Electric School Bus Guidebook

Guide 5: ESB Routing

NEW YORK STATE | NYSERDA

Understanding route characteristics is essential to proper bus and battery choices.

This chapter of the *Electric School Bus Guidebook* answers these questions:

- What factors should I consider when assigning ESBs to specific routes?
- What factors impact ESB range?
- How do I collect the data needed to help assign ESB routes?

Routing Considerations

Key factors for prioritizing your bus routes for electrification include ESB battery range, cost considerations, and equity and environmental impacts.

Key Concepts

Battery Capacity – Different ESB models come with different battery capacities. Vehicle manufacturers' websites will indicate the battery capacity of each model in kilowatt hours (kWh) under ideal operating conditions. Generally, a higher capacity battery will provide greater range and cost more than a lower capacity battery.

Vehicle Efficiency – A more efficient vehicle will have a greater range than a less efficient vehicle (assuming a battery of equal capacity). While the efficiency of diesel and gasoline powered vehicles is measured in miles per gallon, electric vehicle efficiency is measured in kWh per mile. When using kWh/mile, the smaller the number, the greater the efficiency. For example, a vehicle that uses 1 kWh/mile goes twice as far using the same amount of energy as a vehicle that uses 2 kWh/mile. Although many vehicle manufacturers advertise their vehicles' rated efficiency, this usually represents the efficiency under ideal conditions (for example, with a temperature around 70 degrees on a relatively flat route), as there is currently no standardized or government-regulated method for determining this metric, so your mileage may vary from that reported by the manufacturer.

Battery State of Charge – Battery state of charge (SOC) refers to the amount of electricity remaining in the battery at any given time, as a percentage the total usable battery capacity. It is an important factor in determining how far a vehicle can travel. A vehicle with a 50% SOC has half the range that it has when its SOC is 100% (equivalent to a vehicle with one-half tank of gas). Ensuring that an ESB has time to charge to a high percentage SOC will help the vehicle achieve higher range.

Key Activities

Initial actions you can take after reading this chapter include:

- Determine which factors to take into account when making route assignments.
- Modify data collection practices, if needed, to ensure accurate data is available for route analysis.
- Develop route assignments in order of feasibility, ahead of receiving ESBs.
- Coordinate with ESB manufacturers, dealers, and telematics service providers to collect and analyze data on route-specific ESB performance.
- Apply lessons learned from initial routing assessment and assignment to inform future ESB specifications, purchases, and deployments.

Range (miles) = Battery Capacity (kWh) ÷ Vehicle Efficiency (kWh/mile)

The most important factor to consider when making your route assignments is to ensure that an ESB has adequate range (i.e., the number of miles your ESB can travel on a single charge) to successfully complete its route under a variety of operating conditions, such as extreme cold or hot weather. Several factors, described below, affect battery range.

Battery Capacity – Different ESB models come with different battery capacities. See "Key Concepts" on the previous page for more detail.

Ambient Temperature – While ESBs can function at all temperature ranges, they typically function at or above 100% of their rated battery range when the temperature is between approximately 50 and 90 degrees Fahrenheit (°F). In fact, at 70°F, ESBs are particularly efficient and perform at about 115% of their rated battery range. However, ESBs lose battery capacity when operating at temperature extremes. For example, an ESB's range is about 80% of its rated range at 32°F and about 60% at 10°F. ESB range also drops to about 80% once temperatures exceed 100°F.[1] For more information about how weather conditions affect vehicle efficiency, refer to CleanCitiesTV's Route Analysis, Range, and Efficiency Considerations and this presentation by the Electric School Bus Network's South/Gulf Coast ESB Working Group.

Heating and cooling needs – If your ESB has temperature control systems that run off the vehicle's battery, heating and cooling the bus cabin can reduce ESB range significantly (e.g., 30% or more of the battery's energy can be used for cabin heating in some cases).[2]

Other factors – The number of stops on a route, road speed and traffic conditions, heavy cargo/equipment, terrain, and weather/road conditions also affect vehicle efficiency.

