Electric School Bus (ESB) Outreach Session: Bus Technology

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Agenda for today's session

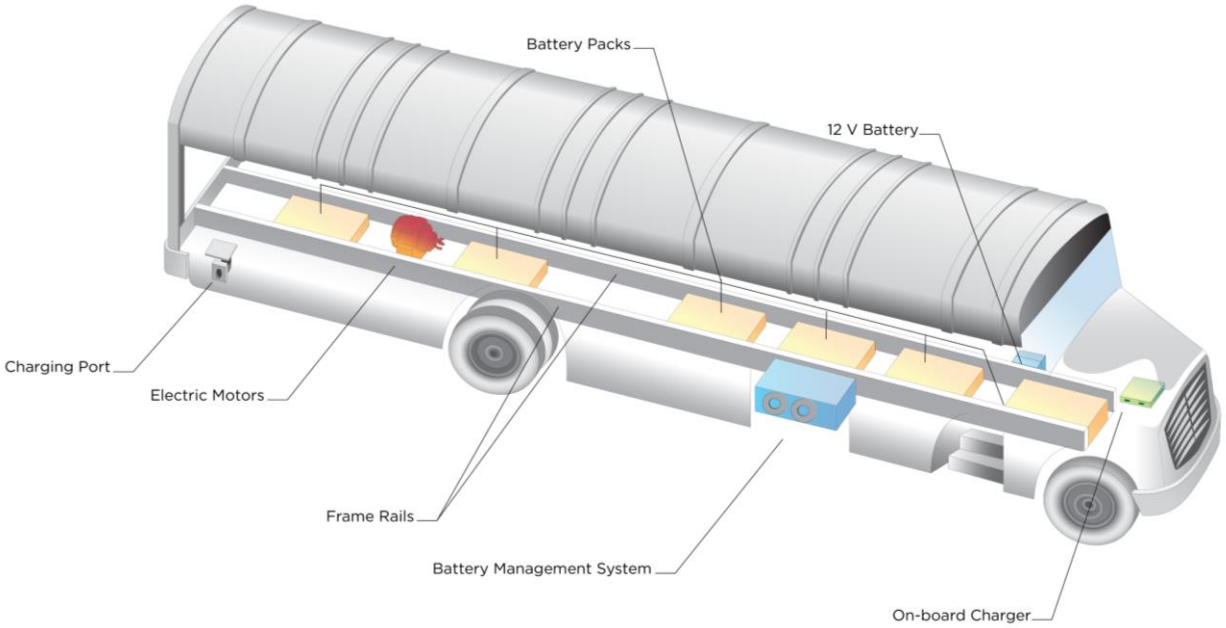
1. Introductions
2. Participant questions
3. Presentation of materials (part 1)
4. Break
5. Presentation of materials (part 2)
6. Breakout sessions for in-depth discussions

Goals of today's session

- Provide overview of electric school bus (ESB) characteristics and benefits
- Discuss ESB operational impacts
- In-depth discussions

Electric vs. internal combustion engine (ICE) school buses

ESB components



What are the key differences between ESBs and ICE buses?

- **Cleaner power source:** ESBs use electricity from the grid stored in a battery pack to power a motor, while traditional ICE buses rely on petroleum-based fuels.
- **No tailpipe emissions:** ESBs do not have a tailpipe and do not emit exhaust.
- **Regenerative braking:** When braking, ESBs reverse the electric motor, recapturing and storing energy, thereby extending bus range.
- **Quieter:** Electric motors provide much quieter rides than ICE buses.

Environmental benefits

What are the environmental benefits of ESBs?

- Air quality improvements
  - Particulate matter (PM), carbon monoxide and ozone => chronic health conditions
  - Children particularly susceptible (e.g., asthma and bronchitis)
  - Disproportionate impacts on rural and low-income students and communities (health and absenteeism)

Environmental benefits

- Other benefits
  - Decreased engine noise (esp. diesels)
  - Decreased brake wear and brake dust
  - Reduced waste disposal – no engine oil, coolant, or transmission fluid

Environmental benefits

- Emission reductions (tons per year)

	CO_2	NO_x	$PM_{2.5}$
Statewide	207,682	648	16
% Reduction	65%	92%	70%

- Accounts for average power plant emissions
- Assumes full replacement (~27K buses statewide), current power plant mix
- Smart charging should decrease emissions
- Reductions will be even greater as grid moves further toward renewables

ESB Components

How does an ESB work?

