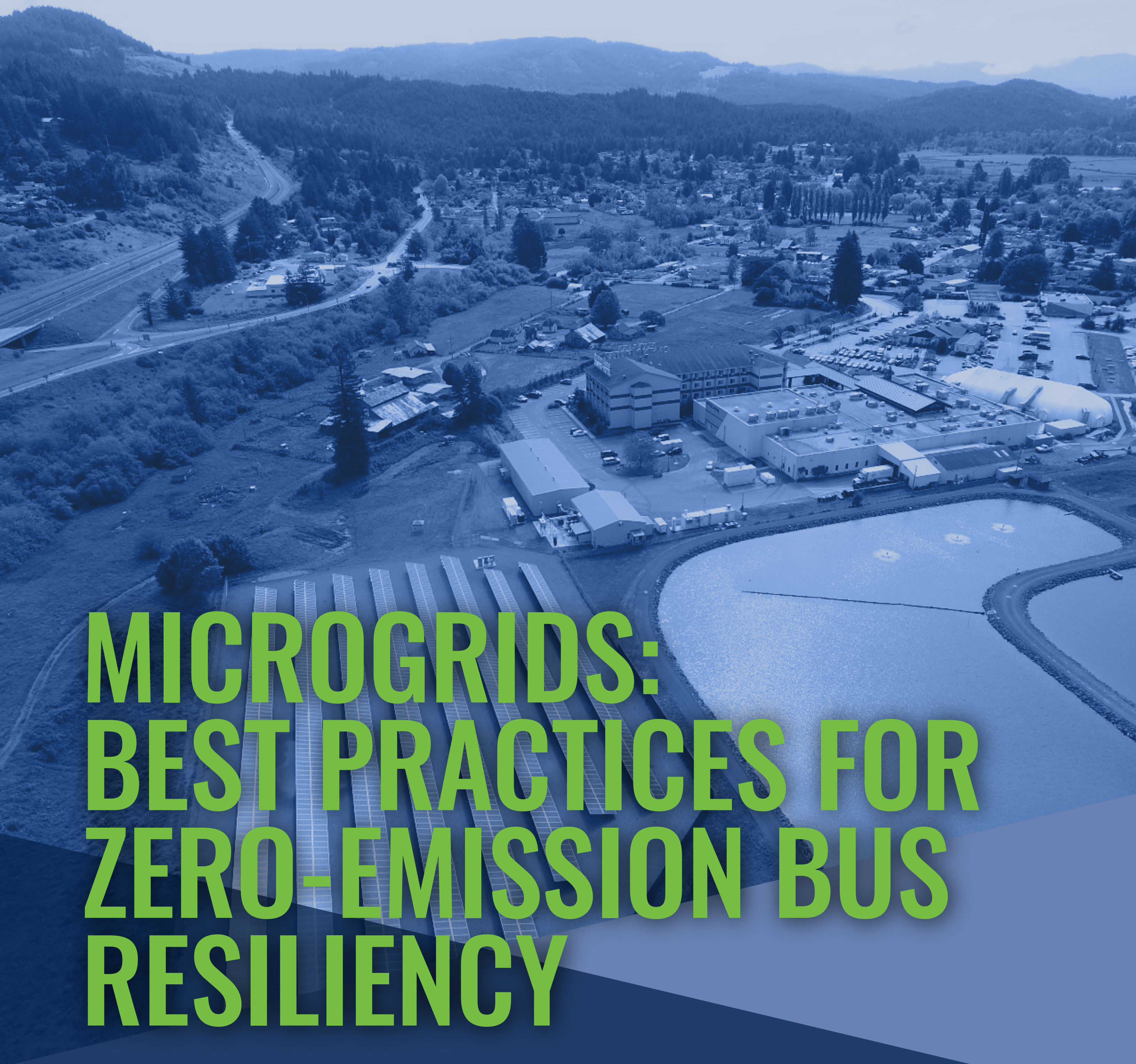

MICROGRIDS: BEST PRACTICES FOR ZERO-EMISSION BUS RESILIENCY

A CALSTART Report
June 2023

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Cover image: An aerial photograph of Blue Lake Rancheria's microgrid in Humboldt County, California. Photo credit: Blue Lake Rancheria.

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List of Acronyms

Acronym	Definition
ATN	Anaheim Transportation Network
BEB	Battery-electric bus
BTM	Behind-the-meter
CARB	California Air Resources Board
CI	Carbon intensity
ELRP	Emergency Load Reduction Program
FCEB	Fuel cell electric bus
FEMA	Federal Emergency Management Agency
FTM	Front-of-the-meter
GHG	Greenhouse gas
kg	Kilogram
kW	Kilowatt
kWh	Kilowatt-hour
LADOT	Los Angeles Department of Transportation
LCFS	Low Carbon Fuel Standard
MW	Megawatt
MWh	Megawatt-hour
PEM	Proton exchange membrane
PPA	Purchase power agreement
TOU	Time-of-use
VTA	Santa Clara Valley Transportation Authority
ZEB	Zero-emission bus

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Executive Summary

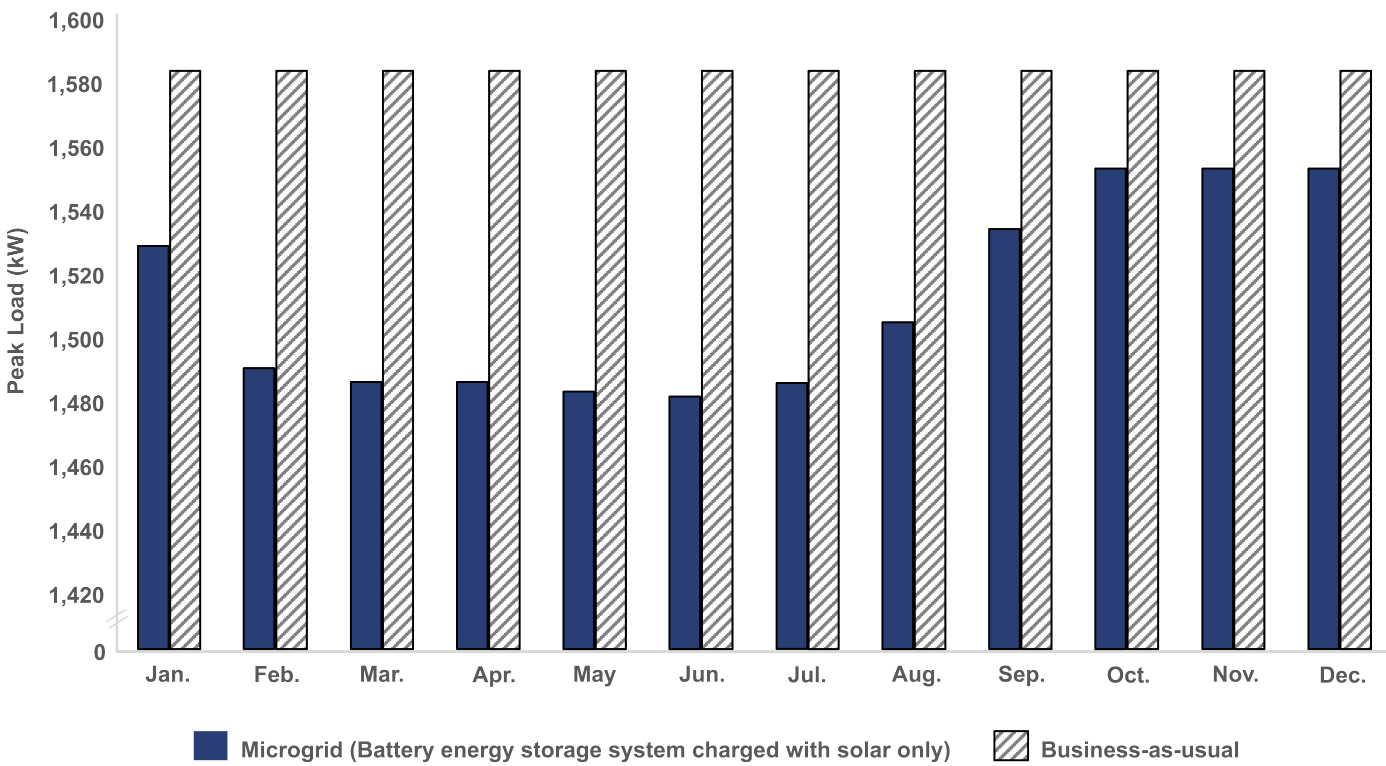
Adoption of zero-emission buses (ZEBs) continues to grow in the United States, increasing 66% from 2021 to 2022 for a total of 5,480 full-size transit ZEBs funded, ordered, and/or delivered across the country (Chard, 2023). The vast majority of these buses are battery-electric, and the electricity needed to power transit fleets, especially large fleets, introduces an enormous load on the utility grid. While currently fewer in number on the road, fuel cell electric buses also require electricity to produce, store, and dispense hydrogen. Both ZEB technologies pose real challenges for future grid management and face increasingly detrimental consequences in the event of utility grid outages.

