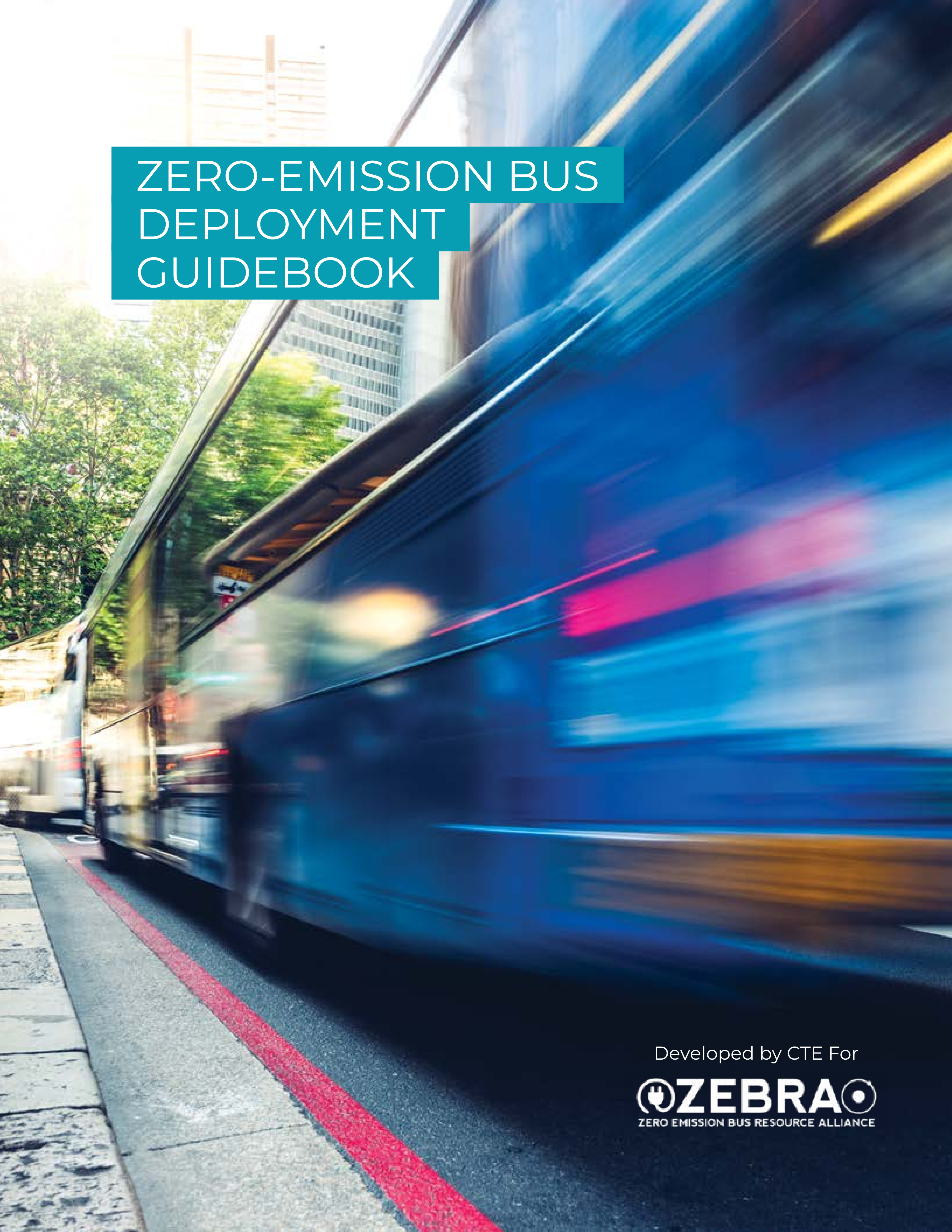
ZERO-EMISSION BUS DEPLOYMENT GUIDEBOOK



Developed by CTE For

ZEBRA
ZERO EMISSION BUS RESOURCE ALLIANCE

(Image Credit: NREL)

ABOUT ZEBRA

The Zero Emission Bus Resource Alliance (ZEBRA) is a professional association which began in 2015 for transit agencies to come together and share lessons learned about zero-emission technologies.

ZEBRA's mission is to advance transit agencies' capacity for zero-emission bus (ZEB) adoption through information exchange, training programs, shared research, and public education. ZEBRA meetings are designed to help connect transit state-of-the-art ZEB practices and reflect ZEB interests as a collective voice.

All transit agencies are welcome to become ZEBRA members, and enjoy access to valuable industry meetings and exclusive content.

To learn more, visit zebragrp.org, or send us an email at info@zebragrp.org.

ABOUT CTE

The Center for Transportation and the Environment (CTE) is a member-supported 501(c)(3) nonprofit organization that improves the health of our climate and communities by bringing people together to develop and commercialize clean, efficient, and sustainable transportation technologies. CTE works on behalf of ZEBRA's membership to provide the group with technical assistance and industry consultation based on extensive experience in ZEB deployments.

Since 1993, CTE has managed a portfolio of over $530 million in team research, development, and demonstration projects. We've helped over 200 US companies move their technologies into the global energy and transportation mainstream. Currently, CTE is heavily involved in the deployment of electric vehicles across the U.S. CTE also works closely with vehicle manufacturers, component providers, and fleet operators, including transit agencies and logistics organizations across the country. Learn more at www.cte.tv

ZERO-EMISSION BUS DEPLOYMENT GUIDEBOOK

TABLE OF CONTENTS

INTRODUCTION

GUIDE OVERVIEW

Deploying zero-emission buses won't be "business as usual" for your transit agency. You will most likely need to modify your planning, operational, and maintenance processes in order to effectively implement the technology. This guidebook will introduce you to the decision-making process for deploying zero-emission buses (ZEBs).