- Powertrain components[1]
  - Battery pack
  - Inverter
  - Traction motor

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1. https://www.nissanusa.com/experience-nissan/news-and-events/how-do-electric-cars-work.html

ESB Components

How an ESB uses energy from the battery[1]

- The battery feeds electricity to the inverter changing the current from DC to AC.
- The inverter sends AC current to the electric traction motor where it creates a magnetic field that powers the motor.
- The motor sends power to the drivetrain which propels the vehicle forward.

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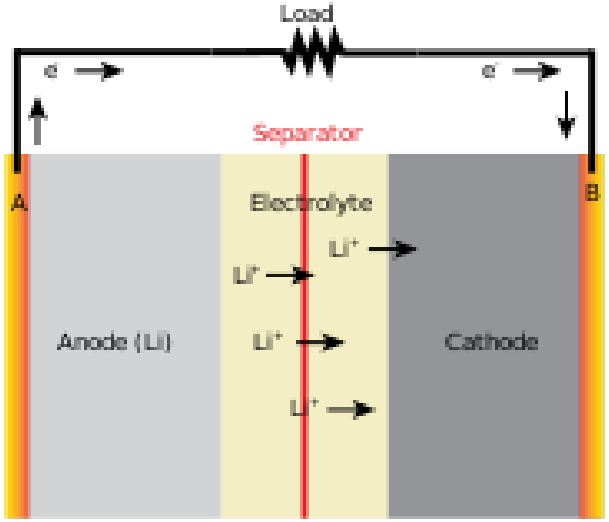
1. https://www.nissanusa.com/experience-nissan/news-and-events/how-do-electric-cars-work.html

Batteries

- A lithium-ion battery includes an anode, cathode, electrolyte, separator, and two current collectors.[1]
  - The electrolyte travels through the separator carrying positively and negatively charged ions.
  - A charge is generated in the positive current collector.
  - Charge runs through the vehicle to the negative charge collector.

- Generally, larger battery size = longer range
  - Varies with powertrain efficiency



A/B: Current collectors; negative (A), positive (B)

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1. https://www.energy.gov/energysaver/articles/how-lithium-ion-batteries-work#:~:text=The%20anode%20and%20cathode%20store,at%20the%20positive%20current%20collector.

Image: https://commons.wikimedia.org/wiki/File:General_discharging_Li_battery_diagram.svg

Battery health

Tips for preserving battery health[1]

- Keep battery state of charge (SOC) between 20-80%.
- Keep batteries between 59 – 95°F.
  - Store and charge your vehicle in temperature-controlled areas where feasible.
  - Note: the built-in thermal management systems that come standard with ESBs help maintain battery temperature during operation
- Use Level 2 charging over DC fast charging when you can

1. https://electricschoolbusinitiative.org/how-electric-school-bus-owners-can-maximize-battery-performance-limiting-aging

Maintenance considerations

- How does ESB maintenance differ from traditional ICE buses?
  - ICE bus engine: about 2,000 components
  - EV bus motor: <100 components
  - Many maintenance requirements are significantly reduced:
    - No engine oil or oil filters
    - Decreased brake wear
    - Annual maintenance savings typically between $4K and $11K per bus
  - *Do not attempt repair of high-voltage systems with untrained in-house staff*

What factors impact vehicle range?

- Climate/weather
  - Cold weather can limit vehicle range
- Topography
  - Steep hills quickly drain energy from the battery and limit range
- The number of students and cargo weight
- The frequency of stops and turns
- Driver performance

Cold weather impacts on ESBs

- ESBs operate best at temperatures around 55°F–60°F.[1]
- When temperature drops, power is used to maintain battery and cabin temperatures, reducing vehicle range.[2]
  - A battery-electric transit bus study showed range decreased by 33% when air temperature was 25°F.[3]
- High temperatures also drain energy to cool the battery and cabin.[4]
  - This loss in battery power is smaller than in cold weather.[5]

1. https://driveelectric.gov/files/esb-cold-weather-help-sheet.pdf
2. https://driveelectric.gov/files/esb-cold-weather-help-sheet.pdf
3. https://driveelectric.gov/files/esb-cold-weather-help-sheet.pdf
4. https://electricschoolbusinitiative.org/all-about-range-and-reliability#:~:text=While%20extremely%20high%20ambient%20temperatures,before%20major%20issues%20can%20arise.
5. https://www.maine.gov/doe/sites/maine.gov.doe/files/2022-06/MaineESBFactSheet.pdf

Image: https://commons.wikimedia.org/wiki/File:IC_Bus_Grill.jpg

Cold weather impacts on ESBs

- Reducing cold weather range impacts.[1]
  - Account for temperature impacts when assigning ESB routes.
  - Park ESBs indoors overnight where feasible.
  - Preheat the battery and cabin while still charging the bus (known as pre-conditioning).
  - Ask the bus manufacturer about options to add extra insulation.
  - Utilize mid-day charging.
  - Consider auxiliary heaters to maintain vehicle temperature.

