Massachusetts Department of Transportation

Massachusetts Zero-Emission School Bus Transition Report

A Report to the Massachusetts State Legislature

Prepared By:

MassDOT Office of Transportation Planning

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1.0 Background

1.1 Legislative Direction

An Act Driving Clean Energy and Offshore Wind (the Act) states that the Massachusetts Department of Transportation (MassDOT), in consultation with the Massachusetts Department of Energy Resources (DOER) and the Massachusetts Department of Elementary and Secondary Education (DESE), shall develop a report analyzing aspects of a transition to zero-emission school buses (ZESBs).[1]

The Act asks for analysis of:

- **(i)** The number of fossil fuel-powered school buses in use in the Commonwealth, delineated by school district.
- **(ii)** The number of zero-emission school buses in use in the Commonwealth, delineated by school district.
- **(iii)** The annual cost of operating fossil fuel-powered school buses including, but not limited to, the cost of purchasing or contracting to use fossil fuel-powered buses and purchasing fossil fuels.
- **(iv)** The annual cost of operating zero-emission school buses including, but not limited to, the cost of purchasing or contracting to use zero-emission buses and the cost of purchasing or contracting to use charging stations and related charging infrastructure.
- **(v)** The projected cost differential between the sale or contracted use of fossil fuel-powered and zero-emission school buses.
- **(vi)** The estimated cost to replace fossil fuel-powered school buses with zero-emission school buses.
- **(vii)** The estimated environmental benefits of replacing fossil fuel-powered school buses with zero-emission school buses including, but not limited to, carbon reductions and related health benefits.
- **(viii)** the number of school districts that own their school bus fleets and the number of school districts that rent, lease or contract for school bus services.

[1] "Chapter 179 - An Act Driving Clean Energy and Offshore Wind," Massachusetts Legislature, August 11, 2022, https://malegislature.gov/Laws/SessionLaws/Acts/2022/Chapter179.

(ix) Recommendations on how to structure a state incentive program to replace or support the replacement of all fossil fuel-powered school buses with zero-emission school buses.

(x) Additional information relevant to informing a statewide plan to replace or support the conversion of all school buses from fossil fuel-powered school buses to zero-emission school buses.

This report responds to the above requirements in the following sections:

- **Section 2.0** responds to the analysis requested in **i**, **ii**, and **viii**.
- **Section 4.0** describes economic and emissions modeling and results relevant to the analysis requested in **iii**, **iv**, **v**, **vi**, and **vii**.
- **Section 5.0** includes the recommendations requested in **ix**.
- The report includes additional information relevant to informing a statewide plan throughout the text, as requested in **x**.

1.2 Report Contents and Definitions

This report includes:

1. Background on the school bus market and readiness of zero-emission school buses in the United States.
2. An overview of the school bus sector in Massachusetts, primarily supported by stakeholder interviews conducted for this study.
3. An overview of the investor-owned utilities in Massachusetts and their Demand Charge Alternative programs.
4. Analysis of the capital and annual operating costs of diesel and zero-emission school buses, a comparison of the total costs of ownership (TCO) for both diesel and electric school buses, and the costs to transition the fleet to electric over three fleet replacement scenarios.
5. Analysis of the environmental and health impacts of the three fleet replacement scenarios.
6. Recommendations for how to structure a statewide incentive program that would support the replacement of fossil fuel-powered school buses with ZESBs.

MassDOT relied on vehicle registration data from the Registry of Motor Vehicles (RMV) on the school bus fleet in the Commonwealth of Massachusetts as of April 5, 2023, and all analysis in this report is representative of the fleet as of this date. This data set defines school buses as vehicles with the RMV-assigned "Use Type" of "school bus" or "apportioned school bus." The Massachusetts school bus fleet, as of April 5, 2023, is summarized in more detail in **Section 2.0**.

MassDOT interviewed stakeholders in the school bus sector in Massachusetts to inform this study. These interviews included a total of 11 school districts that represented a range of sizes and geographic locations; 4 private school bus contractors; 1 school bus dealership; 1 utility provider; 1 electric vehicle (EV) charging equipment vendor; 2 statewide school administration and transportation associations; and 6 state and federal agencies that currently administer ZESB incentive programs. This report is informed by those conversations.

The legislation defines a zero-emission school bus as "a school bus that produces no engine exhaust carbon emissions." For the purposes of this report, ZESBs are synonymous with battery electric school buses, which are the most widely adopted and accessible type of ZESB available in the market. ZESBs share many similarities with diesel-powered school buses, however ZESBs contain high-voltage electrical systems powered by a battery pack and do not include internal combustion-related components that are found in their conventional counterparts.

1.3 School Bus Vehicle Market in the United States

There are more than 480,000 school buses that transport over 25 million children to and from school every day in the United States.[2] Approximately 60 percent of low-income students in the U.S. take a school bus to school, and 45

[2] "EPA Clean School Bus Program - Second Report to Congress Fiscal Year 2022," United States Environmental Protection Agency (EPA), February 2023, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1016LN0.pdf.

percent of non-low-income students ride a school bus.[3] Most of these students travel on diesel-powered school buses, which make up over 90 percent of the U.S. fleet.[4] Other fuel types include gasoline, propane, compressed natural gas (CNG), and a small, but growing segment of electric battery-powered school buses.[5]

School buses are typically classified into four "types" based on their size and construction. Type A and Type B school buses are smaller and typically carry up to 30 passengers, while Type C and Type D school buses are larger and generally carry between 50 to 90 passengers. The most common type of school bus is Type C, making up approximately 70 percent of the U.S. school bus market.[6] For the purposes of this report, school buses are categorized into one of these four types.

The leading Original Equipment Manufacturers (OEMs) for conventional school buses are Blue Bird, IC Bus, and Thomas Built Buses.[7] All three of these OEMs offer a full line of school bus types. As ZESBs have increased in popularity, more OEMs have introduced this technology into their vehicle offerings, including the three most prominent OEMs mentioned, and new manufacturers have entered the market, such as Lion Electric and GreenPower.

School buses are often custom-built by OEMs to meet the needs of their customers. Each state and school district has differing requirements for school buses, resulting in thousands of specifications that OEMs need to meet. Given the production process is not standardized but rather distinct based on the

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[3] "The Longer Route to School," Bureau of Transportation Statistics, January 12, 2021, https://www.bts.gov/topics/passenger-travel/back-school-2019. Low-income is defined as $25,000 for a family of four.

[4] Yaron Miller and Brian Watts, "States and School Districts Clear the Air with Electric School Buses," The Pew Charitable Trusts, September 19, 2023, https://www.pewtrusts.org/en/research-and-analysis/articles/2023/09/19/states-and-school-districts-clear-the-air-with-electric-school-buses.

[5] Leah Lazer, "Electric School Bus Data Dashboard," World Resources Institute (WRI), September 1, 2023, https://electricschoolbusinitiative.org/electric-school-bus-data-dashboard.

[6] Mitul Arora, Dan Welch, and Fred Silver, "Electric School Bus Market Study," CALSTART, November 2021, https://calstart.org/wp-content/uploads/2021/12/Electric-School-Bus-Market-Report-2021.pdf.

[7] James Blue, "Subtle Shifts in School Transportation Industry's Fuel Mix," School Bus Fleet, May 23, 2018, https://www.schoolbusfleet.com/10009615/subtle-shifts-in-school-transportation-industrys-fuel-mix.

customer's specifications, it can be challenging for OEMs to mass produce school buses.[8]

1.4 Readiness of Zero-Emission School Bus Technology

Electric school buses are gaining market share in the United States. As of June 2023, just under 6,000 ZESBs have been awarded, ordered, delivered, or are operating in 49 states, 5 territories, and 4 tribal nations. Over 1,200 of these ZESBs are already, or imminently, transporting students to and from school.[9]

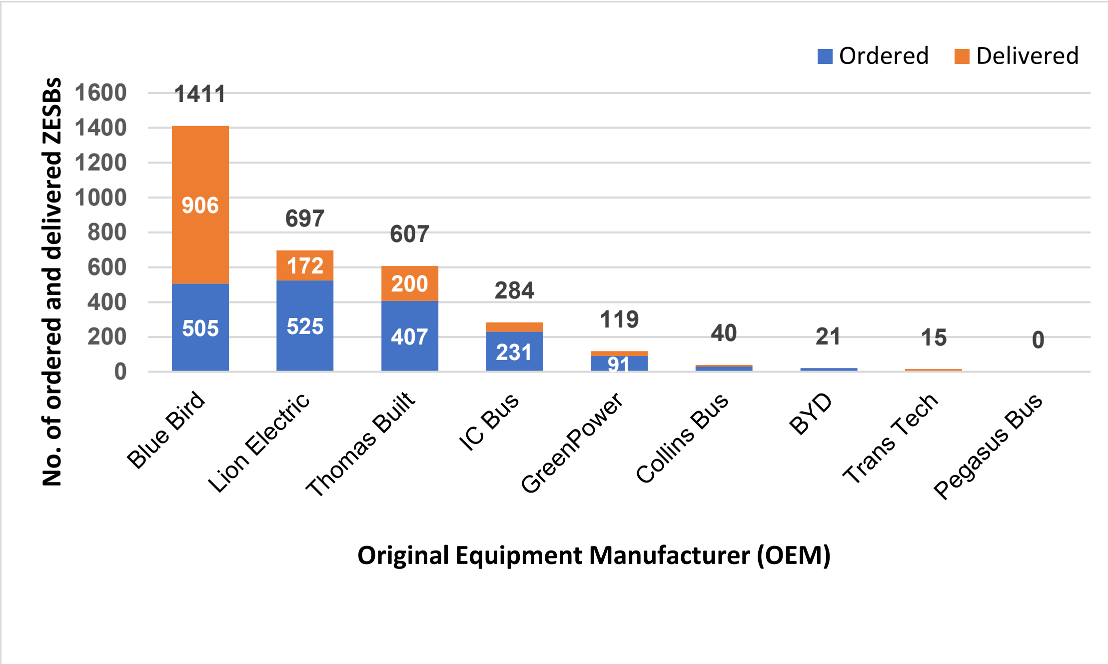
There are approximately 9 OEMs that manufacture 24 ZESB models, ranging from Type A, C, and D. Type B ZESBs are not currently available on the market.[10] Type A school buses have the largest selection of available models, and Type C school buses represent the majority of orders and deliveries. **Figure 1** shows the manufacturers of the 24 available ZESB models and the number of ordered and delivered ZESBs from each OEM as of December 2022.

[8] Bryan Lee and Rachel Chard, "The Electrification of School Buses Assessing Technology, Market, and Manufacturing Readiness," CALSTART, April 2023, https://calstart.org/wp-content/uploads/2023/04/WRI-ZESB-TRL-MRL-Manufacturing-Report_Formatted-APRIL-2023.pdf.

[9] Leah Lazer and Lydia Freehafer, "Dataset of Electric School Bus Adoption in the United States," *Dataset – Version 6*., WRI, June 2023, https://wri-dataportal-prod.s3.amazonaws.com/manual/electric_school_bus_adoption_dataset_v6_2023-08Aug.zip. WRI defines each of these ZESB statuses as follows: Awarded is when a fleet operator has been awarded funds to make a ZESB purchase; Ordered indicates the fleet operator has submitted an award with a bus dealer to purchase a ZESB; Delivered means the ZESB has arrived at the fleet operator's depot; and operating means the ZESB is used regularly on school bus routes to transport students.

[10] Alissa Huntington et al., "Electric School Bus U.S. Market Study," WRI, August 2023, https://files.wri.org/d8/s3fs-public/2023-07/esb-us-market-study-2023.pdf. This estimate is as of March 2023.

Figure 1. ZESB Deliveries and Orders by OEM as of December 2022[11]



Manufacturing capacity for ZESB production in the U.S. is scaling up in response to rising demand. For example, two ZESB OEMs, GreenPower Motor Company and Lion Electric Company, recently built new manufacturing facilities in West Virginia and Illinois, respectively. Additionally, Thomas Built Buses and Lightning eMotors both expanded their existing facilities in part to meet increased ZESB production needs.[12]

Lead times for ZESBs are highly variable depending on a range of circumstances, including the school district's needs, the OEM, and supply chain conditions. California leads the United States in the number of delivered ZESBs, and data from the state's main incentive program for zero-emission vehicles (ZEVs) indicates that the average total lead time for a ZESB is approximately 23 months.[13] Based on stakeholder interviews in Massachusetts, ZESB lead times experienced in the Commonwealth have varied from 3 months to 18 months.

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[11] Lazer, "Electric School Bus Data Dashboard."

[12] Huntington, et al. "Electric School Bus Market Study." Lightning E-Motors builds school buses in collaboration with Collins Bus Corporation see: "Electric School Buses," Lightning eMotors, accessed December 19, 2023, https://lightningemotors.com/electric-school-buses/.

[13] Lee, "The Electrification of School Buses." Data came from California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), which included lead times for a total of 545 ZESB deliveries in California from 2017-2021.

The upfront capital costs of ZESBs in the United States are 3-4 times more expensive than their diesel counterparts. The batteries that power ZESBs are particularly expensive and are the main driver of the higher upfront cost.[14] Cost comparisons of ZESBs and their diesel counterparts can be found in **Section 4.3**.

Battery capacity differs between ZESB manufacturers and types. A sample of the battery capacity and approximate range of some of the 24 available ZESB models as of March 2023 are listed in **Table 1** below. The battery capacities and ranges provided in the table are provided by the OEMs and represent the "nameplate" or claimed estimates, which are the maximum capacity the battery can store and distance the bus can travel when it is fully charged and operating under ideal conditions. The "usable" battery capacity, typically 80 – 90 percent of the nameplate capacity, is the amount of energy that can be discharged from the battery while maintaining the state of health of the battery. The actual vehicle range will vary depending on the specific demands of each route, including distance, elevation changes, and weather conditions.