After working through this guidebook, you will have an increased understanding of:

- Advantages and disadvantages of available ZEB technology
- Dependencies that impact bus performance and costs
- How your unique operational requirements and site characteristics will drive your ZEB deployment strategy
- Available tools and resources that help take your planning efforts further and make your transition easier and more efficient

There is no one-size-fits-all for ZEB deployments. However, the information in this guidebook will provide you with a baseline understanding of the issues you will need to address to properly deploy, operate, and maintain zero-emission buses. It will help you initiate your planning processes, engage with the necessary stakeholders, and ensure that you have the information you need to make the best decisions for your agency.

GOING ZERO-EMISSION

Why go zero-emission?

ZEBs are quieter, more energy efficient, and smoother than conventionally fueled buses due to their all-electric propulsion and auxiliary systems. Implementing zero-emission technology in the public transit sector will help mitigate the impacts of climate change and significantly reduce air pollutants in the communities you serve.

The EPA found that between 1990 and 2015, greenhouse gas emissions in the transportation sector increased more than any other sector[1]. In 2016, transportation accounted for 30% of carbon emissions in the U.S.

Some U.S. states have mandated that transit agencies incorporate ZEBs into their fleets. For example, the California Air Resources Board (CARB) has set a statewide goal for transit agencies to transition to 100% zero-emission bus fleets by 2040[2].

As of mid-2018, almost 500 ZEBs have been delivered in the U.S., with over 1,400 additionally awarded or sold[3]. A list of available models of ZEBs compliant with Buy America Regulations is provided in Appendix A.

California ZEB Requirements

All transit agencies in California must submit a Rollout Plan to the Executive Officer by July 1, 2020 for large transit agencies or July 1, 2023 for small transit agencies. For more information, visit CARB's website[4].

[1] *https://www.epa.gov/transportation-air-pollution-and-climate-change/carbon-pollution-transportation*
[2] *https://ngtnews.com/california-switching-to-zero-emission-transit-buses-by-2040*
[3] *CTE Annual Market Survey*
[4] *https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit*

WHAT ARE YOUR GOALS FOR ZEB DEPLOYMENT?

Your transit agency's priorities and motivations for deploying zero-emission technology will impact your decisions on technologies, fueling strategies, and operational requirements.

- Why is your agency moving towards ZEBs?
- What decisions have already been made related to ZEB deployments?
- What percentage of your fleet are you considering transitioning to ZEBs?
    - Are you interested in testing the technology with an initial pilot program?
    - Are you planning on eventually transitioning your full fleet to ZEBs?
- What are your priorities for the ZEB deployment? Minimizing operating or capital costs? Minimizing disruption to current operations? Reducing air pollution in environmental justice or disadvantaged communities? Complying with regulations?
- How will you measure success?

Consider your long-term ZEB goals before moving forward with any deployment projects. Think strategically about where your agency will end up, and then plan smaller deployment projects that will support your needs. Revisit any long-term fleet transition plans every two years to ensure that your assumptions are still valid. Technological advancements, regulatory requirements, and changes to your agency's operations should be incorporated into your plans.

WHO SHOULD YOU BRING TO THE TABLE?

Coordinating with internal and external stakeholders throughout the planning process will allow you to identify and address potential concerns before you operate buses in service. Engaging stakeholders early will also allow you to identify potential project champions that can help you overcome various obstacles.

Transit agency department staff

Deploying ZEB technology will require input from almost all of your transit agency's departments. This Guidebook and attached worksheets can help frame an internal kickoff meeting with representatives from across your agency to gain support for the plans to deploy ZEB technology, provide background information on ZEB technology, and to identify planning considerations.

Involve staff from the following departments in the planning process:

- **Operations and Planning** – Your operations and planning staff will gather necessary information to inform decisions and develop schedules and timelines. These departments will also identify blocks or routes that would be eligible for ZEB deployment, and will manage the implementation of any necessary operational changes to accommodate charging/fueling times. Operations and planning staff will also track and report deployment data required by any regulatory agencies or transit agency staff.

- **Maintenance** – Your maintenance staff will drive the development of technical specifications for bus procurements. It will be critical that maintenance staff have in-depth knowledge of the bus in order to make repairs that keep the buses in service. Maintenance staff will keep an inventory of spare parts and ensure scaffolding or other tools required for ZEB maintenance are on-site.

- **Facilities** – Facilities staff will be responsible for managing the construction and operation of any fueling or charging equipment and will work closely with maintenance staff to ensure coordinated operation of the ZEB fleet and charging or fueling infrastructure.

- **Finance and Procurement** – Your procurement staff will assist with pursuing funding opportunities, fulfilling grant requirements, issuing Requests for Proposals (RFPs) for buses and charging or fueling infrastructure, and developing financial plans to support the integration of ZEB technology into your fleet. Keeping procurement staff informed on regulatory requirements, technological capabilities, and environmental benefits will help them better identify and pursue potential funding sources.

- **IT** – IT staff can coordinate efforts to manage and analyze bus deployment data and support any telematics that are utilized by the charging or fueling equipment, as well as handle upgrades for additional data access at the depot for buses or chargers.

- **Sustainability Manager** – The sustainability manager will help advocate ZEB implementation, quantify environmental benefits, and identify opportunities for additional environmental programs.