Tips for Extending ESB Range

- **Preconditioning.** You can reduce battery power draw and extend range by initiating heating or cooling while the vehicle is still charging (known as "preconditioning"). Another option to save the battery is to use a diesel or propane fuel-fired heater, although these devices generate emissions and add cost to the purchase price of the vehicle.
- **Driving style.** Rapid acceleration and heavy braking will quickly decrease an ESB's efficiency. As with diesel and gasoline powered vehicles, ensuring smooth braking and limiting hard accelerations will improve efficiency. Previous testing by NYSERDA has found that these behaviors can improve efficiency by as much as 10%. These are also, of course, the same behaviors associated with safe driving. It is important to provide drivers with training that focuses on techniques to maximize efficiency and range. In addition, some vehicle manufacturers offer options that limit vehicle acceleration, thereby helping to increase efficiency. For more information about driver training, refer to WRI's step-by-step guide for school bus electrification.

[1] *Geotab. To what degree does temperature impact EV range? – an analysis on 5.2 million trips taken by 4,200 EVs representing 102 different make/model/year combinations.*

[2] *See https://www.sae.org/news/2022/06/ev-cabin-heat-versus-range-compromises.*

Equity and Environmental Impacts

Equity and environmental impacts should also be considered when selecting routes for your ESBs. Lower-income, historically disadvantaged communities have experienced greater air quality-related health impacts due to their proximity to pollution sources, such as highways, power plants, factories, and medium- and heavy-duty vehicle depots.
By assigning your ESBs to routes serving areas with poorer air quality, you can contribute to the health of these communities. You can use NYSERDA's Disadvantaged Communities map to help identify and prioritize routes that travel through these areas. For more information about how you can include equity in route determination, refer to WRI's article, "How School Districts can Include Equity When Choosing Where to Deploy Electric School Buses First."

Cost Considerations

Cost considerations are important when it comes to routing decisions. Since the per-mile fueling and maintenance costs associated with ESBs are lower than those of diesel and gasoline buses (see the guide on Bus Operations & Maintenance), the longer the route serviced by the ESB, the greater the cost savings over the life of the vehicle. You might initially deploy ESBs on shorter routes while you are learning about their performance; however, once you are confident regarding bus ranges you should consider deploying them on longer routes to maximize per-mile savings.

"Right-Size" Your Battery for Savings

Currently, ESB battery sizes are limited mostly to "standard" and "large" options. Though it might seem logical to purchase ESBs with the largest battery range possible, this approach might not be cost-effective, since battery costs contribute significantly to total ESB prices. By studying your routes and focusing on factors impacting bus range—especially battery capacity, battery state of charge, and vehicle efficiency—you can avoid spending more money than necessary on batteries.

Route Assessment

While many factors influence vehicle range, ESB manufacturers typically estimate their buses' ranges assuming optimal conditions (e.g., ambient temperatures in the 60s and 70s, dry/flat roads). To ensure your ESBs will have sufficient battery capacity to complete their assigned routes, you will need to assess how they will perform under a wide range of operating conditions (refer to Figure 1).[3] Ideally, your ESBs will be able to return to the depot with some remaining charge even under demanding conditions. A range buffer (i.e. extra battery capacity) will reserve battery capacity for traffic, extremely cold days, and other additional energy draws.

Before ESB selection, compile data on your buses' current activity, including distance and duration of trips, idle time, number of stops, deadhead (unloaded) miles, terrain traveled, and fuel consumption. This information will help you determine the daily energy use requirements for each bus and therefore how much battery capacity you will need throughout the day. Once you know the amount of energy required, you can select the buses that will meet your needs. Returning to the depot between morning and afternoon runs may also enable your bus to travel beyond the battery's range in a day. As such, you should also consider how midday charging factors into your bus selection. You should begin by deploying your first few ESBs on relatively short, level, low speed routes, then proceeding to longer, more demanding routes. A phased approach to route assignment provides an opportunity to familiarize yourself with ESB operation before tackling routes with more complexities. Operators can also estimate the potential cost savings associated with running buses on routes of different lengths and power requirements by using a total cost of ownership (TCO) calculator, such as the Electrification Coalition's TCO calculator.