Table 1. ZESB Battery Capacity and Mileage from OEMs[15]

TYPE	MANUFACTURER	BATTERY CAPACITY	CLAIMED RANGE
A	BYD	156 kWh	105 miles
	Blue Bird	88 kWh	100 miles
	Lion Electric	84 – 168 kWh	75 – 150 miles
	Collins Bus	120 kWh	130 miles
C	Blue Bird	155 kWh	120 miles
	Lion Electric	126 – 168 kWh	100 – 125 miles
	Thomas Built Buses	226 kWh	138 miles
	IC Bus	210 – 315 kWh	135 – 210 miles
D	Blue Bird	155 kWh	120 miles
	BYD	255 kWh	155 miles
	GreenPower	194 kWh	140 miles
	Lion Electric	126 - 168 kWh	100 – 125 miles

[14] "Flipping the Switch on Electric School Buses: Cost Factors: Module 1 (Text Version)," Alternative Fuels Data Center (AFDC), accessed September 7, 2023, https://afdc.energy.gov/vehicles/electric_school_buses_p8_m1.html.
[15] Jessica Wang, "Electric School Bus U.S. Buyer's Guide," WRI, March 2023, https://electricschoolbusinitiative.org/buyers-guide

ZESB motors have approximately 20 parts compared to 2,000 in their diesel engine counterparts. With fewer components, some ZESB operators have reported these vehicles are generally easier to maintain, however their high voltage systems require specialized training for maintenance technicians.[16]

Operating ZESBs requires the procurement and installation of appropriate electrical and charging infrastructure at school bus garaging locations. Upgrades or changes to the electricity system may be required both on-site and within the utility distribution system serving the chosen depot location. These upgrades may include the purchase and installation of electrical infrastructure components, such as transformers, meters, switchgear, panels, and chargers.

Each ZESB has a maximum threshold for power acceptance, and it is essential that school bus operators purchase chargers that are compatible with their ZESBs. There are generally three types of chargers that service ZEVs: AC Level 1 (L1), AC Level 2 (L2), and Direct Current (DC). Given the longer dwell times for school buses, L2 chargers are generally the standard, while ZESBs with a more rigorous duty cycle, longer route, and/or shorter dwell time might need a DC fast charger (DCFC), which are more expensive because of their ability to deliver high amounts of energy in a short amount of time.[17]

Charging stations for ZESBs can be "networked" or internet connected, providing the station operators with real-time data and controls. Sometimes referred to as "Smart" charging stations, networked charging stations provide operators with a web-based dashboard application to see all charging stations, status of stations, and control usage of the stations including scheduling when a vehicle connected to the station will receive power. Charging software can help optimize charging schedules, costs, demand, and bus performance. These software packages are often available as part of the overall annual subscription service fees that EV station network providers charge EV charging station operators (i.e., the ZESB owners or school districts). The software can communicate with electric utility grid operators to utilize real-time pricing and demand data from the utility.

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[16] "Flipping the Switch on Electric School Buses: Cost Factors: Module 3 (Text Version)," Alternative Fuels Data Center, accessed September 7, 2023, https://afdc.energy.gov/vehicles/electric_school_buses_p8_m3.html.

[17] Arora, Welch, and Silver, "Electric School Buses Market Study."

2.0 The School Bus Sector in Massachusetts

2.1 School Bus Fleet in Massachusetts

As previously stated, RMV vehicle registration data was utilized to describe the Commonwealth's school bus fleet. This data included characteristics such as passenger capacity, fuel type, age, ownership, garaging location, and odometer readings. The RMV data indicated that there were 9,446 school buses registered in Massachusetts.

There are 398 public school districts in Massachusetts and approximately 400,000 students in Massachusetts are transported by school buses annually.[18] The RMV school bus data available for this analysis did not indicate if all 9,446 of these school buses are used regularly to transport students in the Commonwealth to school. This data does not allow MassDOT to identify which school buses serve which districts nor does it outline school districts' transportation service arrangements or agreements.

Understanding the school bus types in the fleet is important for determining costs given the range of costs between types. The RMV data did not include information regarding school bus types, so each school bus type is categorized by their passenger capacity, as show in **Table 2**.[19] Some of the school buses in the fleet have passenger capacities that fall outside of the typical capacity ranges for Type A, B, C, and D school buses. Consequently, such vehicles are classified as "Other (fewer than 16 passengers)" and "Other (30 to 59 passengers)."

[18] "Massachusetts School and District Profiles," Massachusetts Department of Elementary and Secondary Education (DESE), accessed August 21, 2023, https://profiles.doe.mass.edu/general/generalstate.aspx; "School Bus Safety Fact Sheet," Mass.gov, accessed August 21, 2023, https://www.mass.gov/info-details/school-bus-safety-fact-sheet.
[19] Arora, Welch, and Silver "Electric School Buses Market Study." This report utilized a classification system used by CALSTART and School Bus Fleet Magazine, which details the passenger capacities of each school bus type.

Table 2. School Bus Type Categorization by Passenger Capacity

TYPE	TYPE PASSENGER CAPACITY
A	16-19
B	20-29
C	60-72
D	73-90
OTHER (<16)	0-15
OTHER (30-59)	30-59

Figure 2 summarizes the statewide breakdown of school bus types by passenger capacity. Most school buses in Massachusetts are Types C and D, with passenger capacities between 60 and 90. Just over 14 percent of school buses fall outside of the standard types and are classified as "Other (fewer than 16 passengers)" and "Other (30 to 59 passengers)."

Figure 2. Massachusetts School Bus Fleet Distribution by Type

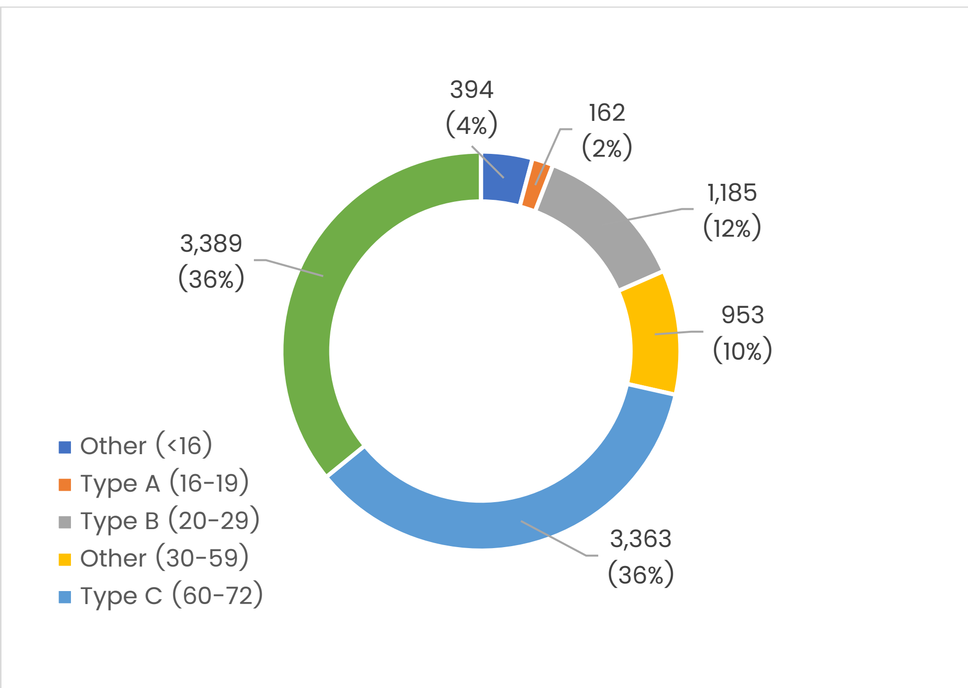
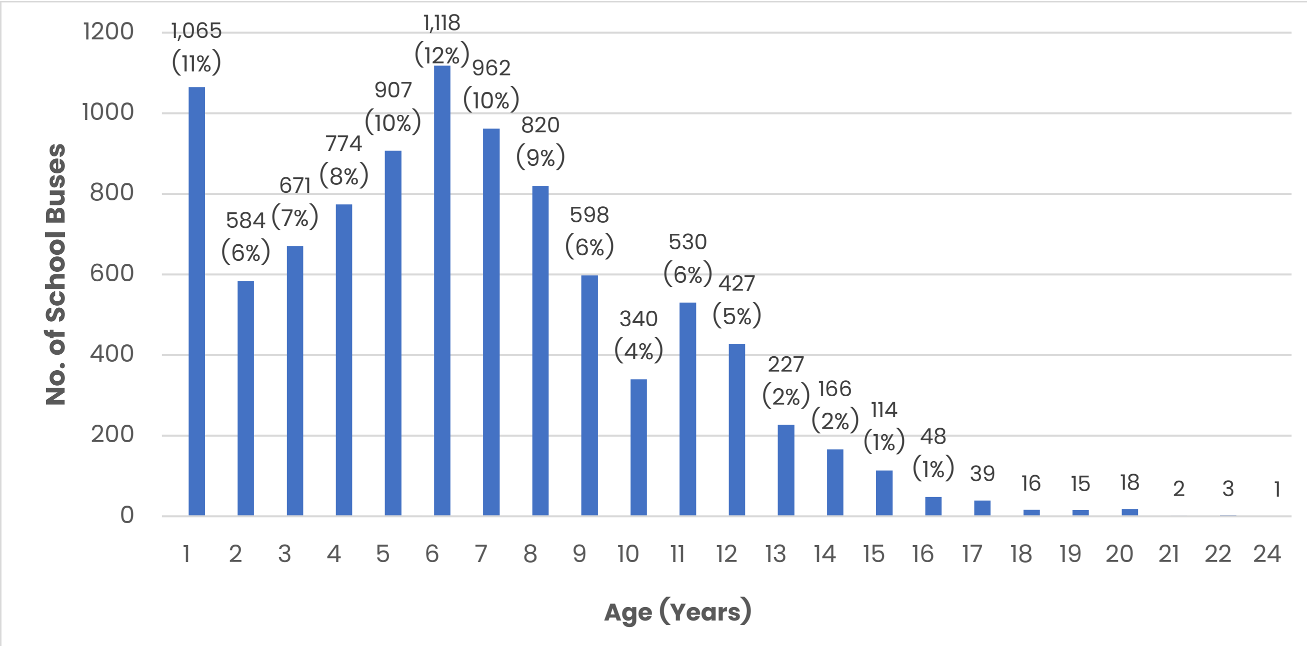


Figure 3 illustrates the Massachusetts school bus fleet distribution by age. The fleet has a median age of five years. Most school buses in the fleet are either 1-5 years old or 6-10 years old, making up 43 percent and 34 percent, respectively. New vehicles account for approximately 11 percent of the fleet.[20]

[20] New vehicles are classified as Model Year (MY) 2023 and MY 2024.

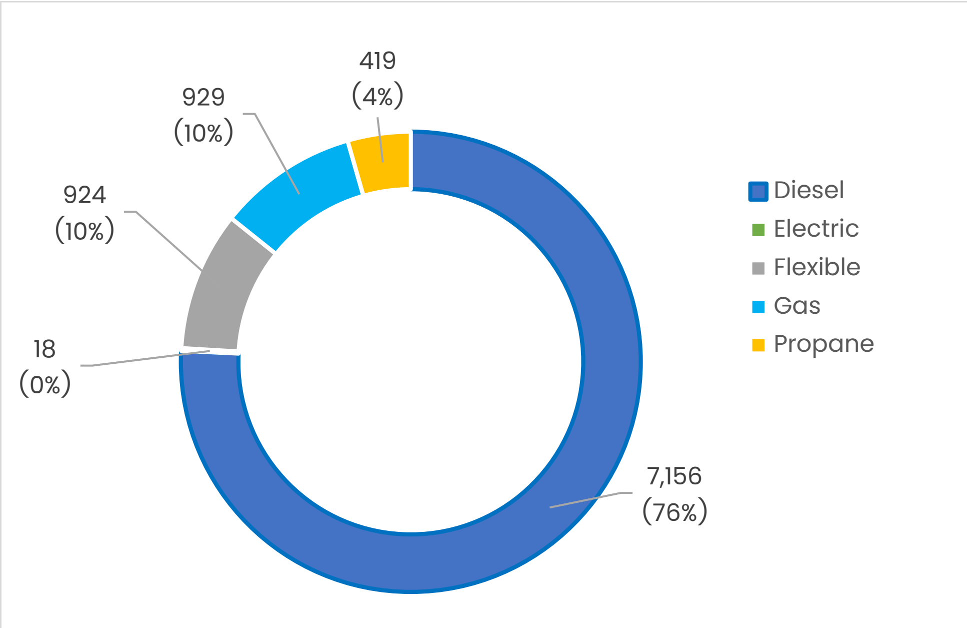
Figure 3. Massachusetts School Bus Fleet Distribution by Age



School buses in Massachusetts are fueled by five different fuel types: diesel, gasoline, flexible fuel, propane, and electricity. [21] Approximately 76 percent of school buses use diesel fuel, followed by gasoline, flexible fuel, propane, and electric (**Figure 4**). There were 18 electric school buses registered in the Commonwealth.

[21] Flexible fuel refers to internal combustion vehicles that can operate on gasoline and any blend of gasoline and ethanol up to 83 percent, such as E85 which is a gasoline-ethanol blend containing 51 percent to 83 percent ethanol.