1. https://driveelectric.gov/files/esb-cold-weather-help-sheet.pdf

Cold weather impacts on ESBs

- Using auxiliary heaters (also known as fuel fired heaters)
  - Emissions vary based on usage and operating conditions.[1]
  - A typical heater consumes an average of 1 gallon of diesel per hour.[2]
  - Some districts in cold weather climates have found they only need to use an auxiliary heater during the 2 coldest months of the year.[3]

1. https://calstart.org/fuel-fired-heaters-emissions-fuel-utilization-regulations-battery-electric-transit-buses/
2. https://calstart.org/fuel-fired-heaters-emissions-fuel-utilization-regulations-battery-electric-transit-buses/
3. https://electricschoolbusinitiative.org/electric-school-bus-series-successfully-operating-cold-weather-three-rivers-michigan-0

Image: https://www.vvkb.com/electric-vehicle-heater-the-complete-guide/

Cold weather impacts on ESBs

- Successful ESB operation in cold weather
  - Three Rivers Community Schools deployed ESBs in Michigan winters as low as -20° Fahrenheit. [1]
  - ESBs often outperform diesel buses:
    - Heavier weight make them less likely to fishtail in snow or ice.
    - ESBs started more reliably and faster in cold weather than diesel buses.
    - The ESB undercarriage are more resistant to road salt, decreasing rust-related maintenance costs.
    - ESBs have saved districts money on fuel and maintenance costs.

1. https://electricschoolbusinitiative.org/electric-school-bus-series-successfully-operating-cold-weather-three-rivers-michigan-0

Cold weather impacts on ESBs

- Successful ESB operation in cold weather.
  - Similar results have been found in Havre, Montana.[1]
    - Havre Public Schools procured two ESBs, for less than the price of one gasoline bus thanks to the state's Volkswagen settlement funds.
    - Operated ESBs as low as -44° Fahrenheit.
    - Reported ESBs outperform their ICE counterparts.
    - Operation costs have been ½ to ¼ of the costs of gas/diesel buses.

1. https://www.npr.org/2024/02/01/1228286377/montana-school-district-finds-its-electric-buses-can-handle-sub-zero-weather

Operator Impact on ESB Range

- Driver performance
  - One EV operation course found that providing drivers proper training resulted in a 20% improvement in range.[1]

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1. https://energysavingtrust.org.uk/sites/default/files/Efficient%20driving%20in%20electric%20and%20low%20emission%20vehicles.pdf

Other impacts on ESB Range

- Regenerative Braking
  - When does regenerative braking occur?[1]
    - When the bus is going downhill.
    - When the bus stops slowly (traffic light, stop signs, traffic, bus stops, etc.).
  - Salt Lake City School District saw a 16% increase in range due to regenerative braking.[2]

1. https://electricschoolbusinitiative.org/all-about-range-and-reliability
2. https://electricschoolbusinitiative.org/all-about-range-and-reliability

Route analysis

Which routes should ESBs be placed on?

- Considerations include:
  - Battery size
  - Battery state of charge
  - Route length
  - Number of routes served
  - Dwell time between routes
  - Climate/weather
  - Terrain
  - Frequency of stops and turns

Route analysis

How far can ESBs go?

- Listed ranges vary from 120 to 210 miles.
  - Route selection should adjust the listed range for cold weather impacts.
  - Mid-day charging is a good option for ESBs serving multiple routes.

- *Note - before deploying ESBs for the first time, be sure to practice with the buses on their new routes and ensure that drivers and technicians are comfortable with the vehicles.*

Typical cost of ESBs vs. ICE buses

	Price of ESB [1]	Price of ICE Bus [2]
Type A	$195,000 to $381,000	$50,000 to $65,000
Type C	$280,000 to $491,000	$100,000
Type D	$327,000 to $521,000	$100,000

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1. https://electricschoolbusinitiative.org/all-about-types-electric-school-buses
2. https://www.cnbc.com/2022/12/10/electric-school-buses-give-kids-a-cleaner-but-costlier-ride-.html#:~:text=ESBs%20are%20expensive%3A%20Battery%2Delectric,versus%20about%20%24100%2C000%20for%20diesel.

