes minimal.[149]

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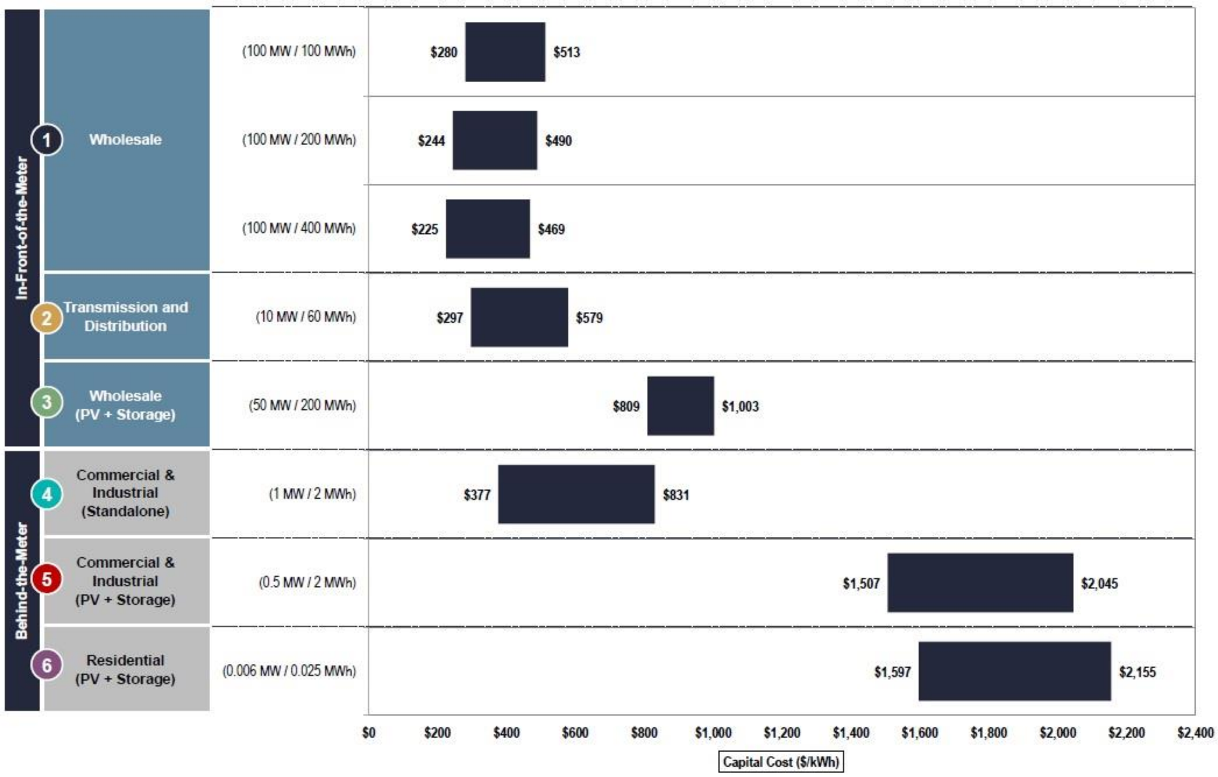
[148] Both approaches have been explored in V2G demonstrations.

[149] Energy Systems Network. 2017. Energy Storage Roadmap Report. Available at http://energysystemsnetwork.com/wp-content/uploads/2019/04/ESN_EnergyStorageRoadmap_Web.pdf.

For stationary ESS, it is important to note the significant range in costs depending on the application being served. Comparing the values from Figure 12 ($587/kWh) and Figure 13 ($1,400/kWh) demonstrates the significant range in stationary battery storage costs. Figure 14 expands this range showing the capital cost for several stationary ESS applications ranging from large systems participating in wholesale energy markets to smaller, home-scale solar-plus-storage systems.

Figure 14. Installed capacity cost for ESS in different applications



Source: Lazard. November 2019. Lazard's Levelized Cost of Storage Analysis-Version 5.0.

A stationary ESS requires ongoing operation and maintenance (O&M) costs. These costs are broken down into variable O&M that vary depending on the energy throughput over time and fixed O&M that occur regardless of the amount of energy throughput over time. Figure 15 from a 2019 NREL report presents variable and fix O&M values from different studies for a 4-hour utility-scale ESS.[150] Variable O&M values range from a low of less than $1/MWh to a high of just over $7/MWh. Estimates of fixed O&M range from a low of $10/kW-year to $40/kW-year.