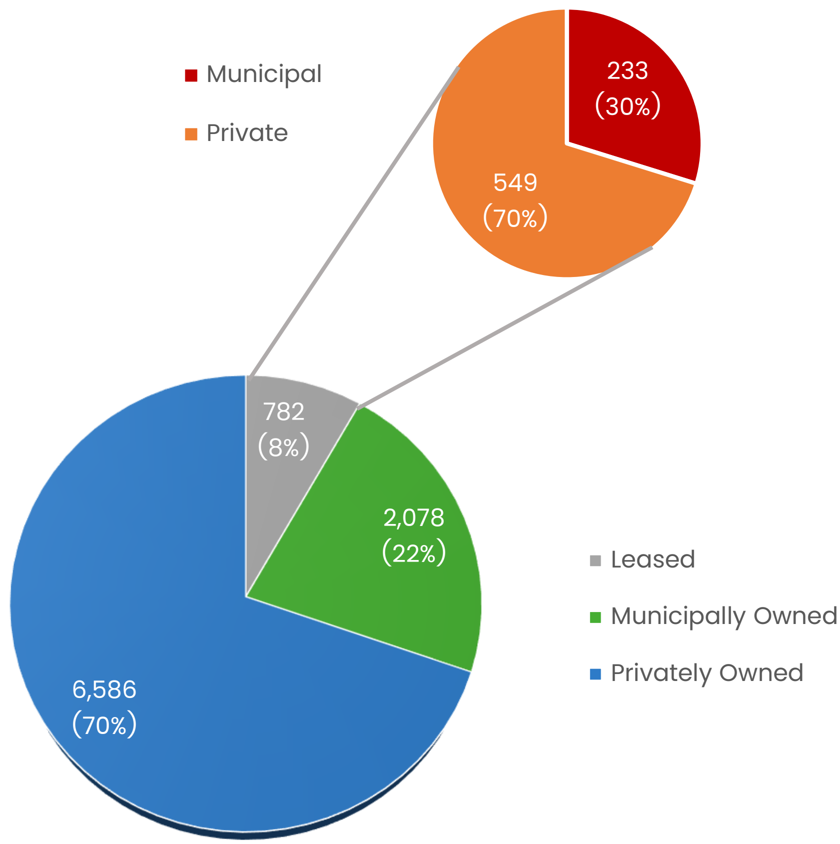
Figure 4. Massachusetts School Bus Fleet Distribution by Fuel Type



School districts in Massachusetts tailor their school transportation ownership and operations arrangements to fit their specific needs and preferences. School districts can either operate their entire fleet, contract out transportation services to a private entity, or choose a combination of those two options. Transportation service arrangements are discussed in more detail in **Section 2.4**.

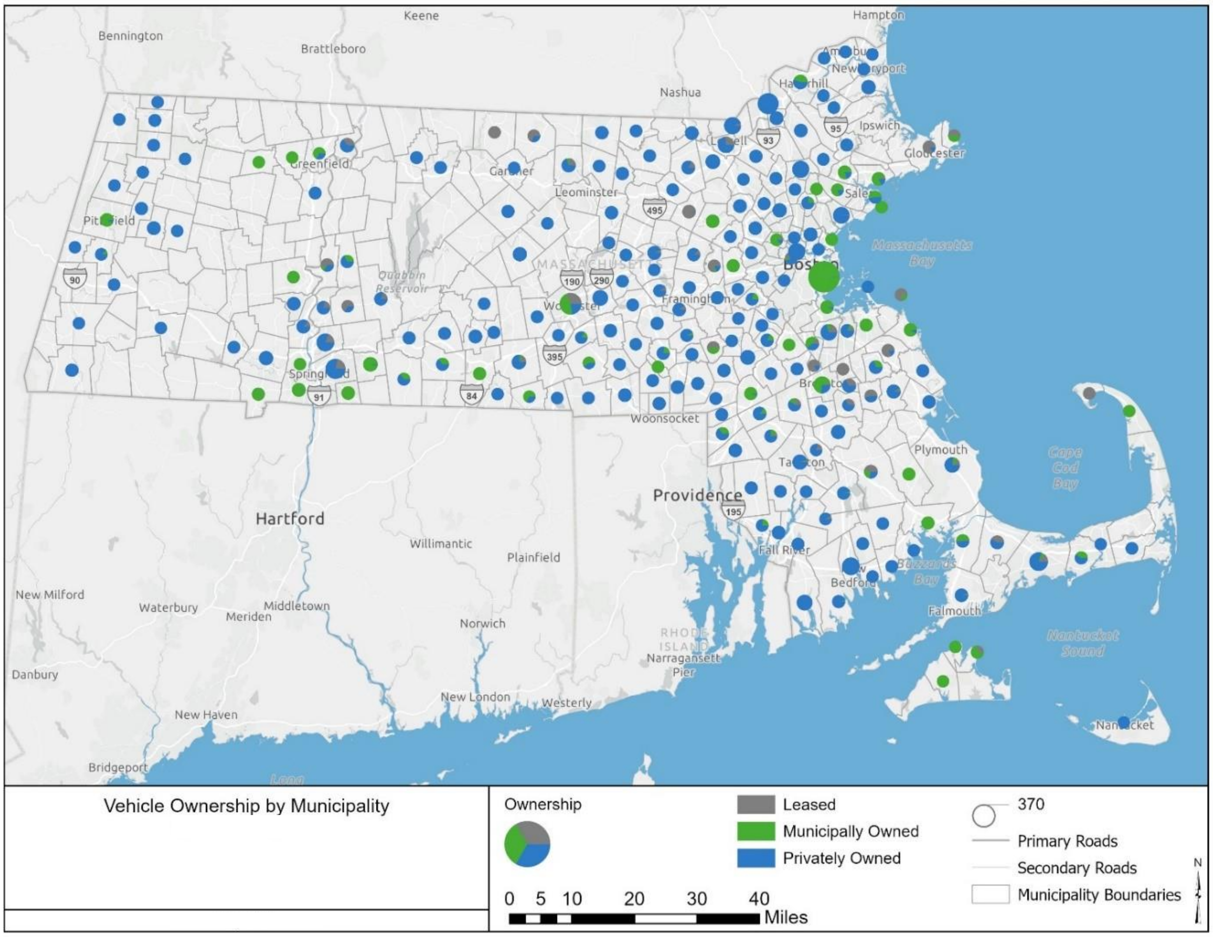
Figure 5 illustrates the breakdown of school bus ownership statewide, with an inset that indicates how many school buses are leased to private or municipal entities. Private entities own more than 70 percent of school buses in the Commonwealth, and of those that are leased, more than 70 percent are leased to private entities. In the Commonwealth, approximately 72 school districts own at least one school bus, while 31 own more than ten. These numbers give us an understanding of the number of school districts that own their school bus fleets, but do not mean they operate, or are served by, only these buses; many of these same districts may partially lease school buses or contract for school bus services.

Figure 5. School Bus Ownership Status



While RMV data used for this study does not indicate the district in which a school bus operates, this data does include the municipality where school buses are garaged. **Figure 6** illustrates the ownership status by garage municipality.

Figure 6. School Bus Ownership by Garage Municipality



In summary, the school bus fleet in Massachusetts as of April 5, 2023 generally consists of larger Type C and D buses, skews young with a median age of 5 years, primarily runs on diesel fuel, and is mostly owned by private entities.

2.2 Regulations and Laws Relevant to School Bus Operations

Numerous regulations and laws in Massachusetts set forth guidelines for how school transportation should operate. The following section provides a summary of the key regulations and laws that govern school bus transportation in the Commonwealth.

Massachusetts statutes establish the responsibility of the School Committee to ensure transportation services are available for students to be transported to and from home and school and other educational programs. The School

Committee for each district has oversight of and responsibility for the school system and establishes criteria to determine if the district's goals and policies are being met.[22]

The procurement method for school transportation services in Massachusetts is governed by Chapter 30B of the Uniform Procurement Act, which regulates the procurement of supplies, services, and real property by school districts, cities, towns, and other local jurisdictions in Massachusetts.[23] Chapter 30B, unless authorized by majority vote, also limits the initial contract term to three years with a possibility for two one-year extensions to the initial three-year contract, for a total potential contract duration of up to five years subject to renegotiation and agreement between the districts and the providers.[24]

Massachusetts law also dictates school bus driver qualifications. Individuals who wish to operate a school bus must obtain a Commercial Driver's License (CDL) with a Passenger (P) Endorsement or a School Bus (S) Endorsement. Drivers also need a school bus driver certificate.[25]

Additionally, school buses registered in Massachusetts are subject to three annual inspections conducted by the RMV during the fall, winter, and spring. The first annual inspection occurs during the months of August and September, the second during December and January, and the third during April and May.[26] These inspections result in a certification or rejection of a school bus meeting state-sanctioned safety standards.

2.3 School Bus Funding

School districts are required by law to provide transportation services for some forms of school transportation. **Table 3** outlines the student populations that

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[22] "Pupil Transportation Guide: A Guide for Massachusetts School Administrators," Massachusetts Department of Elementary and Secondary Education (DESE), August 1, 1996, https://www.doe.mass.edu/finance/transportation/guide.html.

[23] Jeffrey S Shapiro, "The Chapter 30B Manual; Procuring Supplies, Services, and Real Property," Mass.gov, May 2023, https://www.mass.gov/doc/the-chapter-30b-manual-procuring-supplies-services-and-real-property-legal-requirements-recommended-practices-and-sources-of-assistance-9th-edition/download.

[24] Ibid.

[25] "Apply for a School Bus Learner's Permit," Mass.gov, accessed September 19, 2023, https://www.mass.gov/how-to/apply-for-a-school-bus-learners-permit.

[26] "General Law - Part I, Title XIV, Chapter 90, Section 7A," Massachusetts Legislature, accessed September 7, 2023, https://malegislature.gov/Laws/GeneralLaws/PartI/TitleXIV/Chapter90/Section7A.

are guaranteed school transportation by law. According to stakeholder interviews, most school districts provide transportation services to students living more than one mile from their assigned schools, while sometimes providing services for shorter distances for elementary students.

Table 3. Student Populations with Guaranteed School Transportation[27]

TRANSPORTATION REIMBURSEMENT PROGRAM NAME	STUDENT POPULATIONS WITH GUARANTEED TRANSPORTATION (UNDER LAW)
REGULAR DAY TRANSPORTATION IN PUBLIC SCHOOL DISTRICTS	All students in grades K-6 who live more than 2 miles from the school they are attending and live more than 1 mile from the nearest school bus stop.
IN-DISTRICT AND OUT-OF-DISTRICT SPECIAL EDUCATION TRANSPORTATION	All students with an Individual Education Plan (IEP) who take regular transportation to In-District and Out of District public schools. All students with an IEP who require special transportation to in-district and OOD public schools, regardless of distance, and to private schools within the geographic boundaries of the student's home district.
REGIONAL SCHOOL DISTRICT TRANSPORTATION	All students in grades K-12, regardless of distance.
OUT OF DISTRICT VOCATIONAL-TECHNICAL SCHOOL TRANSPORTATION	Students who attend independent vocational-technical school districts and students who live outside of a public school district that houses a vocational technical school.
SCHOOL TRANSPORTATION FOR STUDENTS EXPERIENCING HOMELESSNESS	Students who attend schools at their district of origin that they previously went to prior to becoming homeless, at the request of a parent or guardian, if they live outside of the district's boundaries.
FOSTER CARE STUDENT TRANSPORTATION	Students in foster care who attend schools in their district of origin from the district they currently live in, if it is determined it is in the best interest, regardless of distance.

Though the services described in **Table 3** are required, state funding for most school transportation services in Massachusetts is limited. Funding responsibilities generally fall on municipalities. Municipalities typically cover

[27] "Fulfilling the Promise of Local Aid by Strengthening State-Local Partnerships," Mass.gov, October 13, 2022, https://www.mass.gov/report/fulfilling-the-promise-of-local-aid-by-strengthening-state-local-partnerships.

the cost of their school transportation services through general tax receipts and school bus service fees.[28]

Massachusetts' primary state financial aid program for public elementary and secondary schools is the Chapter 70 program.[29] Chapter 70, however, cannot be used to fund general student transportation in Massachusetts. The exception is for regional school district transportation, which is typically reimbursed by the state at 70 to 90 percent of the total costs.

Additional state and federal funding opportunities primarily target transportation services with higher associated costs and for high-need students. Specifically, the Special Education Circuit Breaker, McKinney-Vento Homeless Assistance Act, and Every Student Succeeds Act (ESSA) offer financial assistance for unique student transportation services.

The Special Education Circuit Breaker is a cost-sharing state program between school districts and the state for expenses related to educating the students who have the highest special education needs. Transportation services for students who are placed in out-of-district programs and are on an Individualized Education Program (IEP) are eligible for state reimbursements up to 25 percent. However, the Circuit Breaker does not require state reimbursement of transportation costs for in district special education transportation.[30]

Under the federal McKinney-Vento Homeless Assistance Act, school transportation for students experiencing homelessness is a mandatory service for the state to qualify for various categories of federal money. Consequently, the state is obligated to provide full reimbursement to school districts that transport these students.[31]

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[28] Ibid.

[29] "Chapter 70 Program," Massachusetts Department of Elementary and Secondary Education (DESE), accessed September 7, 2023, https://www.doe.mass.edu/finance/chapter70/.

[30] "Circuit Breaker Transportation FAQ," Massachusetts Department of Elementary and Secondary Education (DESE), July 9, 2020, https://www.doe.mass.edu/finance/circuitbreaker/transportation-faq.html?section=eligibility.

[31] "McKinney-Vento Homeless Education Assistance Act," Massachusetts Department of Elementary and Secondary Education (DESE), August 23, 2023, https://www.doe.mass.edu/sfs/mv/default.html.