- **Contract Operator** – If your transit agency utilizes contract operators, you will need to review and update their typical terms and requirements to accommodate changes in operations for ZEBs.

- **Board or Executive Leadership** – Your executive team will provide support for the project and assist in establishing goals, as well as identify sources of funding or reallocate resources in support of a fleet transition plan.

- **Public Information Officers (PIOs)** - PIOs will coordinate external communication regarding the ZEB deployments. Any communication or publicizing will help align support and identify potential funding sources for bus deployments.

External stakeholders

Effective planning will allow you to build the case for the benefits of ZEBs with external stakeholders. Some groups may question the higher up-front costs, and some may have concerns about the increased load on power plants. Consider highlighting the community and environmental benefits, as well as the agency's commitment to serving the public with more efficient, cleaner technology to increase support for the project.

Identify contacts at the following organizations to engage during the planning process:

- **Local, state, and federal government** – These government organizations may administer funding opportunities for purchasing ZEBs or conducting planning studies. Your state or county may also have regulations related to ZEB deployment that your agency must comply with. Ensure that you identify and understand any relevant regulations, as well as reporting requirements.

- **Labor unions** – New job tasks may be required to test, operate, and maintain ZEBs. Therefore, coordinating with labor unions will ensure that your staff is aware of any new responsibilities, and that you can address any concerns before your buses arrive.

- **Electric utility** – Your power utility can help you understand how your electricity rate schedule may change after the deployment of ZEBs and identify possible approaches to reduce energy costs. Coordinate early with your utility to plan electrical upgrades, understand infrastructure needs, and discuss possible pilot programs that may be mutually beneficial. The utility may participate or conduct high voltage safety training for transit agency staff.

- **Environmental justice and other interest groups**– Environmental justice communities and community equity groups may be interested in your agency's approach to deploying ZEBs. Engaging with these groups can help your agency understand how to address any potential equity concerns, and ensure that your deployment or fleet transition plans are compliant with regulations.

Early interaction with stakeholders will help you determine their level of support and identify the information they will require throughout the project.

ZEB DEPLOYMENT PROCESS

An overall process for managing a ZEB deployment is shown in **Figure 1** below. This process is iterative, as technological advancements, changes in efficiency and battery life will require adjustments to planning, operation, and maintenance activities. An example schedule for the deployment process is shown in **Figure 2**. Note that there are many dependencies between the various phases of deployment, and some steps may take a longer or shorter time than suggested. It is critical that the infrastructure installation is complete before any buses arrive so that you can begin comprehensive testing immediately.