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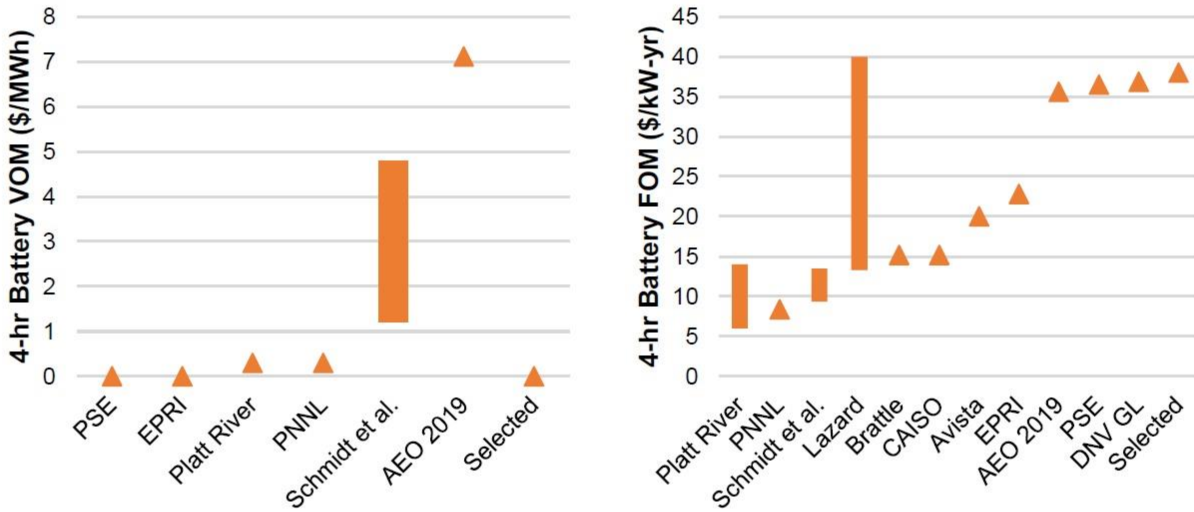
[150] Cole, Wesley, and A. Will Frazier. 2019. *Cost Projections for Utility-Scale Battery Storage*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-73222. Available at https://www.nrel.gov/docs/fy19osti/73222.pdf.

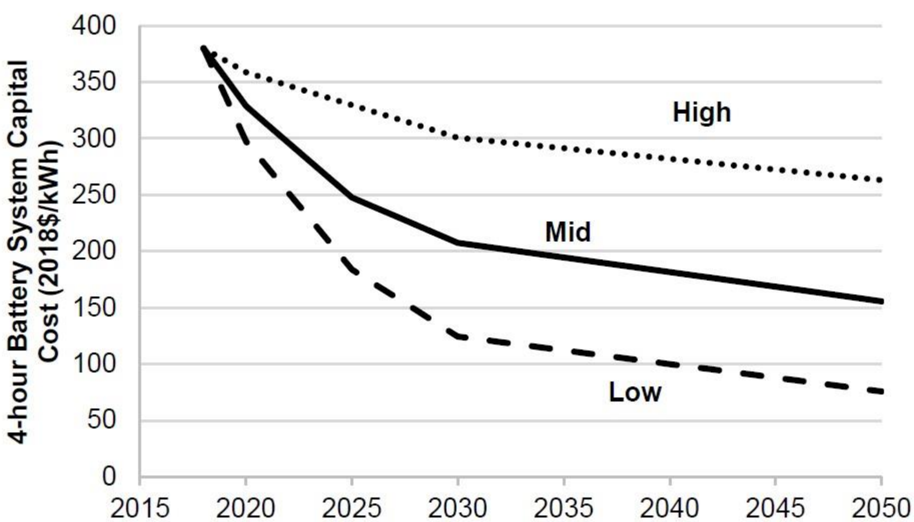
Figure 15. Variable and fixed O&M estimates from different sources



Source: Cole, Wesley, and A. Will Frazier. 2019. Cost Projections for Utility-Scale Battery Storage. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-73222.

Industry analysts forecast continued substantial cost reductions in ESS over the coming decades. Figure 16 provides future cost estimates for a 4-hour battery pack, indicating low, medium, and high projections. ESS costs are expected to decline significantly over the coming decades, expanding existing markets and creating new market opportunities. Figure 16 forecasts 2030 ESS costs ranging from $300/kWh to $175/kWh. Further out into 2050, the cost of an ESS is forecasted at a high of $250/kWh to a low $75/kWh.

Figure 16. Battery cost projections for 4-hour lithium-ion systems



Source: Cole, Wesley, and A. Will Frazier. 2019. Cost Projections for Utility-Scale Battery Storage. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-73222.

The cost of V2G resources and towable ESS, either tow-behind or containerized, may not be substantially different than the cost of a stationary ESS as discussed above. Tow-behind and containerized ESS will require engineering like that of an EV battery pack to protect against damage while being transported. The incremental cost of mobile ESS largely relates to the cost of transporting the unit to the desired location and the incremental cost of an interconnection facility that allows resources to disconnect and reconnect as needed. Regardless of system type—stationary, automotive (EV), towable ESS—costs are forecasted to decline and open new opportunities for cost-effective investments. Next, we provide a discussion of the complexities in assessing the cost-effectiveness of mobile ESS relative to stationary systems for use in emergency relief applications.

EVs are driving additional cost declines above and beyond the battery cells. Each EV has an onboard power control system in many cases silicon carbide power electronics. As such, EVs are driving increased manufacture scale of additional components which are similar between mobile and stationary storage (and which will benefit other DG technologies as well).

