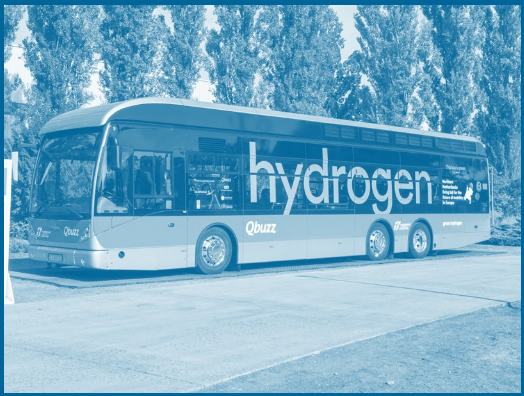


Zero Emissions Bus Technology Fact Sheet

An overview of zero emissions bus technology

Prepared by the Fresno County Rural Transit Agency and Walker Consultants with funding from the California Department of Transportation and the Federal Transit Administration

CALIFORNIA DEPARTMENT OF TRANSPORTATION

Federal Transit Administration

WALKER CONSULTANTS

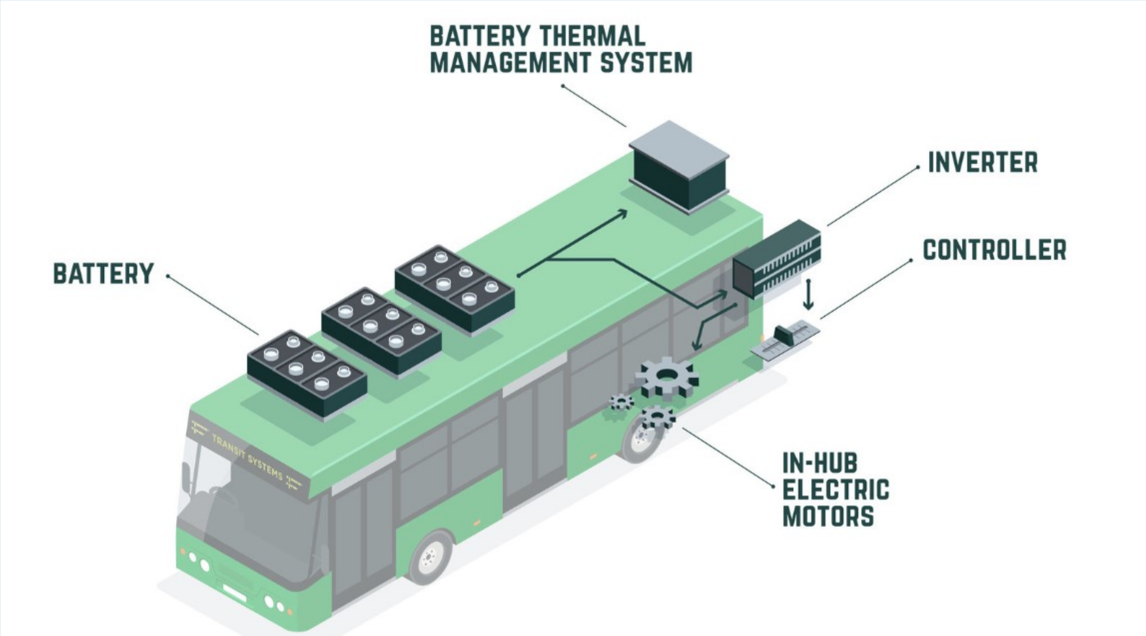
FCRTA
Fresno County
Rural Transit Agency
Accessible EV ***Mobility*** *and* ***Infrastructure*** *For All*

Battery Electric Bus (BEB) Basics

What is a battery electric bus (BEB)?

BEBs are powered by electric motors instead of internal combustion engines (ICE). A BEB uses a battery pack to store electricity that powers the motor. The batteries are charged by connecting the vehicle to an electric power source.