Traditional measures for resiliency, including generators, have serious drawbacks, such as permitting use restrictions, potential failure due to infrequent use, possible interrupted fuel supply during a natural disaster, and harmful greenhouse gas emissions. This report introduces the numerous benefits that microgrids provide for ZEB fleets over conventional approaches to resiliency. It then focuses on the key considerations transit agencies must factor in when implementing a microgrid.

Unlike other resiliency measures, a microgrid can island, or fully disconnect from the utility grid and continue to generate power. Using a wide range of distributed energy resources (DERs) (i.e., solar panels, wind turbines, stationary fuel cells) and energy storage assets (i.e., batteries), microgrids can provide power to a specific load and store excess energy for later use. With this design, these systems use an uninterruptible power supply that starts instantaneously, can power multiple loads through the various energy assets, and offer asset diversification rather than reliance on generators as the sole backup energy source.

Peak shaving is one of the most critical benefits that microgrids provide for transit agencies. By storing self-generated energy during low demand and then deploying this energy when buses are charging, microgrids can reduce power demand even further. This approach, which can help reduce demand charges for the fleet, has major financial implications and can significantly reduce operational costs. To illustrate this concept, Figure ES-1 shows the impact that a microgrid using a 2-megawatt (MW) solar photovoltaic system with about 5 megawatt-hours (MWh) of energy storage has on reducing the monthly peak load for a sample 65-bus fleet.[1]

Figure ES-1. Reduced Monthly Peak Load with Microgrid System



Based on a hypothetical time-of-use rate structure and the estimated monthly peak loads above, the annual business-as-usual utility expenses for the sample 65-bus fleet arrive at around $1.97 million, whereas implementing a microgrid system in which batteries are charged solely with solar would help to reduce the fleet's utility bill to $1.18 million annually. With demand charges at $1.91/kilowatt (kW), a microgrid system would save the fleet $791,000 annually. However, if demand charges reach an estimated $25/kW, the savings would be approximately $810,000 per year. These systems will therefore not only provide resiliency but will work to benefit fleets financially as demand for and the cost of electricity increases in the coming decade.

Using microgrids for zero-emission transportation is a novel application, but numerous transit microgrid projects are already underway across the nation—with some already proving these concepts. Blue Lake Rancheria (BLR), a federally recognized tribal

[1] See the **Sample Microgrid Load Shift Analysis** section of this report and/or the **Appendix** for the complete methodology behind these calculations.

government in the Humboldt Bay area of California, frequently experiences natural disasters such as earthquakes, landslides, heavy rainfall, windstorms, and forest fires. To address the potential disruption to the power supply caused by these events, BLR deployed DERs in the form of a microgrid with a low-carbon backup power system (Schatz Energy Research Center, n.d.). Integrating DERs helps BLR save $200,000 in utility costs annually (Carter, 2019). In addition, BLR's microgrid performed well during several recent blackouts between December 2022 and February 2023 that were caused by a 6.4-magnitude earthquake followed by heavy winter storms, knocking out power to more than 70,000 customers. During these outages, the microgrid powered not only BLR's Level-2 electric vehicle chargers, with capacity to charge its electric shuttle bus, but also an American Red Cross-certified evacuation center and a six-building campus, including tribal government offices, a hotel, restaurants, casino, events center, and telecommunications and water systems for more than 24 hours.[2]

Below is a list of top five high-level factors that transit agencies must consider for microgrids on a project-by-project basis:

1. **Determine purpose:** Identify the type of emergency for which the microgrid is meant to respond. Transit agencies need to evaluate how long an outage is likely to occur during a typical emergency and how long the microgrid will need to provide resiliency.
2. **Identify critical loads:** Pinpoint which loads must continue to have power during a grid outage. This list can include buildings, maintenance bays, data servers, and safety equipment. Transit agencies must also identify the number of vehicles that must have access to power from the microgrid in the event of an outage.
3. **Select acceptable energy assets:** Assess the types of energy assets that can be included in the microgrid. For example, a transit agency needs to determine whether they want to include natural gas or diesel generators in the energy portfolio. In addition, studies to determine how much solar and battery storage can fit onto the site should be conducted.
4. **Calculate energy consumption and power demand:** Estimate energy consumption for buildings and existing loads by analyzing utility bills. Use route modelling or analyze telematics or charger data to estimate energy consumption and power demand.

[2] Zoellick, J., Principal Engineer at Schatz Energy Research Center. Interview. March 6, 2023.

5. **Size microgrid components and optimize for usage:** Use microgrid modelling software to size components and develop a conceptual design (i.e., equivalent to a 10% design drawing) that will meet calculated energy consumption and power demands, as well as other factors identified in previous steps.

CALSTART can help connect fleets with member companies that offer technological components, services, and more for microgrid development and implementation. Contact the following individuals for assistance in investigating these key considerations before planning and building a microgrid:

- Bryan Lee, blee@calstart.org
- Aditya Kushwah, akushwah@calstart.org
- Brian Ballschmidt, bballschmidt@calstart.org

I. Introduction to Zero-Emission Bus Resiliency

Powering Zero-Emission Buses

The environmental benefits of battery-electric buses (BEBs) and hydrogen fuel cell electric buses (FCEBs) are well known: with zero tailpipe emissions, these vehicles help reduce greenhouse gas (GHG) and criteria pollutant emissions, resulting in better air quality, healthier communities, and reduced impacts of climate change. The transportation industry continues to make measurable strides toward electrification. As of September 2022, 5,480 full-size zero-emission buses (ZEBs) were funded, ordered, and/or delivered in the United States—an increase of 66% from 2021 (Chard, 2023).[3]

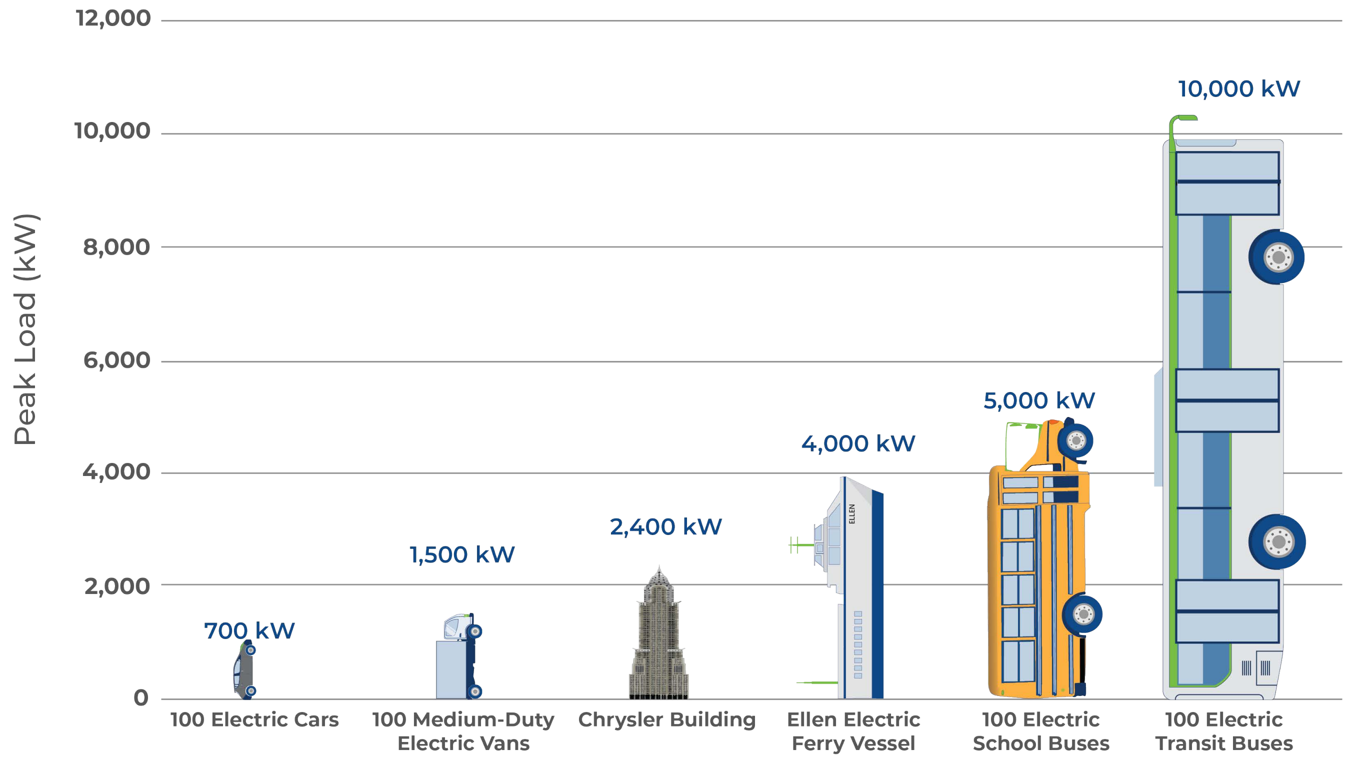
BEBs are the most common ZEB technology on the road, making up over 96% of full-size zero-emission transit buses, and the electricity needed to power them is significant (Chard, 2023). BEBs used for transit applications typically have battery capacities ranging from 440 to 650 kilowatt-hours (kWh) and have rigorous duty cycles, operating for 12 to 14 hours per day. Charging often occurs at night, and entire routes are completed on a single charge. However, some routes may have high-powered, on-route charging that is delivered via in-ground inductive or overhead catenary systems. Large BEB fleets especially consume a considerable amount of power, which introduces an enormous load on the utility grid. As seen in Figure 1, the daily power demand[4] for large zero-emission transit fleets is significantly higher than the iconic Chrysler Building, a 77-story skyscraper.[5]

