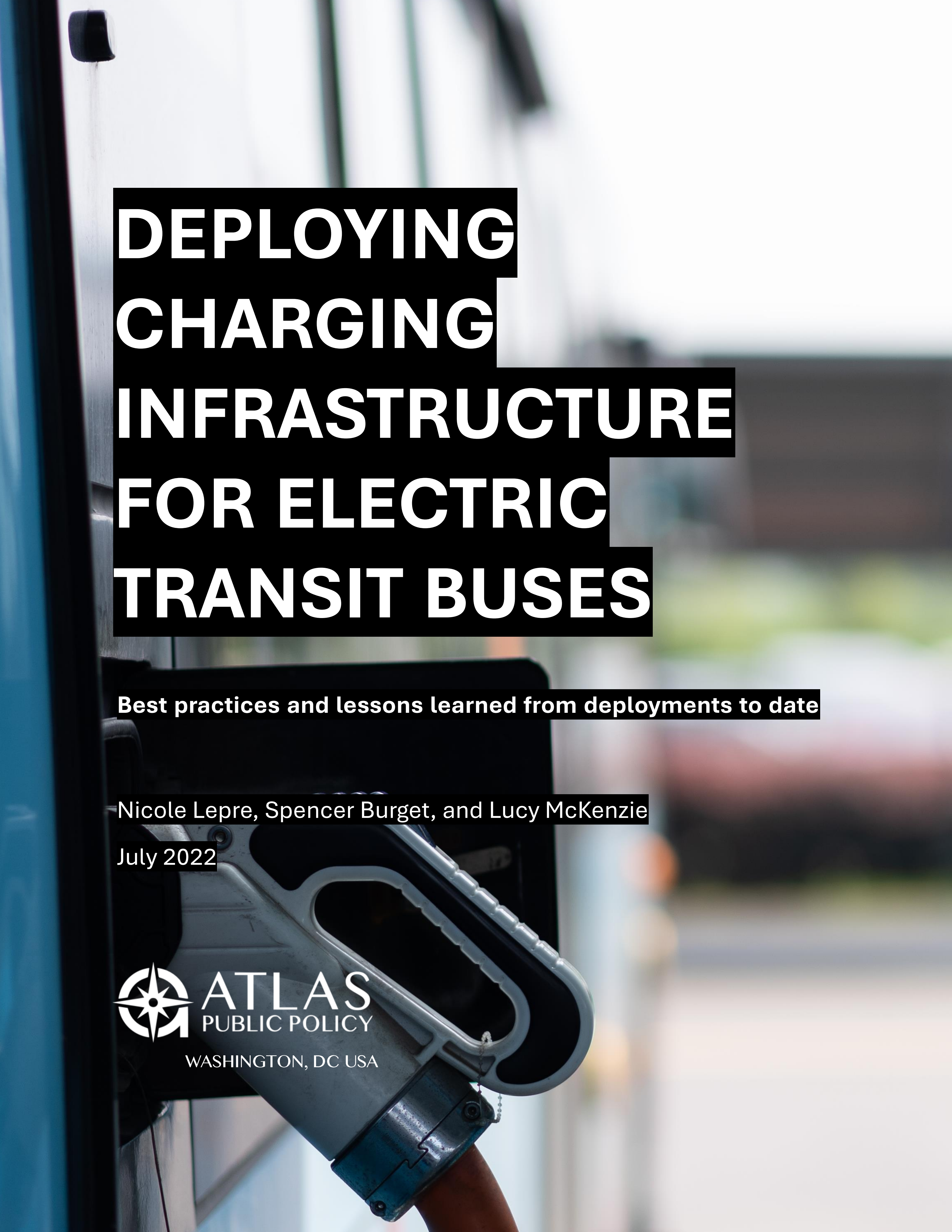

DEPLOYING CHARGING INFRASTRUCTURE FOR ELECTRIC TRANSIT BUSES

Best practices and lessons learned from deployments to date

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Objectives, Methods & Acknowledgements

This study was supported by Environmental Defense Fund. It is aimed at assisting transit agencies as they begin to plan for significant electrification of their bus fleets. It focuses on *battery electric technologies* (not fuel cell technologies) and is limited in scope to *charging* technologies, designs, and choices (rather than *vehicle* technologies, except as these impact charging).

This is not the first study to provide best practices on battery electric bus (BEB) deployment. It complements published expertise in BEB deployment from the Center for Transportation and the Environment (CTE) [1], the National Renewable Energy Laboratory (NREL) [2], and CALSTART [3] [4] [5], among others. These authors are referenced throughout, and transit agencies are advised to consult their work in addition to this report.

As well as drawing from these and other published works, this report incorporates learnings from 29 industry interviews completed between January and April 2022 by Atlas Public Policy staff. Interviewees are listed in Figure 1. These interviews sought to understand latest developments, challenges, solutions, and lessons learned in BEB charging, and to compile specific examples, anecdotes and on-the-ground experiences from those at the forefront of deployment. Atlas Public Policy thanks the interviewees for their time and willingness to share their knowledge.

The remainder of this report details best practices and lessons learned in seven chapters:

- Designing Charging Facilities
- Utility Engagement
- Planning for Grid Resilience
- Ensuring Reliable Charging
- Software-Based Managed Charging Solutions
- Charging Infrastructure Costs and Timelines
- Financing Charging

A final chapter, “Advice From Those Further Down the Road,” reports interviewees’ answers to two final questions:

1. What do you see as the biggest remaining barriers to electrifying bus fleets?
2. What should be a transit agency’s first steps in planning for electrification?

Figure 1: Organizations interviewed for this report

Transit agencies (twelve with BEBs deployed; two just beginning to electrify):

- Foothill Transit , CA
- Long Beach Transit, CA
- Los Angeles Metro, CA
- Santa Clara Valley Transportation Authority, CA
- Chicago Transit Authority, IL
- Transit Authority of River City, KY
- Metro Transit, MN
- Mountain Line, MT
- New Jersey Transit, NJ
- Rochester Transit Service, NY
- New York City Transit, NY
- TriMet, OR
- Metropolitan Transit Authority of Harris County, TX
- King County Metro, WA

Electric utilities with battery electric bus programs:

- Pacific Gas & Electric, CA
- Xcel Energy, CO & MN
- Hawaiian Electric, HI
- DTE Energy, MI
- Portland General Electric, OR

Not-for-profit organizations with electric bus deployment experience:

- Center for Transportation and the Environment (CTE)
- Electric Power Research Institute (EPRI)
- American Public Transportation Association (APTA)
- CALSTART

Engineering firms with electric bus deployment experience:

- HDR
- WSP

Charging and/or managed charging providers:

- ABB
- Amply
- Mobility House
- Proterra

Designing Charging Facilities

Choosing and planning for the charging strategy, or combination of strategies, that best fits a transit agency's unique operating requirements is an essential step towards the successful deployment of electric transit buses. Many of the earliest adopters chose to electrify short circulator or bus rapid transit (BRT) routes utilizing on-route chargers -- these routes were well suited for early battery technology that had extremely limited geographic range but could accept a powerful charge. As battery and charger technology has improved over time, agencies now have a broader range of options.

Evaluating these options requires detailed modeling of energy needs, charging schedules, and operator behavior as well as power and space availability at the depot. In addition, designing around space and power constraints may require facility upgrades and/or the construction of entirely new facilities. Agencies must coordinate their electric bus deployments around these multi-year construction projects. Interviewees stressed the importance of developing a comprehensive transition plan with an end goal in mind, rather than planning one deployment at a time. For transit agencies without strong in-house electrification expertise, CTE and transit agency interviewees recommended working with a consultant or other expert [7].

Developing a Transition Plan

At the core of a comprehensive transition plan is a fleetwide feasibility assessment to identify which bus blocks can be served by available electric bus technology and which blocks may require improved technology, on-route charging, or an alternative solution.

One engineering firm recommended that fleets conduct an energy-based assessment rather than a mileage-based assessment: beyond considering route lengths, agencies should also consider buses' full daily operating schedules, vehicle weight, downtime between blocks, and any operating conditions that may impact energy use. For example, agencies operating in particularly hot or cold climates could experience significant reductions in range due to the energy needed to heat or cool buses. Similarly, routes with significant vertical gain may use more energy per mile traveled. CTE recommended that fleets also incorporate real-world expected mid-life battery degradation into this feasibility assessment.

As they scale up their EV fleets, agencies may also consider modifying their blocks and operations to fit the capabilities of battery electric buses rather than trying to make electric buses work in frameworks designed for diesel buses. Interviewees suggested assessing the potential to change blocks or increase ins and outs in order to identify potential electrification opportunities beyond a one-for-one switch-out with existing diesel buses.

Agencies can then begin to plan their transition to electric buses, taking into account their deployment goals and constraints, remaining useful life of the current fleet, and the condition of existing facilities. The transition plan should inform the fleet replacement schedule, the energy need at each depot, and the facility upgrades needed to support electrification. CTE recommends revisiting this plan every 2 years to incorporate changes to regulatory requirements, agency operations, lessons learned from other deployments, and deployment data [1].

Figure 2: Facilities Buildout Diagrams, LA Metro Zero-Emission Bus Rollout Plan

This figure from LA Metro's Zero-Emission Bus Rollout Plan depicts the proposed design and buildout plan for the conversion of their Division 18 to electric buses. Clockwise (from upper left), the diagrams show existing conditions (December 2018), to construction staging, to full buildout.

Source: Los Angeles County Metropolitan Transportation Authority [6]

Outreach is an important part of the transition planning process. Interviewees recommended engaging electric service providers, agencies that have already deployed electric buses, equipment manufacturers, and third-party consultants or nonprofits. Industry groups such as the Zero Emission Bus Resource Alliance (ZEBRA) and the American Public Transit Association (APTA) are also valuable resources for transit agencies beginning their electrification journey. The Chicago Transit Authority (CTA) suggested developing an internal structure that brings together departments relevant to electrification, and interviewees also stressed the need to consult external stakeholders during the planning process to incorporate the needs of the community.

Metro Transit (Minnesota) and CTA recently published detailed transition plans that can serve as examples for transit agencies just getting started [7], [8]. In addition, every large transit agency in California was required to submit a zero-emission bus rollout plan to the California Air Resources Board (CARB) under the Innovative Clean Transit rule. These plans are all available on CARB's Innovative Clean Transit Website [9]. As of Fiscal Year 2022, all applicants proposing funding for zero-emission projects under the Federal Transit Administration's Buses and Bus Facilities Competitive Grant Program and/or the Low or No Emission Competitive Grant Program are also required to develop a Zero Emission Fleet Transition Plan.

On-Route vs Depot Charging

One of the first decisions an agency needs to make is where it is going to charge its battery electric buses. Agencies can charge buses along routes while they are in service, known as on-route charging, or while parked (often overnight) at a depot. Many agencies also use a combination of the two.