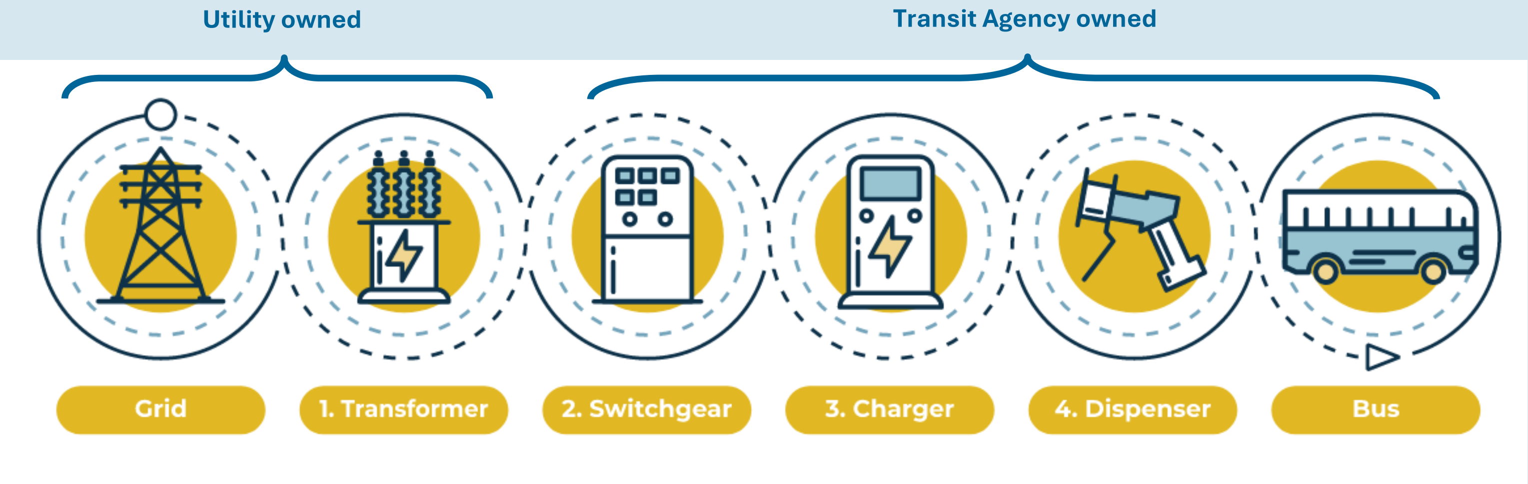
Typically BEB batteries are lithium ion batteries, which are embedded into the bus structure on the top, bottom, or back of the bus depending on the manufacturer. BEBs have an on-board battery management system (BMS), which controls the battery. BEBs have regenerative braking systems, which recharge the battery, turning the motor into a generator and optimizing energy usage.



Source: https://www.transitsystems.com.au/electric-buses

How do you charge a BEB?

BEB charging typically requires a transformer, switchgear, charger, and dispenser. The electric utility is responsible for the grid and transformer and the transit agency is responsible for the switchgear, charger, and dispenser. The charging process is illustrated below:



Source: National Academies of Sciences, Engineering, and Medicine. 2021. Guidebook for Deploying Zero-Emission Transit Buses. Washington,

Charging stations can be networked or non-networked. A non-networked charging infrastructure is not connected to the internet and provides basic charging capabilities absent advanced utilization monitoring or payment capabilities. To install a networked station, the site must have access to a wired or wireless internet connection or cellular service.

Installation costs for chargers are influenced by a variety of factors including the number and type of charging infrastructure, geographic location, site location and required trenching, existing wiring and required electrical upgrades to accommodate existing and future charging needs, labor costs, and permitting. If an agency chooses to power by renewable energy (e.g. wind and solar), those infrastructure costs must be accounted for.

BEB Charging Types

There are three (3) primary types of BEB charging stations including plug-in charging, overhead conductive, and wireless inductive charging. Advantages and considerations of each type of charger is listed in the table below.

Charging Type	Opportunities	Considerations
Plug-in charging—typically used for charging at bus depots.  FCRTA Level 2 Plug-in Charger	• Relatively low cost per charging unit. • Typically does not require an after-market bus retrofit. • Well established, widespread technology. • Charging typically occurs overnight when electrical rates are lower. • Can purchase chargers with multiple charge ports so more vehicles can be charged at one time.	• Cables susceptible to damage and wear. • Cord management, and safety concerns with cord handling and fall risks. • Susceptible to inclement weather. • Potential for theft or vandalism of equipment. • More space intensive than overhead or inductive charging. • Charging multiple buses at a time at a depot can result in utility demand charges.
Overhead Charging– historically used for on-route charging, but can also be used for depot charging.  Example of On-Route Overhead Charging  New York City Metropolitan Transportation Authority Overhead Charging at Bus Depot *Source: New York Governor's office*	• No manual connections required to charge bus. • No cords required. • Fast charging time, potentially enabling agency to purchase BEB with smaller batteries, which are less expensive. • Easier for bus operator to use than plug-in charger. • Less space intensive at a bus depot.	• High capital and maintenance costs. • If installing at bus depot, requires more height and structural support. • Communication between bus and charger is done wirelessly, which may be less reliable than plugging in. If using at a bus depot, the WiFi signals could get crossed between chargers.
Wireless Inductive Charging– typically used for on-route charging, but can be used at depot.  Level 3 wireless charging at Antelope Valley Transit Authority (AVTA), *Source: WAVE*  *Level 2 wireless charging,* *Source: WitriCity*	• Equipment is underground. • No manual connections required to charge bus. • Easy to operate, vehicle drives over charging plate. • Ideal for space constrained sites. • Equipment protected from inclement weather. • Few moving parts that require maintenance. • When deployed on-route, can potentially purchase fewer buses and/or buses with smaller battery sizes	• High cost for equipment and installation. • After market retrofit required to be installed on the BEB, adding to cost. Some vehicle models are not compatible with some charging types. • If installed on-route, need to have a long stop or layover to get meaningful range, charges ~2 miles per minute • Less established technology than plug-in or overhead.