ESSA requires school districts to work with the Massachusetts Department of Children and Families (DCF) to provide, arrange, and fund transportation for students in foster care to the schools that students previously attended prior to their placement in care. This service does not receive state aid; however, these transportation services are eligible for federal aid via approval of a Title IV-E state plan amendment.[32]

2.4 School Bus Contracting Arrangements

School districts in Massachusetts must arrange school transportation services for their students, and there are various stakeholders who determine how a school district will do so. The superintendent is responsible for the execution of transportation policy and regulations, including establishing bus routes.[33] Based on stakeholder interviews, school transportation services are often led by a director of transportation, director of operations, director of finance, or the school business administrator. These school district transportation leaders collaborate with the School Committee and other stakeholders to determine how to provide school transportation services.

School districts may choose to either own and operate their own fleets, lease and operate their school buses, or contract out services to a private bus company. Some school districts choose a mix of these options. For example, some school districts contract both general education and special education services, while other districts contract out general education transportation and provide special education transportation internally.

DESE sent a survey to school districts in April of 2023 asking if they "provide [their] own self-operated regular or special education transportation?" There were 314 school districts that responded. For regular transportation services, 48 stated "yes" and 266 replied "no." For special education transportation services, 81 responded "yes" and 233 responded "no." This survey indicates that most school districts in Massachusetts contract out services to private companies and that school districts are more likely to self-operate special

[32] "Ensuring Educational Stability for Students in Foster Care - Guidance," Massachusetts Department of Elementary and Secondary Education (DESE), January 18, 2018, https://www.doe.mass.edu/news/news.aspx?id=24765.
[33] DESE, "Pupil Transportation Guide."

education services, which generally transport fewer students than general education services.

School districts that want to contract out transportation services are required to follow competitive bidding processes. They issue Requests for Proposals (RFPs) or Invitations for Bids (IFBs) to potential transportation providers, evaluating them based on predefined criteria such as cost, service quality, and safety records. When all other criteria are met, the only remaining determinant is the price. Subsequently, in accordance with Chapter 30B, Section 5, school districts select the lowest responsible and responsive bidder that meets the transportation needs of the students while offering the best value.[34] Contracts with private operators are typically bid on a per bus per day rate and are signed for three years with the option for two one-year extensions or for five years.

2.5 School Bus Fleet Operations

Conversations with both school districts and private bus companies highlight the complex and context-specific nature of school bus operations, which encompass tasks such as route planning, driver training, safety procedures, regulatory compliance, and the provision of specialized services, including transportation for students with disabilities and extracurricular activities.

Each school district designs their school bus fleet operations or directs the private bus company's operations to ensure their individual district's requirements are met. School districts generally provide school transportation services for 180 days per year for general education transportation, special education transportation, travel for sports and extracurricular activities, and vocational school transportation. Some districts provide summer school transportation, which falls outside of the standard 180 days of operation per year.

Daily duty cycles of school buses depend on the school district's needs and typically encompass morning routes, mid-day layovers, afternoon routes, athletic events, and occasional field trips or extracurricular trips. This study did

[34] "General Law - Part I, Title III, Chapter 30B, Section 5," Massachusetts Legislature, accessed September 7, 2023, https://malegislature.gov/Laws/GeneralLaws/PartI/TitleIII/Chapter30B/Section5.

not have access to school bus telematics, but based on stakeholder interviews, the average daily mileage per bus varies from 10 miles to 150 miles.

School bus routes typically remain consistent throughout the year and are structured with the goal of minimizing the total time a student spends on the bus. Stakeholder interviews revealed that school bus routes are often categorized into tiers based on various factors such as distance from the school, grade levels, and start times. Additionally, the daily transportation service schedule may vary depending on the day of the week if the district has inconsistent weekly start or end times.

The number of stops, along with the duration of stop layovers, differs among school districts due to diverse factors, including geographical location, student requirements, and start and end times. Some districts have bus routes with as few as 5 stops and 5 to 10 minutes of layover time. Other districts, specifically those in more rural communities, have longer routes with up to 25 stops per route.

Deadheading is also a consideration for school bus operations due to its impact on efficiency and cost effectiveness. This occurs when school buses operate without passengers, usually to reach their starting points or assigned terminals. Depending on the storage locations of the individual buses, the deadheading varies amongst school districts. Efficient school transportation services tend to design routes to limit deadheading.

2.6 School Bus Fleet Storage and Maintenance

School bus service providers in Massachusetts have varied operating demands, but their fleet storage and maintenance practices are relatively similar. All operators need to determine where and how to store their school buses, whether they own or lease the storage depot, what equipment to keep at the storage facility, and where and how to perform fleet maintenance.

Typically, school district transportation procurement contracts require that a school bus be stored in the same municipality as the school it serves to minimize transit times and ensure timely pick-up and drop-off of students. However, some districts make exceptions if the storage location is still close by. For school districts that own school buses, they tend to store their fleet on school property or at facilities located within the district. Some districts and private operators store their fleets across multiple facilities, while others utilize one location.

School bus operators have the choice of owning or leasing the property where they store their fleet. This decision is primarily determined by the operator's budget and availability of land and storage locations in the district. Interviews suggested that most leasing agreements are 20 years long.

School bus fleets are typically stored in outdoor, central depots, with some depots including limited indoor storage for buses.

Based on stakeholder interviews, the mobility of buses between depots is relatively infrequent. Generally, each depot serves a specific geographic area or school district, and the buses assigned to that depot primarily operate within their designated region. However, in exceptional cases, such as maintenance needs, high-volume passenger events, or emergencies, buses may be temporarily moved between depots to meet demand.

The typical layout of school buses at a storage facility consists of designated parking spaces for each bus. The buses are generally parked side by side in a row format, and there are well-defined lanes for easy access and movement of the vehicles.

At school bus fleet facilities, a range of equipment is stored and utilized. Apart from the school buses themselves, these facilities house maintenance and repair tools, diagnostic equipment, and spare parts to keep the buses in optimal condition. Additionally, they may have fueling stations and bus-washing facilities. If fueling stations are not located at the storage facility, operators typically fuel their fleets off-site at a location close by.

Operators that perform their own maintenance often have a dedicated facility for maintenance and employ full-time mechanics. Other operators perform simple repairs in-house and transfer the vehicle to the dealership or the service provider for major repairs or choose to contract out all maintenance services.

Fleet replacement practices vary between public and privately owned fleets. Generally, school district-owned buses are replaced at the end of a bus's life (between 10 to 15 years). However, specific replacement schedules may be adjusted based on factors like the bus's mileage, condition, and funding availability. For school districts that contract with private companies for school bus services, contract terms often require school buses to be five years old or younger, which incentivizes private fleets to replace their buses more regularly.

2.7 Status of Zero-Emission School Bus Implementation in the Commonwealth

Out of the 9,446 school buses in the Commonwealth, at the time RMV data was extracted for this analysis, 18 were ZESBs. The school bus operators interviewed that currently utilize ZESBs stated that the financial assistance through several government programs enabled them to purchase these buses. Operators also expressed a key success factor for ZESB adoption was a strong relationship with their utility provider. They also emphasized the importance of training drivers, particularly on regenerative breaking, and having specially trained ZESB maintenance operators close by.[35] Broadly, ZESB operators expressed their ambition to continue with a transition to this technology, with quieter bus operation and the absence of diesel emissions among the factors motivating this ongoing transition.

A number of school districts and private operators using ZESBs collaborate with private companies who offer a turnkey ZESB service. These turnkey ZESB service providers typically own the ZESB and associated equipment, thereby reducing the up-front capital cost for their clients. These providers are usually responsible for all maintenance tasks, assist with installing charging infrastructure at the client's storage facility, offer driver training, and aid their clients in seeking financial assistance. The school district is typically

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[35] Regenerative brakes are used in electric and hybrid vehicles and function as an energy recovering mechanism by slowing down the vehicle and converting kinetic energy into a form that can be used immediately or stored for later use. See: "How Regenerative Brakes Work," Energy.gov, accessed November 11, 2023, https://www.energy.gov/energysaver/how-regenerative-brakes-work.

responsible for hiring drivers. This arrangement typically entails a 10–15-year contract.

Some of the school bus operators with ZESB experience have participated in pilot Vehicle-to-Grid (V2G) technology programs. V2G charging technology allows ZESBs to interact with the power grid via a bi-directional charger that facilitates a two-way energy flow. Using this technology, ZESBs can both draw power from the grid to charge their batteries and send stored energy back to the grid.[36] Under a V2G program, the school bus operator is paid for the energy the bus gives back to the grid. Feedback from participants indicated that in theory, this approach could offer advantages to both the operator and the power grid, but that the compensation provided to the ZESB operators was modest, and the training and resources needed for V2G implementation are significant.

Most of the fleet operators interviewed who have not yet adopted ZESBs expressed their interest in buying them--however, the primary barrier to adoption is the higher up-front cost of ZESBs and their associated charging infrastructure compared to their diesel counterparts. Some districts interested in buying ZESBs either applied for funding assistance but didn't receive it, don't have the time or expertise to apply for grants or a plan for how to integrate ZESBs into their fleets, or didn't know funding assistance was available.

Transitioning to ZESBs requires the establishment of charging infrastructure and in many cases, upgrading electric systems to accommodate higher energy demands. Interviews indicated these to be significant logistical and financial challenges.

As mentioned earlier, there are approximately 24 ZESB models available on the market. However, due to the specific needs of each school district, some stakeholders expressed that there are not enough model options and lead times are too long to meet their needs. School bus operators also expressed uncertainty regarding available models meeting their daily mileage needs.

[36] Darlene Steward, "Critical Elements of Vehicle-to-Grid (V2G) Economics," National Renewable Energy Laboratory (NREL), September 2017, https://www.nrel.gov/docs/fy17osti/69017.pdf.

This is particularly a concern for operators with daily bus mileage requirements of 150 miles or more.

Many private operators in Massachusetts rely on resale values to fund their next school bus purchase and ensure their fleet is young enough to meet school district bid requirements. Given the ZESB market is new, there is little information regarding market resale values, which poses a concern for private operators. Similarly, the lifespan of a ZESB is unfamiliar, making fleet replacement planning for school districts and private operators challenging.

3.0 Overview of Massachusetts Investor-Owned Utilities

ZESB adoption, specifically the deployment of charging infrastructure, requires coordination with private and municipal utilities in Massachusetts.

There are currently four investor-owned electric distribution companies that provide electricity services for a majority of towns and cities in Massachusetts:

- NSTAR Electric Company d/b/a Eversource Energy
- Massachusetts Electric Company d/b/a National Grid
- Nantucket Electric Company d/b/a National Grid
- Fitchburg Gas and Electric Light Company d/b/a Unitil

Massachusetts is also served by 41 municipal electric companies delivering power to approximately 50 municipalities across the Commonwealth.[37] This structure creates a patchwork of different providers, each of which maintains the electric distribution infrastructure (i.e., wires, poles, transformers, etc.) for their specific service territory.

The economic analysis in **Section 4.0** includes consideration of Demand Charge Alternative programs for electric vehicle charging, which are only relevant to investor-owned utilities. The focus of this section is on these

[37] "Competitive Supply Glossary," Mass.gov, accessed September 19, 2023, https://www.mass.gov/info-details/competitive-supply-glossary.

investor-owned utilities, and their EV charging programs are discussed in more detail below.

Investor-owned electric utilities charge distribution fees to electric consumers. The prices ("rates") that these utilities charge their customers are highly regulated and set by the Department of Public Utilities (DPU). These utilities must supply electricity largely on demand and typically have limited ways to store it. Consequently, electricity must be distributed immediately to end users, prompting providers to structure pricing in a way that encourages consistent and predictable customer demand.

The investor-owned utilities in Massachusetts assess "demand charges" on commercial customers who demand high power levels over short periods of time. These utilities have structured their rates so that once a commercial customer exceeds a peak demand or load threshold, demand charges are triggered, which are based on the monthly maximum or peak energy kilowatt (kW) demand.[38]

The kW demand of energy use is the key difference between L2 and DC EV charging from a customer pricing standpoint. For example, if a ZESB with a 180 kW battery returns to base with 15 percent charge left, that ZESB would need 153 kW to return to a state of full charge. The school bus operator could charge that bus for 12 hours overnight at an average of 13 kW per hour using a 19.2 kW L2 charger, or a school bus operator could charge that bus in a single hour during the day using a 150 kW DCFC. Both scenarios could be subject to demand charges--however, it is more likely that the daytime DCFC charging scenario would experience higher demand charges due to its higher maximum energy threshold of 150 kW compared to 19.2 kW.

National Grid, Eversource, and Unitil developed Demand Charge Alternative Programs for EV charging, which were approved by DPU.[39] These programs are designed to reduce EV charging station operating costs by providing a tiered,

[38] "Understanding Your Electric Bill: Saving Money On Demand Charges and Power Factor," Mass.gov, April 1, 2019, https://www.mass.gov/doc/understanding-your-electric-bill-saving-money-on-demand-charges-and-power-factor-0/download.
[39] "Electric Vehicle Charging," Mass.gov, June 6, 2023, https://www.mass.gov/info-details/electric-vehicle-charging.

load factor-based discount on commercial customer demand charges.[40] A load factor (LF) is the ratio of the actual kilowatt hours (kWh) delivered during a billing period to the peak load (or peak demand in kW) during the billing period, if the demand was constant over the billing period. These programs are currently available for 10 years starting in 2023. All new and existing utility customers are eligible to enroll in their service area provider's program, provided their EV charging stations are separately metered and the customer is on a qualifying, EV-specific rate schedule.

The Demand Charge Alternative Programs coupled with networked chargers and demand management software can help school bus operators mitigate electric utility demand charges.