6.3. Cost-Effectiveness of Stationary vs. Mobile Energy Storage Systems

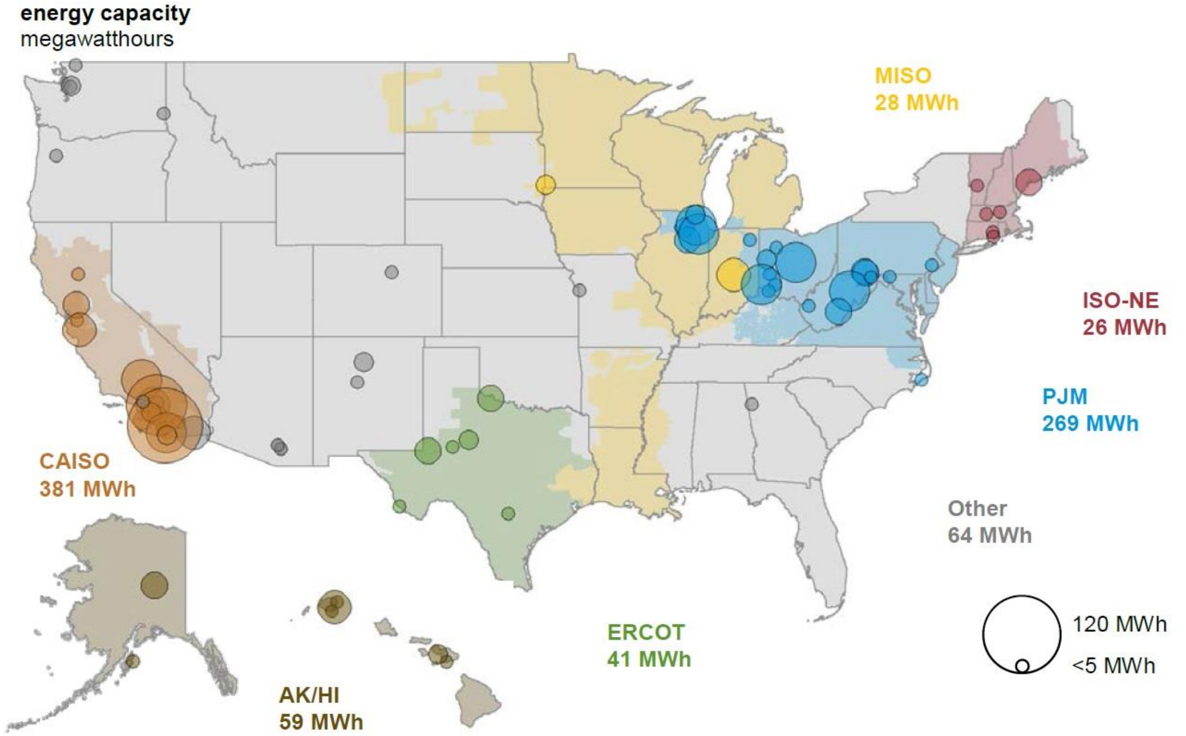
Today, the business case for stationary ESS in grid-connected applications is still evolving. As discussed in Section 4 above, there are numerous services that ESS can provide to the grid and host customers. A Massachusetts-specific study found significant net benefits to ratepayers from ESS investments across the state.[151] However, the value that ESS provide is fragmented and difficult to aggregate given that the benefits accrue to different parties and the functional requirements of storage to serve various applications are not well defined under existing market rules and regulations.[152] As a result, the main markets for ESS today are in regions with favorable wholesale market rules and/or government mandates to encourage storage deployments. Figure 17 illustrates the total installed energy capacity of U.S. large-scale battery installations by region. The majority of the nation's installed battery energy storage capacity is installed within PJM's[153] service territory and in California. PJM created a fast-ramping frequency regulation service that was particularly lucrative for energy storage assets. The California Public Utility Commission in 2013 implemented a mandate for its investor-owned utilities to procure 1,325 MW of energy storage across the transmission, distribution, and customer levels by 2020.

[151] Massachusetts Department of Energy Resources and Mass Clean Energy Center. 2015. State of Charge: A study of Energy Storage uses in Massachusetts Energy Storage Initiative. Available at https://www.mass.gov/media/6441/download

[152] Hledik, R. Lueken, R., McIntyre, C., and Bishop, H. September 2017. Stacked Benefits: Comprehensively Valuing Battery Storage in California. Prepared by the Brattle Group for Eos Energy Stoage. Available at http://files.brattle.com/files/7208_stacked_benefits_-_final_report.pdf

[153] PJM Interconnection is a regional transmission organization (RTO) that coordinates the movement of wholesale electricity in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and the District of Columbia.

Figure 17. Installed battery energy capacity in the United States by region



Notes: Energy capacity data for large-scale battery storage installed in 2017 are based on preliminary estimates.
Sources: U.S. Energy Information Administration, Form EIA-860M, *Preliminary Monthly Electric Generator Inventory*; U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*.

Source: U.S. Department of Energy, Energy Information Administration. May 2018. Battery Market Storage Tends.

Cost-effectiveness refers to the opportunity to invest in energy storage and generate enough revenue over the useful life of the ESS to cover the initial capital expense, ongoing O&M, and a margin for profit. Analyses of the economics of energy storage find that a single revenue or value stream is insufficient to support cost-effective investments today in energy storage and also result in a battery system being underutilized.[154,155]The concept of value stacking refers to the ability of ESS to capture multiple revenue streams and increase utilization rates, leading to a better overall return on investment.[156] Several studies have found that the ability to access the multiple revenue streams or "stack" the benefits is essential for

[154] Rocky Mountain Institute (RMI). *The Economics of Battery Energy Storage*. October 2015. Available at: https://rmi.org/wp-content/uploads/2017/03/RMI-TheEconomicsOfBatteryEnergyStorage-FullReport-FINAL.pdf

[155] Department of Public Service and New York State Energy Research and Development Authority. June, 2018.