On-route charging tends to be more expensive and logistically challenging than depot charging. Agencies may have to acquire land or rights of way in order to install charging stations along their routes. On-route charging requires fast chargers (350kW+) which are more expensive than slower chargers that can be used during longer parking windows. Agencies have little control over when on-route charging occurs, which can lead to high electricity costs due to demand charges and time-of-use-rates. There are also a number of risks associated with locating chargers in public outdoor spaces. Challenges experienced by interviewees included intentional vandalism of on-route chargers, a wayward recycling truck destroying charging structures[1], complaints from neighbors who don't appreciate having chargers being located next to their residences, and on-route chargers shutting off below -20°F. When these or other problems occur, it can be more challenging for agencies to fix or maintain on-route chargers because maintenance staff must travel to reach them. In addition, Santa Clara Valley Transit described that, when relying on on-route charging infrastructure, there are occasional challenges with transit service reliability if one on-route charger is not operational.

As a result, the general consensus among interviewees is that agencies should charge as much as they can at depots and only use on-route charging where necessary for especially long routes or for short circulator routes where on-route charging can enable buses to run continuously. With current battery technology, a substantial portion of agencies' fleets can usually be electrified with just depot charging. Many fleets are opting to start with this "low

[1] This agency was not alone; four out of 11 transit agencies surveyed in a 2018 report experienced non-electric vehicles colliding with on-route charging structures [36].

hanging fruit" before tackling the blocks that may require on-route charging. There is still considerable uncertainty as to how much battery technology will continue to improve in the coming years, and routes that are too long to be electrified today without on-route charging may be possible to electrify in the future.

While most agencies are avoiding on-route charging where possible, there are some benefits to this type of charging in addition to range extension. On-route charging could work well for agencies that do not have space available at depots to install charging infrastructure, and may create a charging ecosystem that is more resilient to power outages because it is decentralized.

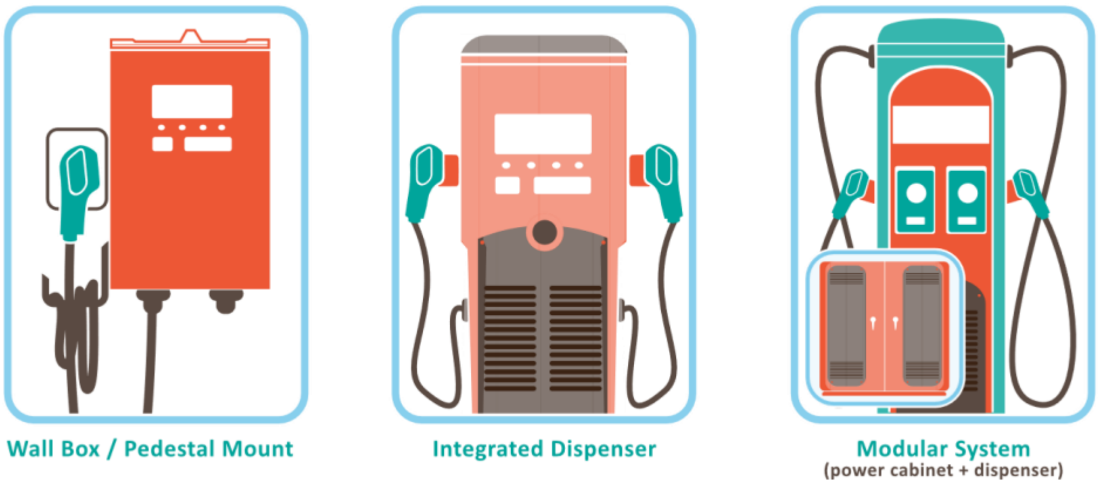
Charging Ratio and Power Level

Once agencies have decided where their buses will charge, the next step is to determine the appropriate power level and charging ratio (the number of buses per charger). These decisions are inter-related, as higher power levels could enable each charger to serve more buses.

Typical bus charging power levels range from 65 to 150 kW for "slow" charging and from 350 to 600 kW for "fast" charging. At these levels, it generally takes five hours or less to fully charge a bus on a slow charger, and 5 to 20 minutes to top off a bus on a fast charger [2]. Bus batteries have limits on how much power they can accept, so it is crucial that agencies ensure that the buses they have procured are capable of taking the power level that they select for their chargers.

While most agencies interviewed plan to have one charger for each bus at their depot, some agencies are considering strategies to share power among buses. Doing so can save equipment costs, utility upgrade costs, and space at the depot. However, using a higher bus-to-charger ratio can introduce additional planning and operational challenges. Having multiple buses depending on a single charger can magnify the impacts of a charger being out of service. Furthermore, if each charger only has one dispenser, agencies may incur additional labor costs to shuffle buses between chargers. A number of agencies are getting around this issue by deploying modular charging systems that separate the charging cabinet (which holds the electrical charging equipment) from the dispenser (which can be as simple as a plug on the end of a cable). This can allow agencies to use multiple dispensers for each power cabinet, along with managed charging software, to automatically shuffle charging between buses and avoid significant manual effort (see Figure 3 and chapter on Software-Based Managed Charging Solutions).

Figure 3: EVSE Equipment Configurations for DC Fast Chargers



This figure from GNA's Electric Vehicle Charging Guidebook depicts different configurations for DC Fast Chargers. The modular system depicted farthest to the right offers agencies flexibility to locate power cabinets separate from dispensers.

Source: Gladstein Neandross & Associates [10]

Citing concerns over charger reliability, some agencies expressed hesitance to fully optimize the use of each charger. Santa Clara VTA, for example, is planning to start with a one-to-one ratio and then add more buses once the system has demonstrated reliability.

Other agencies undertaking large scale deployments are beginning to combine fast and slow chargers at their depots in order to enable more dynamic charging approaches. CTA, for example, is planning to install fast chargers in bus wash lanes so that each bus can get a quick charge right when it comes into the depot and top off in the morning if needed. This will allow CTA to reduce the total number of chargers needed, saving space and equipment costs. CTA's zero-emission bus plan considers three different garage charging strategies, ranging from all slow charging to mostly fast charging. CTA notes in their Charging Forward report that, in practice, even with all slow charging, at least one fast charger would likely also be installed at each garage for maintenance and resiliency purposes [8]. Based on their analysis, utilizing more fast charging reduces total charger costs, reduces peak power draw, and saves space. For one depot modeled, seven fast chargers and nine slow chargers can do the job of 83 slow chargers [8]. However, CTA cites several potential concerns with high fast charger utilization, such as increased battery degradation, added labor costs, and buses losing charge in the cold weather while they are not plugged in.

King County Metro and Metro Minnesota are also planning to use a combination of fast and slow chargers at their depots. King County's new dedicated electric bus depot will feature four 450 – 600 kW fast chargers and 96 pantograph 100 – 150 kW slow chargers, while Metro Minnesota plans to install at least two fast chargers in their depot to provide recovery capabilities in case a bus comes in late, was undergoing maintenance, or did not charge properly overnight [7].

Overall, there are opportunities to save space and money if agencies are willing to take on the planning challenge of pursuing more dynamic and varied charging strategies than the simple one-to-one bus-to-slow-charger approach at the depot. Ensuring reliability when using a more complex charging strategy will require detailed modeling as well as on-the-ground testing. All of the agencies mentioned above had experience charging electric transit buses prior to undertaking a more complex charging strategy.

Plug-in vs Inverted Pantograph Charging Dispensers

As agencies look to scale up deployments, plug-in chargers traditionally used for depot charging can become more challenging to manage. Nearly every agency interviewed considering a deployment of more than five to ten buses has turned to overhead pantograph dispensers for their depot, a technology that historically had been reserved for on-route charging.

The principal benefit that inverted pantograph (SAE J3105-1) dispensers offer over plug-in dispensers is that they simplify the process of initiating and ending a charging session. While it is easy enough to plug and unplug a fleet of five to ten electric buses, that process can become burdensome for fleets of fifty, one hundred, or more. With inverted pantograph charging, an operator or maintenance staff member sets the parking brake and then the pantograph initiates or ends the charging session. King County is working to simplify this process even further by developing technology that will automatically initiate the charging session once the operator pulls the bus in and sets the parking brake. King County noted in a follow-up interview that they have finished developing this technology and that it is working successfully.

Figure 4: Inverted Pantograph Chargers at King County Metro's Test Charging Facility

King County Metro's test charging facility opened in March 2022 uses inverted pantograph dispensers mounted on overhead structures to charge up to nine battery-electric buses simultaneously.

Source: King County Metro [11], [12]

Inverted pantographs also solve another key issue that agencies identified with scaling plug-in chargers: cord management. It can be dangerous to have high voltage cords laying around a depot and managing cords can be a significant burden on operators and maintenance staff. Some solutions are emerging such as electronic overhead cord reels, but pantographs offer the option to remove cords entirely.

The downsides to pantograph dispensers compared to plug-in chargers are that they are more expensive, require more structural support, and may offer less reliable communication between bus and charger because communication is done wirelessly. Traditionally, pantograph chargers in on-route applications have used Wi-Fi signals to communicate between the charger and bus. When agencies began deploying sets of pantograph chargers next to each other in a depot setting, they found that these Wi-Fi signals could get crossed between many adjacent pantographs. As a result, the SAE Medium and Heavy-Duty Vehicle Conductive Charging Task Force is developing an update to the SAE J3105 standard that will use radio-frequency identification (RFID) tags rather than Wi-Fi signals to identify buses. This approach is already being pioneered by King County Metro.

Plug-in dispensers offer a simpler approach that has worked sufficiently well for several (especially smaller) deployments. Cord safety issues can be addressed by installing dispensers on overhead cord reels (see Figure 5).

Fleets should consider their specific needs and facility constraints in considering the tradeoff between the labor costs of plugging in buses and the equipment costs of the pantographs and supporting structures.

Figure 5: Plug-In Dispenser Cord Reels at Foothill Transit's Arcadia Depot

This figure from the National Renewable Energy Laboratory’s Foothill Transit Battery Electric Bus Evaluation shows the overhead structure at Foothill Transit’s Arcadia Depot. Plug-in charging dispensers drop down from motorized hose reels mounted on the gantry structure.

Source: National Renewable Energy Laboratory [13]

Box 1. Designing a Charging Ecosystem is Not One-Size-Fits-All

TriMet in Portland Oregon is a notable exception to several trends in charging strategy that demonstrates how agencies can tailor their charging strategy to their unique needs and characteristics. After an initial deployment of five buses in 2018 and five more in 2021, Tri Met is preparing for its next deployment of 24 buses set to arrive in 2023. TriMet has designed a unique charging strategy that will utilize central “charging islands” each equipped with 12, 160 kW chargers. Buses will be manually cycled through the island overnight with the goal of charging 3 buses from each charger per night. The chargers are intentionally designed to be as simple as possible in order to ensure reliability. Each charging box has a single plug-in dispenser, ensuring that if one box goes down, only one dispenser is affected. TriMet’s on-site staff and available space at outdoor depots enables this manual approach, though they did also note the need to develop operation and maintenance training and processes for staff to follow when things don’t go as planned.

Wireless Inductive Charging

Agencies have a third choice when it comes to choosing charging dispensers: wireless inductive charging dispensers. These large metal charging pads are sunk into the ground and wirelessly transfer electricity to a bus parked above. Inductive charging for transit buses has been piloted through a handful of deployments dating back to 2014 and recently came into the limelight as the technology of choice for Antelope Valley Transit Authority (AVTA), the first all-electric transit agency in North America [14, 15]. AVTA has deployed 12 250kW inductive charging stations as range extenders with three more on the way [16]. These on-route inductive stations supplement 87 plug-in conductive chargers at the depot [14].