4.0 Evaluating the Costs and Environmental Benefits of Zero-emission School Buses

4.1 Fleet Replacement Scenarios

FLEET REPLACEMENT SCENARIO DEFINITIONS

To enable comparisons of ZESB costs and environmental benefits with their conventional counterparts, three school bus fleet replacement scenarios were defined, as outlined in **Table 4** below, reflecting futures in which ZESB fleet share follows three different adoption pathways. The fleet replacement scenarios cover the period from 2023-2036. This fourteen-year analysis period aligns with the approximate life expectancy of a school bus and concludes in 2036, the year following the cessation of Advanced Clean Trucks rule (ACT rule) sales percentage escalations, described below.

In all three fleet replacement scenarios, the total number of school buses operating in Massachusetts remains constant at 9,446 vehicles over the analysis horizon, to simplify the analysis. Similarly, the proportion of vehicles

[40] "Demand Charge Alternative Program for Massachusetts," National Grid, August 2023, https://www.nationalgridus.com/media/pdfs/bus-ways-to-save/ev/cm9464-demand-charge_one-pager.pdf.; "Commercial Electric Rates (MA)," Unitil, August 1, 2023, https://unitil.com/sites/default/files/2023-08/MA_Comm_Elec_Rates_0823.pdf.

by body style (inferred by gross vehicle weight rating or "regulatory class") also remains constant.

Table 4. School Bus Fleet Replacement Scenario Definitions

Current Fuel Mix	This scenario assumes that the number of ZESBs in the fleet (18) does not grow beyond 2023 levels. All other new vehicles will be conventional fossil fuel-powered school buses and would replace like for like in terms of vehicle weight class and fuel type. This scenario is included only to allow the calculation of the total cost of ZESB adoption and associated emissions impacts.
ZEV Compliance	Under this scenario, school bus manufacturers comply with the ACT rule adopted by Massachusetts in 2021 and taking effect in Model Year (MY) 2025 sales.[41] The rule requires an increasing fraction of all medium and heavy duty vehicle sales, in weight classes 2B through 8, in Massachusetts beginning with MY 2025 be zero-emission vehicles. These fractions vary by vehicle weight class. While the ACT rule applies to all MHDV sales and does not specifically apply to school buses, this scenario assumes that ZESB manufacturers comply with the ACT rule sales fraction schedule by vehicle weight class set out in the regulation.
ZESB Swap	This scenario models an immediate shift to 100 percent ZESB purchases. Beginning in 2024, all new school buses entering the fleet are ZESBs.

[41] "MassDEP Files New Regulations to Reduce Emissions, Advance Market for Clean Trucks in the Commonwealth," Massachusetts Department of Environmental Protection (MassDEP), December 30, 2021, https://www.mass.gov/news/massdep-files-new-regulations-to-reduce-emissions-advance-market-for-clean-trucks-in-the-commonwealth.

Table 5 illustrates the ACT rule zero-emission vehicle (ZEV) sales requirements. The Class 7-8 Tractors sales percentages do not apply to school buses.

Table 5. ACT Rule Sales Percentage Requirements[42]

MODEL YEAR (MY)	CLASS 2b-3	CLASS 4-8	CLASS 7-8 TRACTORS
2025	7%	11%	7%
2026	10%	13%	10%
2027	15%	20%	15%
2028	20%	30%	20%
2029	25%	40%	25%
2030	30%	50%	30%
2031	35%	55%	35%
2032	40%	60%	40%
2033	45%	65%	40%
2034	50%	70%	40%
2035+	55%	75%	40%

Table 6 breaks down Massachusetts' school bus fleet by regulatory class and grouped by the ACT rule sales percentage class groups. The majority of school buses are Class 7 and would therefore be subject to the Class 4-8 ACT sales requirements.

[42] "Background Document on Emergency Regulation Amendments to 310 CMR 7.40," Massachusetts Department of Environmental Protection (MassDEP), December 30, 2021, https://www.mass.gov/doc/310-cmr-740-background-document/download.

Table 6. Massachusetts School Bus Fleet Proportions by ACT Regulatory Class Groups

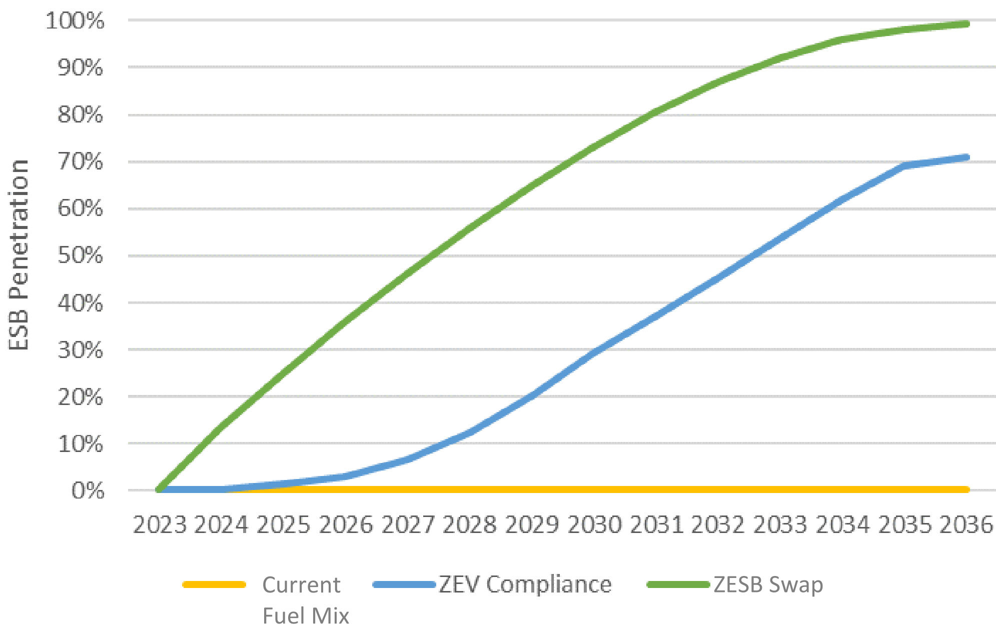
REGULATORY CLASS	COUNT OF VEHICLES	TOTAL VEHICLES IN ACT RULE CLASS GROUPS	PERCENTAGE OF VEHICLES IN FLEET BY ACT RULE CLASS GROUPS
2	49	1,352	14%
3	1,303		
4	353	8,094	86%
5	5		
6	252		
7	6,776		
8	708		

FLEET REPLACEMENT SCENARIO ZESB FLEET SHARE

Figure 7 below illustrates the estimated ZESB fleet share for each analysis year (2023-2036) of each fleet replacement scenario, as defined in **Table 4**. These fleet share estimates take into account the age distribution of the Massachusetts school bus fleet and a custom scrappage curve that defines the probability of vehicles retiring from the fleet changes with age.

While used ZESBs may circulate in the fleet and individual fleets may buy and sell individual vehicles over time, this analysis examines the statewide school bus population.

Figure 7. Estimated ZESB Fleet Share by Fleet Replacement Scenario, 2023-2036



ZESB fleet share is lowest for the Current Fuel Mix scenario; by design, the fleet never gains more than 18 ZESBs (0.2 percent of the fleet).

The ZEV Compliance scenario results in a ZESB fleet share of 71 percent by 2036. The conversion rate for this scenario slows slightly in 2035, and then begins to flatten as the Class 4-8 sales fraction ceases to increase in that year.

The ZESB Swap scenario would achieve a nearly full ZESB fleet by 2036. The fleet share reaches 92 percent electric in 2033 and 99.4 percent electric at the end of the analysis timeframe in 2036. Though outside the stated analysis horizon, the analysis predicts full electrification under the ZESB Swap scenario by 2038.

4.2 Key Assumptions and Inputs Considerations

Estimating the economic and environmental impacts of the three fleet replacement scenarios required assumptions about the fleet activity, including average daily miles driven, charging requirements, and a range of unit costs.

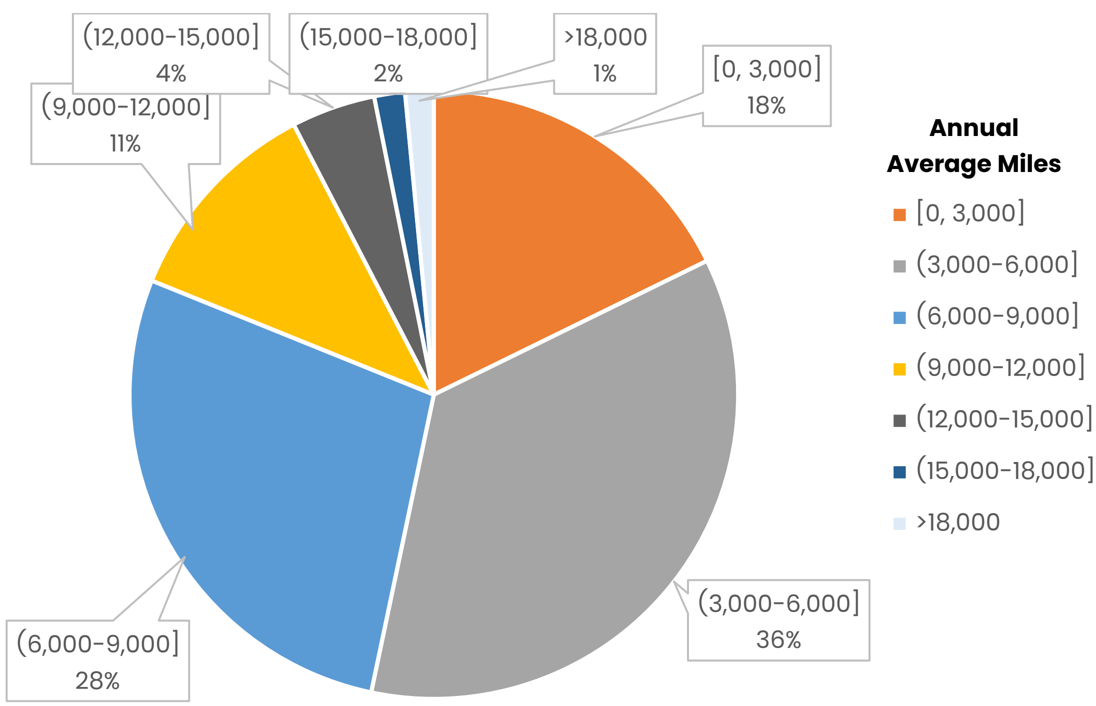
4.2.1 Fleet Activity and Mileage Assumptions

The average annual vehicle miles travelled (VMT) for each regulatory class and age was estimated using the annual RMV mileage data from 2018-2022, available for only 8,007 school buses. The results from the school buses with mileage data were then scaled to reflect the full fleet of 9,446 school buses.

For the annual VMT calculation, the number of school bus operating days in Massachusetts was estimated to be 156. The Massachusetts school year is 180 days and on average, each school bus is assumed to be used as a spare vehicle approximately 13 percent of the time, or 24 days per year.[43]

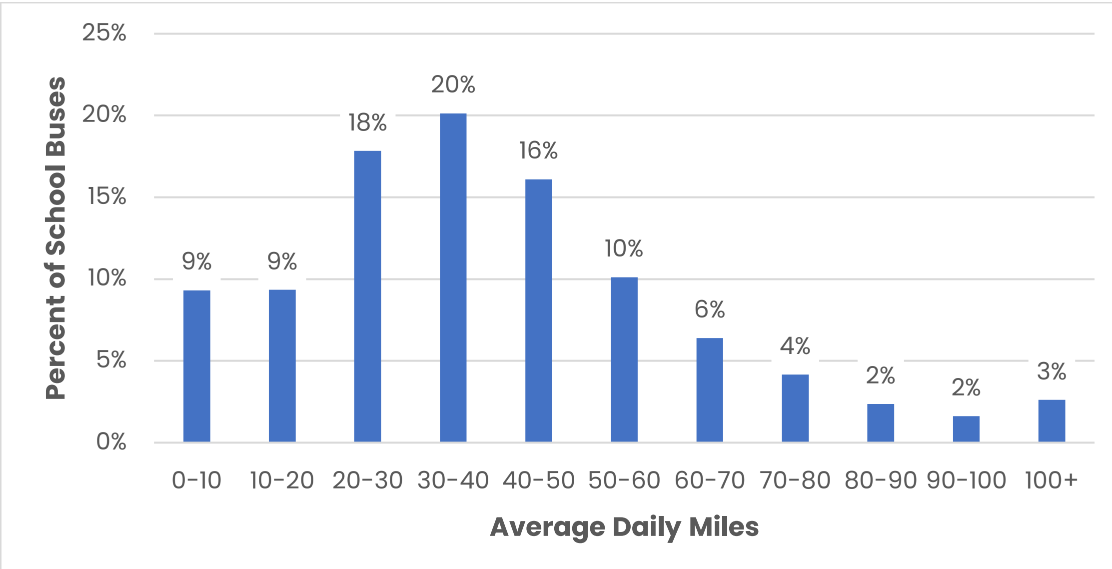
The distribution of annual miles driven for school buses in Massachusetts is presented in **Figure 8**, while **Figure 9** shows the distribution of daily miles driven.

Figure 8. Distribution of Annual Average Miles Driven by School Buses in Massachusetts



[43] A spare vehicle is a vehicle kept in reserve in case another vehicle in the fleet cannot be driven. The 13 percent spare estimate was derived from stakeholder interviews.

Figure 9. Distribution of Average Daily Miles Driven by School Buses in Massachusetts



As **Figure 9** shows, only 3 percent of daily miles driven exceed 100 miles. The daily mileage results were used to determine the charging strategy for each school bus in the fleet, as described in **Section 4.2.2** below.