[156] Hledik, R. Lueken, R., McIntyre, C., and Bishop, H. September 2017. Stacked Benefits: Comprehensively Valuing Battery Storage in California. Prepared by the Brattle Group for Eos Energy Storage. Available at http://files.brattle.com/files/7208_stacked_benefits_-_final_report.pdf

cost-effective investments in storage today.[157, 158, 159] For example, one case study of a commercial building in San Francisco found that stacking the value of energy storage serving primarily to reduce a commercial customer's demand charges on their monthly electric bill whiles also providing grid services (resource adequacy, frequency regulation, and load following) tipped the economics in favor of energy storage.[160]

The cost premium for mobile ESS relative to stationary battery energy storage systems is difficult to measure given the limited number of commercially available mobile energy storage products and the site-specific nature of energy storage system costs. The incremental costs for mobile ESS is largely associated with the labor and fuel costs for delivering the mobile energy storage units to where they will be placed into service. In addition, there may be incremental costs associated with the grid interconnection that accommodates connecting and disconnecting the mobile energy storage unit as needed. It is reasonable to assume a cost premium in the range of 5 percent to 10 percent for these factors.

There are two primary benefits that mobile ESS offer relative to stationary systems. The first is that they are flexible and can be relocated as the need for grid support changes over time. This flexibility could potentially avoid creating a stranded asset. If a stationary battery were designed and built to relieve a constraint on the grid and conditions change and the constraint no longer persists, the stationary storage system would be stranded. This means that it would no longer be generating value and thus the initial unamortized investment would be stranded or considered a sunk cost. A mobile energy storage system in this case could be relocated once the constraint no longer persists to a different location on the grid that would benefit from an energy storage asset.[161]

Mobile ESS offer the flexibility to be located to serve different applications over a given year. For example, a substation may be over-loaded during a few summer months and the use of energy storage could create significant value by avoiding or deferring investments upgrades. During the other months when the substation is not at risk of becoming over-loaded, the mobile storage asset could be relocated to a different location to provide a different valuable service. This flexibility offers value; however, it is difficult to quantify the economic benefit that energy storage flexibility offers.

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[157] Rocky Mountain Institute (RMI). *The Economics of Battery Energy Storage*. October 2015. Available at: https://rmi.org/wp-content/uploads/2017/03/RMI-TheEconomicsOfBatteryEnergyStorage-FullReport-FINAL.pdf

[158] Department of Public Service and New York State Energy Research and Development Authority. June 2018. New York State Energy Storage Roadmap Staff Recommendations. Available at https://www.ethree.com/wp-content/uploads/2018/06/NYS-Energy-Storage-Roadmap-6.21.2018.pdf.

[159] Hledik, R. Lueken, R., McIntyre, C., and Bishop, H. September 2017. Stacked Benefits: Comprehensively Valuing Battery Storage in California. Prepared by the Brattle Group for Eos Energy Storage. Available at http://files.brattle.com/files/7208_stacked_benefits_-_final_report.pdf

[160] [160] Rocky Mountain Institute (RMI). *The Economics of Battery Energy Storage*. October 2015. Available at: https://rmi.org/wp-content/uploads/2017/03/RMI-TheEconomicsOfBatteryEnergyStorage-FullReport-FINAL.pdf

[160] Department of Public Service and New York State Energy Research and Development Authority. June, 2018.

[161] It is conceivable that a stationary battery system could be deconstructed and moved to a new location thus avoid stranding the asset. This would create significant costs beyond those associated with the relocation of a mobile energy storage system.

The second major benefit of mobile energy storage over stationary energy storage is its use in emergency relief operations. This, again, is made possible by the flexibility that mobile ESS offer relative to stationary battery energy systems. In 2017, major disasters in the United States impacted more than 25 million Americans (nearly 8 percent of the U.S. population) ranging from flooding, hurricanes, and wildfires and imposing significant costs on families and communities nation-wide.[162] Experts predict that the nation will experience more frequent and powerful natural disasters driven by a changing climate. There is growing interest in energy resilience in light of the more frequent and intense storms driven by climate change leading to prolonged power outages.[163] However, it is also generally understood that there is a lack of agreement on how to measure and quantify energy resilience.[164]

It is beyond the scope of this report to conduct a cost-effectiveness analysis given the current immature nature of the mobile energy storage market segment. Qualitatively, it is plausible that the combined benefits of flexibility and energy resilience could offset all or most of the likely cost premium for mobile ESS over stationary systems. This would most certainly be the case when the capital cost of a towable mobile energy storage system is largely justified by its use during outage conditions. As discussed in Section 4 above, the capital cost of a self-mobile energy source in the form of different EV platforms is largely justified by the mobility services provided during blue sky conditions. This offers a clear economic advantage over a stationary system for which the capital investment is justified based solely on its use as a grid, non-mobile energy storage system. This report suggests additional values that have not yet been part of the discussion on the economics of ESS—flexibility, resilience, and mobility. These values can be "stacked" on the traditional values of ESS that are discussed in the literature.