Wireless charging offers a number of benefits by eliminating the need for any manual connection. In on-route applications, wireless chargers reduce the risk of collisions with non-transit vehicles, obstructions of roadways or sidewalks, and vandalism. They are also aesthetically pleasing, which may ease environmental permitting processes in some states and appease residents.[2] In a depot application, these dispensers can simplify the charging process and save space, although an above-ground charging cabinet is still required. The

[2] Some states, including California and Washington, require visual impact assessments as part of their state environmental review. One agency mentioned having to implement treatments to beautify chargers in public places.

primary drawback to wireless charging is the relative nascency of the technology and the high capital and construction costs. Inductive charging is still some years behind conductive charging in terms of the breadth of product offerings and interoperability with all bus manufacturers.

Space Needs

Transitioning from a diesel to an electric bus fleet may require significant changes to agency facilities in order to accommodate charging equipment, electrical upgrades, and other modifications to existing operations. Electrical equipment, from transformers and switch gear to power cabinets and dispensers, can take up a considerable amount of space. One of the principal challenges described by transit agencies was the need to minimize the loss of parking spaces in already crowded depots while making room for the electrical equipment needed to run an electric fleet.

Several agencies interviewed are preserving bus storage space by separating power cabinets from dispensers. The power cabinet takes up most of the space, while the dispenser can be as simple as a plug on the end of a cable attached to a small pedestal or overhead support. Depending on the manufacturer, this dispenser can be up to 500 feet away from the power cabinet, allowing agencies more flexibility in where they locate power cabinets. One agency plans to place power cabinets against the walls on the edges of the parking area, minimizing losses to bus storage capability.

Another common solution is to build overhead structures or gantries to mount charging equipment. These structural supports may take up a few feet every several parking spaces, but they allow for space-saving overhead charging dispensers in the form of either inverted pantographs or cord reels. LA Metro, who is particularly space constrained, plans to mount power cabinets in addition to inverted pantograph dispensers on overhead gantry structures (Figure 6). Depending on the structural integrity of the facility, cord reels or even inverted pantographs may alternatively be mounted directly to existing ceiling structures.

Figure 6: Design Rendering of Charging Infrastructure Layout for LA Metro

Source: ZEBGO, December 2019

This figure from LA Metro's Final Rollout Plan depicts gantry-mounted chargers, conduit, and associated pantographs above buses, with power cabinets along the outside. The design is intended to address space constraints at their depots.

Source: LA Metro [6]

Manufacturers are developing space-saving technologies that combine multiple power cabinets and electrical equipment into one structure. In this way, charging equipment capable of charging up to 20 vehicles simultaneously plus medium-voltage transformer and switchgear can be collocated in a footprint two-thirds the size of the equipment if it were installed individually [17]. Manufacturers are also working on space-saving approaches that combine EV charging infrastructure with the inverters needed to support storage and solar.

Even with these space-saving strategies, space remains a significant challenge, particularly in dense urban locations. Parking loss is inevitable in most cases and many fleets are looking towards new facilities to accommodate their growing electric bus fleets: designing a facility for electric buses from the ground up is considerably easier than trying to retrofit an existing facility that was designed with diesel buses in mind. Six out of 14 agencies interviewed expect to construct a new electric-ready depot as part of their transition.

Operational Staffing Needed for Charging

The exact workforce needs of a given charging design will depend heavily on the scale of the deployment, and on the agency's existing experience with electric systems. Agencies that have experience operating electric light-rail, trolley buses, or even diesel-hybrid buses will be better prepared to deploy, operate, and maintain battery-electric buses. Agencies should identify gaps in their own staffing and work preemptively to build capacity with electric systems. Utilities, consultants, and other agencies can be excellent sources of advice and resources for agencies just beginning to familiarize themselves with electric technology.

Electric buses have different operational requirements than diesel buses. For example, agencies must decide who is responsible for plugging and unplugging buses to charging equipment or turning on pantograph charging, and who will shuffle buses between chargers, if required. Transit agency staff contracts may have restrictions on who can handle high voltage equipment. One agency interviewed added additional shifts for maintenance staff to come in to unplug buses in the morning, as bus operators could not perform fueling functions under their existing contract. Agencies should engage maintenance staff and any relevant labor unions early in the transition to understand how new electric bus operations fit into existing contracts.

Agencies can design their charging strategy to minimize operational changes. For example, an agency with adequate overnight staffing may opt to install simple plug-in chargers and manually move buses between them (see the TriMet example in Box 1). Alternatively, a staff-constrained agency may use automated pantograph dispensers so that staff are not needed to initiate or end charging sessions. Agencies can also use a managed charging software solution to shift charge between buses during the night without having to physically relocate the buses (see Software-Based Managed Charging Solutions chapter).

Sequencing Charging Facilities: From Pilot to Full Electrification

Agencies are taking many different approaches to choosing which depots and blocks to begin with on their electrification journey. Most agencies have started with a pilot project of five to ten buses. This pilot has typically been intended to build support for electric buses, test infrastructure and processes, and develop internal experience and learnings. Agencies have commonly selected prominent, visible bus routes and/or routes that further environmental justice outcomes. As agencies begin to scale, many are targeting the depots that require the least modification, taking into account available service capacity, space constraints, the need for facility upgrades, and ownership/easement considerations.

New York City Transit's most significant constraint is electric service capacity. As a result, they are spreading out their initial deployments to make use of the available power available at each depot and managing utility upgrades where necessary. Doing so will enable the agency to deploy 60 buses across five different depots without significant upgrades at all but one depot.

LA Metro, on the other hand, is primarily space constrained. They are electrifying each depot in its entirety one at a time, starting with the depots that have enough space on site so as not to have to displace buses during construction, and saving the most space-constrained depots for last [6].

CALSTART advised that agencies should also consider whether they own, lease, or share a depot when sequencing electrification. Agencies may run into challenges in investing in improvements at leased facilities, due to risk of relocating, and utilities may also be hesitant to upgrade service connections if long-term demand is not guaranteed. LA Metro described challenges coordinating easements at a shared property where construction would impact parking spaces belonging to a different public agency.

Among routes that can be feasibly electrified, some transit agencies are prioritizing routes in communities that have historically experienced high levels of air pollution. For example, Metropolitan Transit Authority of Harris County is planning to first electrify routes serving communities disproportionately affected by vehicle emissions, Alameda-Contra Costa Transit District (AC transit) is prioritizing routes in disadvantaged communities (as defined by California SB 535), and Metro Transit developed an equity and environmental justice prioritization tool through community engagement that will directly inform deployment decisions at the block level [18] [19] [7].

In the early pilot stages, battery electric buses may experience more downtime than diesel buses as technologies are tested and agencies adapt to new operations. Agencies should undertake sufficient planning and testing to ensure that they can maintain reliable service on these routes and avoid negatively impacting the communities that they seek to benefit. It is especially critical to guard against potential impacts to service reliability in environmental justice communities.

A number of interviewees suggested that, where possible, it is important for agencies undertaking pilot projects and small-scale deployments to ensure that the concepts used will be able to scale to larger deployments. Several agencies interviewed are using pilot deployments as an opportunity to test scalable charging strategies. While it may require more work initially, these agencies will be well prepared when it comes time to scale. Further, utilizing replicable strategies from the beginning can avoid the operational headache of having mismatched charging infrastructure left over from pilot deployments.

King County Metro, for example, is designing a 40-bus pilot with a focus on automated pantograph charging and managed charging software that they hope will enable them to scale to their fleet of more than 1,500 buses. Already, they are developing key learnings that will help them scale more rapidly, such as fine tuning a system that automatically connects the pantograph when the bus parks. This technology will avoid the need for an operator to flip a switch to engage the pantograph, a relatively minor inconvenience with 40 buses but a more significant operational undertaking with 1,500.

Santa Clara VTA is similarly approaching electrification with scale in mind. VTA's plan is to electrify their fleet in 34 bus blocks, which roughly coincides with the size of the existing parking blocks at their depots. They have designed a microgrid solution that uses overhead structures to support both solar panels and pantograph charging dispensers. Simultaneously, they are using an integrated 1 MW power cabinet with a contained transformer that can accept medium voltage straight from the grid. Once this approach is tested and proven, it can be easily replicated in 34-bus increments.

Still, a number of agencies expressed feeling overwhelmed and under-resourced when it comes to planning for electrification. This can lead agencies to implement solutions that feel most feasible near-term and cross the more challenging bridges as they come. For example, one agency is using wall-mounted plug-in chargers with their pilot buses even though they know that they do not have the space or the labor to scale stand-alone plug-in chargers to the remainder of their fleet. Interviewees suggested seeking outside expertise from consultants, engineering firms, NGOs, utilities, and/or other transit agencies to assist with initial planning and reduce overwhelm.

Utility Engagement

Electric utilities have one of the most significant roles to play in development and execution of a transit agency's bus electrification transition plan. There is wide agreement across published research that transit agencies should engage their utilities early in the process of electrifying their bus fleets, and when asked what a transit agency's first step should be, 14 out of 25 interviewed transit agencies and utilities emphasized the importance of engaging with utilities early. Metro Transit in Minneapolis, Minnesota, stated that one of their key areas of success was in establishing good interagency relationships with electrical specialists at their utility, Xcel Energy.

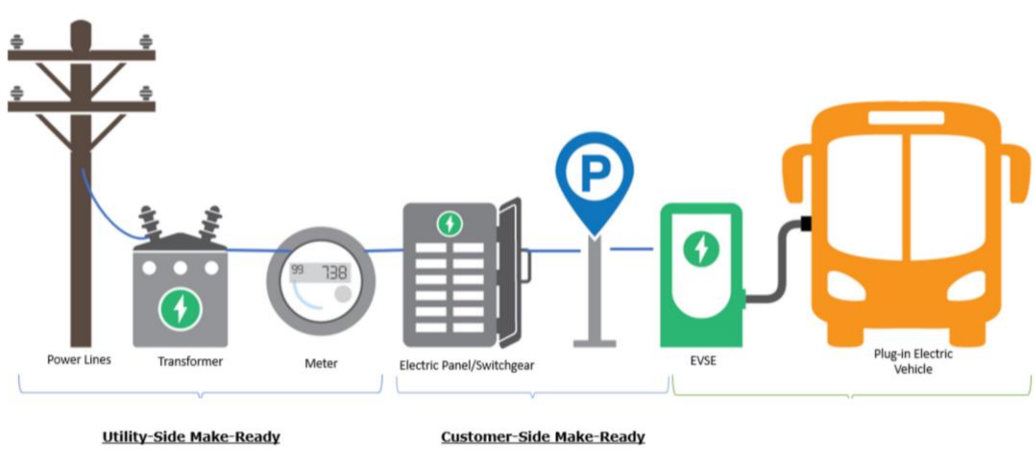
Charging electric buses requires substantial electrical capacity and, in many cases, will require upgrades to electrical infrastructure. Utilities provide essential information about how long these upgrades will take and how much they will cost the transit agency. Upgrades can take a long time to complete, in some cases years, so it is essential for transit agencies to consult with their utility early. Pacific Gas & Electric (PG&E) noted that early utility engagement is especially critical for transit agencies who intend to install solar or storage at their charging facilities, since these technologies trigger unique interconnection processes that can take time.