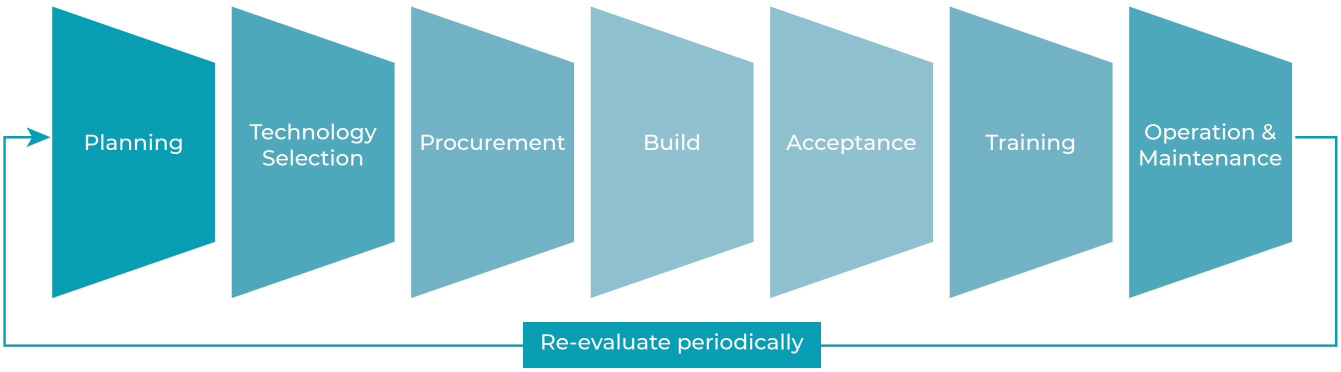


Figure 1*. Generalized ZEB deployment management process*

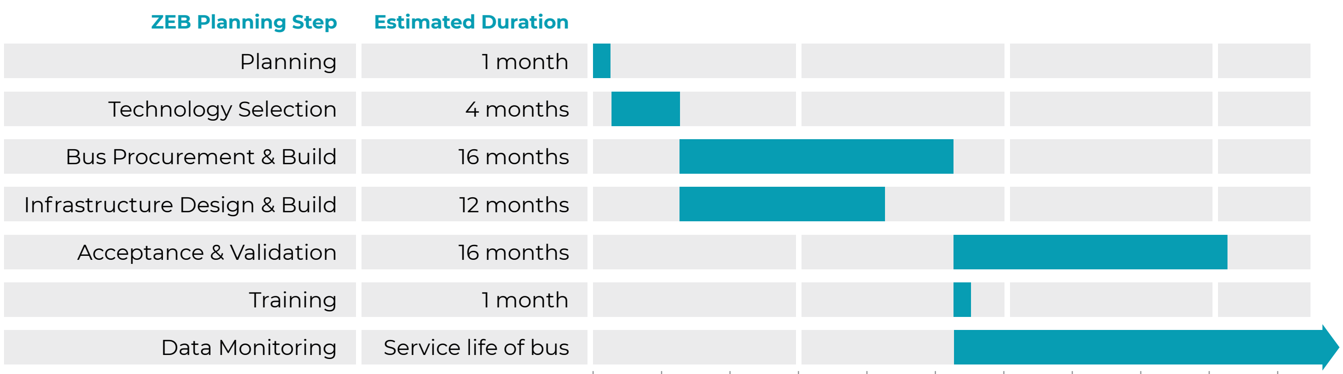


Figure 2*. Example schedule of ZEB deployment activities*

PLANNING

Deploying ZEBs can be challenging. Therefore, careful planning up front is crucial in order to avoid costly changes, gain the support that you need for your deployment, select the best technology for your transit agency, and successfully integrate the new technology into your existing operations. ZEBs may be new to your agency, so selecting the most appropriate technology will require a full understanding of the capabilities of various qualifying technologies and how these technologies can best be utilized to meet your service needs. Increasing your understanding about ZEBs will allow you to anticipate potential issues throughout the useful service life of your buses.

Bus modeling and route simulation is a cost-effective method to assess the operational requirements of your zero-emission bus fleet. Modeling will help you understand range requirements, determine energy consumption on various routes, identify routes that are feasible for the ZEB to complete, and inform charging schedule requirements. Your route model should account for your potential ZEB specifications, climate, route topography, grades, and speeds.

The information in this section will outline the considerations that will need to be incorporated into your planning efforts. You may want to write a plan for your ZEB deployment that can be reviewed and approved by your agency's leadership or relevant government agencies. Your plan should include:

- Operational goals or requirements
- Inventory and description of services, vehicle types, and applicable facilities
- Technology requirements and selections for meeting service needs
- Schedules for procurement and construction
- Deployment plan and any operational changes needed to allow for successful implementation
- Bus and infrastructure testing plans
- Performance metrics for monitoring success and identifying areas in need of improvement
- Staff training plans
- Financial and funding plans

What information do you need to get started?

Your goals for ZEB technology deployment will inform all subsequent decisions. The following information will serve as inputs for your deeper preparation exercises such as efficiency modeling and utility dialogues so you may best utilize ZEBs in your service area:

- **Route data** – Data for representative routes in your service area will support modeling efforts. The results of modeling will help you understand the energy requirements for completing various routes, which will inform vehicle range requirements, blocks that would be eligible for ZEB deployment, and the fleet size needed to complete required service.

- **Operational need for ZEBs** – Based on the goals of your deployment, your transit agency may have already identified a specific need that ZEBs could fill. For example, a downtown circulator may represent a route that can achieve visibility for the new fleet. Modeling efforts will help confirm if your planned blocks are feasible for your selected technology.

- **Operating metrics for non-ZEB fleet** – Establishing a baseline for operations of your non-ZEB fleet such as monthly or annual mileage, fuel and maintenance costs, and availability can be used to compare costs and performance once the ZEBs are in service.

- **Climate information** – On-board HVAC systems require a significant amount of energy, especially for Battery Electric Buses (BEBs). Higher heating and cooling requirements can have a large impact on range. Outdoor BEB parking in cold weather can also impact charging rates. Review monthly average temperatures and common weather patterns that may impact driving conditions (e.g., snow, ice, extreme heat, extreme cold) to determine cabin heating and cooling requirements. Fuel Cell Electric Buses (FCEBs) produce some waste heat that may be used to heat the cabin. The waste heat may be able to keep passengers comfortable when ambient temperatures reach as low as 20°F.

- **Planning documents** – Review agency documents such as Capital Infrastructure Plans, a Climate Action Plan, vehicle retirement schedules, financial constraints, and priorities for future investments to identify how ZEB technology will fit into your agency's planning cycles and activities.

- **Electric utility information** – Review past electricity bills to understand your electricity costs and the utility rate schedule. After deploying ZEBs, you may be moved to a different rate schedule. It is important to understand your options for different rates to determine the most efficient and affordable way to deploy and charge your buses. Request reliability reports to understand what frequency and types of outages you should plan for.

TECHNOLOGY SELECTION

What are the available ZEB Technologies?

When selecting the best technology for your transit agency, you should consider the information gathered during the planning process. More information on BEBs and FCEBs is provided in the tables below. Electric trolleys with overhead wires are also viable zero-emission technology but are not described further in this guidebook.

ZEB TECHNOLOGY COMPARISON

	BATTERY ELECTRIC BUS	FUEL CELL ELECTRIC BUS
Reliable Range	< 150 miles on a single charge (or indefinite range with on-route charging)	> 200 miles before refueling
Fueling Technology	Depot or on-route charging • Plug-in charging • Wireless inductive charging • Overhead conductive charging	Hydrogen storage and fueling station • Purchased liquid or gaseous hydrogen (most common) • Produce hydrogen on-site through electrolysis or natural gas reformation
Capital Costs	• BEBs are currently more expensive than diesel buses • Charging infrastructure costs vary and do not scale easily; incrementally more charging infrastructure will be required for more buses	• FCEBs are currently more expensive than BEBs • Fueling infrastructure costs vary and depend on the required fueling rate. • Infrastructure scales more easily with similar equipment and space requirements. Additional buses do not necessarily require additional infrastructure
Fueling Considerations	• Depot-charged buses may require hours to fully recharge • Electricity rates will have a significant impact on fuel costs	• Refueling procedure and time required are slower than diesel buses, but similar to Compressed Natural Gas (CNG) fueling • Electricity costs may be significant if producing hydrogen on-site • Relatively few hydrogen suppliers across the country; costs may vary based on the distance from the supplier