All ZESBs of regulatory Class 4 and above were assumed to use diesel-powered heaters during winter months only (between November and March). Class 2-3 school buses are assumed to use batteries for heat, given these smaller vehicles would require far less energy to heat.

The number of winter school bus operating days from November to March was estimated to determine the days that diesel heaters would operate. There are typically 109 weekdays from November to March and 17 weekday holidays, which leads to a total of 92 winter school days, of which each vehicle would actually operate 80 days (due to the 13 percent spare vehicle assumption). Multiplying the average daily VMT by 80 yielded the winter mileage, which was then distributed in the same manner as with average annual VMT, by regulatory class and age. This winter operating day estimate was used to calculate the emissions from diesel heaters, as described in **Section 4.4**.

4.2.2 Charging Requirement Assumptions

CHARGING FEASIBILITY STRATEGIES

A charging feasibility analysis was performed using a model that incorporated the battery capacity, number of days of operations, weather conditions, average daily mileage, and average speed to determine fleet charging strategies and energy requirements.

One of the following two charging strategies was assigned to each school bus based on estimated energy consumption rates and various operational conditions:

1. ZESBs charge solely on L2 (19.2kW) EV chargers overnight. L2 chargers offer fleet owners the lowest cost EV hardware options, smallest space requirements per bus, lowest cost for installation, and lowest ongoing costs for operations and maintenance (O&M).
2. ZESBs complete daily operations with DCFC EV stations capable of charging buses at 150kW per hour during a mid-point of daily operations to ensure sufficient battery charge. DCFC EV charging stations need additional space per bus and are significantly more expensive compared to L2 EV chargers.

CHARGING FEASIBILITY ASSUMPTIONS

The charging assumptions detailed in **Table 7** below were used to determine the charging feasibility of the 9,446 school buses based on the two charging strategies.

Table 7. Charging Feasibility Model Assumptions

PARAMETER	VALUE
Bus Manufacturer	Navistar (most prevalent diesel bus make deployed in MA)
Bus Model	Electric CE 210 kW (ZESB most similar to diesels deployed in MA)
Number of School Days	156 (Based on assumptions stemming from spare bus ratios)
Weather Conditions	Strenuous (i.e., hot and cold weather with related diesel heater use)
Average School Bus Speed	25 mph[44]
Minimum State of Charge (SOC)	15% (industry standard minimum SOC best practice)
Maximum State of Charge (SOC)	85% (industry standard providing buffer against battery degradation)

Each bus is assumed to begin the day with a minimum 85 percent state of charge (SOC) and its daily mileage is considered feasible if it ends the day above a 15 percent battery SOC. This range considers that operating at a SOC above 85 percent leads to battery degradation and that operating below 15 percent risks the vehicle running out of charge before it can return to the garage.

When the average daily miles driven for a bus end with a SOC greater than 15 percent, that bus is considered feasible for electrification under an L2 (19.2kW) overnight EV charging scenario to meet all daily service cycle energy needs.

For each bus that fell under 15 percent state of charge after the L2 overnight only charging scenario, a midday DCFC (150kW) EV charging session option was tested in the model to see if the bus could service the remaining route miles. The school buses that could meet its energy needs with a DCFC session during the daily service cycle were considered feasible for electrification.

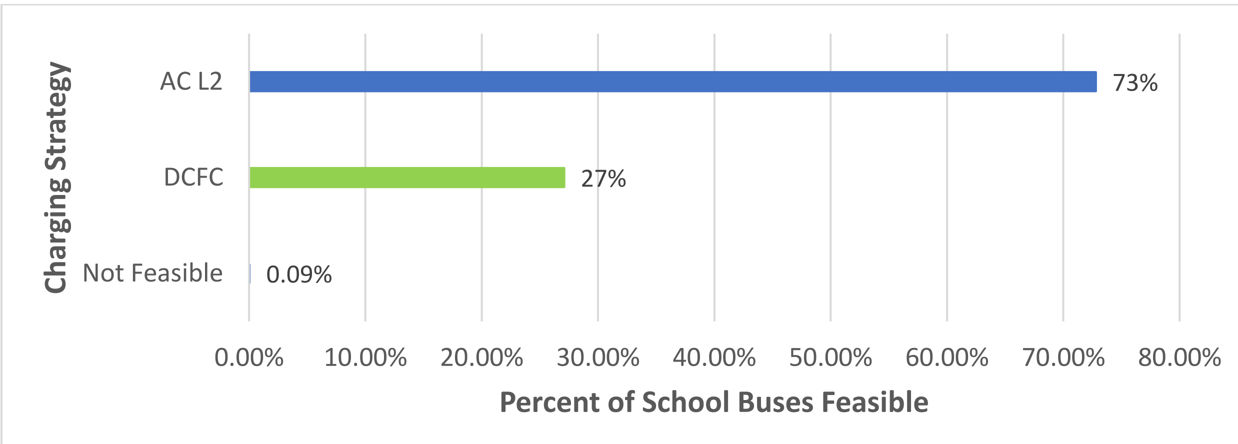
CHARGING FEASIBILITY RESULTS

The results of this high-level charging analysis are illustrated in **Figure 10**. An estimated 73 percent of the Massachusetts school bus fleet would be feasible

[44] Adam Duran and Kevin Walkowicz, "A Statistical Characterization of School Bus Drive Cycles Collected via Onboard Logging Systems," SAE International Journal of Commercial Vehicles 6, no. 2 (2013): 400–406, https://doi.org/10.4271/2013-01-2400.

for overnight L2 (19.2kW) EV charging alone, while the remaining 27 percent can complete their service routes with one mid-day DCFC EV charging session. Less than one tenth of a percent of the fleet could not complete their daily mileage under either charging strategy, with these school buses most likely used for longer field trips or special routes.

Figure 10. Percent of School Buses Feasible by EV Charging Strategy



These charging results were utilized to determine the use of L2 charging or DC fast charging strategies in the fleet replacement scenario cost estimates in **Section 4.3.2**.

For the fleet replacement scenario cost estimates and environmental impact analysis below, it was assumed that all fossil fuel-powered school buses could be replaced on a 1:1 basis with ZESBs of the same vehicle class. While less than one percent of the school bus fleet was unsuitable for electrification, the state-wide nature of this analysis and the fact that none of the replacement scenarios reach 100 percent ZESB adoption by 2036 justified the use of a 1:1 replacement ratio.

4.2.3 ZESB and Diesel School Bus Cost Assumptions

School bus fleets, whether powered by fossil fuel for or zero-emission sources, are subject to the following four categories of lifecycle costs: 1) capital acquisition costs; 2) operations costs; 3) maintenance costs; and 4) end-of-life costs. Each of the four main cost categories are detailed below in 2022 dollars with information on three schools bus types (A, C, & D) for ZESBs and diesel-powered school buses.[45] These cost assumptions are representative and actual costs associated with ZESB adoption will vary based on a range of factors, such as the vehicle makes and models chosen, vehicle specifications, school district needs, site upgrades, and utility provider.

In the subsections that follow, red-colored numbers are used to illustrate ZESB costs that exceed conventional diesel buses, while green-colored numbers are used to illustrate ZESB costs that offer comparable savings.

The capital acquisition costs in **Table 8** and **Table 9** were utilized to estimate the fleet replacement scenario costs in **Section 4.3.2**.

The "total" values for Type C school buses in **Table 8 – Table 14** represent the cost assumptions utilized in the total cost of ownership (TCO) analysis in **Section 4.3.1**.

CAPITAL ACQUISITION COST ASSUMPTIONS

Table 8 below details the capital acquisition costs associated with L2 charging for ZESB deployment.

[45] Michelle Levinson et al., "Recommended Total Cost of Ownership Parameters for Electric School Buses: Summary of Methods and Data," World Resources Institute, January 30, 2023, https://www.wri.org/research/recommended-total-cost-ownership-parameters-electric-school-buses-methods-data. Unless otherwise noted, all cost data for ZESBs and diesel buses cited are derived from WRI. Additional information was provided by utilities, Massachusetts school bus owner/operators, vehicle and equipment manufacturers, and information derived from MassDOT data as cited in this section.

Table 8. Capital Acquisition Costs per School Bus: Zero-Emission (L2) vs. Diesel by Type[46]

VEHICLE TYPE	TYPE A		TYPE C		TYPE D	
Fuel type	Electric	Diesel	Electric	Diesel	Electric	Diesel
MSRP 2022 ($/vehicle average)	$271,393	$58,484	$352,012	$103,140	$378,459	$127,606
Level 2 EV Charger (19.2kW) Hardware	$3,814	$0	$3,814	$0	$3,814	$0
Level 2 EV Charger (19.2kW) Installation	$6,661	$0	$6,661	$0	$6,661	$0
Incremental Land Acquisition for EV Charger (12 sq. ft. @ $268,400 / acre MA average)[47]	$74	$0	$74	$0	$74	$0
Total	**$281,942**	**$58,484**	**$362,561**	**$103,140**	**$389,008**	**$127,606**
Additional ZESB Capital Costs vs Diesel	**$223,458**		**$259,421**		**$261,402**	

Table 9 below details the additional capital acquisition costs that are associated with DCFC deployment in Massachusetts.

Table 9. Additional DCFC Capital Acquisition Costs per ZESB[48]

Fuel type	Electric
DCFC (150kW) Hardware & Installation[49]	$234,219
Incremental Land Acquisition for EV Charger (260 sq. ft. @ $268,400 / acre MA average)[50]	$1,602
Total	**$235,821**

Investments and upgrades are often needed on the utility's side of the electrical meter, such as a separate meter, larger transformer, new electrical service, or a new substation.[51] It is important to note that the L2 and DC EV charging hardware and installation costs outlined in **Table 8** and **Table 9** represent the customer-side acquisition and installation costs and do not include utility-side cost estimates.

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[46] Table 8 illustrates the capital costs associated with the estimated 73% of school buses in Massachusetts that could rely solely on L2 chargers.
[47] MassDOT land value analysis; HNTB data on average EV charging station space requirements for L2 and DCFC stations.
[48] The additional DCFC capital costs in Table 9 would apply to the estimated 27% of school buses in Massachusetts that would need both an L2 charger and a DCFC.
[49] DCFC hardware and installation costs are estimates from previous MassDOT study.
[50] MassDOT land value analysis; HNTB data on average EV charging station space requirements for L2 and DCFC stations.
[51] Ibid.

ANNUAL SCHOOL BUS OPERATIONS COST ASSUMPTIONS

ZESBs potentially offer several operational cost savings advantages to diesel vehicles based on reduced costs for energy, greater energy efficiencies, and reduced need for additional fluids such as diesel exhaust fluid. **Table 10** below details the annual operations costs per school bus associated with L2 charging or DC fast charging.

Table 10. Annual Operations Costs per School Bus: Zero-Emission vs. Diesel by Type[52]

VEHICLE TYPE	TYPE A		TYPE C		TYPE D	
Fuel type	**Electric**	**Diesel**	**Electric**	**Diesel**	**Electric**	**Diesel**
Annual vehicle mileage (miles/year) [53]	7,069	7,069	7,069	7,069	7,069	7,069
Overall fuel economy (MPGe)	39.46	10.5	22.1	6.59	25.32	6.32
Average Energy Costs ($/kWh and $/gallon)	$0.19	$3.26	$0.19	$3.26	$0.19	$3.26
Diesel exhaust fluid ($/gallon)	$0	$0.03	$0	$0.03	$0	$0.03
Total	$1,297	$2,215	$2,315	$3,529	$2,021	$3,680
ZESB Operating Cost Savings	**$918**		**$1,214**		**$1,659**	

Table 10 above does not factor in demand charges. **Table 11** illustrates potential demand charge costs. To streamline the cost analysis, only demand charges from investor-owned utilities with Demand Charge Alternative Programs (National Grid, Eversource, and Unitil) were considered. These programs consist of rate components such as a kW demand charge and a kWh base distribution rate.

Demand charges are based on the peak rate of electricity consumption in kWs at a facility each month over a specific time interval. The demand charges in the existing programs range from $3.04 - $19.82/kW. The kW rates in **Table 11** represent a weighted average based on how many school buses are garaged in each utility service region. They are categorized by "low utilization" and "high utilization," where low utilization represents the weighted average $/kW in the greater than 5 percent and less than or equal to 10 percent load factor

[52] The annual operations costs in Table 10 would apply to all ZESBs, regardless of whether they utilize an L2 charger or DCFC.

[53] The annual average school bus mileage (7,069) from the RMV mileage data was utilized for these cost estimates.

category, and high utilization represents the weighted average $/kW in the greater than 15 percent load factor category.

The kWh cost estimates were calculated using the same approach as the demand charge kW costs.