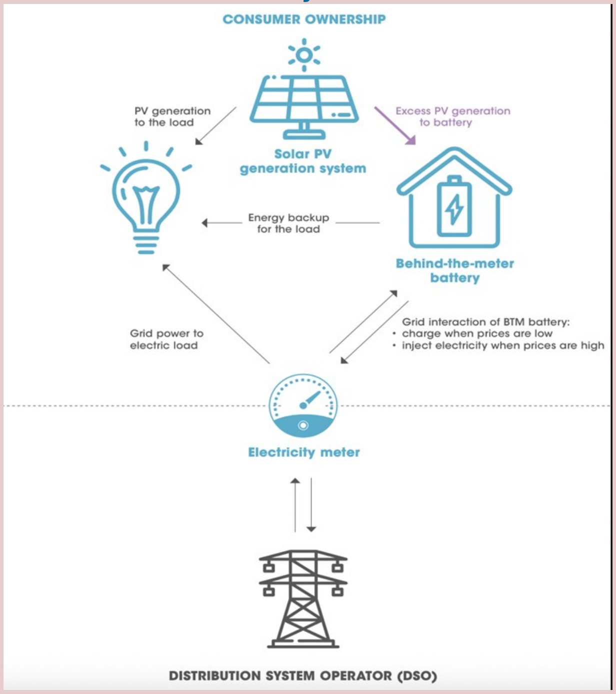
Innovative Charging Strategy—Microgrids

Transit agencies can consider reducing their reliance on the electrical grid and saving energy costs by installing solar or wind infrastructure. The energy produced onsite can power electric vehicle fleets. Because solar is generated during the day and charging typically occurs overnight, battery energy storage is required. To save space, solar infrastructure can be installed over BEB parking spaces as a solar carport.

Microgrids use the energy produced by renewable energy sources and store it to power transit fleets. The microgrids can supply emergency power during grid outages. Microgrids can still connect to the electric grid, but can also operate on "island mode" using the solar and battery supply. Microgrids are supported by an intelligent management system to reduce energy consumption and increase reliability. Microgrids also have the potential of serving as multi-modal resiliency hubs, providing amenities such as electric bike share, carshare, and cell phone charging.

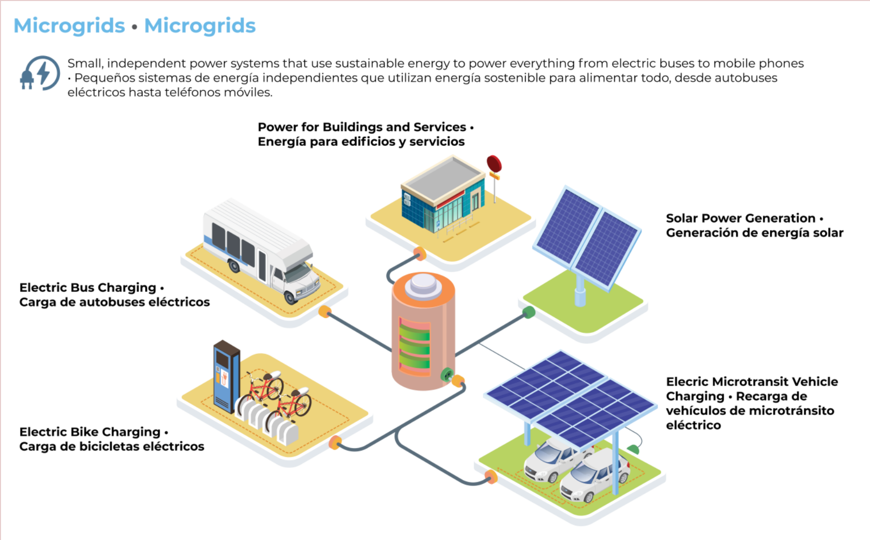
Transit agencies that have deployed microgrids include the Montgomery County Department of Transportation and Martha's Vineyard Transit Authority. Fresno County Rural Transit Agency recently completed a Microgrid Feasibility Study and is planning to deploy five pilot microgrid/multi-modal resiliency hubs in rural communities.