BATTERY ELECTRIC BUS CHARGER INFRASTRUCTURE SUMMARY

Plug-in Chargers
(Image Credit: Rodrigo Garrido/Reuters)

Overhead conductive charging (Image Credit: CTE)

Inductive Charging (Image Credit: CARTA)

Figure 3. *Charging technology examples*

	TYPICAL INSTALLATION	ADVANTAGES	DISADVANTAGES
Plug-in Charging	• At the depot, shop, or garage • Used to charge buses for a few hours (usually overnight or during layovers) • Currently one or two chargers required per bus • Charge power: 50 to 125+ kW	• Consolidation of charger and bus maintenance needs at one location • Lower unit cost • Additional chargers can be added for redundancy • Buses not restricted to specific routes	• Buses must be taken out of service to charge • Total infrastructure cost may be more expensive for a larger fleet than other charging solutions • Slower charging • Larger space footprint • Potential for high power requirements if buses charge simultaneously
Overhead Conductive Charging	• Typically installed on route or at transit centers where layovers may occur • May be used at the bus yard or maintenance facility • One charger serves multiple buses • Charging for 5 to 20 minutes at higher power • Charge power: 175 to 450 kW	• Allows for indefinite bus operation • Buses are able to remain in service while charging on-route • Total infrastructure costs may be less expensive if fewer chargers are needed for a larger fleet • May increase resilience during power outages if chargers are on a different utility feed or service area	• Pantographs may require additional maintenance • Higher unit costs • Less redundancy due to fewer chargers, which could result in service outages • High power ratings result in higher peak demand • Land rights are required for on-route chargers • May interfere with road clearances, or require a dedicated pull-off • Less flexibility in route assignments or to use buses for special service and emergency purposes since buses must stay near a charger
Wireless Inductive Charging	• Typically installed on route or at transit centers where layovers may occur • May be used at the bus yard or maintenance facility • One charger serves multiple buses • Charge power: 50 kW to 250 kW	• Buses are able to remain in service while charging on route • No manual connections or moving parts • Could be used by multiple vehicle types • No right-of-way restrictions • Total infrastructure costs may be less expensive if fewer systems are needed for a larger fleet • May increase resilience during power outages if chargers are on a different utility feed or service area	• Higher unit costs • Less redundancy due to fewer chargers, which could result in service outages • Land rights required for on-route chargers • Efficiency varies based on bus alignment • No interoperability among different providers • Not all Original Equipment Manufacturers (OEMs) offer inductive charging

FUEL CELL ELECTRIC BUS FUELING INFRASTRUCTURE SUMMARY

Hydrogen Fueling Station (Image Credit: AC Transit)

Figure 4. *Example hydrogen fueling technology*

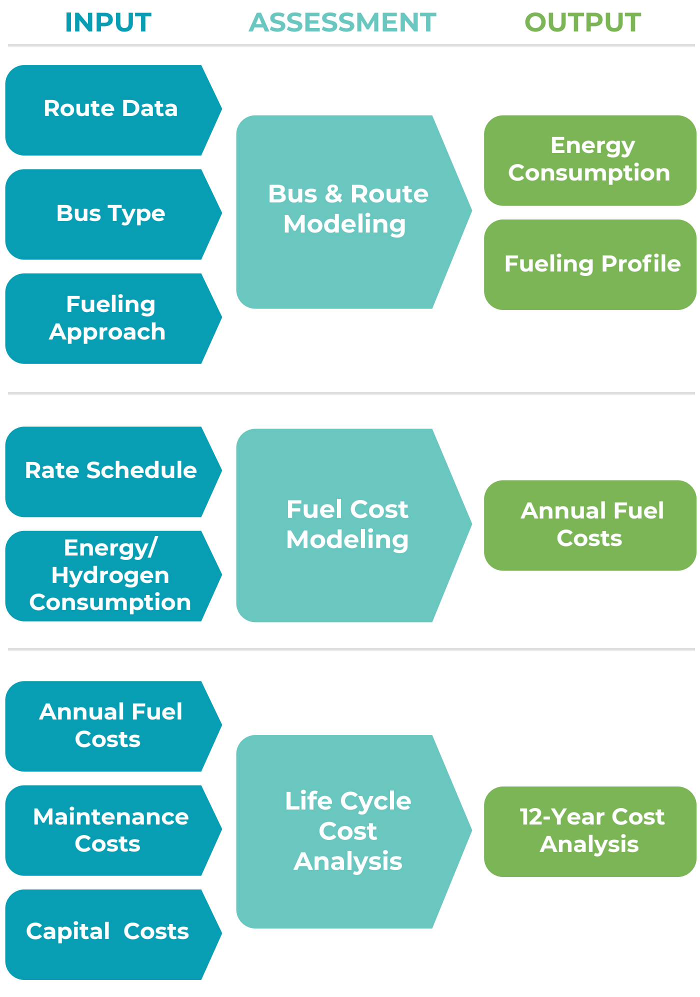
	TYPICAL INSTALLATION	ADVANTAGES	DISADVANTAGES
Purchase liquid hydrogen from a supplier	• Delivered to the transit agency's fueling facility via trucks • Requires cryogenic storage	• Less equipment to maintain • Lower energy costs • Similar procedure to diesel delivery • Lowest initial cost for small fleets or tests	• Maintenance fees may be required • Potential for fuel disruptions, since there are limited suppliers and fuel delivery may be over long distances
Purchase gaseous hydrogen from a supplier	• Delivered to the transit agency's fueling facility via trucks or a pipeline • Gaseous hydrogen must be stored in pressure vessels		
Produce hydrogen on-site through electrolysis	• Electricity is used to split water into hydrogen and oxygen, and the hydrogen is captured and stored	• Opportunities to utilize renewable energy to produce hydrogen, reducing the carbon footprint of operations • Transit agency controls and manages production • Renewable fuel source	• High electricity consumption • Variable costs due to energy requirements • Additional equipment needs • May be more expensive than purchasing • Service may be disrupted if hydrogen production system experiences a failure • Significant ground storage needed
Produce hydrogen on-site through natural gas reformation	• Steam and methane from natural gas react at high temperatures to produce carbon dioxide and hydrogen		

How do I assess which ZEB technology is right for my transit agency?