In order to understand how transit agencies and utilities can best work together on bus electrification, it is useful to understand the different types of electrical infrastructure needed to support chargers and which parts of the system transit agencies are generally responsible for funding. In general, this infrastructure can be broken down into three segments, illustrated in Figure 7.

- Utility-side make-ready infrastructure (also called "line extension" infrastructure)
- Customer-side make-ready infrastructure (also called "electric vehicle supply infrastructure"), and
- The chargers themselves (also called the electric vehicle supply equipment ("EVSE")).

Depending on the utility that serves them, a transit agency could be responsible for part or all of the cost of all three segments. The Financing Charging chapter provides examples of the kinds of programs available at some utilities to offset costs, sometimes significantly. Large transit agencies with substantial electrification plans may also have the option of taking 'primary service' from their utility, where the transit agency owns the electrical infrastructure that is normally on the utility's side of the meter and takes service directly from their utility's primary, high-voltage lines. Agencies should reach out to their utility to determine what cost share and program options might be available.

Figure 7: Electric Bus Charging Infrastructure



This figure illustrates utility-side make-ready infrastructure, customer-side make-ready infrastructure, the charger/EVSE for electric bus charging stations.

Source: San Diego Gas & Electric® Company [20]

Future Proofing

There are several relatively simple future proofing steps that transit agencies can take to lower the cost of future charging infrastructure deployment. Common recommendations from interviewees included installing conduit for more chargers than just the current deployment and laying transformer pads in anticipation of additional transformers in the future. For transit agencies who choose to install extra conduit for future expansion, oversizing conduit was recommended in case future higher-power chargers require larger conduit. One transit agency described this as an important lesson learned since they installed extra conduit but then needed to re-trench and increase the conduit size in order to accommodate higher power chargers. Long-range planning can allow further future proofing by utilities, enabling them to make transformer, substation, and other upgrades to serve the transit agency's longer-term power needs, rather than performing more incremental upgrades which tend to be more costly and may take longer overall. When asked what transit agencies can do to facilitate such future proofing, many interviewees emphasized the value of firm, long-term electrification plans with clear deadlines. Three interviewees explained that their utilities will generally only invest in electrical grid upgrades to serve load they are confident will be used.

Even with such planning, there is likely still a limit to how much future proofing a utility will be able to provide. For example, PG&E's EV Fleet Program, which offers infrastructure upgrades for Transit Agencies and other medium- and heavy-duty vehicle charging sites, will only provide enough capacity to support the vehicles that the site commits to deploying over the next five years. This reduces the potential for stranded assets if plans change or get scaled back.

Some transit agencies interviewed described challenges associated with providing their utility with firm, long-term plans. For example, RTS explained that their electric bus deployment schedule is dependent on available funding, which is uncertain, and therefore it is challenging to provide the concrete deployment timelines that their utility has requested. This transit agency is therefore taking an incremental approach -- only making utility upgrades necessary to support near-term charging needs. Leading agencies, such as New York City Transit, are building electrification and potential future depot upgrades into their capital planning processes.

Electricity Bills

Utilities are also valuable partners in helping transit agencies understand how their electricity bills will change as they deploy electric buses and how they can minimize their bills. Several utilities offer rates specifically designed for transit buses, such as time-of-use rates that line up with transit bus schedules, or demand charge relief programs. For more detailed information the different types of rate options and their impact on electric buses, see the Software-Based Managed Charging Solutions chapter.

Planning for Grid Resilience

Resilience to power outages has gained increased focus among transit agencies in recent years as fleets begin to move towards full scale deployments and climate events intensify. A number of different approaches are currently being investigated and piloted by agencies and the research community.[3] At this stage, no one approach has emerged as a one-size-fits-all silver bullet.

There are several principals that hold true regardless of the chosen grid resilience solution. First, no solution will provide 100 percent service capacity in 100 percent of emergencies. Developing a resiliency plan will help agencies determine the situations that they need to prepare for and what level of service they need to provide in each situation. Secondly, for many agencies, resilience will become a more significant concern once their fleet reaches high levels of electric bus penetration. One agency mentioned keeping a small reserve of non-electric buses that can be used as backup in case of power outages. Finally, fleets should take a system-wide approach to resilience. Agencies with more decentralized charging – multiple electrified depots or more on-route charging locations – may have more built-in resilience against local outages. The more places buses can charge, the more resilient the agencies' system will be as a whole.

Developing a Plan

The first step for agencies is to develop a resiliency plan. Interviewees suggested that it is important for agencies to define exactly what resilience means for their operations, and what risks they are comfortable taking. Risks may vary regionally. Interviewees in California, for example, mentioned public safety power shutoffs by utilities in response to fire danger. While it is nearly impossible to prepare for a multi-day, system-wide catastrophic outage, agencies can identify and prepare for common disruptions to their electrical service.

CTE recommends that agencies request reliability reports from their utility to study where, how often, and how long power outages have occurred at their depots. From here, agencies

[3] For example, upcoming research under the National Academies of Sciences, Engineering, and Medicine's Transit Cooperative Research Program will study resilience and emergency response planning for zero-emission fleets [35].

can define the base level of service that needs to be provided in an emergency. This minimum service requirement may depend on the type of emergency.

By analyzing the characteristics and frequency of power outages against the minimum service requirements during an emergency, agencies can estimate their power needs during an emergency and if needed, implement solutions to provide the necessary level of power. Resiliency solutions can be expensive and are rarely used but may be crucial in the event of an outage. Agencies may benefit from talking to other entities with established emergency response plans, such as schools and hospitals, to learn from their experiences [1].

Interviewees identified four potential grid resilience solutions:

- Grid hardening
- Generator port + mobile power source
- Redundant electric service
- Microgrid

The remainder of this chapter provides detail on each of these solutions.

Resilience Solution A: Grid Hardening

The most common outages are caused by a tree falling on a line, an animal chewing through a power box, a vehicle running into equipment, or other similar isolated cases. Utilities are working hard to improve the overall resilience of the electrical grid to these types of incidents. Interviewees suggested that agencies should speak with their utility to determine what is possible in terms of grid hardening to reduce the frequency of outages at their location.

Utilities are also pioneering strategies to reduce the impact of large-scale outages from hurricanes, snowstorms, or wildfires. Agencies may want to be involved in these processes to ensure that their operations are being prioritized in any long-term resilience planning.

Resilience Solution B: Generator Port + Mobile Power Source

Generally, the cheapest and easiest way to provide resilience is through a generator port combined with a mobile power source such as a generator or battery bank. From a technical standpoint, it is fairly easy to add a generator port to an electrical system during construction that can be compatible with a range of available mobile source options. Currently, the most cost-effective mobile power source is likely to be a diesel, propane, or natural gas generator, but in the future mobile battery banks or fuel cells could offer a viable zero-emission alternative. This is especially true in locations where it may be difficult to permit a diesel generator [1].

One engineering firm interviewed suggested that transit agencies look into leasing, renting, or otherwise utilizing a procurement scenario whereby they can have the power source when they need it but are not paying the full cost of ownership and storage. This would allow agencies to free up space at the depot by storing the power source off-site when it is not in use.

Resilience Solution C: Redundant Electric Service

Interviewees described that in some scenarios, it may be possible for an agency to procure redundant service at a depot from their utility, effectively building resilience into their electricity supply. One depot may be able to tie into two feeders either from the same substation or two different substations. If one feeder goes down, they would then be able to switch power to the other feeder and continue operations.

This type of redundancy is only feasible if a depot is close to two feeders with available capacity. It requires additional electrical service infrastructure upgrades to connect to both feeders, as well as a switchgear capable of switching service. It also may require the agency to purchase reserved capacity on the alternate service, which can be expensive. Lastly, this approach only provides resilience from localized outages. If an outage is large enough to affect both feeders, the depot will still be left without power.

Resilience Solution D: Microgrid

A solar and storage microgrid represents a promising solution to depot resiliency, providing zero-emissions backup power independent of the grid and potentially offering co-benefits of zero-emission energy generation, load management, and revenue from participation in utility demand response programs or ancillary service markets. However, engineering firms and charging companies interviewed reported that microgrid solutions are still very expensive, and rarely pencil out based on these benefits alone. As a result, agencies risk spending significant sums to protect from low-likelihood scenarios.

As solar and battery costs continue to decline, microgrid solutions could become more common. In addition, increased interest in grid resilience from utilities, policymakers, and industry may unlock new sources of funding for agencies to leverage for microgrid solutions. Agencies with high on-peak rates, demand charges, and overall expensive electricity may be able to make a better financial case for a microgrid. Agencies in areas with low solar output could also consider microgrids powered by wind or fuel cells.

Santa Clara VTA was able to fully fund its microgrid through grants from the Low Carbon Transit Operating Program (LCTOP) and the California Energy Commission. At VTA's depot, a 20-foot by 60-foot outdoor area adjacent to the parking block will host an all-in-one structure with the electrical gear and charging equipment to charge 34 buses, plus battery storage for a 1.5 MW solar array (see Figure 8). In addition to resilience from power outages, which is especially important given California's wildfire-driven public safety power shutoffs, VTA will gain an additional 3-4 hours of off-peak charging time through their battery storage system. The microgrid will also allow them to reduce demand charges and downsize their electrical service connection.

Figure 8: Santa Clara Valley Transportation Authority Facility Design

This figure from a January 2022 press release depicts a design rendering of Santa Clara Valley Transportation Authority's planned microgrid and charging system. One-and-a-half megawatts of solar paired with four-megawatt hours of battery storage will reduce energy costs and provide backup electricity for up to 20 hours of emergency operations.

Source: Santa Clara VTA [21]

Martha's Vineyard Transit Authority has also deployed a microgrid solution to power their fleet of 14 electric buses in case of a power outage. During normal operations, the microgrid is connected to the grid and can store or feed power back to the grid. Martha's Vineyard uses solar-powered on-route chargers to maximize the use of solar energy during the day. [22].

Overall, there is no one size fits all solution for providing resilience during power outages. Resilience is emerging as a key area of study for the industry and several solutions are already being tested by early adopters. Many agencies just beginning their electrification journey may not need to make significant resilience investments until these technologies are more established and potentially more cost effective. Still, planning around potential resilience options may benefit facilities planning and reduce future costs. Additional funding from public agencies and utilities, who are increasingly concerned about grid resilience, may also help ease this pain point for transit agencies in the future.

Ensuring Reliable Charging

Almost all transit agencies interviewed expressed that reliable bus service is the most important priority for fleet managers. Being able to ensure chargers are reliably operational is key to a successful electrification program. Interviewees and research revealed a number of best practices for developing maintenance expertise, choosing charging vendors, and strengthening service agreements to maximize charger reliability.

Maintenance Staffing

Electric buses and chargers are fundamentally different systems than diesel buses and pumps. Maintenance staff who know the ins and outs of a diesel engine may be new to electric technologies. Maintaining charging systems is still an emerging area of workforce development. Each charging manufacturer has nuances, and training may not fully translate from one manufacturer to another. Notably, some charger manufactures will often require, as a term of the warranty, that anyone who works on charging equipment be certified by the manufacturer.