To advance the understanding of the cost-effectiveness of mobile ESS, several comparative case studies should be developed. This should begin with identifying the technical performance of an ESS and finding detailed cost estimates for comparable mobile and stationary ESS. Specific use cases should be developed, and the economic value assessed—including estimates of the value of flexibility and resilience, and perhaps mobility if the comparable mobile unit is an EV.

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[162] Kaniewski, D. Investing in Mitigation to Build a More Resilient Nation. 2018. FEMA. Available at https://www.fema.gov/blog/2018-01-11/investing-mitigation-build-more-resilient-nation

[163] Wilson Rickerson, W., Gillis, J. and Bulkeley, M. April 2019. The Value of Resilience for Distributed Energy Resources: An Overview of Current Analytical Practices. A report prepared for the National Association of State Regulatory Commissions. Available at https://pubs.naruc.org/pub/531AD059-9CC0-BAF6-127B-99BCB5F02198

[164] Wilson Rickerson, W., Gillis, J. and Bulkeley, M. April 2019. The Value of Resilience for Distributed Energy Resources: An Overview of Current Analytical Practices. A report prepared for the National Association of State Regulatory Commissions. Available at https://pubs.naruc.org/pub/531AD059-9CC0-BAF6-127B-99BCB5F02198

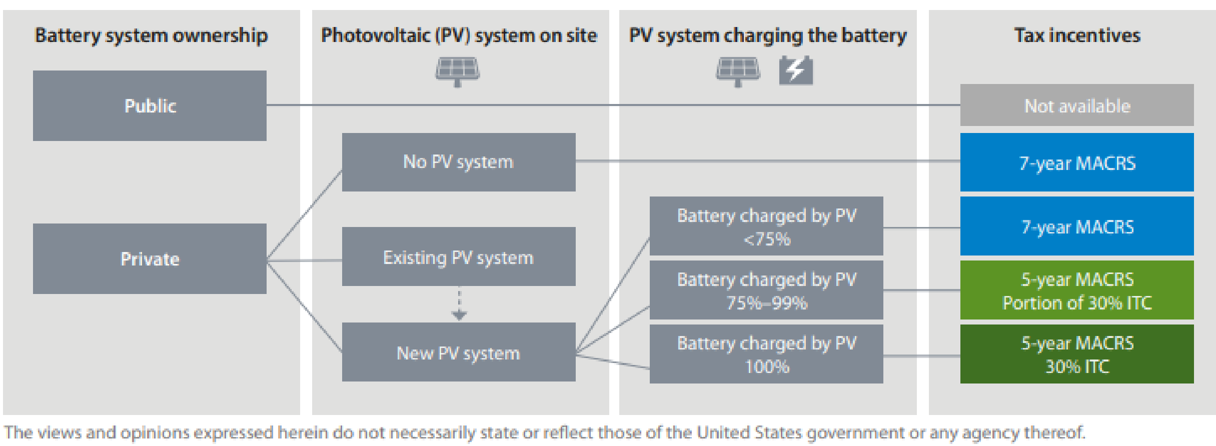
6.4. Incentives and Financing Mobile Energy Storage Systems

There are national, state, and private incentives and financing mechanisms available to help fund mobile ESS. This section outlines the available incentives for both EVs and towable mobile ESS at the three identified levels.

Federal

Depending on the system type and configuration, mobile ESS are eligible for the same types of financing mechanisms available today for stationary systems. The available incentives are different depending on whether it is towable or self-mobile energy storage system. One of the financing mechanisms available to all privately owned ESS is the Modified Accelerated Cost Recovery System (MARCS). At the national level, move-in-place systems only receive incentives through the Federal Investment Tax Credit (ITC) if the system is paired with existing or new solar. Different system configurations have access to different incentive levels. The mechanisms available for each configuration can be found in Figure 18. These specific incentives would be available to all move-in-place mobile ESS.

Figure 18: Financing mechanisms for energy storage nationally



Source: National Renewable Energy Laboratory (NREL). Federal Tax Incentives for Energy Storage Systems. January 2018. Available at: https://www.nrel.gov/docs/fy18osti/70384.pdf

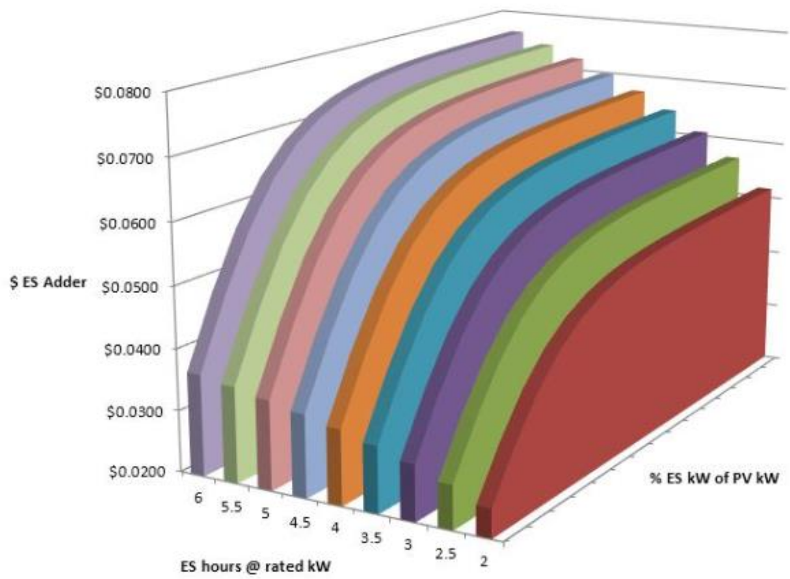
EV purchases are eligible for the federal Internal Revenue Service (IRS) tax credit. This credit is between $2,500 and $7,500 for a newly purchased EV, which varies based on the size of the vehicle and the capacity of the vehicle's battery.[165] This credit is limited to 200,000 EVs sold per manufacturer. GM has triggered the incentive decline and Tesla is no longer eligible for the incentive due to the limit.