[3] For the full inventory of funded, ordered, and/or delivered zero-emission transit buses in the United States as of 2022, see CALSTART's Zeroing in on ZEBs report at https://calstart.org/zeroing-in-on-zebs-2023/.

[4] Demand refers to the maximum amount of electrical power consumed at a given time, whereas energy is the amount of power used over a period of time. A demand charge is typically calculated using 15-minute interval data and the highest rate of energy consumed during a billing period measured in kilowatts (kW) (United Power, 2020).

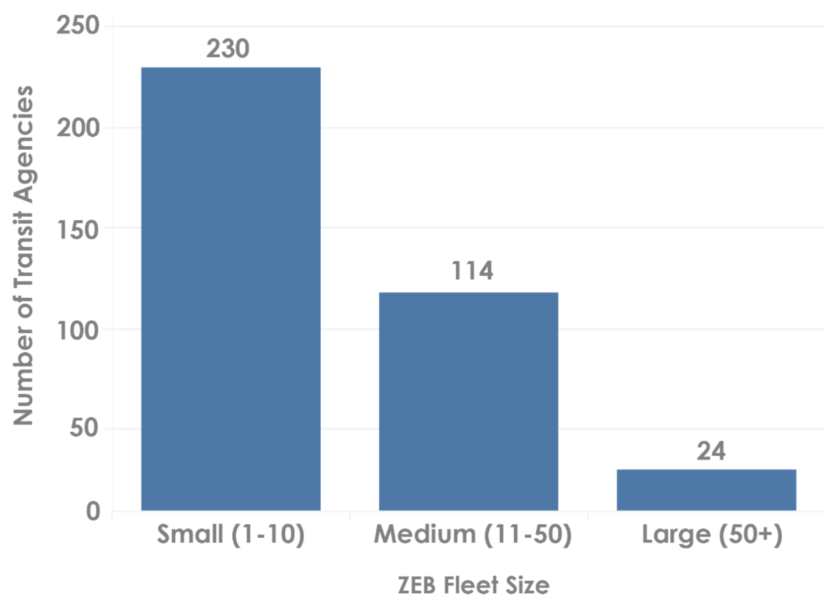
[5] All assumptions used to develop Figure 1 are included in the **Appendix**. This figure is an updated version of CALSTART's original "Peak loads for various electric vehicle fleets" graph (CALSTART, 2015).

Figure 1. Power Demand Comparisons



As of this writing, the vast majority of BEB fleets are comprised of 10 or fewer vehicles (Figure 2), but transit agencies will inevitably electrify a greater proportion of their vehicles—and eventually their entire fleet—as the technology matures and governments enact regulations that encourage, incentivize, or mandate zero-emission adoption.

Figure 2. Distribution of U.S. Full-Size Zero-Emission Bus Fleet Size (Chard, 2023)

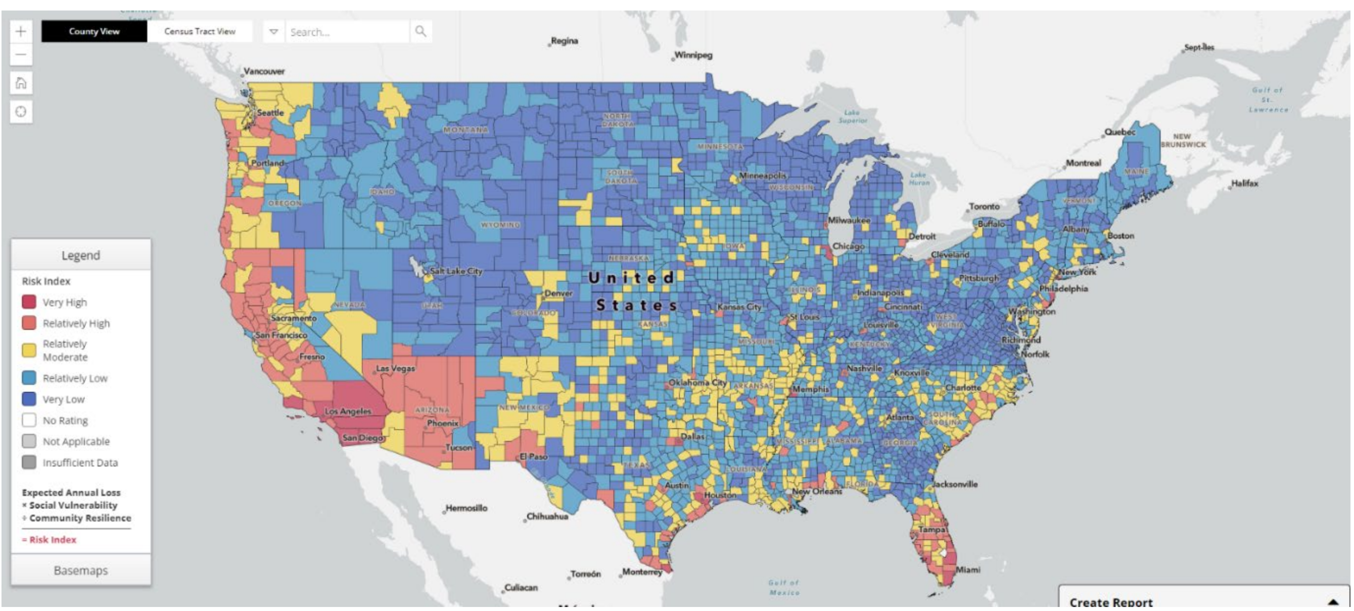


As fleets begin to deploy BEBs at scale, energy and power demands from the utility grid will increase. While currently fewer in number on the road, FCEBs also require electricity; standard FCEBs can store 40 to 60 kilograms (kg) of hydrogen. Approximately 50 kWh are required to produce 1 kg of hydrogen through electrolysis. Hydrogen compression, chilling, storage, and dispensing equipment are also energy intensive and create a large load, or standby power, on the utility grid. Both ZEB technologies pose real challenges for future grid management and increasingly detrimental consequences in the event of utility grid outages.

Resiliency: Why It Matters

Since all ZEBs rely on access to the grid for fuel, extended grid outages will effectively disable a fully electric fleet. The U.S. grid is relatively stable and, in most cases, can provide energy to customers. Reliability is typically measured with metrics such as the System Average Interruption Duration Index, the Customer Average Interruption Duration Index, and the System Average Interruption Frequency Index. Based on these metrics, the average customer could expect to experience one outage or service interruption per year that lasts two hours (Eudy, 2018). However, traditional reliability metrics do not factor in major, unpredictable events, including storms, hurricanes, natural disasters, terrorism, and cyberattacks. Much of the United States is vulnerable to natural disasters or extreme weather (Figure 3).[6]

Figure 3. National Risk Index for All Natural Hazards (FEMA, 2021)



[6] Figure 3 shows natural disaster risk by geographical region in the United States. Visit https://hazards.fema.gov/nri/map to access the Federal Emergency Management Agency's (FEMA) National Risk Index interactive online map (FEMA, 2021).