Model comparison

	Type A		Type C			Type D
Model	Bluebird Microbird G5	BYD Type A	Bluebird Vision	Lion Electric	Thomas Built Buses Saf-T-Liner C2 Jouley	Bluebird All-American
Cost	$235,602 -$381,317	$287,000 -$290,000	$308,029 -$491,330	$341,229 -$399,055	$309,571 -$425,347	$327,356 -$521,459
Battery Size	88 kWh	140.76 kWh	• 124 kWh • 157 kWh	• 126 kWh • 168 kWh	226 kWh	124 kWh
Range	100 miles	105 miles	Dependent on battery size • 100 miles • 120 miles	Dependent on battery size • 100 miles • 125 miles	138 miles	100 miles

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Source: https://electricschoolbusinitiative.org/all-about-types-electric-school-buses

Repowered Buses

- What is a repowered school bus?
  - The engine is removed from an IC bus and an electric powertrain is installed on the remaining body and chassis.
- Repower companies:[1]
  - Bison EV Retrofits
  - Blue Bird Corporation
  - Legacy EV
  - REVO Powertrains
  - SEA Electric
  - Unique Electric Solutions

1. https://www.wri.org/insights/repowering-electric-school-buses

Repowered Buses

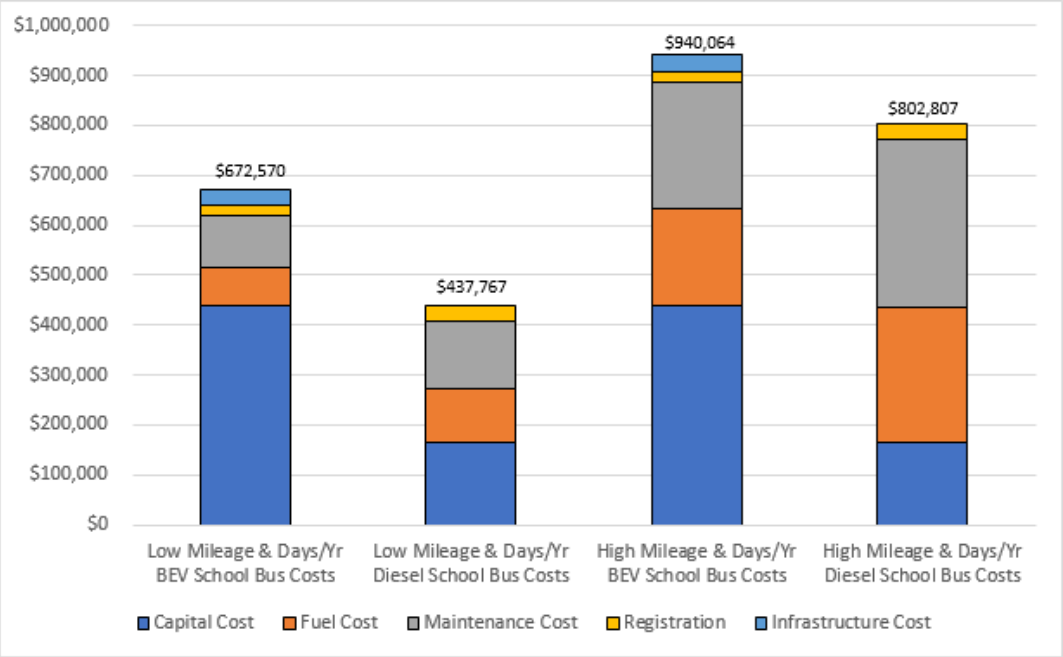
- Costs range from $110,000 to $180,000 (excluding cost of used bus).[1]
- Repowered buses are not available for EPA Clean School Bus funding.
- Eligible for Diesel Emission Reduction Act program funds.[2]
- Note – In the rare instance where ESB funding only requires a hole to be drilled in the engine block to satisfy scrapping requirements, scrapped buses can be converted to repowered buses.
  - EPA CSB funding requires both the chassis and engine to be disabled to satisfy scrapping requirements. This would make repowering the vehicle not an option.[3]

1. https://www.wri.org/insights/repowering-electric-school-buses
2. https://www.wri.org/insights/repowering-electric-school-buses
3. https://www.epa.gov/cleanschoolbus/clean-school-bus-program-grants

Cost-effectiveness

- What are the costs and savings associated with bus electrification?
  - ESB cost factors.
    - Up-front - Vehicle and EVSE cost (higher).
    - Operating – Utility charges, maintenance savings (typically lower).
    - Resale/Salvage – Vehicle/battery (uncertain).
    - Subsidies/Incentives – discussed in later slides.
  - Potential for payback prior to retirement.
  - Total cost of ownership (TCO) preferred metric over $/mi.