Behind the Meter Battery and Solar PV Interactions



Source: International Renewable Energy Agency

Potential Microgrid Applications



Source: Walker Consultants

Multi-modal Resiliency Hub Concept

Source: Walker Consultants

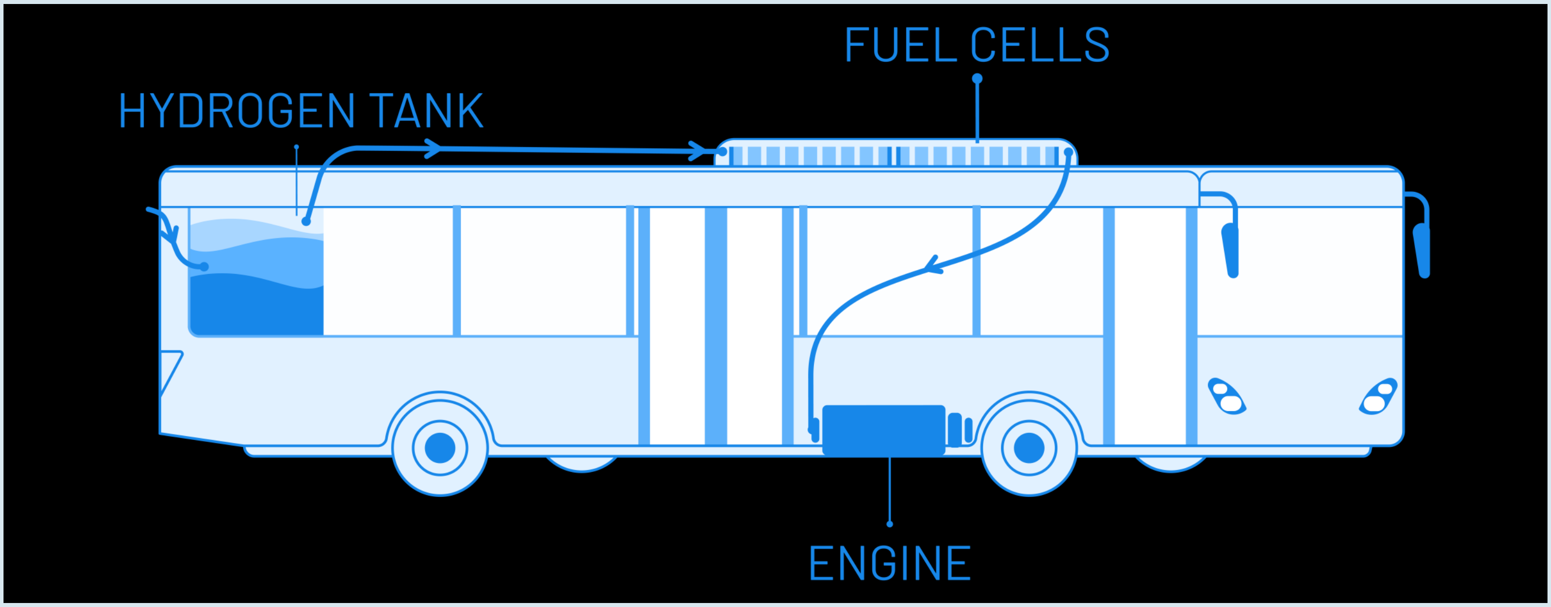
Montgomery County, MD Bus Depot

Source: Enel North America

Fuel Cell Electric Bus (FCEB) Basics

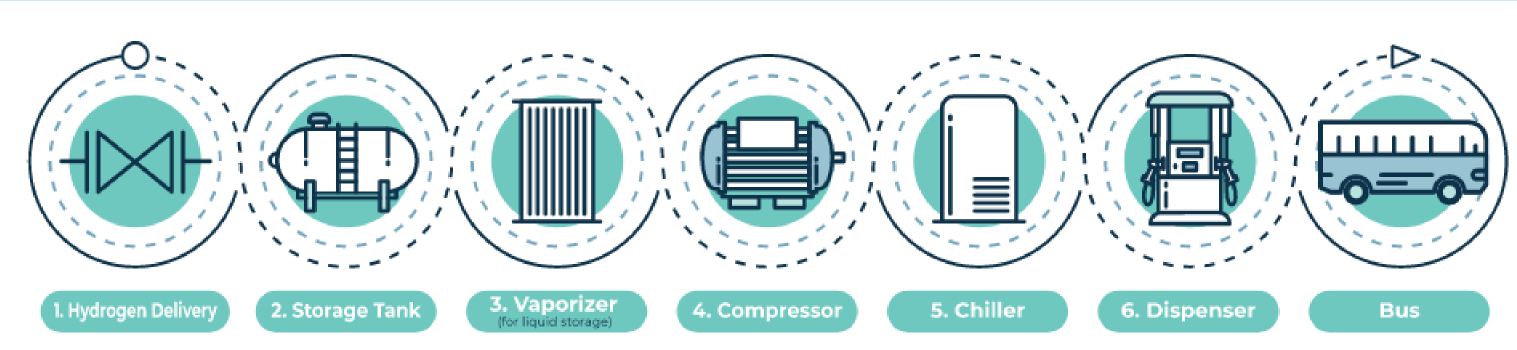
What is a fuel cell electric bus (FCEB)?