States such as California, Oregon, and Washington have seismically active areas, meaning utility infrastructure may be damaged or destroyed during an earthquake. In December 2022, Humboldt County in California experienced a 6.4-magnitude earthquake that left thousands of residents and businesses without power (USGS, 2022). Blue Lake Rancheria, a federally recognized tribal government in Humboldt County, also lost power during the earthquake—but because of their Low-Carbon Community Microgrid Project, the community was able to keep the lights on and their Level-2 electric vehicle charger operational. (See the **Real-World Transit Microgrid Projects** section for more information on this microgrid case study.)

Between January and March 2023, California also experienced a series of atmospheric rivers that brought record-breaking rain, snow, flooding, mudslides, and blackouts (Gorman, 2023). In addition, when weather conditions require it, California's utilities have initiated public safety power shutoffs in areas prone to wildfire to ensure equipment does not start fires. These power shutoffs last an average of 30 hours (CARB, n.d.).

Extreme outages are not limited to California: in 2021, a massive grid outage in Texas that occurred during a winter storm resulted in a loss of power for more than 4.5 million homes—many for several days—and over $195 billion in property damage (The University of Texas at Austin Energy Institute, 2021). The Gulf Coast region experiences the annual threat of hurricane impacts. In the aftermath of Hurricane Maria in 2017, Puerto Rico experienced the worst blackouts in American history (U.S. Energy Information Administration, 2018). In September 2022, Hurricane Ian, the country's fifth strongest storm to reach land, battered Southwest Florida—though due to billions invested in grid resiliency and solar-powered communities such as Babcock Ranch now in place, much of the affected area recovered power quickly (Taylor, 2022; Hanley, 2022).

Resilience, defined by the U.S. Department of Energy as "the ability of a system or its components to adapt to changing conditions and withstand and rapidly recover from disruptions," has consequently become an issue of extreme importance for transit agencies as fleets electrify (U.S. Department of Energy, 2017). Moreover, if ZEBs were effectively disabled in the event of an extended grid outage, public approval of and user acceptance of these vehicles would swiftly decline. Fleets must also be able to continue to play a role in government disaster plans, as buses are often used to transport first responders or to evacuate people in areas that have lost power. Transit agencies will face the reality of full-stop disruptions to transit service if resiliency measures are not put in place. It is important to note that due to site and financial constraints, most transit agencies will feasibly provide enough resiliency for up to 30% of a fully electric fleet to operate during an emergency outage.

Traditional Resiliency Measures

Fleets have historically addressed grid outage concerns for ZEBs through the methods listed below. These approaches to resiliency can help prevent a complete power shutdown at a bus depot, but they are not capable of supporting full resiliency.

Multiple Feeders

When electricity arrives at a depot through a single feeder, failure deprives the site of power since no alternative pathway exists to bring electricity to the bus chargers. This risk can be mitigated by deploying two feeders at the depot, which provides a backup feeder if one feeder fails. However, this approach does not protect the depot from a utility grid outage, as all feeders rely on the grid for power.

Generators

Fleets can use generators to mitigate utility grid outages. Generators use natural gas or liquid fuels, such as diesel, to produce electricity. While generators can produce power in the event of a grid outage, this technology has several disadvantages:

- Permitting: Many jurisdictions have air quality regulations that limit generator use. For example, in some air quality management districts in California, emergency backup generators can be used for only 200 hours per year (South Coast Air Quality Management District, n.d.). This allotment means that the generators are effectively restricted for emergency use only.
- Maintenance: Like internal combustion engine vehicles, generators must be maintained, which burns fuel and adds to overall costs.
- Failure: Many emergency generators are run infrequently, especially in areas with high grid reliability, and these low-utilization levels can result in generators failing to start when transit agencies would need them most (Ericson, 2019).
- Cost: The levelized cost of energy from a generator is high given use limitation regulations and the infrequency of outages. Furthermore, many utilities prohibit the export of power from a generator to the grid, meaning generators cannot be used to create revenue. Generators that are installed and rarely used quickly become sunk costs. One option to reduce costs is to rent a temporary generator during an extended outage, but obtaining a generator during an emergency could prove extremely difficult.
- Fuel Supply: A generator must retain access to fuel to operate. Diesel can be stored onsite to power a generator when needed, but it can be challenging to resupply

diesel during an emergency as first responders will likely receive priority for diesel supplies. Natural gas can be piped to the site, and the generator will continue to work as long as the natural gas pipeline network is intact. In rare cases, though, the natural gas pipeline network can be disrupted.

- Emissions: Generators produce GHG, nitrogen oxides, and particulate matter emissions, potentially negating the benefits of electrifying transit buses. Moreover, fugitive emissions and leakage are concerns for generators powered by natural gas. While not a priority in the midst of a disaster, developing alternatives can prevent emissions from becoming an issue.

Public Charging

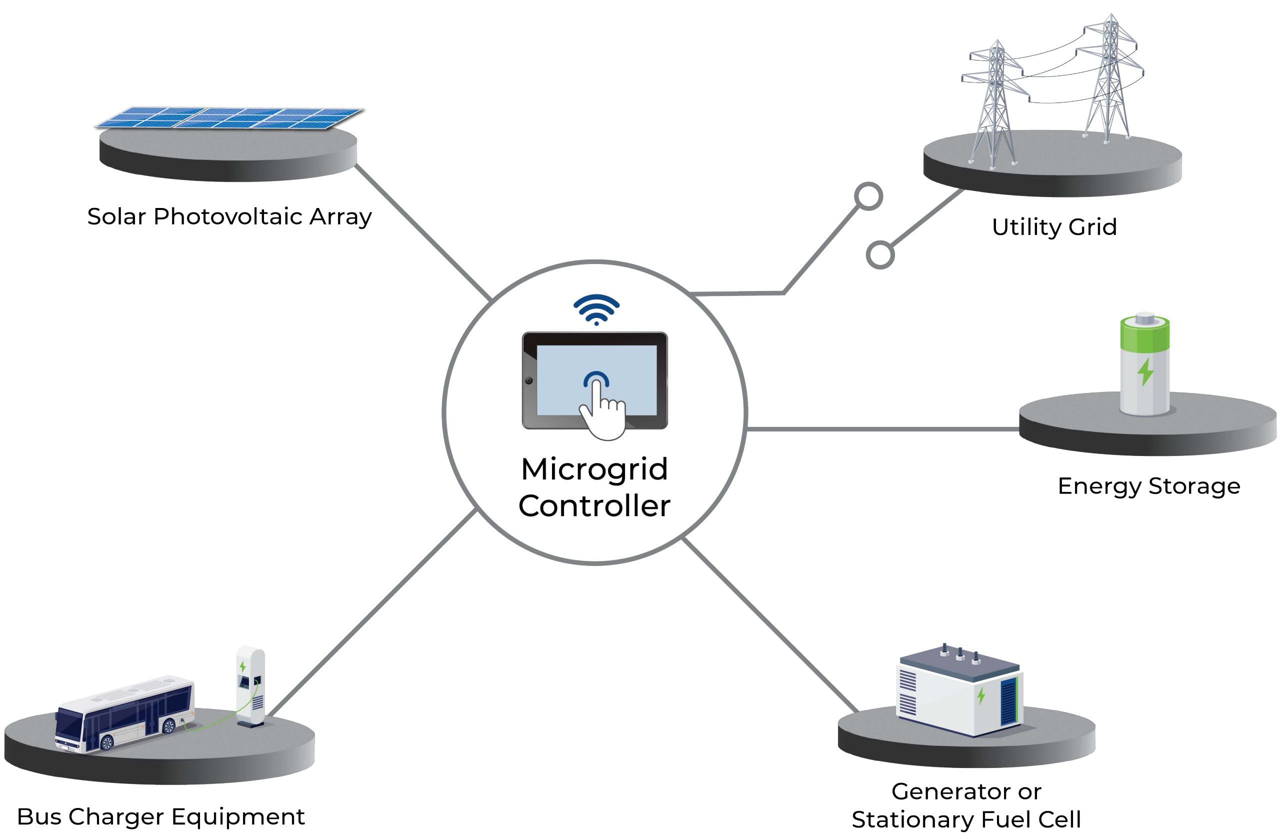
A fleet can use public charging as a form of resiliency. Public charging will likely be restricted to buses of smaller size given that public charging lots are not constructed to handle larger transit buses (i.e., the parking spots are designed for passenger cars rather than medium- and heavy-duty vehicles). This form of resiliency is effective only in the event of localized grid outages. If a widespread grid outage occurs, the public charging station is also at risk of losing power.