Table 11. Annual Operations Costs per School Bus: Demand Charges[54]

VEHICLE TYPE	TYPE A		TYPE C		TYPE D	
	DCFC (low utilization)	L2 (high utilization)	DCFC (low utilization)	L2 (high utilization)	DCFC (low utilization)	L2 (high utilization)
Annual vehicle mileage (miles/year)	7,069	7,069	7,069	7,069	7,069	7,069
Overall fuel economy (MPGe)	39.46	39.46	22.1	22.1	25.32	25.32
Peak kW Monthly Usage	150	19.2	150	19.2	150	19.2
Months per Year	12	12	12	12	12	12
MA Weighted Avg. Demand Charge/kW	$3.22	$12.77	$3.22	$12.77	$3.22	$12.77
Total Annual ZESB $kW Demand Charge Costs	$5,788	$2,943	$5,788	$2,943	$5,788	$2,943
Annual kWh Used	6,825		12,187		10,637	
MA Weighted Avg. Demand Charge/kWh	$0.098449	$0.07189	$0.098449	$0.07189	$0.098449	$0.07189
Total Annual ZESB $kWh Demand Charge Costs	$672	$491	$1,200	$876	$1,047	$765
Total Annual Demand Charge Costs	**$6,460**	**$3,434**	**$6,988**	**$3,819**	**$6,835**	**$3,708**

ANNUAL SCHOOL BUS MAINTENANCE COST ASSUMPTIONS

ZESBs offer potential maintenance advantages versus their diesel counterparts due to their simplified mechanical components, as shown in the "Annual Maintenance Costs" row in **Table 12** below.[55]

However, ZESBs are currently subject to several increased costs versus diesel school buses, primarily stemming from increased costs to insure the vehicles

[54] The costs in Table 11 estimate demand charges that could be associated with ZESBs.
[55] Alternative Fuels Data Center. "Flipping the Switch on Electric School Buses: Cost Factors: Module 3."

based on the higher overall vehicle prices, as well as incremental additional costs from EV charging station ongoing networking and maintenance.

Table 12. Annual Maintenance Costs per School Bus: Zero-Emission vs Diesel by Type

VEHICLE TYPE	TYPE A		TYPE C		TYPE D	
Fuel type	**Electric**	**Diesel**	**Electric**	**Diesel**	**Electric**	**Diesel**
Average Annual Miles	7,069	7,069	7,069	7,069	7,069	7,069
Overall maintenance & repair costs ($/mile)	$0.24	$0.40	$0.29	$0.57	$0.31	$0.62
Annual Maintenance Costs	**$1,697**	$2,828	**$2,050**	$4,029	**$2,191**	$4,383
Level 2 EV Charger (19.2kW) Networking	$454	$0	$454	$0	$454	$0
Level 2 EV Charger (19.2kW) Maintenance	$536	$0	$536	$0	$536	$0
Liability-only cost to insure ($/year)	$4,786	$4,786	$6,770	$6,770	$12,300	$12,300
Full coverage cost to insure[56] ($/year)	$14,812	$9,068	$22,548	$12,660	$28,088	$17,575
Total	$22,285	$16,682	$32,358	$23,459	$43,569	$34,258
Additional ZESB Maintenance Costs	**$5,603**		**$8,899**		**$9,311**	

DC EV fast chargers are subject to increased ongoing maintenance costs compared to L2 EV chargers. These increased costs stem primarily from the fact that DCFC equipment, by providing significantly higher power (150kW vs. 19.2kW) outputs over short time periods, have hardware that is routinely subject to higher temperatures, or thermal loads, during operations. These high operating temperatures require cooling systems within the DCFC equipment, and these cooling systems need routine maintenance. **Table 13** details the ongoing costs related to annual DCFC equipment maintenance.

Table 13. Additional Annual DCFC Maintenance Costs per ZESB by Type

VEHICLE TYPE	TYPE A		TYPE C		TYPE D	
Fuel type	**Electric**	**Diesel**	**Electric**	**Diesel**	**Electric**	**Diesel**
DCFC (150kW) Networking	$522	$0	$522	$0	$522	$0
DCFC (150kW) Maintenance	$2,237	$0	$2,237	$0	$2,237	$0
Total	**$2,759**		**$2,759**		**$2,759**	

[56] Insurance costs can vary significantly due to factors like deductible structure, market characteristics (character of local juries, repair costs, perceived danger), coverage, caps on payouts, and other considerations.

For fleet owners that keep their vehicles for their full lifetime, additional mid-life battery overhaul costs may be incurred. Electric vehicle batteries, like all batteries, are subject to degradation over years of successive charging and discharging cycles. Battery degradation means a diminished capacity for batteries to store energy over their lifetime. Most ZESB manufacturers, like conventional vehicle manufacturers, offer battery warranties for five to eight years, often guaranteeing a range minimum, and offering a full battery replacement if range decreases past warrantied thresholds.

Table 14 details the potential mid-life ZESB battery overhaul costs as well as end-of-life battery salvage values (based on composite average battery sizes for each bus type).

For the TCO estimate in **Section 4.3.1**, mid-life overhaul costs for ZESBs were assumed at 8 years. Diesel school buses did not have associated mid-life costs because diesel engines are typically replaced at 250,000 miles or more, which is beyond the estimated lifetime mileage of the Commonwealth's fleet.[57]

Table 14. Mid-Life Overhaul & Battery Salvage Value per School Bus: ZESBs vs Diesel School Buses by Type

VEHICLE TYPE	TYPE A		TYPE C		TYPE D	
Fuel type	Electric	Diesel	Electric	Diesel	Electric	Diesel
Mid-Life (~8 year) Battery Overhaul Costs	$9,070	$0	$15,162	$0	$14,329	$0
Battery Size (kW)	119	0	199	0	188	0
Total Battery Salvage Value	$50	$50	$50	$50	$50	$50
Battery Salvage Value ($50/kW)	$5,950	$0	$9,950	$0	$9,400	$0
Total	$3,120	$0	$5,212	$0	$4,929	$0

VEHICLE END-OF-LIFE AND RESALE VALUE

Compared to the extensive market data that exists for diesel school buses, assessing the end-of-life and resale values of ZESBs is challenging due to scarcity of data. Most ZESBs deployed have been operating for five years or less and therefore have not yet reached the end-of-life stage.[58] Consequently,

[57] Michael Kay et al., "Bus Lifecycle Cost Model for Federal Land Management Agencies," United States Department of Transportation, September 30, 2011, https://rosap.ntl.bts.gov/view/dot/9548.
[58] Alissa Huntington et al., "Electric School Bus U.S. Market Study."

no end-of-life or resale values were used in the TCO or fleet replacement scenario cost analysis.

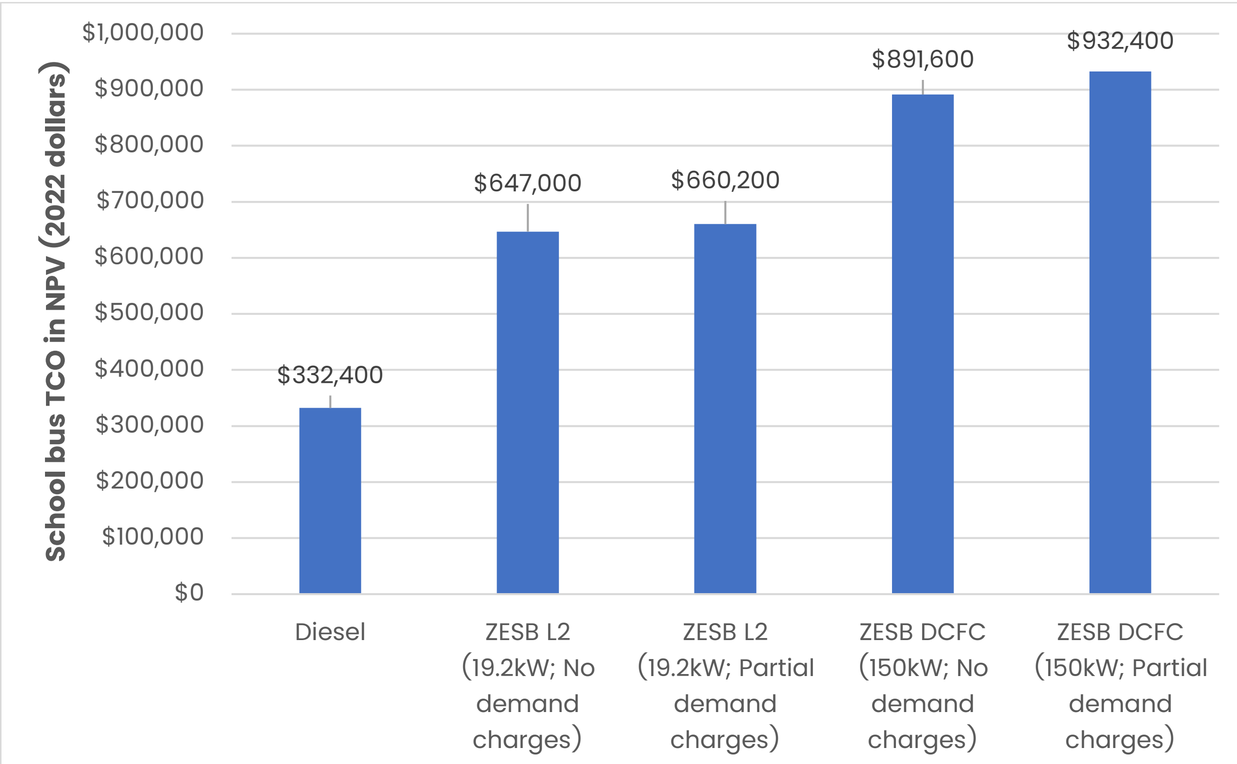
4.3 Estimated Costs of Ownership and Fleet Replacement Scenarios

4.3.1 Lifetime Total Cost of Ownership (TCO) Estimates

Table 15 illustrates a TCO assessment for Type C ZESBs and diesel school buses. The TCO analysis encompasses all major cost components - capital, annual operating and maintenance, mid-life overhaul, and the battery salvage value cited in **Section 4.2.3** above - expressed in net present value (NPV), assuming a 7 percent discount rate, a fourteen-year useful life, and 7,069 annual miles driven. The analysis compares how charging methods (L2 vs. DCFC) and electricity costs (no demand charge operation costs from **Table 10** vs. Demand Charge Alternative program operation costs from **Table 11**) impact cost estimations.

The TCO analysis for Type C school buses illustrates the same trend found with Type A and D school bus TCO estimates: for all school bus types, regardless of electricity utilization or charging strategy, ZESBs are currently more expensive to own compared to their diesel counterparts.

Table 15. Type C School Bus Total Cost of Ownership (TCO) Analysis in Net Present Value (NPV) (2022 dollars)[59]



4.3.2 School Bus Fleet Replacement Scenario Capital Costs

The school bus fleet replacement scenario costs estimated in this section are based on the 2022 capital cost estimates for diesel and electric school buses, including the charging hardware, installation, and incremental land acquisition costs, detailed in **Table 8** and **Table 9**. Each year assumes an inflation rate of 3 percent for the capital costs.

In each of the three fleet replacement scenarios the total number of school buses operating in Massachusetts remains constant at 9,446 vehicles over the analysis horizon. Similarly, the proportion of vehicles by body style (inferred by gross vehicle weight rating and aligned with Type A, C, and D) also remains constant.

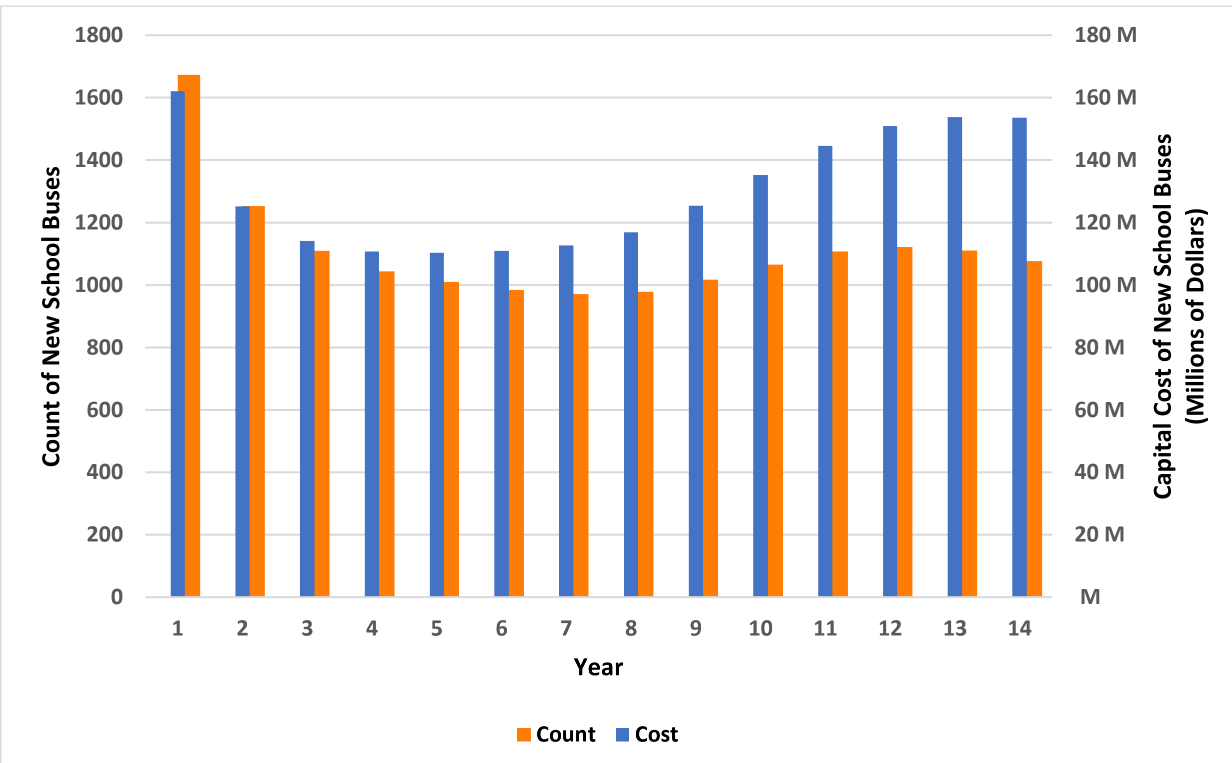
[59] Partial demand charges refer to the Demand Charge Alternative Program costs outlined in Table 11.