FCEBs are similar to BEBs in that they have similar propulsion systems and both store energy to power an electric motor. The key difference is that while BEBs store energy in batteries, FCEBs store energy in a hydrogen fuel tank which is converted to electricity by a fuel cell. The electricity then charges the on-board battery pack. FCEB range is similar to conventional buses and have a short refueling time, similar to compressed natural gas (CNG) buses. FCEBs also have a regenerative braking system like BEBs. The key components of an FCEB are illustrated in the figure below.



How do you fuel a FCEB?

FCEBs are fueled by hydrogen, which can be produced on-site or delivered, and can be stored as a liquid or gas form. Transit agencies need to have a hydrogen fueling station, which typically includes a hydrogen delivery system (delivered by a supplier or produced on-site), hydrogen storage tanks (must be above-ground), vaporizer (for liquid storage), a compressor, chiller, and dispensing system. The figure below illustrates the hydrogen fueling process.



Source: National Academies of Sciences, Engineering, and Medicine. 2021. Guidebook for Deploying Zero-Emission Transit Buses. Washington, DC: The National Academies Press. https://doi.org/10.17226/25842.

Gray Hydrogen

Produced from fossil fuels without carbon capture at the point of production. Most hydrogen produced today is gray hydrogen

Blue Hydrogen

Produced from fossil fuels with carbon capture at the point of production

Green Hydrogen

Hydrogen produced by a carbon neutral production pathway, most commonly through electrolysis (splits water into hydrogen and oxygen)

FCEB Fueling Considerations

To deploy hydrogen fuel, transit agencies need to have a hydrogen fueling station or partner with another agency to share a station. However, agencies need to ensure the fueling equipment is compatible with the FCEBs. The station can be permanent or temporary. Examples of each is included below.

Permanent Fuel Station

Stark Area Regional Transit Authority (SARTA) Fuel Station, Source: SARTA

Temporary Fuel Station

Sunline Transit Agency Mobile Hydrogen Fuel Station , Source: Jay Calderon, The Desert Sun

Transit agencies have the opportunity to either generate hydrogen on-site or have it delivered. Benefits and considerations of both approaches is summarized in the table below.

Production Method	Benefits	Considerations
Produce hydrogen onsite through natural gas reformation or electrolysis  *AC Transit Hydrogen Fueling Station Source: W.L Butler*	• Agency manages hydrogen production. • Agency not reliant on third-party vendor to set hydrogen price or supply. • If producing hydrogen via electrolysis, can use renewable energy eliminating emissions and lowering energy costs. • Per unit price of hydrogen can be lower than for hydrogen delivery.	• High capital costs, maintenance requirements, and space needed. • Hydrogen production failures may result in service disruption. • Requires compressors and a refrigerator. • Depending on production system used, can have significant energy usage.
Purchase liquid or gaseous hydrogen and have it delivered 	• Less equipment on-site, saving space and resulting in lower operations and maintenance costs. • Avoids energy costs associated with producing on-site. • Could be beneficial for small fleets or test fleets that do not have the demand to warrant owning and maintaining hydrogen production equipment. • Fueling process is similar as for CNG fuel.	• Cost of hydrogen is significantly higher than other fuel types. • Emissions associated with trucking hydrogen (if conventional trucks used). • Supplier dictates hydrogen cost. • Transit agency relies on third-party for manufacturing and distribution. • Risk of hydrogen leakage during delivery. • Concern with maintaining hydrogen purity during delivery.

ZEB Best Practices

Conduct vendor due diligence Zero emission bus technology is still relatively new and evolving. Unfortunately the industry has experienced turnover which can lead to obsolete vehicles and infrastructure for vendors. Prior to selecting technology, it is important that transit agencies carefully review the qualifications of vendors including company financial status, history, reputation, and deployment examples. Speak with other transit agencies that have successfully deployed the technology to learn about their experience.

Verify vehicle specifications. Industry standards for ZEB deployment are evolving as the technology matures. The *Guidebook for Deploying Zero-Emissions Transit Buses* has a list of industry standards that have been used in other ZEB specifications. Carefully evaluate the range provided by the manufacturer to determine whether it is based on Altoona testing alone and what battery life cycle the range considers. Consider compatibility of vehicle and fueling infrastructure. Often times BEBs will have proprietary charging infrastructure. If an Original Equipment Manufacturer (OEM) goes out of business, consider if and how that vehicle could be charged.