II. Microgrids: The Future of Transit Resiliency

Defining a Microgrid

A microgrid is a local grid that uses distributed energy resources (DERs) and energy storage assets to provide power to a specific load. A microgrid must be able to island, meaning the entire system can disconnect from the utility grid and continue to generate power. This functionality is managed by a switch at the point of connection with the utility grid and a controller decides when to connect and/or disconnect (Figure 4).

Figure 4. Zero-Emission Bus Fleet Microgrid Diagram



A wide range of DERs and energy storage assets such as solar panels, wind turbines, and stationary fuel cells power microgrids. Natural gas turbines or diesel generators can also support microgrids but inherently possess many of the limitations and disadvantages listed in the previous section. Energy storage assets, such as batteries, are often deployed in microgrids to store excess energy for later use. A variety of energy generation and storage sources implemented in a microgrid provides options for deploying the most appropriate type of power generation. Daytime utility grid outages could result in the microgrid providing power through solar panels to maximize its use of carbon-free energy. Nighttime utility grid outages may require the use of a natural gas generator and/or a battery energy storage system when intermittent energy sources are not generating power.

Microgrids also offer flexibility. Some microgrids can serve as the primary source of power for a facility—the microgrid would remain disconnected from the utility grid by default but could reconnect to the grid to receive backup power or to export excess energy. However, most microgrids will be designed to remain connected to the utility grid on a regular basis and use a combination of utility grid power and self-generated electricity to meet the existing load and to export excess generation to the grid. During an outage, the microgrid will then disconnect from the utility grid and use its distributed energy and energy storage resources to power the ZEB load. The controller will shut down or disconnect nonessential parts of the facility and provide power only to vital assets to support the ZEB fleet.

Benefits for Zero-Emission Bus Fleets

Resiliency

A key distinction between a microgrid and other resiliency solutions, such as a solar system without energy storage, is that a microgrid must be able to island from the utility grid. Microgrids are a superior solution to provide transit fleets with resiliency for the following reasons:

- Instantaneous Power: Most backup generators take time to start up, but a microgrid can use an uninterruptible power supply to start instantaneously, providing power as soon as a utility grid outage occurs.
- Flexibility: Backup generators are usually tied to an individual load and can provide power only to that specific load. Microgrids offer more flexibility because the various energy assets can power multiple loads.
- Asset Diversification: Many sites currently opt to use generators as their sole backup energy source, but generators can fail to turn on. Microgrids can provide multiple sources for energy generation. If one source fails, other fallback energy assets are available for use.

Peak Shaving

Microgrids can also be used to manage power demand. Many fleets already employ smart charging, which controls a network of chargers in real-time to minimize total power demand for the entire fleet while ensuring that the vehicles are fully charged and ready for service at the end of the charging session. A microgrid can reduce power demand even further by storing self-generated energy during times of low power demand and then deploying this energy when the buses are charging. This approach, which can help reduce demand charges for the fleet,[7] is known as peak shaving. Generator use is typically restricted by air quality/environmental regulations, and these restrictions generally preclude the use of generators for peak shaving.

Peak shaving is valuable because it reduces overall power demand, which has major financial implications and can significantly reduce operational costs. Utilities typically levy a demand charge based on peak power draw during a billing period, which can be substantial (Table 1). In many cases, demand charges represent most of the utility cost for a transit agency.

[7] Regardless of electric use throughout a billing period, the maximum power demand (kW) for any period is determined by a single spike. As a result, customers may be charged higher electricity rates during each utility's defined peak hours. Customers must therefore select the appropriate demand block based on their daily usage, as they may be charged a penalty if they exceed the predefined demand block limits. Moreover, if a customer's usage exceeds a certain grace period, they will be charged a higher price with a penalty.

Table 1. Summary of Demand Charges for the States with the Highest Utility Demand Charge Rates in the Country (National Renewable Energy Laboratory, 2017)

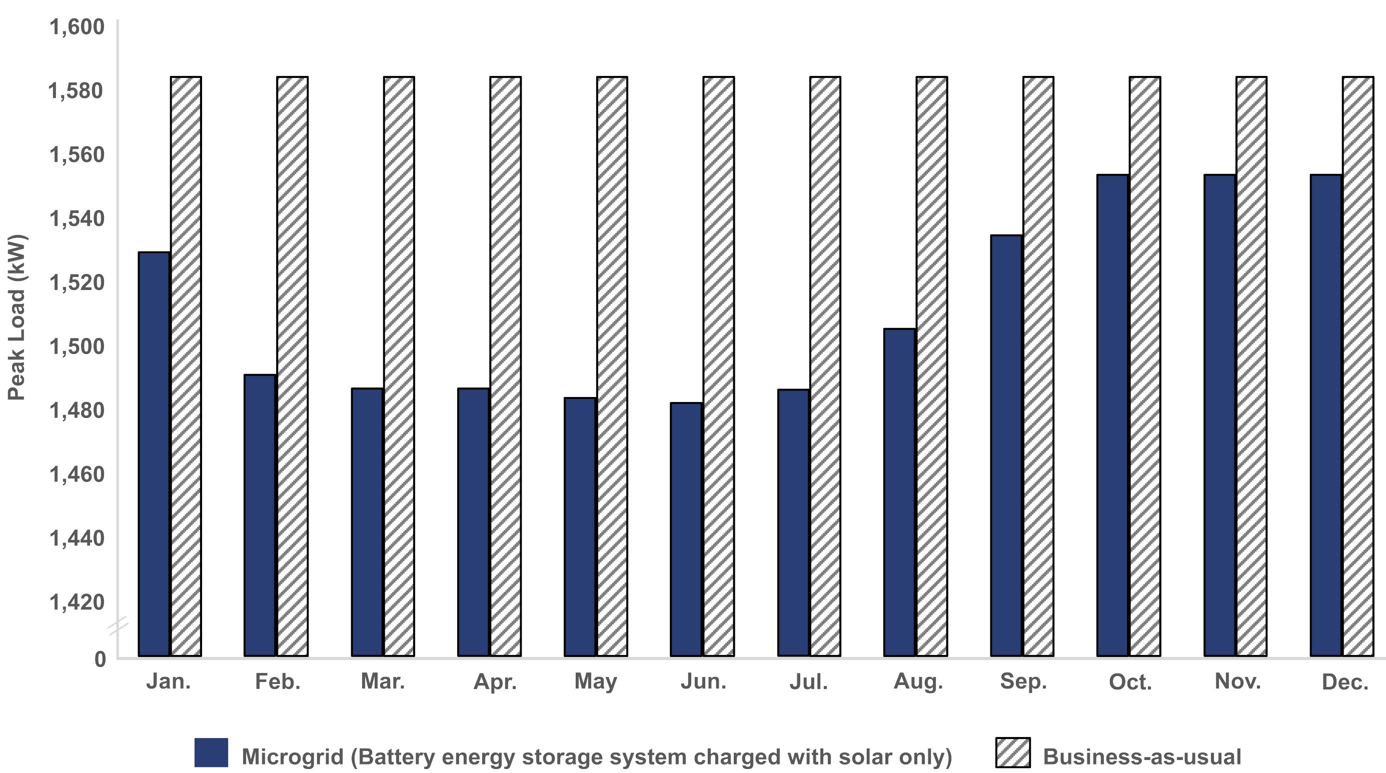
State	Maximum Charge Across All Utilities ($/kW)	Average of All Utility Maximum Charges ($/kW)	Median of All Utility Maximum Charges ($/kW)
New York	$51.25	$9.30	$4.30
California	$47.08	$11.45	$10.60
Colorado	$46.43	$21.68	$16.65
Massachusetts	$41.25	$19.14	$15.50
Arizona	$35.45	$18.82	$18.50
Nebraska	$30.00	$14.82	$15.70
Illinois	$30.00	$16.58	$16.63
Georgia	$28.70	$5.83	$3.60
North Carolina	$25.65	$15.61	$15.63
Vermont	$25.39	$17.43	$16.05

With significant variation in demand charges between states, and even between utilities within the same state, a microgrid that deploys stored, generated energy for charging can help reduce these expenses for transit agencies.