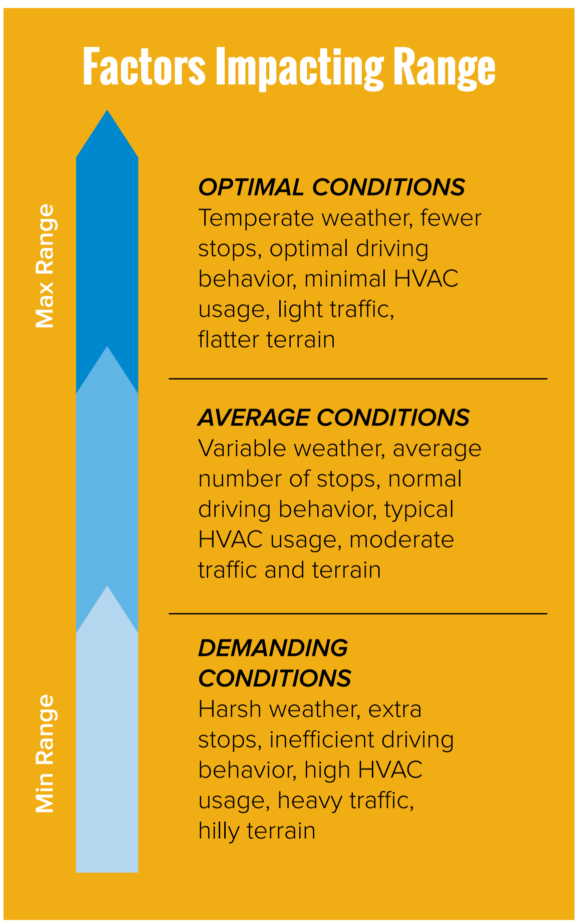


Figure 1: Operating Conditions Effecting ESB Range

[3] See https://www.proterra.com/blog/understanding-range-clarity-behind-the-calculations/

Fleet Electrification Plan

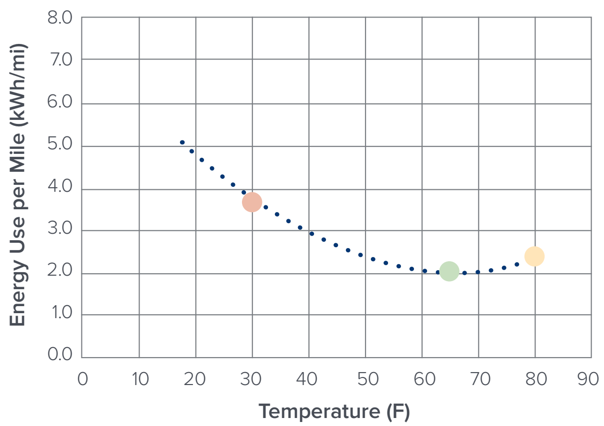
A Fleet Electrification Plan is an action plan that identifies and prioritizes recommendations to assist fleets in making informed decisions regarding their ESB transition. NYSERDA provides technical assistance for school districts in developing ESB Fleet Electrification Plans (for more information or to apply for a Fleet Electrification Plan, email schoolbus@nyserda.ny.gov). Contractors, which are typically engineering/architecture firms, provide an assessment to determine the requirements to conform to the 2027 and 2035 ESB transition requirements, at no- or reduced-cost to the district or third-party operator.

The Conceptual Charging Strategy, Electrical Utility Analysis, and Phasing Plan components of a Fleet Electrification Plan are covered in Guide 6: Electric School Bus Storage and Charger Site Planning.

Sweet Home Case Study – Fleet Electrification Plan: Route Analysis

Sweet Home Central School District (Sweet Home) elected to prepare for the NYS transition to all ESBs by developing a Fleet Electrification Plan that would provide the district with the planning tools and flexibility necessary to ensure a seamless transition by 2035. In September of 2022, Sweet Home Central Schools contracted with Wendel through NYSERDA's P-12 Clean, Green Schools Initiative program, to receive technical assistance in developing a Fleet Electrification Plan. The Fleet Transition Plan included Route Analysis, Utility Analysis, Conceptual Charging Strategy, and Phasing Plan. The Conceptual Charging Strategy, Electrical Utility Analysis, and Phasing Plan components of a Fleet Electrification Plan are covered in *Guide 6: Electric School Bus Storage and Charger Site Planning.*

Range Estimates



Temp (F)	Tolerance (± F)	Est. Eff. (kWh/mi)	Est. Range (mi)
30	2	4.0	80
65	5	2.1	155
80	2	2.4	135

Notes:

- Based on 320 kWh "safe range", i.e. 90% of total usable battery
- Battery size estimate comes from ViriCiti data
- Using on temperature ranges shown and ViriCiti data, the above efficiencies and daily ranges can be expected
- Actual data from Greater Bridgeport Transit Low/No Grant
- Proterra 440 kWh battery electric bus