Before conducting any detailed analyses, you may want to complete a high-level assessment of how you might use ZEBs to meet your service requirements. Due to range limitations, deploying ZEBs may not be a 1:1 replacement fleetwide, therefore you may want to conduct an initial screening of your current blocks taking into account distance, duration, grade, and power and speed requirements. This assessment may allow you to identify which blocks may be a 1:1 replacement for diesel buses, and which may not be candidates for ZEBs at the current time.

After a high-level assessment, consider modeling routes that are representative of your service area to more specifically understand the costs and energy requirements of operating ZEBs. Bus modeling and route simulation is a cost-effective method to assess the operational requirements of your zero-emission bus fleet.

***Figure 5**. Example ZEB Assessment Process*



Bus & Route Modeling – Modeling results will inform energy consumption for your proposed routes, incorporating topography and HVAC needs. Based on your agency's need for heating and cooling and the characteristics of its routes (e.g., steep grades), energy requirements for a ZEB can range from less than 1.5 kWh/mi to well over 4 kWh/mi. Modeling will allow you to determine the energy required to complete a trip, which will inform 1) the time required to charge/refuel a bus before it is put back into service, and 2) fleet composition and size, depending on service needs and the chosen ZEB technology.

Electricity Rate/Fuel Cost Modeling – Estimate the fuel costs to operate your ZEB fleet, and compare those costs to your non-ZEB fleet.

- For BEBs, work with your local power utility to understand how your rate schedule may change as your electricity consumption increases. Important cost considerations for electricity include peak demand charges and time of use rates.
- For FCEBs, your fuel costs will include energy and labor costs related to additional staff time to operate the fueling stations, as well as the costs to either purchase hydrogen from a supplier or produce it on-site.

Life Cycle Cost Modeling – Incorporate capital, fueling, and maintenance costs over the life of your bus to develop a 12-year cost analysis.

Bus and Infrastructure Design

The results of your modeling efforts will inform the types of technology that you will need to meet your service goals. Regardless of the technology you select, keep in mind that deploying ZEBs will likely require operational changes to accommodate charging or fueling times, such as changes to current blocks. Due to current range limitations and the logistics of bus refueling or charging, a full fleet transition will likely not be a 1:1 replacement with ZEBs. Many agencies find that they will need more total buses to fully transition to ZEBs than their current fleet.

Long-term planning

When planning infrastructure installations, consider your long-term goals for deploying zero-emission buses. Identify opportunities for scaling up to avoid repeating costly construction activities. For example, if you need to construct additional electrical infrastructure to deploy BEBs, or if you need additional land to accommodate additional hydrogen storage or generation for FCEBs, you may want to consider completing any construction work that would be needed for a larger, future deployment.

Transition Plans are Living Documents

You should revisit any long-term fleet transition plans every two years to ensure that your assumptions are still valid. Technological advancements, regulatory requirements, and changes to your agency's operations should be incorporated into your plans.

PROCUREMENT

After determining the performance requirements or selecting the bus and charging technology for your deployment, you will need to develop technical specifications that define how you expect your bus to perform in your service area and climate. The American Public Transit Association (APTA) is developing BEB-specific procurement guidelines. At the time of publication, the draft guidelines were open for public comment.

Refer to your current fleet's bus retirement schedule to identify when to procure ZEBs so they can replace non-ZEBs at the end of their service life and avoid early retirement of conventional fuel buses.

Paying for ZEBs

Local, state, and federal funding may be available. Review available grant or loan programs from the following agencies:

- Federal Transit Administration
- Department of Energy

Leasing may be a beneficial option for your transit agency to limit the amount of funds spent at one time.

BUILD

Maintain regular communication with the selected bus and infrastructure OEM throughout the build to stay informed of any production delays or schedule changes. Facilities staff will need to coordinate regularly with OEMs to support infrastructure installation.

Regardless of the selected ZEB technology, permitting will most likely be required for fueling infrastructure installation. FCEB deployments may also require facility retrofits to accommodate safety standards and regulations for hydrogen storage and distribution (e.g., gas detection, ventilation). If your transit agency utilizes CNG buses, you may be familiar with the requirements.

When developing a schedule for the design and build of your buses and fueling infrastructure, ensure that your fueling infrastructure is installed and functional before any buses arrive. Otherwise, you may have buses on-site that you cannot fuel and therefore cannot use. This can limit your ability to test your buses during the acceptance period, putting you at risk if there are any issues with the buses.

ACCEPTANCE

After your buses are delivered and your fueling infrastructure is installed, you will want to test the performance and functionality to ensure that everything performs as expected and meets contractual requirements. Bus procurement contracts have a set period of time for an agency to test and accept the bus, which may need to be a longer term for ZEBs than conventional buses. Testing should confirm that the bus demonstrates acceptable performance under all realistic conditions.