Sample Microgrid Load Shift Analysis

To illustrate how microgrid systems can reduce utility costs and add resiliency to support grid independence, the following example considers a hypothetical monthly peak load for 65 zero-emission transit buses.[8] A microgrid system comprised of a battery energy storage system charged solely via solar photovoltaic can reduce overall peak load as well as overall energy consumption. Figure 5 below shows the impact that a 2-megawatt (MW) microgrid with about 5 megawatt-hours (MWh) of energy storage has on reducing the monthly peak load for the sample 65-bus fleet. Implementing this type of microgrid system has a significant impact on peak load throughout the year, which will aid in lowering the demand charge portion of a fleet's utility bill.

Figure 5. Reduced Monthly Peak Load with Microgrid System



Furthermore, many sectors will shift toward electrification to transition from fossil fuels. As a result, the cost of electricity will rise in the future due to various factors, including increased overall demand, continued deployment, use of battery-electric vehicles, and inflation. The demand for electricity is therefore expected to increase and compound in the near future (Revel, 2022). To analyze the impact of demand charges on transit agency

[8] For more information on the methodology used to calculate this sample microgrid load shift analysis, see the **Appendix**.

operations, a hypothetical time-of-use (TOU) rate structure was created to estimate the utility costs and effects of demand charges with and without a microgrid system in place (Table 2).

Table 2. Hypothetical Time-of-Use Rate Structure

Time-of-Use (TOU)	Energy Charges ($/kWh)	Demand Charges ($/kW)
On-peak	$0.38147	$1.91
Off-peak	$0.16824	$1.91
Super off-peak	$0.14497	$1.91

Based on this TOU rate structure and the estimated monthly peak loads in Figure 5, the annual business-as-usual utility expenses for the sample 65-bus fleet arrive at around $1.97 million, whereas implementing a microgrid system in which batteries are charged solely with solar would help to reduce the fleet's utility bill to $1.18 million annually.

To take rising demand charges into account, Table 3 below assesses the impact of higher demand charges up to $25/kW. With demand charges at $1.91/kW, a microgrid system would save the fleet $791,000 annually. However, once demand charges reach $25/kW, the savings would be approximately $810,000 per year.

Table 3. Annual Utility Cost Per Estimated Future Demand Charges

Demand Charge ($/kW)	Annual Utility Bill Business-As-Usual (million)	Annual Utility Bill with Microgrid (million)	Savings (million)
$1.91	$1.97	$1.18	$0.791
$10.00	$2.12	$1.32	$0.796
$15.00	$2.21	$1.41	$0.801
$20.00	$2.31	$1.50	$0.806
$25.00	$2.48	$1.60	$0.810

With the proper microgrid in place, fleets will save more on their utility bills as demand charges rise. These systems will not only provide grid resiliency in the event of an outage but will work to benefit fleets financially as demand for electricity increases in the coming decade.

Demand Response Programs

Utility companies constantly manage the grid, balancing electricity supply with electricity demand. Demand for electricity can exceed supply for an extended period, and utilities then struggle to balance this shift, potentially resulting in brownouts and blackouts. To address this, utilities have developed demand response programs, which allow customers to switch their power usage to times with lower power demand. Most demand response programs have focused on customers reducing power consumption by turning off or decreasing use of major appliances, like air conditioning. A microgrid can be used as a form of demand response. During a demand response event, the microgrid can island and produce its own power, reducing the load on the grid and helping prevent complete and prolonged outages.

Demand response programs are typically developed and implemented by utilities. As a result, the rules of each demand response program will vary by utility. Most demand response programs are designed to encourage customers to shed or shift traditional loads such as air conditioning or washing and drying machines. However, there are some demand response programs that microgrids could potentially use. The California Public Utilities Commission authorized the Emergency Load Reduction Program (ELRP). This program pays customers to reduce energy consumption or increase electricity supply after the California Independent System Operator declares a grid emergency. When a grid emergency is called, customers who shed load or increase supplies to the grid are eligible to be compensated at a rate of $2/kWh (California Public Utilities Commission, n.d.). An electric fleet could potentially benefit from ELRP if their managed charging provider uses the charging management system to shed charging load during a grid emergency. Alternatively, a microgrid owner could potentially take advantage of ELRP by islanding during a grid emergency to shed load or export power from solar panels or batteries.

Low Carbon Fuel Standard Credits

In California, Low Carbon Fuel Standard (LCFS) credits are awarded based on GHG emissions displaced as a result of using alternative fuels. The California Air Resources Board (CARB) assigns a carbon intensity (CI) value to each type of alternative fuel. Fuels with a lower CI earn more LCFS credits. By using renewable assets in a microgrid, a transit agency can earn a lower CI for electricity dispensed to transit buses. Oregon also has an LCFS program, and other states are proposing or considering similar programs,[9] including Washington and Colorado.

LCFS credits can be sold to generate revenue. This revenue can be used to displace the capital costs of the microgrid or the cost of utility infrastructure upgrades. Table 4 displays LCFS revenue estimates for one electric transit bus and one small bus.[10]

Table 4. Estimated LCFS Credit Revenue

LCFS Credit Price	Annual Revenue from LCFS Credits for One Transit Bus	Annual Revenue from LCFS Credits for One Small Bus
$50	$7,083	$1,907
$75	$10,624	$2,861
$100	$14,166	$3,814
$125	$17,707	$4,768
$150	$21,249	$5,722
$200	$28,332	$7,629

This LCFS credit revenue analysis is based on California LCFS credits. In this example, transit buses are assumed to consume 352 kWh of electricity per day, operate 312 days per year, and displace diesel fuel. Small buses are assumed to consume 96 kWh of electricity per day, operate 312 days per year, and displace gasoline fuel. LCFS revenue does vary depending on the price of LCFS credits. As of November 2022, LCFS credits were trading at approximately $60 per credit (SRECTrade, 2022).[11] Due to LCFS credit price volatility, sensitivity analysis on LCFS revenue was included.

[9] Visit https://theincubex.com/states-and-provinces-with-lcfs-markets-2/ for more information on which states and provinces have LCFS programs.

[10] A small bus is a Class 3–6 bus that is shorter than 30 feet, including electric cutaway buses and transit vans.

[11] LCFS credits are not automatically awarded. To earn LCFS credits, transit agencies need to complete the reporting requirements in their state to earn credits and then sell the credits through an exchange to generate revenue. Alternatively, a fleet may opt to hire a company to complete the reporting requirements and sell the LCFS credits on their behalf.

Microgrid Design

While microgrids have been employed by other industries for decades, using this technology for zero-emission transportation is a novel application. One key challenge that a microgrid serving zero-emission vehicles must overcome is the amount of power and energy that these vehicles consume. As illustrated in Figure 1, large bus fleets will need a considerable amount of energy on a daily basis.

As shown in Figure 4, most microgrids employ renewable energy assets, such as solar panels and battery energy storage systems. Solar and battery energy storage systems are not energy dense; as a result, in most cases, the solar and battery energy storage potential of a site is limited. A transit agency should maximize the amount of solar and battery energy storage installed on their site, but this technology usually provides enough power for up to one day's worth of resiliency. During the design process, transit agencies need to make decisions about the critical load they want to serve and the level of resiliency for their fleet (i.e., number of vehicles that will remain in operation during an outage) they would like to achieve with the microgrid. For example, a microgrid can be designed to provide increased resiliency during a short outage (i.e., 24 hours or less), or it can be designed to provide less resiliency for a longer period (i.e., several days). Navigating this question will require transit agencies to evaluate the tradeoffs between the amount of resiliency and other constraints, like the cost of the microgrid.

A transit agency can also deploy additional energy assets to increase resiliency. Diesel or natural gas generators can be added to provide power during longer outages, though they produce emissions and are restricted by air quality regulations in some jurisdictions. Some transit agencies are looking for a zero-emission generator. New assets including stationary fuel cells are currently being developed for zero-emission resiliency solutions, as well as experiments with business models and operational models for fuel cells. The emerging technologies below could potentially play more of a role for resiliency in the future:

- Proton exchange membrane (PEM) and alkaline fuel cells use hydrogen to produce power. PEM fuel cells are used in FCEBs, but they can also be used for stationary applications. One advantage of PEM and alkaline fuel cells is their ability to load follow (i.e., quickly increase and decrease their power level) for rapid response to outages and/or changes in power demand that occur during charging. The main disadvantage to PEM fuel cells is that they need access to hydrogen to function. The price of hydrogen will need to decrease for this technology to be an economically viable solution.