TriMet engaged its electric utility, Portland Gas and Electric (PGE), to provide charger maintenance services. TriMet described this arrangement as very beneficial, highlighting that PGE has experience with electrical equipment and is therefore well-qualified to maintain charging equipment.

Other transit agencies interviewed echoed the idea that having experience with electrical equipment is valuable for providing charger maintenance. For example, King County transit and CTA described their experience operating high-voltage equipment for their trolley and/or rail services as an advantage in their transition to operating electric buses. New York City Transit, which also operates electric rail service, described plans to develop strategies around maintenance of their electric bus chargers (using maintenance contracts and in-house facilities support personnel)..

AC Transit is seeking to develop their own training center for zero-emission technological skills [19]. AC Transit already reports conducting over 23,000 hours of training across 19 courses in support of their fleet of 15 fuel cell and battery electric buses. Many of these courses are held in partnership with charger or bus manufacturers.

One interviewee emphasized the value to both the transit agency and the manufacturer of establishing formal service level agreements (“SLAs”). They described service and maintenance as the biggest area of miscommunication, with some transit agencies expecting 24/7 maintenance availability from charger manufacturers since they are used to having in-house operations and maintenance staff for their diesel operations. They explained that formal SLAs can avoid this kind of miscommunication and allow manufacturers to ensure they are properly staffed to meet the service requirements in the SLA.

Spare Parts

Long Beach Transit noted that some spare parts are relatively inexpensive but can have long lead times. They therefore recommended keeping an inventory of these inexpensive spare parts. Transit agencies can require their charging vendors to provide a list of key parts to include in a spare parts inventory as well as information on pricing and typical lead times for other parts [1]. Foothill Transit noted that over time, there is a risk that spare parts might not meet the specifications of the original parts. This risk should be discussed with vendors.

Ensuring Strong Charging Vendor Contracts

Several interviewees described the importance of including strong and clear requirements in vendor contracts to ensure charger uptime. Metro Transit in Minnesota recently conducted five case studies on transit agencies that have deployed electric buses and one of the key lessons learned was the importance of developing "strong contractual language for vendor contracts including performance metrics [7]." Several interviewees described challenges with determining the responsible party when charger issues arose, causing confusion and delays in getting chargers back online. In a progress report from Portland General Electric on its electric bus project with TriMet, PGE reported challenges getting bus and charger vendors to resolve communications issues, resulting in long periods of buses being offline [23].

Below is a list of contract terms for transit agencies to consider including in charging vendor contracts to facilitate smooth operations, based on interviews with transit agencies, utilities, and engineering firms:

1. Define charger availability requirements based on bus service requirements

As mentioned in the Designing Charging Facilities chapter, determining charger requirements through modelling or data analysis is an important first planning step. These requirements should also inform charger availability requirements included in transit agencies' vendor procurements. APTA is currently working with transit agencies and other stakeholders to develop standard technical requirements for transit agencies to include in requests for proposals (RFPs) for charging equipment. A draft of this sample RFP includes a section where the transit agency specifies details about their electric bus operation strategy including, among other details, the following:

- ✓ Number of buses and their make and model
- ✓ Type of charger (plug-in, overhead pantograph, wireless) and their required power levels
- ✓ Dwell times and charging windows for buses
- ✓ Third-party hardware and software systems for charge management and operational data collection and reporting that the chargers will need to integrate with
- ✓ Weather conditions in which chargers will need to operate (temperature, humidity, precipitation, severe airborne dust conditions, severe winter road maintenance processes, etc.)

2. Specify compliance with charging standards

Published reports and interviewees emphasized that it is important for charging equipment to comply with charging standards. Charging standards facilitate interoperability so that products from a variety of manufactures can be used together. This helps protect against the risk of a manufacturer going out of business and discontinuing certain products, and provides flexibility to select different providers in the future.

There are different standards for different types of chargers, as listed in CTE's Guidebook for Deploying Zero Emission Buses [1]:

- Plug-In chargers: Society of Automotive Engineers (SAE) J1772 for DC chargers and SAE J3068 for AC chargers
- Overhead chargers: SAE J3105 for overhead chargers

Notably, several interviewees explained that there is some ambiguity and variation in how to interpret standards and therefore it is necessary for vendor procurements to include more specific technical requirements than simply requiring adherence to standards. Transit agencies can consult with other transit agencies, consultants, or publicly available resources such as the forthcoming work from APTA to determine exactly what these requirements should be. One charging provider explained that it is regretfully common for transit agencies to have their purchased bus not work with their purchased charger because the standard has been interpreted in two different ways. The interviewee explained that, while it is really the vendor's responsibility to adhere to standards, transit agencies can do research and talk to other transit agencies to make sure to select charging and bus manufacturers who have worked together in the past.

Another way to ensure interoperability between chargers and buses, besides specifying adherence to standards and other technical requirements, is to use the same vendor for the charger and bus. Importantly, this option comes with the drawback of generally being more expensive than selecting charging vendors and bus vendors separately [1].

3. Define minimum response times for specific charger issues

CTE noted that some transit agencies include in their vendor contracts liquidated damages if there are delays in bus deliveries or infrastructure installation, or if equipment isn't meeting any uptime requirements in warranty documents or other contract terms.

4. Establish long-term maintenance commitment, and/or require vendors to share essential technical information needed for equipment operation and maintenance once the warranty period is over

One transit agency interviewed described a situation in which, after the expiration of a two-year charging equipment warranty, the transit agency had charger performance issues that they were unable to address without expertise from the vendor, who instead wanted the transit agency to enter into an expensive service contract.

5. Require bus manufacturers and charging providers to test the bus-charger connection before accepting delivery

One transit agency stated that if they were to re-do anything, it would have been adding this requirement.

6. Specify key software requirements, including the following:

- ✓ For transit agencies using a third-party charge management or data monitoring provider, require Open Charge Point Protocol (OCPP) compliance.
- ✓ The Electric Power Research Institute (EPRI) described the value of having local rather than cloud-based controls, as this allows site monitoring, data collection, and remote management to continue even if the internet connection goes down.
- ✓ Require that software updates on buses and chargers be tested offsite by the provider with the transit agency's specific combination of chargers and buses before the update is rolled out.

7. **Require remote monitoring and diagnostics**

   Several interviewees explained that the majority of charger issues can be diagnosed and remedied remotely. ABB E-mobility estimated based on their experiences working on electric bus chargers that about 90 percent of issues can be diagnosed remotely and more than 60 percent can be fixed remotely. Remote monitoring can also identify charger issues proactively rather than only identifying them once a charger is needed. Long Beach Transit listed this ability to identify charger issues as a key function of a good charging software service.

Software-Based Managed Charging Solutions

Paired with the right hardware, managed charging software can be used to control which chargers are used, when, at what power level, and from which power or storage source. This can generate substantial cost and operational benefits for utilities.

Several interviewees and published reports described successful experiences with managed charging software. Some transit agencies interviewed have chosen not to use managed charging software thus far for a variety of reasons, including a lack of confidence in managed charging software to deliver on its promises as well as uncertainty that the benefits would justify the costs of the service at the current scale of their electric bus deployment. Any managed charging strategy should be developed with careful consideration of a transit agency's specific operational needs and comparison of the potential benefits and costs of managed charging services.

Key Potential Benefits to Managed Charging

In order to assess these key considerations, it is important to understand the potential benefits of software-based managed charging solutions. Figure 9 describes four key benefits that managed charging software has the potential to provide to transit agencies. Each of these is further expanded upon below.

Figure 9: Key Potential Benefits of Managed Charging Software for Transit Agencies

	Reduce electricity bills	Minimize demand charges and charging during on-peak times when electricity rates are high. Can also enable participation in utility demand response events.
	Reduce investment in chargers & utility upgrades	Reduce total kW charging capacity needed by enabling buses to charge in parallel or sequence, reducing investments in charging equipment and utility upgrades
	Reduce labor requirements	Reduce the need to manually plug and unplug chargers
	Maximize use of renewable energy	Match charging to periods of high renewable energy generation.

1. Reduce Electricity Bills

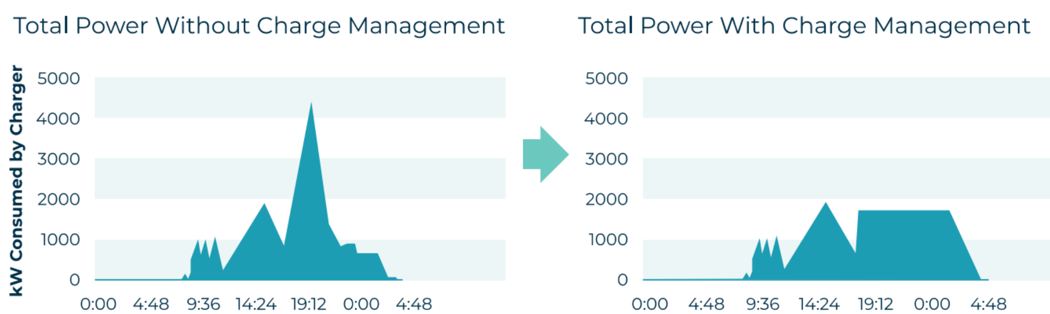
Electricity bills for commercial customers, such as transit agencies, generally include demand charges and often include time-of-use ("TOU") energy rates, where electricity rates are higher during times of high electricity demand ("on-peak times") than during times of lower demand ("off-peak times").

Demand charges are common components of non-residential electricity rate structures and can add substantial costs utility bills. These charges are assessed on a cost-per-kW basis and are calculated from the electric utility customer's highest power (kW) demand during a given period. Demand charges are typically assessed on the highest demand during a billing period or year and may also have a time-of-day component where higher charges are assessed at on-peak times.

Demand charges present a challenge for electric bus charging costs because simultaneously charging buses can create a spike in power demand which, even if infrequent, trigger high demand charges and push up utility bills. Managed charging software can minimize *('peak shave')* these spikes through intelligent charger scheduling that flattens the peak or by drawing on batteries or other distributed energy resources to supply power during peak events. Figure 10, taken from the CTE Guidebook for Deploying Zero-Emission Transit Buses, illustrates how managed charging software can spread charger demand over more time to avoid high peaks in demand [1].

Managed charging software can also optimize energy use against TOU rates, reducing bills by charging buses more during low-cost hours and less during high-cost hours.

Figure 10: Managed Charging Can Decrease Peak Power Demand



The figure above, from CTE's Guidebook for Deploying Zero-Emission Transit Buses, illustrates how managed charging software spreads charging demand over a longer period of time to avoid peaks in demand.

Source: Center for Transportation and the Environment [1]

2. Reduce Investment in Chargers & Utility Upgrades

Managed charging can reduce charger capacity requirements, allowing fewer power cabinets to serve a greater number of buses. In addition, lower peak demand means fewer and less expensive utility service upgrades, potentially delivering substantial cost savings and shorter timelines for powering charging infrastructure. For example, initial estimates suggested that LA Metro would need 20 megawatts ("MW") of electrical capacity to support charging at their depots, but they were able to develop a managed charging strategy that allowed them to decrease their capacity requirement to 10-12 MW.