What testing should I do when my bus arrives?

The acceptance period should be used to test the full operation and functionality of each bus. Your testing should include testing all conditions that your bus may expect to encounter during revenue service. In addition to your existing bus acceptance procedures (e.g., inspections, bus wash, IT system configuration), you should consider conducting the following tests:

- **Operating Range** – Test the total range of the bus under various conditions, such as in different traffic patterns, with different HVAC and auxiliary loads, or weighted with ballast such as sandbags. For BEBs, record the total range when operating the bus over the usable state of charge (SOC). For FCEBs, record the total range to an empty tank.
- **Maneuverability** – Drive the bus on "challenging" locations in the service area (e.g., steep grades, hill starts, difficult turns, hard acceleration).
- **Performance at "low" SOC** – Determine how performance changes when operating the bus at low SOC. Operating the bus at low SOC is not recommended while in regular service, as this impacts battery life, but it should be tested at delivery. Confirm with your OEM what would be considered "low" SOC (usually below 20%). For FCEBs, test performance at challenging locations in your service area where higher power outputs would drain the battery.

TRAINING

Agency staff will need to be trained on driving and maintaining the ZEBs. Driving habits can significantly affect ZEB efficiency and performance compared to diesel buses, and some features may be new to drivers. Over 20% differences in energy efficiency have been observed based on driving style[5]. Train drivers on concepts, working principles, and details on regenerative braking, mechanical braking, hill holding, and roll back. Training on optimal driving habits, such as the optimal levels of acceleration and deceleration to maximize the efficiency, should be provided. Track improvements in driver performance, and identify if additional training will be required to address specific issues.

The operator's compartment may have different gauges, compared to conventional buses. An overview of dashboard controls and procedures when a warning signal is initiated should be conducted.

Maintenance staff will need to understand how to service and troubleshoot all-electric propulsion and auxiliary systems, how to work with the on-board diagnostic systems, and how to safely handle high voltage systems. Safety training on the hydrogen systems will also be critical for FCEBs. ZEB technology will most likely be new and unfamiliar to most maintenance staff, therefore ensure that all maintenance staff receive adequate training to limit vehicle downtime.

Operations and planning staff should receive training on what route and schedule adjustments may be necessary given the range limitations and fueling requirements of ZEBs. For example, BEBs' operation time can become limited if a scheduled charge is missed or delayed for any reason.

Coordinate training for local first responders in advance of revenue service deployment. Ensure that emergency personnel have the contact information for a designated staff member within the transit agency in the event of an emergency.

The OEM typically provides training classes and documentation. Procurement contracts should include any expected training requirements, manuals, and other applicable documentation.

OPERATION & MAINTENANCE

After your ZEB fleet is in revenue service, consider collecting and analyzing bus data to better understand performance, range, reliability, and cost. Evaluating the bus performance and the limitations of the technology can help validate your assumptions and will allow you to determine the most effective and efficient use of the buses throughout your service area. Funding agencies may have requirements for data collection and reporting, if grant funds were used to purchase vehicles.

Transit agency boards may also expect regular reporting on the ZEB deployment to include performance evaluations, emissions reductions, and operational cost comparisons to other fleets. ZEB deployment data will also be valuable to other transit agencies.

It is expected that the usable energy of the batteries will degrade over time. Ensure that you incorporate this consideration in your planning processes, as a ZEB may not be able to complete the same blocks at the end of its service life as it was able to upon delivery.

[5] *CTE observations from ZEB deployment data*

FOR MORE INFORMATION

Other resources are available for you to reference while you are working toward a ZEB deployment.

RESOURCE NAME	DESCRIPTION
Zero Emission Bus Resource Alliance (ZEBRA)	National professional association for transit agencies to share lessons learned about zero-emission buses.
Center for Transportation and the Environment (CTE)	Non-profit engineering and planning firm that works to advance the adoption of zero-emission vehicle technologies. CTE hosts the annual Zero-Emission Bus Conference, an excellent way to learn more about the ZEB industry and network with peers.
Federal Transit Administration (FTA)	Offers funding opportunities for ZEB deployment, such as the Low or No Emission Vehicle Program and Bus and Bus Facilities Program.
National Renewable Energy Laboratory (NREL)	Provides public reports on data from ZEB deployments.
Alternative Fuels Data Center	Provides Federal and state laws and incentives for alternative fuels and vehicles, air quality, fuel efficiency, and other transportation-related topics.
West Coast Center of Excellence in ZEB Technology (CoEZET)	Hosted by the SunLine Transit Agency, CoEZET brings educational services to transit agencies looking to deploy ZEBs.
Midwest Hydrogen Center of Excellence (MHCoE)	Center to support the adoption of hydrogen-powered, zero-emission vehicles in Midwestern public transit.
American Public Transportation Association (APTA)	APTA offers conferences and resources for transit agencies looking to deploy ZEBs.
International Association of Public Transport (UITP)	International non-profit advocacy organization for public transport authorities and operators, policy decision-makers, scientific institutes and the public transport supply and service industry.

APPENDIX A – AVAILABLE ZEB MODELS

APPENDIX A.1 – AVAILABLE BEB MODELS

Only models compliant with Buy America Regulations are included, and only publicly available information from OEM publications is listed. Note that this table may not reflect all currently available bus models in the U.S. market. The table will be updated periodically.