- Solid oxide fuel cells can use natural gas to produce power.[12] These fuel cells operate most effectively at a constant power level and therefore struggle to load follow. This solution is ideal when a base load, such as a building, requires a constant load. With further research, the energy generation cost of solid oxide fuel cell power generators is expected to be equivalent to that of diesel and natural gas generators.
- Mobile generators that use hydrogen and fuel cells to produce power are also being developed. This technology can be paired directly to a charger. While still in early development stages, this solution will produce a model for using fuel cells to power vehicle chargers directly and provide fleet resiliency.

Total Cost of Ownership and Operating Model Considerations

Total Cost of Ownership

A microgrid can provide a lower total cost of ownership than traditional charging infrastructure. Microgrids are unique in that they can generate revenue. When calculating a microgrid's total cost of ownership, the following factors should be considered:

- **Capital expenditures** are the upfront capital costs associated with a microgrid. These expenditures include the cost of purchasing microgrid equipment, constructing and installing the microgrid, and any permitting required for the project.
- **Operational expenditures** are the ongoing costs associated with operating the microgrid. These expenditures can include maintenance costs, repair costs, and fuel costs if a generator or fuel cells are used.
- **Incentives** are provided by several governmental programs for charging infrastructure, which can help to reduce the capital expenditures associated with installing a microgrid.
- **Grid services** allow a microgrid to generate revenue, as well as increase cost savings. These services include peak shaving, demand response, and voltage regulation.

[12] Visit https://www.bloomenergy.com/blog/everything-you-need-to-know-about-solid-oxide-fuel-cells/ for more information on how solid oxide fuel cells function.

- **Tax benefits** are available if a microgrid incorporates renewable assets. For example, the installation of these types of assets, like solar panels and battery energy storage systems, are subject to the Investment Tax Credit.
- **LCFS credits** earned by a California-based transit agency can increase if the renewable content of the energy produced from a microgrid increases.

Operating Model

The operating model that a transit agency chooses to employ is determined by both regulatory and market factors. Each state has a different regulatory framework for microgrids, and some of these operating models may not be economically feasible or legal in every state. Consult **Section III. Key Considerations** for more information on high-level steps to design and conceptualize a microgrid based on state regulations and individual depot/fleet needs.

Front-of-the-Meter

Microgrids located at utility distribution systems will use a front-of-the-meter (FTM) model. In most cases, the utility will own and operate the microgrid for the benefit of customers. Customers downstream from the microgrid will receive power if the utility grid goes down. In most cases, utilities will charge a higher per-kWh rate for energy to recover the costs of the microgrid.

Behind-the-Meter

Microgrids located on the customer's side of the meter will use a behind-the-meter (BTM) model, meaning that, in most cases, the microgrid is located directly on the customer's property. There are two main operational models for BTM microgrids:

- Customer Owned: The transit agency finances, builds, owns, and operates the microgrid.
- Third-Party Purchase Power Agreement (PPA): A third-party company finances, builds, and operates the microgrid. This service is often bundled with charging infrastructure. The third-party company then signs a PPA with the transit agency to provide power. This operating model allows a fleet to deploy a microgrid without upfront capital costs.

Real-World Transit Microgrid Projects

Transit agencies are now receiving funding for microgrids as regulations mandate the transition to fully electric fleets. The following examples are not comprehensive of all microgrid projects currently undertaken across the country:

- **Blue Lake Rancheria (BLR)**, a federally recognized tribal government, is situated in the Humboldt Bay area of California, around 300 miles north of San Francisco. Located on the northeastern side of Humboldt Bay, and approximately five miles inland from the Pacific Ocean, this rural area is situated near the offshore intersection of three tectonic plates and frequently experiences natural disasters such as earthquakes, landslides, heavy rainfall, windstorms, and forest fires. To address the potential disruption to the power supply caused by these events, BLR deployed DERs in the form of a microgrid with a low-carbon backup power system. This microgrid not only reduces BLR's GHG emissions but also enhances its resilience, ensuring that it is well-equipped to handle any disruptive events. The microgrid system configuration consists of the following (Schatz Energy Research Center, n.d.):
    - 420-kW solar photovoltaic array
    - 1,150-kW/1,950-kWh battery energy storage system
    - Microgrid management system, point of common coupling (PCC) protective relay, and 1-MW backup diesel generator

  Integrating DERs helps BLR save $200,000 in utility costs annually (Carter, 2019). In addition, BLR's microgrid performed well during several recent blackouts between December 2022 and February 2023 that were caused by a 6.4-magnitude earthquake followed by heavy winter storms, knocking out power to more than 70,000 customers. During these outages, the microgrid powered not only BLR's Level-2 electric vehicle chargers, with capacity to charge its electric shuttle bus, but also an American Red Cross-certified evacuation center and a six-building campus, including tribal government offices, a hotel, restaurants, casino, events center, and telecommunications and water systems for more than 24 hours.[13]
- **Montgomery County Transit** (Ride On) in Maryland has deployed and is currently operating a microgrid at their Brookville Bus Depot.[14] This microgrid deployed 2 MW

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[13] Zoellick, J., Principal Engineer at Schatz Energy Research Center. Interview. March 6, 2023.

[14] Visit https://www.canarymedia.com/articles/clean-fleets/the-countrys-biggest-electric-bus-microgrid-is-open-for-business for more information on Montgomery County Transit's microgrid.

of solar, a 4-MWh battery energy storage system, and natural gas generators to provide resiliency for their ZEB fleet. The microgrid is primarily designed to protect against grid outages from extreme weather events. It will support up to 44 ZEBs with the ability to expand to 70 vehicles.

- **The Los Angeles Department of Transportation** (LADOT) was recently awarded funding to build out a solar and storage microgrid to power one of the largest fleet charging systems in the country.[15] LADOT plans to deploy 1.54 MW of solar and overhead bus charging/solar canopies and a 4.5-MWh battery energy storage system. The microgrid will be paired to 104 chargers and five 1.5-MW charging cabinets. Once completed, the microgrid will provide sufficient energy for 12 buses in the event of a utility grid outage.
- **The Anaheim Transportation Network** (ATN), which operates a fleet of 82 buses in Southern California, is in the process of building out its microgrid with charging stations, batteries, and other solar infrastructure as it transitions to zero-emission.[16] ATN will deploy multiple battery energy storage systems; microgrid controller units; and heavy-duty, electric battery charging stations at two of their facilities in Anaheim.
- **The Santa Clara Valley Transportation Authority** (VTA) in California will build a microgrid by deploying 1.5 MW of solar at a bus yard with available rooftop space and an overhead carport canopy.[17] This system will be paired with a battery energy storage system that can store 4 MWh of electricity and 1 MW of peak output power to provide emergency backup electricity for up to 20 hours. VTA will also be able to easily connect a temporary generator to provide additional backup power in the event of extended outages.

[15] Visit https://ladot.lacity.org/dotnews/los-angeles-department-transportation-install-solar-and-storage-microgrid-and-ev-charging for more information on LADOT's microgrid project.

[16] Visit https://www.metro-magazine.com/10137553/anaheim-transportation-network-lands-5m-clean--energy-grantor more information on ATN's microgrid project.

[17] Visit https://www.proterra.com/press-release/vta-solar-powered-microgrid/ for more information on VTA's microgrid project.

III. Key Considerations

Developing and constructing a microgrid is a critical but highly resource-intensive solution to build ZEB fleet resiliency. Below is a list of top five high-level factors that must be considered for microgrids on a project-by-project basis:

1. **Determine purpose:** Identify the type of emergency for which the microgrid is meant to respond. Transit agencies need to evaluate how long an outage is likely to occur during a typical emergency and how long the microgrid will need to provide resiliency.
2. **Identify critical loads:** Pinpoint which loads must continue to have power during a grid outage. This list can include buildings, maintenance bays, data servers, and safety equipment. Transit agencies must also identify the number of vehicles that must have access to power from the microgrid in the event of an outage.
3. **Select acceptable energy assets:** Assess the types of energy assets that can be included in the microgrid. For example, a transit agency needs to determine whether they want to include natural gas or diesel generators in the energy portfolio. In addition, studies to determine how much solar and battery storage can fit onto the site should be conducted.
4. **Calculate energy consumption and power demand:** Estimate energy consumption for buildings and existing loads by analyzing utility bills. Use route modelling or analyze telematics or charger data to estimate energy consumption and power demand.
5. **Size microgrid components and optimize for usage:** Use microgrid modelling software to size components and develop a conceptual design (i.e., equivalent to a 10% design drawing) that will meet calculated energy consumption and power demands, as well as other factors identified in previous steps.