3. Reduce Labor Requirements

Managed charging software can enable power sharing among buses, eliminating the need for staff to manually unplug, move, and re-plug buses for them to share power while at a depot. Manually plugging and unplugging chargers is labor intensive, especially for larger fleets, and labor restrictions may restrict who can perform these functions and when. For example, some labor restrictions do not allow overnight work or do not allow bus drivers to perform fueling operations. Note that this reduced labor need is accompanied by the need to install additional dispensers, so that buses can be plugged into the charging system at the same time for sequential or parallel charging. This can add to the cost of managed charging.

4. Maximize Use of Renewable Energy

Managed charging software can be especially valuable to transit agencies whose depots incorporate renewable energy and/or battery storage. Maximizing charging when solar energy production is high or using stored renewable energy requires software that can communicate between charging equipment, solar arrays, and storage systems. Similarly, agencies who wish to support greenhouse gas or other climate goals could potentially schedule charging to occur when the grid's renewable generation is highest (subject to driving schedules).

Assessing the Value of Managed Charging Solutions

Interviewees described the importance of determining the magnitude of the benefits that could be delivered by software-based managed charging solutions to a specific agency in order to assess whether these benefits outweigh the costs. Interviewees described four considerations that could help determine the value of software-enabled managed charging to a specific agency:

- Load flexibility
- Fleet Size
- Labor requirements and restrictions, and
- Electricity Costs

1. Load Flexibility

A transit agency's service schedule affects their flexibility to avoid on-peak charging. Some vehicles may have long charging windows that allow them to schedule their charging to avoid on-peak rates or high peak demand and realize bill savings. Others may need to charge at a high power level for their entire charging window to meet service requirements, which reduces the value of charging management. Foothill Transit, for example, described having limited flexibility to delay or downgrade charging power and still ensure buses are ready when they need to be used.

2. Labor Requirements and Restrictions

Managed charging software can reduce the amount of manual labor required to plug and unplug chargers and move buses between chargers. Many transit agencies explained that labor requirements do not allow bus drivers to perform fueling services, meaning they cannot be the ones to plug and unplugging chargers. Several transit agencies also explained that labor restrictions do not allow employees to work past certain hours. As a result, transit agencies may not be able to execute managed charging strategies that require manual plugging and unplugging, especially during overnight hours. Rochester Transit Service explained that their current managed charging strategy is to tell floor managers not to plug in before 11pm. Due to challenges with this strategy, they are currently meeting with managed charging vendors to develop a software-enabled strategy.

In a presentation given by Santa Clara VTA at the 2020 Zero Emission Bus Conference, the transit agency described the importance of software to provide automatic power control for reducing costs against peak time-of-use utility rates, as well as to ease constraints on charging due to unavailability of labor from 1:00 – 3:45 AM [24].
Of Southern California Edison's three electric fleet partners, only one used an automated managed charging strategy and that fleet had lower electricity costs as a result. One fleet tried to implement a manual strategy to avoid off-peak charging, but this was not sustainable due to staffing shortages, resulting in significant cost increases. The report explains:

Fleet 1 is the only operator whose EVSE vendor provided charging management option. … As a result of this implementation, (fleet 1 had a) very successful history of avoiding charging during on-peak time period…; whereas the other two fleets relied on staff management of charging operations and experienced charging during on-peak time and correspondingly higher costs per kWh [25].

3. Fleet Size

Fleet size can affect whether paying for charge management software (and associated hardware) makes sense for a transit agency. For smaller fleets, manually plugging and unplugging chargers may be sufficient to manage costs. Engineering firm HDR explained that, in their experience, large fleets often have more complex operational requirements, such as sequencing charging to manage energy costs, and therefore more commonly realize savings from managed charging than do smaller fleets.

4. Electricity Costs

HDR also emphasized the impact of electricity rates on the cost-benefit analysis of managed charging software. Managed charging has the potential to generate more savings in areas with high electricity rates than in areas with cheaper electricity. For example, TriMet in Portland, Oregon determined that due to the low cost of electricity from their utility, they did not yet need managed charging. Whether or not a transit agency is billed for electricity on a TOU rate also affects the potential savings managed charging can provide. For example, Mountain Line in Missoula, Missouri, conducted an analysis with a consultant that found that managed charging would likely cost more than it would save due largely to the fact that they are not billed on a TOU rate.

Some utilities offer demand charge waivers or relief to transit agencies, and this greatly affects the value of managed charging. Several transit agencies interviewed emphasized the significance of demand charges. Foothill Transit explained that when they first started operating electric buses in 2010, they were incurring significant demand charges. Their utility, Southern California Edison, then developed a rate that includes demand charge relief. Notably, many demand charge relief programs phase demand charges back in, meaning transit agencies should prepare to manage their charging load for when demand charges are back.

Managed Charging Challenges

Several transit agencies expressed a lack of confidence that charging management software could deliver on some of the described services. In particular, transit agencies described challenges or doubts related to software's ability to integrate with existing fleet management and route scheduling software. When asked what key functions an ideal managed charging software would provide, many transit agencies described a service that can minimize electricity costs while ensuring that every bus reaches its required state of charge by the time it needs to begin service. Transit agencies operating in cold climates also emphasized the importance of integrating weather conditions into the charging plan, noting the substantial impact of cold weather on vehicle range or charging speed. Managed charging providers are developing software products that take these factors as well as others, including impact on range due to terrain, number of passengers, driving behavior, and use of air conditioning or heat, into account in executing charging strategies that meet service needs and keep electricity bills as low as possible.

Utilities, engineering firms, consultants, and other agencies can be valuable resources for navigating the market for managed charging software.

Charging Infrastructure Costs and Timelines

Costs

Though transit agencies may see reduced “fueling” costs and potentially reduced maintenance costs over the lifetime of electric buses and charging equipment, upfront costs for electrification are substantially higher than for diesel buses. The cost of electric buses, charging equipment, utility upgrades, and facility modifications make the upfront costs of bus electrification high. When asked for the biggest remaining barrier to bus electrification, ten out of 29 interviewees discussed high upfront costs (see section ‘Advice From Those Further Down the Road‘).

It is also important to consider that upfront costs can vary dramatically from transit agency to transit agency. For example, depending on a transit agency’s fleet, deployment goals, and existing facilities, the scope of needed modifications can range from relatively simple installation of a few chargers to building a whole new facility with solar panels and battery storage. Similarly, depending on the electrical grid capacity constraints in a given area, utility upgrade costs can vary significantly. To contend with these cost barriers, rapidly advancing technology, and the case-by-case nature of costs, transit agencies should analyze short- and long-term costs as part of their transition plans. Interviewees also suggested that transit agencies should consult a variety of sources, not just equipment providers, on cost information. Transit agencies that have deployed electric buses, utilities, and third-party experts are all important sources of cost information.

Publicly-available data on charging infrastructure costs are few and far between. Those that are available bucket costs in varying ways and encompass a variety of charger configurations, power requirements, and needed facility upgrades, making them difficult to compare.

CTA’s February 2022 bus electrification plan describes the agency’s blueprint, including estimated costs, to electrify its fleet of over 1,800 buses by 2040 [8]. The plan considers eight electrification scenarios with varying charger and garage configurations, ranging from all slow charging to “mostly fast charging,” and estimates the capital costs under each of the eight scenarios. Charger infrastructure capital costs range from approximately $0.7 to $2.1 billion, with approximately a quarter of a billion dollars estimated for electrical upgrades.

LA Metro also includes in their rollout plan cost estimates to electrify more than 2,000 buses across 10 of its divisions by 2030. They state that they expect the capital costs associated with this transition to come to between $1.3 billion and $1.6 billion, with infrastructure costs making up $900 million to $1.4 billion of the total [6]. Across these 10 divisions, LA Metro expects to install 1,010 150 kW chargers and 39 450 kW chargers.

AC Transit released a Zero Emission Transit Bus Technology Analysis in December 2021 that included cost data from its electric bus deployments through June 2021. They reported that the charging infrastructure at their Oakland Division, which consists of six stationary ChargePoint CPE250 chargers and one mobile CPE250 shop charger, was built at a total cost of $896,937 [19]. It is not clear whether this figure includes facility upgrade costs.

Foothill Transit also provided some cost data from their deployments in a June 2021 report from NREL. They report $655,000 for hardware and installation costs associated with one 500 kW charger at their Pomona Transit Center [26].

Utility Southern California Edison (SCE) provided some cost information in their April 2021 Final Evaluation Report from the electric bus deployments that they worked on as part of their Electric Transit Bus Make-Ready program [25]. SCE worked with three transit agencies and provided the make-ready infrastructure to support 30 charging ports and 31 electric buses across the three agencies' deployments. These three deployments are described in Table 1.

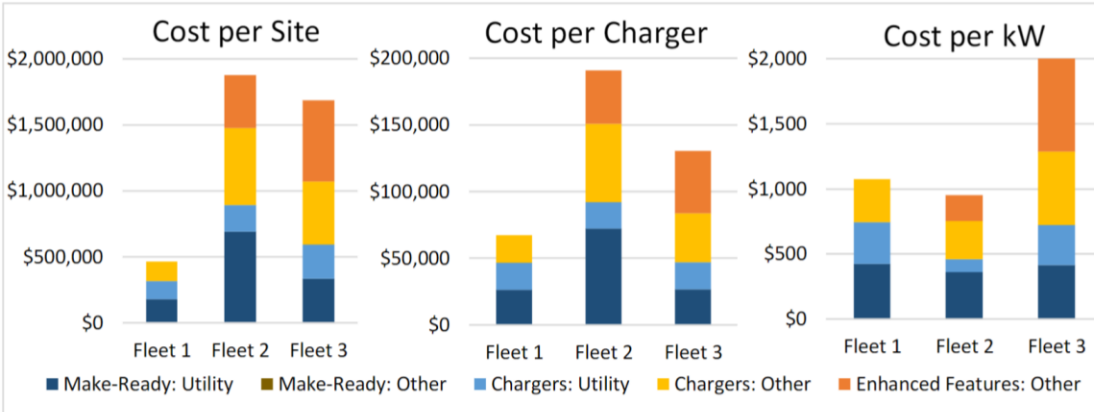
Table 1: Summary of deployments supported by Southern California Edison's Electric Transit Bus Make-Ready Program

	Fleet 1: Victor Valley Transit Authority	Fleet 2: Porterville Transit	Fleet 3: Foothill Transit
Buses	Seven 40-ft electric buses	Ten 40-foot electric buses	33 electric buses
Chargers	Seven 62.5 kW DC chargers	Ten 200 kW DC chargers	Twelve 60 kW DC chargers and one 125 kW DC charger

Source: [25]

Based on these three deployments, SCE provided the cost information in Figure 11.

Figure 11: SCE Electric Transit Bus Make-Ready Priority Review Project Infrastructure Costs



The figure above is from SCE's April 2021 Final Evaluation Report and shows cost associated with electric bus deployments from three transit agencies SCE worked with as part of their Electric Transit Bus Make-Ready program. Table 1 describes these three deployments.