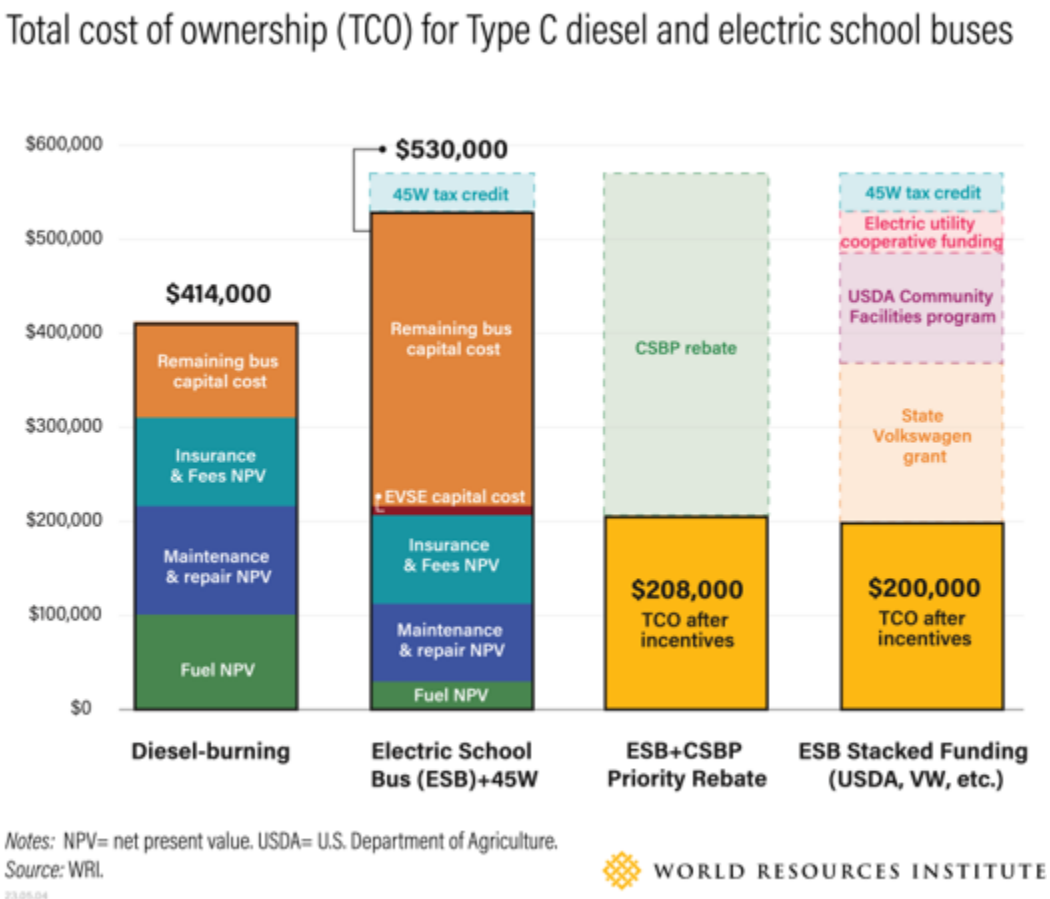
Cost-effectiveness - example TCO scenarios



Source – NY State Electric School Bus Roadmap

- Potential TCO reductions over time (e.g., production at scale, battery tech advances, V2G)

Impact of financial incentives



1. https://electricschoolbusinitiative.org/all-about-total-cost-ownership-tco-electric-school-buses

Training and Deployment

- Dealerships and manufacturers often provide training for drivers and maintenance staff as a part of the purchase contract.
- Alternatively, districts can provide their own training or contract with a third party.
- Make sure to coordinate training with local emergency services.

Training and Deployment

- Will operating an ESB require a new commercial driver's license (CDL)?
  - No. PA also recently waived the under the hood section of the CDL test for school bus drivers.[1]

- Lead Times.[2]
  - The average time from receipt of funding to ESB delivery is 16 months.
    - Deliveries have ranged from less than 3 months to 3 years (likely due to pandemic-related supply chain issues).