CALSTART can help connect fleets with member companies that offer technological components, services, and more for microgrid development and implementation. Contact the following individuals for assistance in investigating these key considerations before planning and building a microgrid:

- Bryan Lee, blee@calstart.org
- Aditya Kushwah, akushwah@calstart.org
- Brian Ballschmidt, bballschmidt@calstart.org

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Appendix

Figure 1 Methodology

The assumptions listed in Table A-1 were utilized to develop Figure 1. Power Demand Comparisons.

Table A-1. Assumptions for Power Demand Comparisons

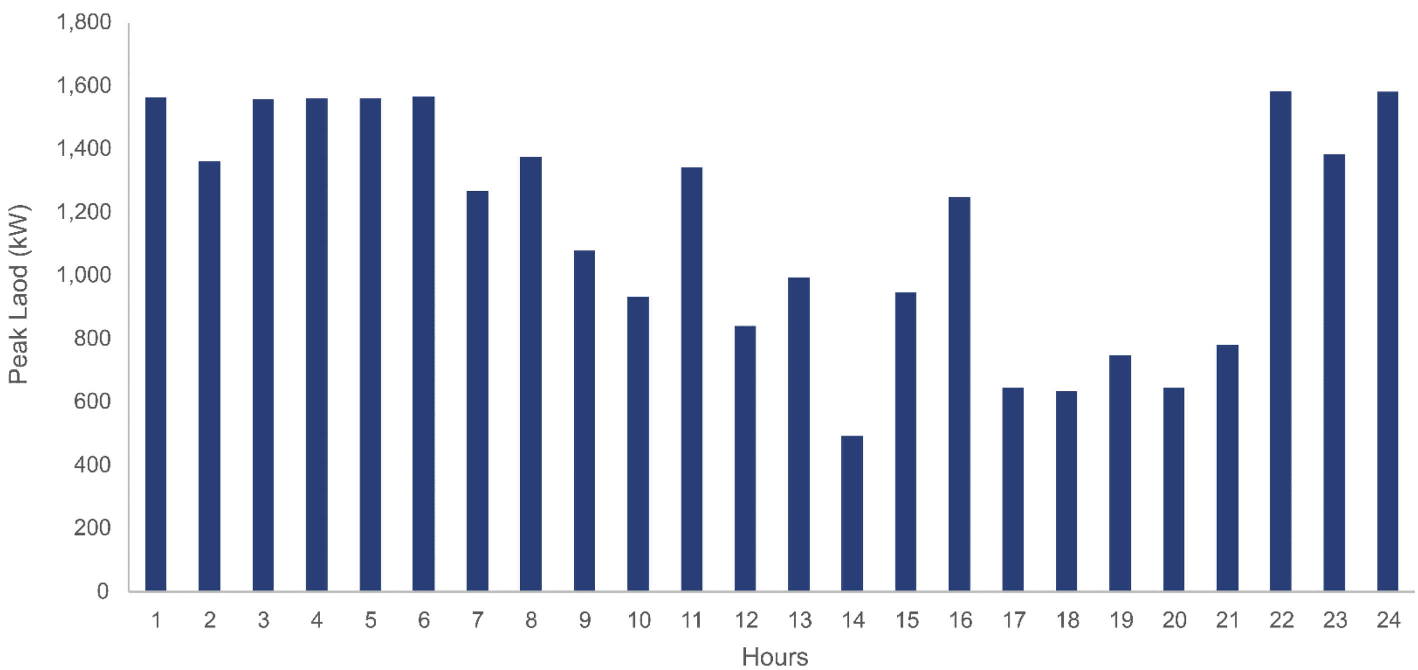
Fleet	Number of Vehicles/Structures	Power Demand Per Vehicle (kW)	Total Power Demand (kW)
100 Electric Cars	100	7	700
100 Medium-Duty Electric Vans	100	15	1,500
Chrysler Building	1	2,400	2,400
Ellen Electric Ferry Vessel	1	4,000	4,000
100 Electric School Buses	100	50	5,000
100 Electric Transit Buses[18]	100	100	10,000

[18] The depot for a medium-sized fleet typically houses 100–200 buses.

Sample Microgrid Load Shift Methodology

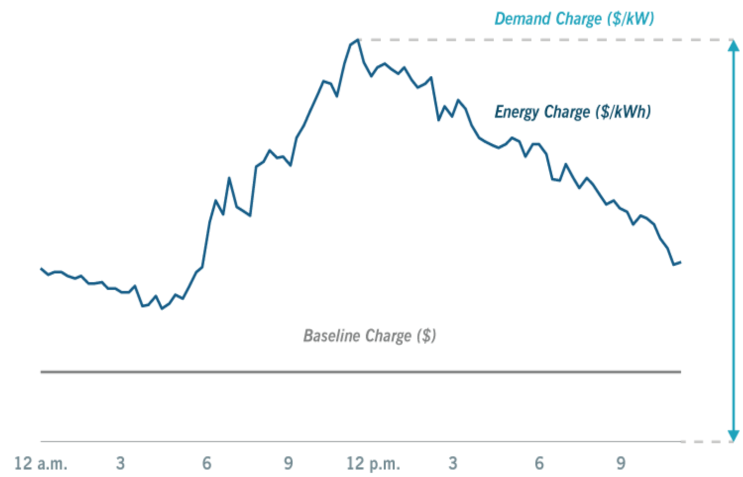
The financial analysis provided in the **Sample Microgrid Load Shift Analysis** section is based on the daily load profile provided in Figure A-1. This load schedule is for a hypothetical fleet that has deployed 65 ZEBs. This load profile was used to calculate the business-as-usual peak loads. CALSTART then simulated the behavior of a microgrid to estimate the peak loads with a microgrid deployed. These results are displayed in Figure 5. Reduced Monthly Peak Load with Microgrid System.

Figure A-1. Sample Daily Peak Load for 65 Zero-Emission Transit Bus Fleet



This example also provided calculations to demonstrate the potential savings that can be realized by deploying a microgrid. The utility bill for a transit agency consists of energy charges (i.e., charged per kWh of electricity) and demand charges (i.e., charged by kW of power drawn from the grid). Figure A-2 illustrates the difference between these parameters.

Figure A-2. Demand Charge Example (Duke Energy, 2019)



CALSTART calculated savings from deploying a microgrid by analyzing the reduction in power demand. CALSTART simulated the behavior of a microgrid to estimate peak load under both scenarios. The annual business-as-usual utility expenses and the annual utility expenses with a microgrid in place were then calculated. This analysis assumed a hypothetical TOU tariff for energy charges and a demand charge using the rates detailed in Table 2. The total utility bill was calculated using the three equations listed below.

Equation 1. Monthly Demand Charges Calculation

$$Monthly\ Demand\ Charges\ (\$/month) = Demand\ charge\ (\$/kW) * Monthly\ peak\ demand\ (kW)\ in\ 15\ minute\ interval\ data$$

Equation 2. Monthly Energy Charges Calculation

$$Monthly\ Energy\ Charge\ (\$/month) = Energy\ charges\ (\$/kWh)\ for\ TOU\ rate * Total\ energy\ consumed\ (kWh)\ in\ TOU$$

Equation 3. Monthly Utility Bill Calculation

$$Total\ Utility\ Bill\ (\$/month) = Demand\ charge\ (\$/month) + Energy\ charge\ (\$/month)$$

Demand charges/subscription costs ($/kW) are determined based on the month's 15-minute peak power use (max kW per month) as mentioned in Equation 1. Energy charges ($/kWh) are calculated based on total energy utilized (kWh). The energy costs fluctuate depending on the TOU rate. For a single day, the hypothetical on-peak, off-peak, and super off-peak rates were considered. The total energy charges for the month were calculated by multiplying the energy spent during these TOU times by the respective electrical energy rates (Equation 2). Finally, the demand/subscription charge and the energy charges were summed to arrive at the annual utility bill (Equation 3).