165 U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Electric Vehicle: Tax Credits and Other Incentives. Available at: https://www.energy.gov/eere/electricvehicles/electric-vehicles-tax-credits-and-other-incentives

State

The Commonwealth of Massachusetts has increased the incentives available for ESS in recent years. The DOER Energy Storage Initiative launched various energy storage funding programs and incentives.[166] Those that are relevant to ESS include the energy storage adder incorporated in the Solar MAssachusetts Renewable Target (SMART) Program and the proposed Clean Peak Standard (CPS). The energy storage component included in the SMART program allows for an adder to the base solar compensation rate depending on the storage system's energy storage and power capacities. Figure 19 provides a visualization of how the energy storage adder increases based on the duration and power relative to the local PV system. For example, if the storage system is long duration and charges exclusively from the local solar generation, it will receive the highest possible amount from the energy storage adder.

Figure 19. SMART program energy storage adder blocks



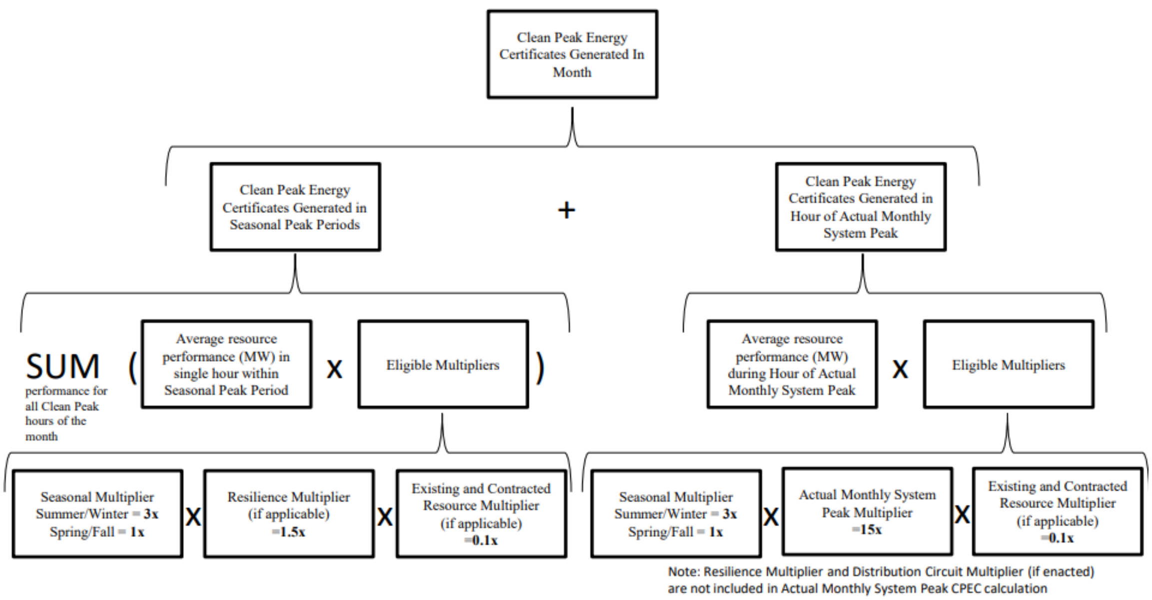
Source: Weaver, John. Massachusetts' SMART program is a go, but the details matter. PV Magazine. September 2018. Available at: https://pv-magazine-usa.com/2018/09/28/massachusetts-smart-program-is-a-go/

While the energy storage adder in the SMART program incentivizes customers installing solar to add energy storage to their systems, the proposed Massachusetts Clean Peak Standard (CPS) provides additional revenue streams for energy storage systems in configurations beyond those connected to a PV system. Under the proposed CPS, a Clean Peak Resource includes new renewables, existing renewables that pair contractually or physically with new energy storage, new energy storage that charges primarily

[166] https://www.mass.gov/energy-storage-initiative

from renewables, and demand response resources.[167] The current proposal allows qualifying systems to generate Clean Peak Energy Certificates (CPECs) for energy exported to the grid, or alternatively, demand reduced, during predefined Seasonal Peak Periods (SPP). Furthermore, CPECs can generate multipliers based on season, actual monthly system peak, resilience provisions, and—possibly in the future—location on the distribution system. Figure 16 presents the proposed formula to calculate monthly CPECs earned. CPECs are calculated on a monthly basis by adding together the credits generated during the predefined peaks, including the system's multipliers, with the credits generated during actual system monthly peak, including the system's multipliers. The system's multipliers will remain the same based on the technology available, but the energy provided during these defined critical periods may change the credits generated monthly.