Carefully review OEM contracts and request pertinent information. For BEBs, each OEM specifies a minimum and maximum state of charge (SOC). Charging rates vary based on SOC. Request that OEMs specify allowable charge rates at varying SOCs. Ensure OEM contract includes driver training as well as fueling/charging training. Ensure vehicle acceptance criteria is clearly communicated in final vehicle contracts. Ensure contract terms include adequate time for proper vehicle testing. Carefully review OEM battery and/or fuel cell warranties to ensure terms and conditions are easily understood and reasonable. The OEM should provide explanations of all disclaimers that could affect the ability to file for a warranty claim. Consider establishing a not to exceed cost for mid-life battery or fuel cell replacement. Require your bus and fueling infrastructure OEMs to provide a list of critical and recommended spare parts for on-site inventory. For other spare parts, request pricing and typical fulfillment timelines. Ask OEMs to provide a list of preventative maintenance activities, the time interval, skills needed, and required parts to complete each task.

Understand infrastructure installation costs. Many vendors exclude the cost of installation from their infrastructure costs, while the installation costs can often be as expensive or more expensive than the equipment itself. Request that vendors provide installation cost estimates or that they recommend vendors that could provide an estimate. Estimates for EV infrastructure should come from a certified electrician.

Conduct a bus modeling and route simulation. In this process, an initial block screening should be conducted, considering both mileage and time. Additionally, fuel economy needs to be analyzed which is dependent on a variety of factors such as elevation and topography, bus specifications, driving cycles, passenger loads, and ambient conditions. One tool available for this modeling is the Argonne System Modeling and Control Group's free application Autonomie to perform powertrain modeling and simulation (link included on following page). There are also third-party experts who have developed modeling tools to help transit agencies choose the right technology for their operations.

Allocate time and resources to training. ZEB operation and maintenance requires specialized training. All staff need to be aware of the unique hazards associated with battery chargers and hydrogen fuels, including high-voltage cables, battery fire and explosion hazards, and high-pressure gas hazards. BEB operation, especially, requires specific training on proper docking, braking, and shut down, and a general understanding of BEB operation. Drivers should know how battery state of charge (SOC) relates to range and how environmental factors can affect range, so that sufficient charge can be maintained according to the planned route. Staff should be trained on high-voltage hazard training, hydrogen fuel safety training, and first responder training. Provide training so that technicians understand how to service and troubleshoot all-electric propulsion, balance of plant for FCEBs, and auxiliary systems. They should also know how to work with the onboard diagnostic systems, and should be trained on safe work practices for hydrogen and high-voltage systems, to include the handling, storage, and disposal of batteries. The *Guidebook for Deploying Zero-Emission Transit Buses* has a list of potential training topics.

ZEB Best Practices

Establish key performance indicators for ZEB deployment, including factors such as:

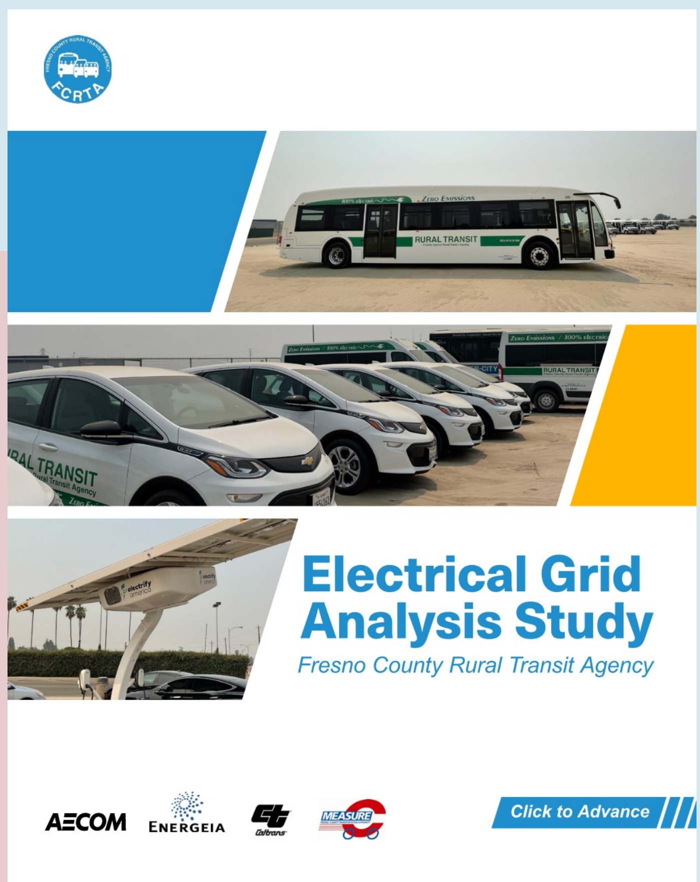
- Fuel cost per mile
- Energy efficiency—note that energy consumption provided by OEMs typically does not account for grid-to-charger loss, charger-to-bus loss, or standby energy consumption.
- Vehicle availability—how often vehicles could be put into service.
- Utilization—actual usage of ZEB fleet compared to possible usage.
- Compare performance to non-ZEB fleet vehicles.
- Emissions reductions.