1. https://www.media.pa.gov/pages/PENNDOT-details.aspx?newsid=807
2. https://www.wri.org/insights/where-electric-school-buses-us#:~:text=This%20range%20varies%20from%20less,for%20all%20school%20bus%20types.

Safety

- What are the important safety considerations for ESBs?

- Vehicle fires are a risk when operating any vehicle.
  - As a result of extensive battery testing and built in safety measures, fires are significantly less likely to occur in an ESB than an ICE bus.[1]
  - The placement of the battery helps to make rollovers (a common cause of fires) less likely.[2]
- However, if a fire does occur, they can be intense and difficult to put out.
  - Emergency responders' risk electric shock when trying to put out lithium-ion battery fires.[3]
  - Lithium-ion batteries can also experience “uncontrolled increases in temperature and pressure”.[4]

1. https://electricschoolbusinitiative.org/all-about-electric-school-bus-battery-safety
2. https://electricschoolbusinitiative.org/all-about-electric-school-bus-battery-safety
3. https://www.ntsb.gov/safety/safety-studies/Pages/HWY19SP002.aspx
4. https://www.ntsb.gov/safety/safety-studies/Pages/HWY19SP002.aspx

Safety

- It is important to coordinate with first responders, vehicle operators, and maintenance staff to provide training on the safest way to work with ESBs and best practices in case of an emergency.

- Emergency Response Guides and other helpful resources can be found online at the National Fire Prevention Association website. [1]

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1. https://www.nfpa.org/EV

Stakeholder Engagement

- Early and frequent engagement of key stakeholders is an important step towards successful ESB deployment.

- Key stakeholders include:
  - Electric Utilities
  - Operators/technicians
  - District leadership
  - School boards
  - Community members/students
  - Vehicle dealers/manufacturers

References

- CALSTART: Electric School Buses Market Study – An analysis of the current ESB market.
- CALSTART: Fuel-Fired Heaters: Emissions, Fuel Utilization, and Regulations in Battery Electric Transit Buses – A study on the use of fuel-fired auxiliary heaters on electric buses.
- Department of Energy Alternative Fuels Data Center: ESB Education – A video series focused on everything ESBs including cost factors and vehicle requirements.
- Department of Energy: How Lithium-ion Batteries Work – A summary on the chemistry behind lithium-ion batteries.
- Electrification Coalition: DRVE Tool – Allows users to input fleet data to help optimize EV deployment.
- Environmental Defense Fund: Electric School Bus Fact Sheet – Focusing on environmental benefits of ESBs.
- Environmental Protection Agency (EPA): Clean School Bus Program – EPA's most recent Report to Congress on its Clean School Bus Program.

References

- Joint Office of Energy and Transportation: Cold Weather Impacts on Electric School Buses – Information on ESB performance in cold weather.
- National Public Radio: Montana school district finds its electric buses can handle sub zero weather – Case study of a school district in Montana succeeding with their ESBs.
- Nissan: How Do Electric Cars Work? – An overview on how electric vehicles and their parts work.
- World Resources Institute Electric School Bus Initiative: All About Types of Electric School Buses – A market report and a guide to the available ESBs on the market.
- World Resources Institute Electric School Bus Initiative: All About Range and Reliability – An overview of ESB range.
- World Resources Institute Electric School Bus Initiative: Funding Clearinghouse – An overview of available ESB funding opportunities.

References

- World Resources Institute Electric School Bus Initiative: How Electric School Bus Owners Can Maximize Battery Performance by Limiting Aging – Tips for preserving ESB battery health.
- World Resources Institute Electric School Bus Initiative: The Electric School Bus Series: Successfully Operating in Cold Weather in Three Rivers, Michigan – Information on the successful deployment of ESBs in Three Rivers, Michigan.
- World Resources Institute Electric School Bus Initiative: The State of Electric School Bus Adoption in the U.S. – An overview of the current ESB landscape.
- World Resources Institute: Why Electric School Buses – Download and customize a 'pitch deck' to share information on the benefits of school bus electrification.
- World Resources Institute Electric School Bus Initiative: 8 Things to Know about Electric School Bus Repowers – A Repower overview

Thank you for attending

Please fill out our bus operator survey
https://erg.qualtrics.com/jfe/form/SV_1TSWbJ9oxxD0EBM

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