Figure 20. How Clean Peak Energy Certificates are calculated



Source: Department of Energy Resources (DOER). 225 CMR 21 Clean Peak Standard Regulation. September 2019. Available at: https://www.mass.gov/doc/225-cmr-21-clean-peak-standard-regulation/download

The DOER revived the MOR-EV program on January 1, 2020 following the provision of additional funding through state budget.[168] DOER will make at least $27 million dollars available per year in 2020 and 2021 to EV incentive programs. The MOR-EV program offers up to $2,500 to battery electric vehicles.

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[167] Department of Energy Resources (DOER). 225 CMR 21 Clean Peak Standard Regulation. September 2019. Available at: https://www.mass.gov/doc/225-cmr-21-clean-peak-standard-regulation/download

[168] Department of Energy Resources (DOER). MOR-EV Home. 2019. Available at: https://mor-ev.org/

Additionally, the state has an Electric Vehicle Emissions Inspection Exemption which exempts EVs from the otherwise-required state motor vehicle emissions inspections.[169]

Private

A 2019 Massachusetts Department of Public Utilities order made Massachusetts the first in the United States to incentivize BTM battery storage by allowing utilities to pay customers who utilize their local battery storage to meet system demand and dispatch to the grid during peak events.[170] The details of how customers are compensated varies by utility, but this allows for utilities to directly make payments to customers who will agree to reduce their demand or dispatch energy to the grid during certain peak hours. Mobile ESS are well suited to provide BTM demand reduction during peak periods accessing this revenue stream.

Green Energy Consumers Alliance's Drive Green Program provides pre-negotiated discounts on qualified plug-in EVs at participating dealerships in Massachusetts and Rhode Island.[171] The organization also provides extensive educational materials and guidance on how a consumer can purchase the best EV for their budget and lifestyle.

Another option for private financing mechanisms for mobile ESS is through a third-party financing arrangement. Private investors can benefit from the value of services provided as well as any applicable incentives to create a mutually beneficial agreement with shared savings among the involved parties. This arrangement has become popular among solar and solar-plus-storage systems. Wood Mackenzie projects that 78 percent of commercial solar, including solar-plus-storage installations, will be third-party owned by 2021.[172] The intensive operating requirements for ESS, especially mobile systems, make third-party ownership ideal for these storage systems.

Beyond the financing mechanisms identified above, financing that may become available in the future to support assets that provide the grid or emergency communications with resilience will be especially useful for mobile ESS.

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[169] Department of Energy Resources (DOER). MOR-EV Home. 2019. Available at: https://mor-ev.org/, page 165.

[170] Cote, Matthew S. Massachusetts incentivizes energy storage systems for commercial property owners. Renewable Energy Work. July 2019. Available at: https://www.renewableenergyworld.com/2019/07/03/massachusetts-incentivizes-energy-storage-systems-for-commercial-property-owners/#gref

[171] Green Energy Consumer Alliance. *Drive Green*. Available at: https://www.massenergy.org/drivegreen

[172] Davis, Michelle. *Commercial Solar May Be 78% Third-Party Owned by 2021*. Greentech Media. April 2018. Available at: https://www.greentechmedia.com/articles/read/commercial-solar-expected-to-be-78-third-party-owned-by-2021

7. Conclusions

This report evaluated two main types of mobile energy storage: (1) self-mobile ESS in the form of electric LDVs, electric utility vans, and electric buses; and (2) towable systems, which include tow-behind ESS trailers and containerized energy storage transported via semi-trailer trucks. Examples of these types of mobile energy storage that are available on the market today can be found in Section 2.1.

Battery ESS are being deployed at scale in EVs with an estimated energy storage capacity for EVs sold in 2018 of 13.5 GWh. In addition, the market for stationary ESS is rapidly expanding. This growth is driven by cost declines, energy market rule changes to encourage investments in ESS as grid resources, and state policies supporting investments in ESS to create a flexible grid to accommodate expanding production of renewable sources of generation. This report evaluated the opportunity to use self-mobile ESS in the form of different EV platforms and towable ESS, either in trailer or containerized, to serve in emergency relief operations. When not serving emergency relief operations, mobile ESS can create value providing services to host customers or in utility-scale applications.

The V2G literature is vast and recognizes the potential benefits that EVs can provide when evaluated as mobile ESS. Several experimental projects in the United States and abroad demonstrate bi-directional power flows to and from EVs and the grid and the communications and control technologies necessary to strategically charge and discharge power from an EV's onboard ESS. The economics of V2G are still speculative at this time given the limited demonstration projects to date. There are several start-up companies seeking to build the hardware and software solutions to unlock the V2G potential. V2G resources can serve many if not all of the markets that stationary ESS serve today, including both BTM and FTM applications as discussed in Section 4.

The primary use cases for mobile ESS focused on in this report are off-grid, microgrid, and minigrid. A fourth use case represents a variant of both the microgrid and minigrid use cases and includes grid-forming capabilities to harvest energy from stranded DG resources during outage conditions. The report discusses how mobile energy storage can service each of these use cases and addresses their equipment costs, BOS (balance of system) costs, and soft costs. The analysis presented in this report shows that battery system equipment cost in $/kWh for the off-grid and microgrid use cases are higher than that of the minigrid and grid-forming use cases.