Understand Electrical Grid Limitations. Charging BEBs requires a significant amount of energy. It is important that transit agencies have an awareness in the electrical grid system in the service area. Most utilities have publicly available "hosting capacity" GIS maps. These maps typically illustrate the electricity grid's capacity to host new load. The key comparison is the utility's estimated forecast of energy load on the asset vs. what the asset is rated to handle. Agencies can consider engaging utility companies to help better understand this data and/or get a better sense of constraints at a high level. Agencies can also consider conducting a grid analysis study (see FCRTA example below).

Coordinate with electric utility early to understand how utility rate structure may change and explore potential programs and incentives offered by the utility. Demand charges (also called surge charges) can have significant implications for BEB operations that use fast chargers or multiple chargers simultaneously. Transit agencies can consider purchasing a charge management system to manage utility bills. Hydrogen fueling stations also require significant power for compression.

Allow adequate time for vehicle acceptance testing. During the vehicle acceptance testing period, consider testing for operating range, maneuverability, performance at low State of Charge, performance with HVAC running, performance during different terrains and elevations, and performance with high passenger load. Ensure the timeline agreed to with the OEM allows for these procedures to occur prior to deploying vehicles.

Consider vehicle weight and passenger capacity. BEBs tend to be heavier than FCEBs. The weight of the BEB is influenced by the size of the battery. Especially on high-ridership routes, consider limitations on passenger load prior to selecting BEB battery size.



Best Practice—FCRTA Electrical Grid Capacity Study

The Fresno County Rural Transit Agency (FCRTA) received a Caltrans Sustainable Communities grant to conduct an Electrical Grid Analysis. This study identified the impacts of increased electrification on the electric grid system and the unique challenges faced by rural communities in Fresno County. Through this study, FCRTA learned there is a lack of grid capacity at its Selma maintenance facility. Therefore, FCRTA is installing solar infrastructure throughout the facility with a goal of achieving net zero at the facility.

Due to the expansive service area FCRTA covers, the agency needs to charge in rural communities. The study also suggested the need to install microgrids to reduce reliance on the grid in rural communities. FCRTA is actively establishing partnerships and pursuing funding to install microgrids.

A link to the full study is provided here.

Considerations when Selecting ZEB Technology

Consideration	Battery Electric Buses (BEBs)	Fuel Cell Electric Buses (FCEBs)
Infrastructure Needs and Scalability	Types of BEB chargers include plug-in, overhead conductive, and/or wireless inductive. Due to range limitations, BEB fleet sizes may need to be larger than for FCEBs. Adding more BEBs is likely to result in the need for additional charging infrastructure, occupying more space.	Must have a hydrogen storage and fueling station. Can either purchase hydrogen to be delivered as gas or liquid hydrogen (liquid is more common in transit context, as it allows for higher storage capacity) or produce hydrogen on-site through electrolysis or natural gas reformation. Concern with resiliency if hydrogen fueling station is not operational, especially if there is no alternative available. Adding FCEBs to an existing fleet does not require additional charging infrastructure, but may require additional storage. Hydrogen is highly flammable, so adequate ventilation and leak detections systems are needed.
Vehicle Options	Fewer BEB options currently on the market compared to CNG or diesel, but more options than FCEBs. More heavy-duty BEB options available than electric cutaways and vans.	More limited FCEB vehicle options, no cutaways or shuttles on the market currently.
Vehicle Costs and Maintenance	BEBs cost more than diesel, gas, and CNG buses, but approximately 30% less than a FCEB. Most BEB maintenance costs come from cab, body, and accessory systems. Battery capacity degrades over time, impacting BEB performance. Agencies have experienced issues with availability of parts.	FCEB purchase price higher than BEBs, partly due to the high capital cost of the fuel cell. Maintenance costs lower than CNG and diesel, but can be higher than BEBs. The fuel-specific components and onboard hydrogen storage increase the number of components for maintenance.
Vehicle Range	Range shorter than FCEBs, and is impacted by passenger load, elevation, temperature, and driver operations. Usage of HVAC on-board deplete the battery as well. Range of less than 150 miles is typical.	Range comparable to CNG bus, can have range up to 300 miles depending on duty cycle. FCEBs tend to perform better than BEBs in a variety of climates and on hilly terrain.
Refueling Time and Process	Depot plug-in charging can require hours to fully charge depending on charger type and vehicle battery size. Charging requires more staff training and is significantly different than for CNG buses.	Refueling time and process similar to CNG buses, typically ten minutes or less.
Energy Efficiency	Because energy is transmitted directly from charger to battery, BEBs tend to have higher tank to wheels efficiency than FCEBs.	FCEBs tend to have lower tank to wheels efficiency than BEBs, as FCEBs use hydrogen to produce electricity which charges the battery.
Electricity Usage	BEB charging has significant electrical demand. A charge management plan and potentially software are recommended to reduce utility bills. To reduce grid impacts, can install renewable energy resources (e.g. solar and wind) on-site at bus depot and/or satellite locations. These systems typically need battery storage to store the energy produced. However, these systems have associated capital and operating costs.	If producing hydrogen on-site, can have significant electrical demand. Can lower this demand if implementing renewable energy sources.
Emissions	No tailpipe emissions. Zero emissions if powered by renewable energy, such as solar or wind.	No tailpipe emissions. Trucking hydrogen has emissions associated with the transport vehicles (unless vehicles are zero emission). Can produce hydrogen via electrolysis which if powered by renewable energy sources is zero emission.