Source: Southern California Edison [25]

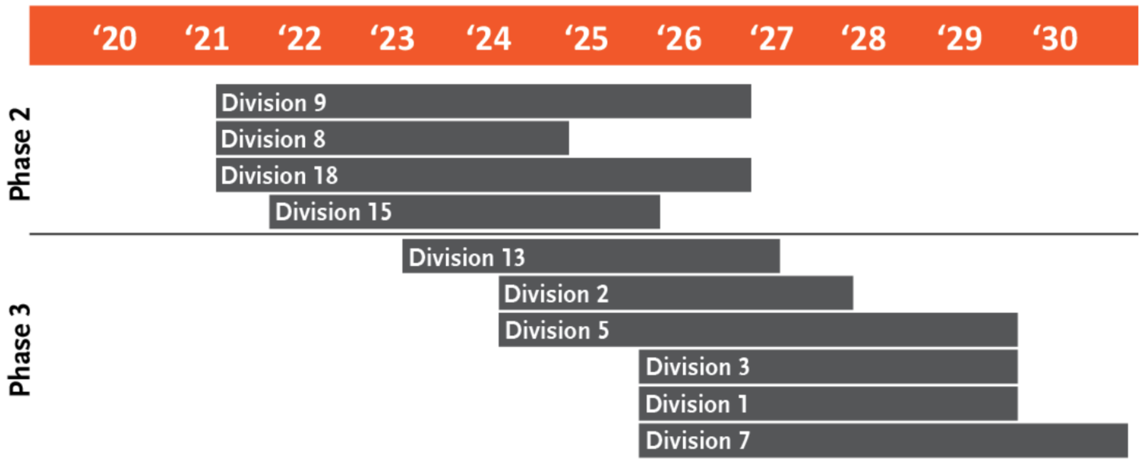
Timeline

Timing is a key consideration for transit agencies deploying electric buses that should be incorporated into transition planning. One of the processes that many interviewees noted as requiring a long lead time is utility upgrades. Several utilities explained that some transit agencies have not been aware of how long electrical upgrades can take and have therefore procured buses before realizing that they will not be able to use them as soon as they had planned. Utilities should be consulted near the beginning of the electrification process to make sure transit agencies develop deployment plans with feasible timelines.

Permitting is another part of the process that several interviewees recommended transit agencies be sure to start early and leave adequate time for. If new depot facilities are required, planning, permitting, and building them can be a long process. Agencies planning to build new facilities are generally beginning by electrifying fleets at their existing facilities in parallel.

Figure 12 provides an example timeline from LA Metro's transition plan.

Figure 12: Example Timeline for Transitioning LA Metro's Bus Fleet



This figure is from LA Metro's March 2121 Final Rollout Plan, which details how they plan to electrify more than 2,000 buses across 10 of their divisions by 2030. This timeline includes utility applications to supply additional power to the divisions, plus procurement, design, construction and installation of charging facilities and equipment.

Source: Los Angeles Metro [6]

Several interviewees and best practices reports described the importance of planning for charging before procuring buses. Long Beach Transit, RTS, Mountain Line, and HDR all explained that a common mistake made by transit agencies is to start by planning for bus procurement rather than developing a charging infrastructure plan. Interviewees noted that this sometimes happens because agencies move to take advantage of available funding for buses before having an infrastructure plan in place (see Financing Charging chapter). If charging installations then take longer than bus deliveries, buses will have to be stored and will move through their warranty schedules before they are able to be used.

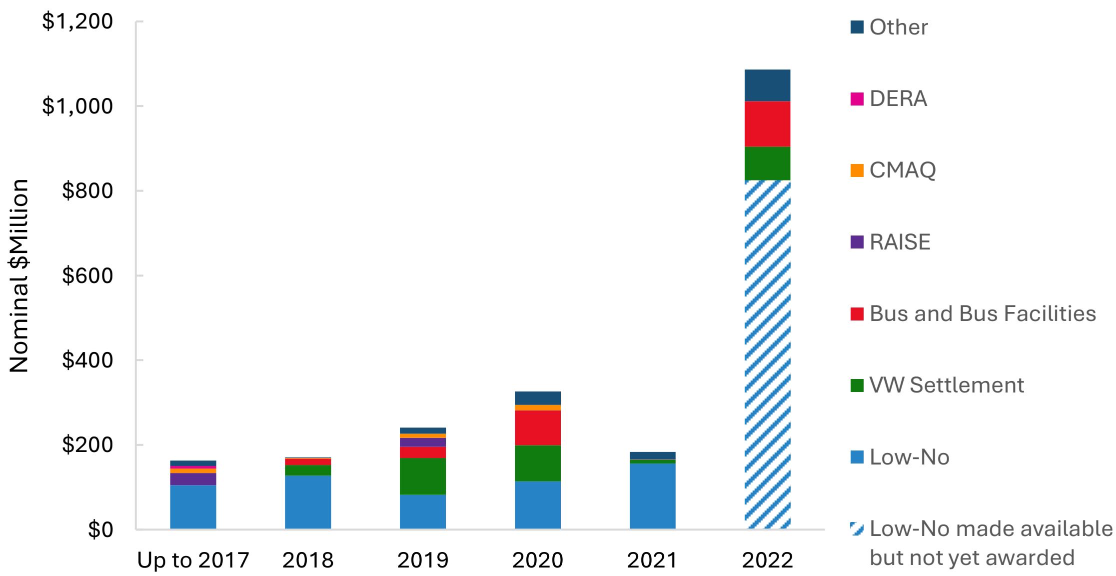
CTE also emphasized the importance of making sure charging infrastructure is installed and functional before buses arrive in order to make sure the buses can be tested during the acceptance period [1]. CTA, for example, explained that in order to mitigate the risk of having electric buses arrive before chargers (or vice versa), they chose to select one lead vendor who would be responsible for managing all parts of the project, including bus equipment, charger equipment, and charging infrastructure design and construction. This type of turnkey approach was noted to be more expensive than procuring buses and chargers separately.

Financing Charging

The significant upfront costs of battery electric buses and charging infrastructure paired with fuel savings over the lifetime of the vehicle represents a new financial model for agencies that have been operating non-electric fleets. Agencies' existing financial planning may not account for the increased capital expenditures and decreased operating expenditures that come with an electric fleet.

Funding from federal, state, and local governments as well as electric utilities has played a crucial role in enabling electrification to date. Policy support is ramping up, especially through the Infrastructure Investment and Jobs Act signed in November of 2021 (see Figure 13), but so too is the competition for funding. Agencies considering electrification should familiarize themselves with available funding sources and position themselves to take advantage of these funds.

Figure 13: Federal and Select State Grant Funding Awarded for Battery Electric Buses to Date



In the above figure, funding awards have been compiled from public funding announcements. Included are the Low or No Emission Vehicle Program (Low-No), state-administered Volkswagen Settlement (VW Settlement) programs, the Buses and Bus Facilities program, Rebuilding American Infrastructure for Sustainability and Equity (RAISE), and the Congestion Mitigation and Air Quality Improvement program (CMAQ), Diesel Emissions Reduction Act (DERA), and some state-level programs, including HVIP, NYTVIP, and Washington's Green Transportation Capital Grants Program (Other). 2022 Low-No funding is estimated based on the FY 2022 notice of funding opportunity. See Table 2 for more information on federal programs.

Source: Atlas EV Hub [27]

Best Practices for Funding Electric Transit Buses

Utilizing multiple funding sources can significantly reduce the cost of electrification. Examples include using one grant to fund buses and another to fund charging infrastructure, using a state grant to meet the match requirements of a federal grant, or stacking non-utility funding with participation in a utility program. However, transit agencies interviewed consistently cited timing as one of the greatest challenges to successfully stacking funding. If using two or more grant programs to fund a single deployment, agencies will need to coordinate the timelines of these programs to ensure that the funds are available when they are needed. Manufacturer delays, on both the bus and charger side, can also further complicate this delicate balancing act, making firm timeline commitments from vendors critical.

Agencies should also be aware of any other stipulations attached to funding to ensure that they will be able to comply. For example, the Federal Transit Administration generally requires that buses be in use for a minimum of 12 years. One agency experienced recurring issues with several buses purchased through the Low-No program in 2014 and was forced to petition the Federal Transit Administration to retire these buses early and return a portion of the undepreciated value of the original grant. Using federal funding may also trigger additional environmental review.

Funding programs may also not cover the full cost of an electric bus deployment. There are many associated costs, such as facility analysis, concept design, and staffing, that may not be eligible for funding. In addition, many grants may require match funding. Agencies should ensure that they have adequate resources to cover the associated costs of a deployment before they commit to a grant.

As agencies begin to scale electrification from pilot projects to full adoption, they will need to go beyond one-off grants and secure consistent funding flows. Leading agencies are already beginning to look to build electrification into their capital planning processes to reduce dependency on increasingly competitive grant programs.

Federal Programs to Support Bus Electrification

The Low or No Emissions Program is the only federal program dedicated entirely to funding alternative fuel transit buses. However, transit electrification may be eligible under other federal programs, such as those that fund air quality improvements or transportation capital projects.

Federal grants typically require agencies to contribute matching funds which can include State and local grants, certain sources of agency revenue, or non-government sources.

Match requirements range from 0 to 20 percent depending on the type of project and tribal, rural, or socioeconomic designations.

The Infrastructure Investment and Jobs Act (IIJA), signed in November 2021, authorized up to $108 billion for federal public transportation programs, including more than $30 billion for programs that have historically funded electric buses. In addition, the Biden Administration has signaled its intention to prioritize projects that reduce greenhouse gas emissions [28]. The IIJA presents an unprecedented opportunity for transit agencies to access funding for electrification.

Table 2 shows federal programs that can support transit bus electrification. The sections below provide deep dives on the programs that have provided significant funding for electric transit buses to date.

Table 2: Potential Federal Funding Sources for Electric Buses and Charging Infrastructure

Program (hyperlinked)	**Focus**	**BEB funding awarded to date (Percent of total awards)[4]**	**IIJA Funding (Fiscal Year 2022 to 2026)[5]**
[Low or No Emissions Program (Low-No)]()	Equipment purchase	$585 M (88%)	$5.6 B
[Buses and Bus Facilities]()	Facility upgrades	$231 M (11%)	$5.1 B
[Rebuilding American Infrastructure with Sustainability and Equity (RAISE)]()	Surface transportation capital projects	$49 M (<1%)	$7.5 B
[Congestion Mitigation and Air Quality Improvement Program (CMAQ)]()	Air quality improvement	$35 M (<1%)	$13.2 B
[Diesel Emissions Reduction Act (DERA)]()	Emissions reductions from diesel vehicles	$7 M (<1%)	None[6]

[4] Atlas EV Hub

[5] Build.gov

[6] The Diesel Emissions Reduction Act received $90 million for FY 2022 and would receive $150 million in FY 2023 under the President's proposed budget: https://www.epa.gov/system/files/documents/2022-03/fy-2023-epa-bib.pdf

Low or No Emissions Program

The Federal Transit Administration's Low or No Emission Vehicle Program is the largest single funding source for the purchase of electric transit buses to date.