As noted previously, proper testing and operation procedures must be addressed prior to any mobilization. There are active regulations in place that prohibit transporting batteries above a 30 percent state of charge (SOC). Therefore, it is anticipated that the deployment requirements for mobile energy storage must be discussed and agreed upon with the authorities having jurisdiction (AHJ).

Mobile energy storage can pair with a wide variety of generators to create hybrid systems and are designed to be plug-and-play, requiring minimal reconfiguration once on site. A diesel or natural gas generator can pair with mobile energy storage, which can reduce the cycling of the generator and prolongs its life. Specifically, not only can energy storage feed part of the load during peak load events, it can also alleviate the need for the generator to run continuously.

Decisions about the design and deployment of mobile energy systems should consider five key principles: resiliency, reliability, interoperability, hazard prevention, and cost. The **resiliency** of mobile systems must meet the minimum requirements of broader emergency relief systems, with consideration to system recovery times, reliability of services, and preservation of societal well-being. Mobile ESS may be exposed to more extreme conditions than their stationary counterparts. Thus in order to maintain power **reliability** to critical services during emergency events, mobile ESS may require more durable—and more costly—components. **Interoperability** standards must ensure that mobile systems are compatible with the equipment at the sites to which they provide power, as well as with emergency response infrastructure and protocols. **Hazard prevention** standards must ensure the safety of the equipment operators, individuals at the site, utility workers, and the general public, particularly against the risks of thermal runaway and electrical fire. Finally, the **cost** of mobile systems will affect the economic feasibility of their use for emergency relief operations as compared to substitute technologies.

Mobile ESS face many of the same site-relevant deployment constraints as stationary systems, yet have additional requirements attributable to their portability. Adherence to existing codes and standards for system equipment, construction, interconnection, transportation, and permitting should be considered a minimum threshold for system design and deployment. Space requirements and equipment clearances must be considered when vetting critical sites as candidates for use of mobile ESS, as they may be a barrier to the use of mobile ESS at particular sites. Further, numerous site-specific actions may be necessary to prepare a property to interconnect and safely operate mobile systems. In circumstances where mobile ESS cannot be located at the same site as the energy loads they will serve, it may be necessary to stage the mobile units offsite and install interconnection power lines between the site and the offsite staging area. Electrical interconnection of mobile ESS to existing electrical distribution infrastructure must consider system compatibility with the sites and will require electrical safety equipment to protect personnel, the mobile units, and the site-based infrastructure.

Entities responsible for ensuring availability of critical services during an emergency event will need operational protocols to ensure that mobile ESS can be dispatched and will operate in a manner that meets or exceeds standards for system resiliency. Such protocols should be harmonized to guidelines in existing emergency planning documents. The responsible parties must validate that any mobile ESS dispatched to serve critical loads are physically and operationally compatible with the existing site. Given finite resources, operational protocols should include a system-to-site pairing of ESS which prioritizes the most critical services while “right-sizing” the dispatched units to reduce cost and increase resource availability for lower-priority sites when possible. Protocols should ensure sites are prepared to receive mobile ESS. As differing types of events (e.g. meteorological, tectonic, hydrologic) may pose various logistical challenges to transporting or interconnecting storage systems, personnel must be prepared to assess the feasibility of deploying mobile resources at the time of an event. Operational protocols should ensure emergency management personnel are prepared to manage the operating schedules of mobile resources. Emergency planning should consider the communication requirements which exist at multiple levels across the energy storage equipment, critical facilities, and operations personnel.

There are three domains of regulation that pertain to the design of mobile ESS and their deployment at a site: (1) permitting, inspection, and interconnection processes that govern DERs; (2) safety standards testing and certification for manufactured vehicles; and (3) safety standards testing and certification for manufactured battery equipment. The commercial availability of mobile systems with the capability to discharge power to the grid are a relatively new and evolving phenomenon. To the authors' knowledge, there is no domain of regulation that fully covers some of the mobile systems discussed in this report, and regulatory gaps exist. Entities intending to use such technologies should seek guidance from their electric utility, local permitting authority, and professional engineers.

Mobile energy storage is a valuable resource as it can serve a wide variety of applications for both normal and emergency scenarios. Prior to implementation, it is important to be attentive of regulations, power requirements, and associated costs. Presently, new mobile energy storage applications are actively expanding with the growing interest in these technologies as alternative energy solutions.

Mobile ESS may open pathways to new and novel business opportunities to increase the adoption of and reliance on intermittent renewable generation, and may provide customers with energy distribution options.

Mobile ESS offer economic advantages over stationary ESS. Emergency response planning includes investments in equipment that is used infrequently and only during outage conditions. The ability of mobile ESS to provide services the rest of the time (during blue sky conditions) creates value to offset the initial capital investment. In addition, the capital cost of mobile ESS is largely justified by the mobility services provided during blue sky conditions. A municipal agency that purchases vehicles might consider buying an electric vehicle with V2G capabilities. The agency would then have the option to deploy the vehicle during outage conditions as part of an overall ERP.