ZEB Deployment Resources

Guidebook for Deploying Zero-Emission Transit Buses | The National Academies Press - Guidebook that provides public

transit agencies with best practices, case studies, and lessons-learned from previous deployments of battery electric buses, fuel cell electric buses, and related infrastructure.

Zero Emission Bus Resource Alliance | zebragrp.org —Professional association for transit agencies in the U.S. and Canada to share lessons-learned about zero-emission buses.

Argonne GREET R&D Model (anl.gov) - Argonne National Laboratory tool that simulates well-to-wheel emissions of various vehicle types and can be a useful resource in estimating emissions reductions.

Autonomie - Vehicle & Mobility Systems Department - Argonne National Laboratory (anl.gov) - Argonne National Laboratory simulation tool that evaluates the impacts of ZEBs on vehicle energy consumption, performance and cost.

Design Guidelines for Bus Transit Systems Using Electric and Hybrid Electric Propulsion as an Alternative Fuel (archive.org) — FTA document that provides transit agencies with an overview of the technology, recommended safety specifications in bus design, and training for personnel that will enable them to understand the implications of purchasing, operating, and maintaining electric and hybrid-electric buses. In addition, the document is intended to provide basic information on electrical and operational safety for transit and non-transit personnel, such as emergency responders to an accident.

Home | H2tools | Hydrogen Tools - The Department of Energy's Hydrogen Program has resources for safety training for hydrogen vehicles.

Hydrogen Fuel Cell Engines and Related Technologies Course Manual | Department of Energy—Produced by College of the Desert and SunLine Transit Agency with funding from the FTA, this course manual features technical information on the use of hydrogen as a transportation fuel.

H2FAST: Hydrogen Financial Analysis Scenario Tool | Hydrogen and Fuel Cells | NREL—National Renewable Energy Laboratory tool that agencies can used to understand financial implications of hydrogen.

Heavy-Duty Refueling Station Analysis Model (anl.gov) - Argonne National Laboratory model that allows agencies to compare the cost of different hydrogen refueling options, identify cost drivers of current hydrogen refueling technologies for various station configurations, and identify demand profiles of heavy-duty fuel cell electric vehicles.

Microsoft Word - PreparingToPlugInYourBusFleet_12-4-2019.docx (publicpower.org) - Edison Electric Institute guide that is organized around 10 key things that transit agencies should know about electric companies and fleet electrification.

Hydrogen Readiness - California Governor's Office of Business and Economic Development—State website that includes a Hydrogen Station Permitting Guidebook and Hydrogen Stations Buyer's Guide.

Fuel Cell Electric Bus Evaluations | Hydrogen and Fuel Cells | NREL—National Renewable Energy Laboratory evaluates FCEBs to provide evaluation results of fuel cell bus development and performance compared to conventional baseline vehicles.

Featured News & Blog | CTE—Center for Transportation and the Environment provides ZEB news and resources for transit agencies.

Sustainable Bus - Electric Bus and Sustainable Mobility. (sustainable-bus.com) - Provides ZEB news from around the world.

Fleet Electric Vehicle Implementation Checklist (energy.gov) - Alternative Fuels Data Center checklist for selecting electric fleet vehicles and installing infrastructure.

Home | Hydrogen Fuel Cell Partnership (h2fcp.org) - Industry/government collaboration, based in California, aimed at expanding the market for fuel cell electric vehicles.

Arches H2 - Public-private partnership to create a statewide clean hydrogen hub in California and beyond.

Technical Assistance and Resources for Transit Agencies · Joint Office of Energy and Transportation (driveelectric.gov) - Resources for transit agencies created by the Joint Office of Energy and Transportation.

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