Funds are primarily used for the purchase or lease of low- or no-emission buses and the construction of charging infrastructure but can also be used to construct or renovate facilities to accommodate low-or no-emission buses. Starting in 2022, applicants for zero-emission vehicles must submit a Zero-Emission Transition Plan and spend five percent of their award on workforce development and training as outlined in their plan.[7]

Buses and Bus Facilities

The Federal Transit Administration's Buses and Bus Facilities program offers both formula funds to states and competitive grants directly to transit agencies. Funds are primarily used to upgrade or construct bus facilities but can also be used for the purchase of buses and charging infrastructure. Funding is available for all bus facilities, not just those supporting zero-emission buses. Like the Low No program, applicants for zero-emission vehicles must submit a Zero-Emission Transition Plan and spend five percent of their award on workforce development and training as outlined in their plan.

RAISE (Formerly BUILD and TIGER)

The Department of Transportation's Rebuilding American Infrastructure with Sustainability and Equity (RAISE) discretionary grant program funds a wide selection of surface transportation capital projects. Electric buses and charging infrastructure may be eligible for RAISE grants as part of a larger project. Recent examples include Rockford, Illinois implementing an electric bus circulator route as part of a street reconstruction project and Derby, Connecticut constructing a multimodal transportation center with new electric buses [29].

Congestion Mitigation and Air Quality Improvement Program

The Congestion Mitigation and Air Quality Improvement Program funds transportation projects that improve air quality to help states meet the requirements of the Clean Air Act. Funds are distributed to state and local governments according to formulas set by the Federal Highway Administration and the Federal Transit Administration.

Funds may be used for any transit capital expenditures otherwise eligible for FTA funding as long as they have an air quality benefit and are located in a non-attainment area. For

[7] The Federal Transit Administration published guidance on Zero-Emission Transition Plans in March 2022 [38]

example, in 2017 CTA was awarded $8 million for the purchase of up to 10 Electric Buses and two on-route Charging Stations [30].

Diesel Emissions Reduction Act

The Diesel Emissions Reduction Act (DERA) funds grants and rebates to reduce emissions from diesel engines including through electric vehicle replacements. Funding is available directly from the Environmental Protection Agency through national grants and may also be available from some state agencies through pass-through grants. Recent examples include a national grant for the University of Colorado Boulder to replace two diesel transit buses with electric buses [31].

Other Federally-Funded Programs

Agencies interviewed also mentioned the following federally funded programs that may fund transit bus electrification:

- Capital Investment Grants
- Metropolitan, Statewide & Non-Metropolitan Planning
- Formula Grants for Rural Areas
- State of Good Repair Grants
- Surface Transportation Block Grant Program
- Urbanized Area Formula Grants

State Programs to Support Bus Electrification

Funding for electric transit buses and charging infrastructure may also be available from state governments. Agencies should identify funds available for electric transit buses in their state. In some cases, state funding may be used to cover the match requirement of federal grants. The list below highlights examples of the types of state programs that may be available to fund electric transit buses and charging infrastructure:

Volkswagen Settlement Trust

Following a 2017 settlement, Volkswagen was required to fund a $2.925 billion mitigation trust fund. Each state, tribe, and territory has since established programs to use these funds to reduce emissions from heavy-duty diesel vehicles. Under the settlement agreement, funds may cover up to 100 percent of the cost of new all-electric transit buses, including charging infrastructure. Agencies should identify the agency responsible for administering their state, tribe, or territory's Volkswagen Settlement and inquire about the availability of funds for electric transit buses.

Medium- and Heavy-Duty Voucher Incentive Programs

California, New York, and New Jersey offer point-of-sale rebates for the purchase of electric transit buses. These vouchers are generally available on a first come, first served basis and are applied at the time of purchase, saving transit agencies the paperwork and uncertainty of grant applications. Voucher programs can run out of funds quickly, so agencies should track timelines.

Clean Fuel Standards

Several states including California, Oregon, and Washington regulate the carbon intensity of transportation fuels through market-based mechanisms known as clean fuel standards. Under these standards transit agencies may be able to earn credits from their charging stations and then sell those credits to generate revenue. For example. AC Transit reports collecting more than $115,000 in revenue from its fleet of 15 fuel cell and battery electric transit buses in 2020 through California's Low Carbon Fuel Standard [19]. Navigating these markets can be complicated; AC Transit uses a third-party vendor to manage their credits.

Utility Programs to Support Bus Electrification

Some utilities have dedicated programs to support transit bus electrification. These programs can include utility-owned and operated charging, funding for charging infrastructure (utility-side make-ready, customer-side make-ready, or the EVSE), advisory services to help fleets develop strategic electrification plans, or specific electric rates that can help transit agencies reduce their electricity costs. Below are examples of these four types of utility programs:

Utility-Owned and Operated Charger Example: Portland General Electric – TriMet partnership

In Portland, Oregon, TriMet, participated in an electric transit program offered by Portland General Electric (PGE), where PGE installed and paid for three chargers [32]. PGE is responsible for operations, maintenance, and monitoring for the charging equipment, and TriMet pays for those services. Trimet described this arrangement as beneficial, as it allows TriMet to focus on managing buses. Some transit agencies interviewed expressed hesitation to participate in a charging infrastructure program that would require granting easements to third parties, such as utilities.

Make-Ready Infrastructure and Charger Rebate Example: Southern California Edison – Foothill Transit partnership

Foothill Transit participated in the Charge Ready program offered by its electric utility, Southern California Edison (SCE), under which SCE funded and installed the make-ready infrastructure necessary to support the chargers for Foothill Transit's electric buses, both on Foothill Transit's side of the meter and on SCE's side of the meter (see Utility Engagement chapter for background on customer- and utility-side make-ready infrastructure) [25]. SCE also provided rebates for 50 percent of the cost of the chargers themselves.

Fleet Advisory Services Example: DTE Energy

In Michigan, DTE Energy's eFleets Advisory Services provide transit agencies with a seven-step roadmap to help them develop and execute fleet electrification plans. Through the program, DTE provides agencies with recommendations specific to the fleet's mileage and power demands, estimates on fuel savings, information on available incentives, and overall cost estimates and workplans for installing charging infrastructure [33].

Transit Bus Rate Example: Hawaiian Electric E-Bus Pilot Rate

Hawaiian Electric's E-Bus pilot rates encourage electric bus fleets to charge during the day when solar energy is abundant, and overnight when electricity demand is low. For example, on Oahu, where agencies would usually pay 25c/kWh, they can pay 21c/kWh during the Mid-Day period (9am to 5pm) and 23c/kWh during the Off-Peak period (10pm to 9am). Demand charges typically paid by commercial customers are also eliminated during the Mid-Day and Off-Peak periods. These rates are designed to encourage agencies to avoid charging during the On-Peak period from 5 to 10 PM when the rate is 37c/kWh and demand charges apply [34].

Advice From Those Further Down the Road

Each of the 29 interviewees were asked what they see as the biggest remaining barriers to electrifying transit bus fleets. The responses were collated and are presented in Figure 14. The sum of column 3 - the number of interviewees citing each barrier – is greater than 29, as many interviewees listed more than one barrier.

Figure 14: Interviewee answers to the question “What do you see as the biggest remaining barriers to electrifying transit bus fleets?”

Barrier	Description	No. of interviewees citing barrier
Funding / upfront costs	Upfront funding for buses and charging infrastructure. Three interviewees mentioned that this is a particular challenge given reduced ridership since the beginning of COVID-19.	10
Electric bus range	One interviewee specifically pointed to range reduction issues in cold weather; two others referred to challenges in high temperatures. A number of interviewees indicated that a 250-mile actual operating range would allow them to fully electrify.	8
Need for paradigm shift	BEBs require different operations and expertise than diesel. Two interviewees suggested that some fleet operators are averse to changing their operations. Others referred to the significant staffing capacity and education needed to do so. Another interviewee suggested that fear of the unknown is a barrier.	6
Need for agencies to contract with multiple technology providers	Interviewees referenced the lack of turnkey providers, resulting in the common need for agencies to contract with bus, charging, and managed charging providers separately. Interviewees also referenced the lack of fully and successfully integrated software solutions.	4

Barrier	Description	No. of interviewees citing barrier
Lack of workforce development resources	Agencies suggested that additional training materials and assistance is needed from technology manufacturers.	2
Space constraints	Lack of available space to fit charging infrastructure. Six out of 14 agencies interviewed expect to construct a new electric-ready depot as part of their transition	2
Lack of peer-to-peer sharing/ demonstrations/ published guides	One agency indicated insufficient study of operational costs over the lifetime of the vehicle, including workforce development costs.	2
Power	Lead time and permissions/access for utilities to get additional distribution system capacity installed	2
Lack of Automation	Need to reduce manual work involved in charging buses	1
Reliability of chargers	Need for charging equipment to meet a higher reliability standard	1
Reliability of electric buses	Need for electric buses to meet a higher reliability standard	1
Lack of data needed to seek approval for beneficial bus rates	Lack of real-world transit bus data needed to understand load curves and design and justify beneficial electric rates for transit	1
System reliability	Need to develop solutions to power outages as agencies ramp to full electrification	1

Each of the twelve transit agencies with electric buses deployed were also asked the question *"What should be an agency's first steps in planning for electrification?"* Seven out of twelve answers referenced the need to engage early with the agency's electric utility. Beyond that, the answers differed, as shown in Figure 15.

Figure 15: Transit agency answers to the question "What should be an agency's first steps in planning for electrification?"

7 out of 12 agencies: Engage with your utility

- Everyone looks at vehicles first, but infrastructure is more important
- Look long term, understand peak loads, determine infrastructure need, then think about the space required

\- Rochester Transit Service, NY

- Start slow, be incremental, but plan for the ability to scale
- Don't do this in a vacuum: set up committees, make sure people are on the same page

\- Trimet, OR

Reach out to the Zero Emission Bus Resource Alliance. The purpose of this group is to share experiences openly without outside influence. They have resources, transition plans, etc.

\- Foothill Transit, CA

- Be aware that bus & charger manufacturers may overpromise range, economy, & reliability
- Look at multiple charging approaches

\- Mountain Line, MT

- Read other agencies' transition plans, visit their facilities, & talk to their fleet operators
- Develop an internal structure connecting departments that are relevant to electrification

\- Chicago Transit Authority, IL

- Understand the pros & cons of each technology
- Understand your agency's needs & potential to be flexible (e.g. with shorter blocks, more ins and outs, shortening routes)

\- Transit Authority of River City, KY

Include workforce training & engagement plans with depot, safety & central maintenance staff

- New York City Transit, NY

- Test out different buses (manufacturers often let agencies test for 90 days)
- Communicate with local government on permitting
- Get contracting staff involved asap

- Santa Clara Valley Transportation Authority, CA

- "Plan, plan, plan"
- Start with the end in mind: what do you want the system to look like at the end, what are your priorities and guiding principles?
- Make resiliency a priority

- LA Metro, CA

Utility capacity planning, design & service construction have long lead items; start early

- Metro Transit, MN

Everyone is focused on purchasing buses. Think about charging infrastructure first.

- Long Beach Transit

- Partner with companies that have deployed product
- Be honest about what's important -- what are your KPIs and how will they be collected? How will the outcome of the project inform future efforts?

- King County Metro, WA

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