OEM	Bus Model	Bus Length	Battery Capacity	OEM-Advertised Range
BYD	K7M	30’	215 kWh	150 miles
	K7M-ER	30’	266 kWh	185 miles
	K9S	35’	299 kWh	145 miles
	K9S-ER	35’	352 kWh	215 miles
	K9M	40’	324 kWh	156 miles
	K9MD	40’	352 kWh	200 miles
	K11M-Low Capacity	60’	578 kWh	220 miles
	K11M	60’	578 kWh	220 miles
Ebus (Bus repowering)	EBUS22	N/A	130kWh	Not provided
GILLIG	Ebus	40’	444 kWh	150 to 210 miles
Green Power	EV250	30-32’	210 kWh	> 175 miles
	EV300	35’	260 kWh	> 175 miles
	EV350	40’	320 kWh	> 185 miles
	EV400	45’	320 kWh	> 185 miles
	EV550	45’ Double Decker	> 478 kWh	> 240 miles
New Flyer	Xcelsior CHARGE Rapid Charge	35’	160 kWh	75 miles
		35’	213 kWh	100 miles
		40’	160 kWh	75 miles
		40’	213 kWh	100 miles
		40’	267 kWh	115 miles
		60’	213 kWh	55 miles
		60’	267 kWh	70 miles
		60’	320 kWh	85 miles
	Xcelsior CHARGE Long Range	35’	311 kWh	155 miles
		35’	388 kWh	195 miles
		40’	311 kWh	155 miles
		40’	388 kWh	195 miles
		40’	466 kWh	225 miles
		60’	466 kWh	135 miles
Nova Bus	LFSe	40’	Not provided	Not provided
	LFSe+	40’	594 kWh	211 - 292 miles
Proterra	Catalyst XR (DuoPower™)	35’ or 40’	220 kWh	97 – 120 miles
	Catalyst XR (Prodrive)	35’ or 40’	220 kWh	92 – 114 miles
	Catalyst E2 (DuoPower™)	35’ or 40’	440 kWh	161 – 234 miles
	Catalyst E2 (Prodrive)	35’ or 40’	440 kWh	150 – 212 miles
	Catalyst E2 max	40’	660 kWh	232 – 328 miles
	Catalyst E2 max (Prodrive)	40’	660 kWh	213 – 290 miles

APPENDIX A.2 – AVAILABLE FCEB MODELS

Only models compliant with Buy America Regulations are included, and only publicly available information from OEM publications is listed. Note that this table may not reflect all currently available bus models in the U.S. market. The table will be updated periodically.

OEM	Bus Model	Bus Length	Fuel Cell Power	Battery Capacity	OEM-Advertised Range
ENC	Axess-FC	35’	150 kW	Not provided	260 miles
		40’	150 kW	Not provided	260 miles
New Flyer	Xcelsior CHARGE H2	40’	160 kW Rated Motor Power; 85 kW (Net)	150 kW	Not provided
		60’	210 kW Rated Motor Power; 85 kW (Net)	150 kW	Not provided

APPENDIX B – ZEB GUIDEBOOK WORKSHEET

Use the worksheets below to help walk through the ZEB planning process. Blank rows are included at the bottom of each worksheet for you to add your own information that may not be captured in the suggested items.

WHAT ARE YOUR GOALS FOR ZEB DEPLOYMENT?

CONSIDERATIONS	TRANSIT AGENCY RESPONSE
Why is your agency moving towards ZEBs?	
What decisions have already been made related to ZEB deployments?	
What percentage of your fleet are you considering transitioning to ZEBs? • Are you interested in testing the technology with an initial pilot program? • Are you planning on eventually transitioning your full fleet to ZEBs? • Are you interested in reducing air pollution in environmental justice or disadvantaged communities?	
What are your priorities for deployment? • Minimizing operating or capital costs? • Minimizing disruption to current operations? • Complying with regulations?	
How will you measure success?	

WHO SHOULD YOU BRING TO THE TABLE?

STAKEHOLDER TYPE	NAME	ORGANIZATION	EMAIL	PHONE
Operations and Planning Staff				
Maintenance Staff				
Facilities Staff				
Planning Staff				
Finance and Procurement Staff				
IT Staff				
Sustainability Manager				
Contract Operator				
Board or Executive Leadership				
Local Government				
State Government				
Federal Government				
Labor Unions				
Power Utility				
Environmental Justice Groups				
Other Interest Groups				

WHAT INFORMATION DO YOU NEED TO GET STARTED?

NAME	COMPLETE?
Route data	
Operating metrics for non-ZEB fleet • Monthly or annual mileage • Fuel and maintenance costs • Availability	
Operational needs for ZEBs • Planned routes or area for deployment • Other established uses or applications	
Climate information • Monthly average temperatures • Common weather patterns (e.g., snow, ice, extreme heat, extreme cold)	
Planning documents • Capital Improvement Plans • Vehicle retirement schedule • Financial plans and constraints	
Utility bills and rate schedule information	

WHICH ZEB TECHNOLOGY DO YOU PREFER?

NAME	AGENCY PREFERRED TECHNOLOGY	NOTES
Bus Technology		
Fueling Infrastructure Technology		

HOW DO YOU ASSESS WHAT ZEB TECHNOLOGY IS RIGHT FOR YOUR TRANSIT AGENCY?

ASSESSMENT	RESULTS/NOTES
Bus Route Modeling	
Fuel Cost Modeling	
Life Cycle Cost Analysis	

ACCEPTANCE

TEST	DATE COMPLETED	RESULTS/NOTES
Inspection		
Bus Wash		
IT System Configuration		
Operating Range		
Maneuverability		
Performance at "low" SOC		

TRAINING

COURSE NAME	COURSE DATE	COURSE DESCRIPTION