Source: Center For Transportation and the Environment

The analysis established that the district could be served by 56 ESBs, with an additional 11 spare ESBs (67 total), which is the same number of buses and spare ratio in use today. The anticipated energy requirements for each route were determined, and the maximum energy usage was calculated at 285.8 kWh. Wendel recommended that Sweet Home utilize multiple bus battery sizes to complete their routes, including 62 buses with 226 kWh batteries and five buses with 321 kWh batteries. This choice is based on the following:

- **Sweet Home prefers to retain their current school bus manufacturer if possible.**
- **The 226 kWh battery in the Thomas Built Bus is large enough to complete a majority of the routes.**
- **Larger battery ESBs were required to complete the remaining, longer routes.**
- **The IC 315 kWh ESB was selected for these five routes, though the actual manufacturer may differ based on battery size availability when these routes are scheduled for electrification.**
- **Smaller ESBs could be used on some routes if desired, but these ESBs would be very limited in the routes that they could be placed on, complicating bus scheduling.**

Through the Route Analysis and diesel bus performance data, Wendel was able to provide Sweet Home with an estimate of the energy savings they can expect from transitioning to ESBs. The switch to ESBs from diesel buses would save approximately 8,247 MMBtu of energy or a 57% reduction in energy consumption. This would also result in a reduction in energy costs of approximately $137,903 per school year.

Today, Sweet Home has started implementing their Fleet Electrification Plan. They have applied for 4 Thomas Built Buses through the NYS Truck Voucher Incentive Program, which will be delivered in early 2024. Sweet Home expects to have the ESBs and chargers in operation for the 2024–2025 school year.

Performance Assessment

Once you have identified a route assignment for a particular ESB, you should conduct a more targeted performance assessment. One way to estimate an ESB's ability to complete a route is to take it on multiple test drives and record the SOC at the end of the day as well as the specific conditions (e.g., rain, temperature of 45°F., five extra miles travelled due to road closure) for each day of operation. Collecting this data over a wide range of temperatures and driving conditions and using different drivers will give fleet managers more confidence in assigning ESBs. Keeping each ESB on its assigned route will help minimize the risk of running out of power before returning to the depot.

Telematics

Telematics systems use devices that connect to the vehicle through the on-board diagnostic system and collect information about factors that impact range, including speed, acceleration, braking patterns, and battery SOC. Telematics systems can allow for a more rigorous analysis of real-world ESB performance and help you push your new buses to their full potential and maximize cost savings. Many ESBs come with such systems already installed. Alternatively, these devices can be integrated after purchase by telematics service providers to generate tailored, bus-specific performance reports for your range analysis. Before you purchase an ESB, ask your dealer or vehicle manufacturer if a data collection system is included or needs to be added to your bus specifications. You can also confer with a telematics provider to ensure the desired data collection and performance reports can be provided once your ESBs are operational.

Large-scale ESB Deployment Considerations

While most school districts begin their fleet electrification process by deploying a small number of ESBs, some districts and transportation contractors may purchase a large number of ESBs (e.g., 25 or more) at once. In such cases, a more structured approach to route assignment is needed. For example, fleet operators should collect detailed performance data for each route using data loggers or telematic devices on their current diesel and gasoline buses. This process allows for precise selection of ESB requirements and route assignments in advance of bus delivery, as well as a broader assessment of fleet needs including specifications for spare bus capacity.

Additional Resources

CleanCities TV: Route Analysis, Range, and Efficiency Considerations – Clean Cities TV is the educational media channel of the U.S. Department of Energy's Clean Cities program. This resource provides information on route analysis, range, and energy considerations for electric vehicles.

Electric School Bus Network's South / Gulf Coast ESB Working Group Slides – CALSTART's ESB Network has regular presentations from industry leaders on school bus electrification. This regional working group meeting on May 17, 2023, included a presenter from InCharge.

Electrification Coalition: Total Cost of Ownership Calculator – The Electrification Coalition is a nonpartisan, non-profit organization assisting in the widespread adoption of EVs.

Geotab: "To what degree does temperature impact EV range?" – This study provides an analysis on 5.2 million trips taken by 4,200 EVs representing 102 different make/model/year combinations.

WRI: "How School Districts Can Include Equity When Choosing Where to Deploy Electric School Buses First" – An article from the World Research Institute that provides school districts with actionable ways to incorporate equity in their routing decisions.

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