CURRENT FUEL MIX REPLACEMENT SCENARIO COSTS

The Current Fuel Mix replacement scenario costs serve as a point of reference for comparing the additional costs of ZESB deployments in the ZEV Compliance and ZESB Swap cost estimates. Under this scenario, the school buses in the fleet are replaced by school buses of the same fuel type and school bus type (A, C, and D).

In the Current Fuel Mix replacement scenario, an estimated $1.82 billion in capital costs is projected to be spent on 15,519 new school buses through 2036 in Massachusetts. **Figure 11** below details the annual count of new school buses and associated capital costs under this scenario.

Figure 11. Current Fuel Mix School Bus Fleet Replacement Scenario: Annual Count of New School Buses and Capital Costs (Nominal Dollars)



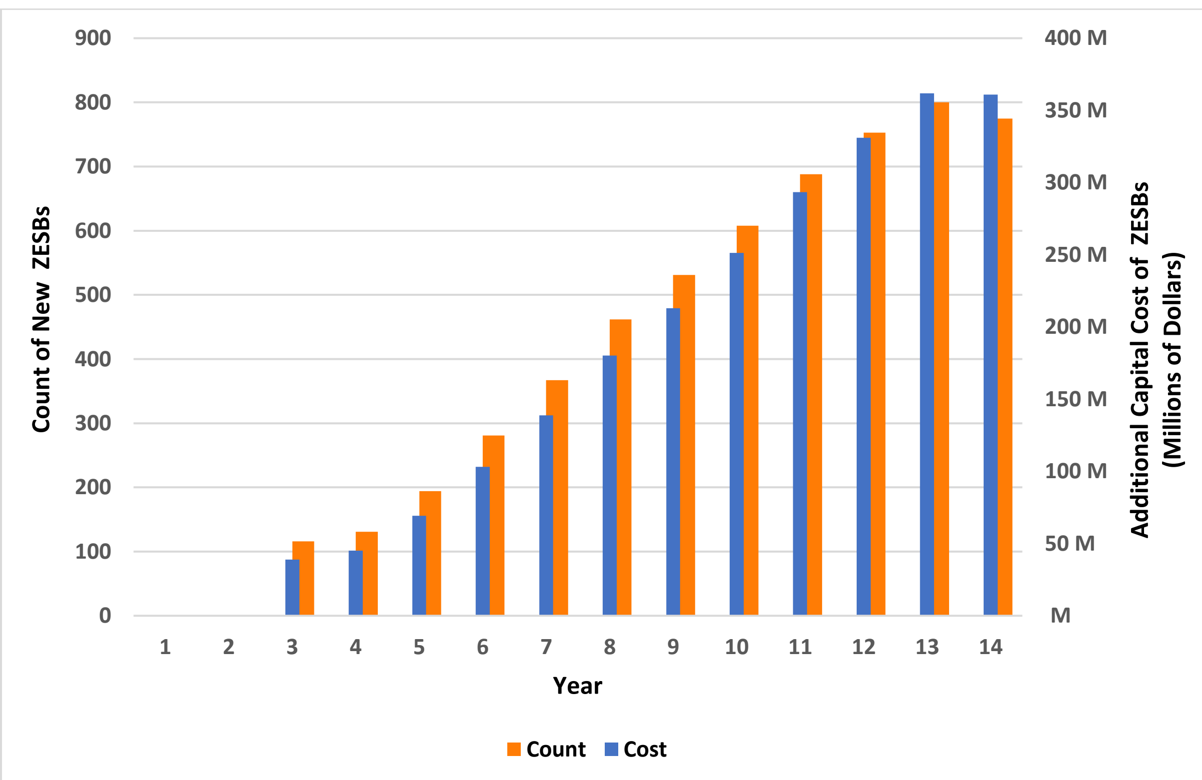
ZEV COMPLIANCE REPLACEMENT SCENARIO COSTS

The ZEV Compliance scenario represents the additional capital costs of ZESB adoption within a framework where all school bus OEMs comply with the ACT rule sales percentage requirements. This framework aligns with minimum adherence to the ACT rule, already adopted by the Massachusetts Department of Environmental Protection (MassDEP) beginning with MY 2025 Class 2b-8 vehicles, and models ZESB adoption through 2036 at the same rate as the ACT sales fractions apply, as visually represented in **Figure 7** in **Section 4.1**.

As described in the charging feasibility analysis in **Section 4.2**, not all ZESBs in Massachusetts could feasibly charge using solely L2 chargers. The ZEV Compliance scenario assumes 27 percent of the fossil fuel-powered school buses replaced with ZESBs will have both a L2 EV charger for overnight charging and a DCFC for midday charging.

In the ZEV Compliance scenario, an estimated 5,706 new ZESBs are purchased through 2036. This would cost an additional $2.4 billion in ZESB and charging infrastructure capital costs compared to the Current Fuel Mix scenario. **Figure 12** below details the annual count of new ZESBs and associated capital costs under this scenario.

Figure 12. ZEV Compliance School Bus Fleet Replacement Scenario: Additional Annual Count of New ZESBs and Capital Costs (Nominal Dollars)

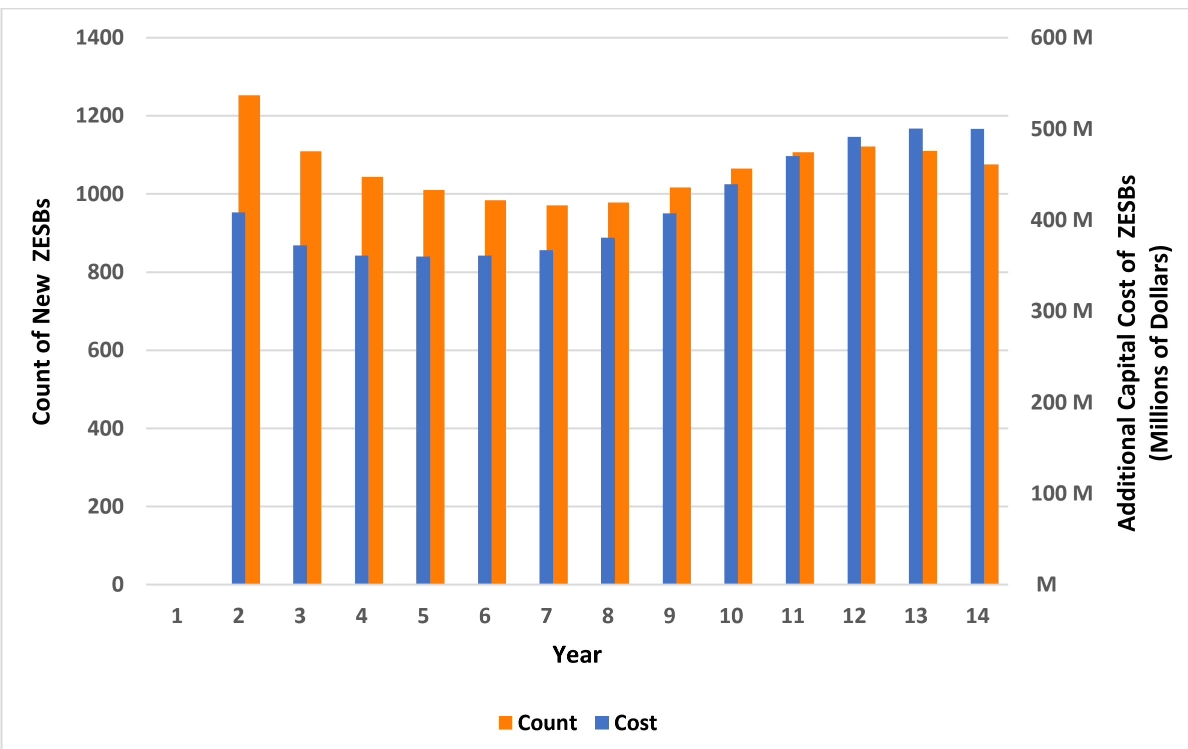


ZESB SWAP REPLACEMENT SCENARIO COSTS

The ZESB Swap replacement scenario illustrates the additional capital costs of a ZESB transition where 100 percent of new school buses replaced annually are ZESBs. Like the ZEV Compliance scenario, the ZESB Swap scenario assumes 27 percent of the fossil fuel-powered school buses replaced with ZESBs will have both a L2 EV charger for overnight charging and a DCFC for midday charging.

In the ZESB Swap scenario, an estimated 13,846 new ZESBs are purchased through 2036. This would cost an additional $5.4 billion in ZESB and charging infrastructure capital costs compared to the Current Fuel Mix scenario. **Figure 13** below details the annual count of new ZESBs and associated capital costs under this scenario.

Figure 13. ZESB Swap School Bus Fleet Replacement Scenario: Additional Annual Count of New ZESBs and Capital Costs (Nominal Dollars)



ZESB COST IMPACTS BY SCHOOL BUS FLEET OWNERSHIP MODEL

As discussed in **Section 2.0**, school buses in Massachusetts are either owned by a school district, leased by a school district or private operator, or owned by a private operator. Private entities own more than 70 percent of school buses in the Commonwealth, and of the 8 percent of school buses that are leased, more than 70 percent are leased to private entities.

School bus ownership models have different implications for how school districts incur the costs of providing ZESB transportation services. It is important to note that in cases when school districts enter into lease agreements or contract their operations to private companies, they typically structure their agreements on a per-bus, per-day cost. Each ownership model changes how school districts experience the costs to transition their school transportation services to zero-emission as follows:

- ***Municipally Owned:*** School district bears all ZESB capital costs upfront and the ongoing operational and maintenance expenses, including higher insurance costs and potentially high demand charges. The district might also receive the full benefits of potential lower fuel and maintenance costs compared to their diesel counterparts.
- ***Leased:*** School district defrays a significant portion of ZESB capital bus and charging infrastructure costs and incurs higher per bus per day costs compared to their diesel counterparts, depending on the terms of the lease agreement. The school district might also be responsible for ZESB maintenance and operational expenses depending on the lease terms.
- ***Privately Owned:*** School district eliminates all upfront ZESB capital costs but pays higher per bus per day costs compared to their diesel counterparts as the private contractors amortize their capital expenses into the annual fees the school districts pay for transportation services.

4.4 Estimated School Bus Air Quality Impacts

Emissions and health impacts from school buses of all the fuel types in the Commonwealth's fleet fuel mix (diesel, gasoline, propane, and electric) were estimated for the three fleet replacement scenarios for the analysis period of

2023-2036. Tailpipe--as well as brakewear and tirewear--emissions were estimated for each fuel type by multiplying annual VMT per regulatory class and age by the appropriate emissions rate. This analysis excludes upstream emissions from electricity generation and fossil fuel manufacturing.

For the three fleet replacement scenarios, the school bus emission effects of the following pollutants were estimated:

- Greenhouse gases (GHGs), represented as carbon dioxide equivalents or CO_2e. [60]
- Four Clean Air Act criteria pollutants and precursors: nitrogen oxides (NOx), volatile organic compounds (VOCs), fine particulate matter (less than 2.5 microns, expressed as PM2.5), and coarse particulate matter (less than 10 microns, expressed as PM10).

Emissions rates for diesel and gasoline were estimated in the Environmental Protection Agency's (EPA) Motor Vehicle Emissions Simulator (MOVES).[61] Propane emissions rates were converted to diesel emissions rates using Argonne National Laboratory's Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool. The emissions rates used in the analysis were specific to regulatory class, fuel type, and vehicle age.

ZESB emission rates include those from diesel heaters, brakewear, and tirewear and were estimated separately in MOVES. The MOVES emissions rates for Auxiliary Power Units (APUs) were determined to be the most appropriate for representing diesel heaters because they are based on scientific literature studying APUs in use on actual vehicles. Alternatives examined included using European studies and using the certification rates from the EPA's non-road compression ignition engine emissions standards as described in 40 CFR 60 Subpart IIII and 40 CFR I(U)(1039). Using MOVES APU rates is a more realistic approach because MOVES uses instrumented real-world data rather than a regulatory standard and involves fewer

[60] Since greenhouse gases include several compounds, this analysis used carbon dioxide equivalents (CO_2e), a composite unit that includes CO_2 as well as other greenhouse gases. CO_2e normalizes each other pollutant in terms of the warming potential of an equivalent amount of CO_2. Other GHGs included in CO_2e include nitrous oxide (N_2O) and methane (CH_4).

[61] MOVES3.1 was the latest version at the time of this analysis.

assumptions to use. Following EPA and FHWA, we assume no change in emissions rates from these diesel heaters on ZESBs over time.[62]

Additionally, ZESBs were assumed to emit pollutants from brakewear and tirewear at the same rates as conventional school buses.[63]

4.4.1 Total Medium and Heavy Duty vs. School Bus Emissions

The emissions and health impact results in **Sections 4.4.2** and **4.4.3** below only represent a comparative assessment exclusively among the school bus fleet replacement scenarios. The results do *not* represent net emissions or health impacts from an incentive program.

This is because the ACT rule mandates increasing sales percentage requirements for all Class 2b-8 vehicles sold in Massachusetts starting from MY 2025. With the ACT rule in place, an incentive program for ZESBs may not produce additional sales of medium and heavy duty ZEVs. Due to the high penalty cost of ACT non-compliance and the high cost of medium and heavy duty ZEVs, OEMs are expected to supply ZEVs up to the ACT rule sales percentages, but not beyond. Thus, a ZESB incentive is likely to redistribute ZEV sales within the regulated vehicle categories towards ZESBs over other ZEVs, resulting in more ZESB sales but fewer other regulated medium and heavy duty ZEV sales in Massachusetts.

This study only provides a comparison of emissions and health impacts from school buses, under various levels of school bus electrification. This study does not explicitly model the ultimate emissions outcomes across all medium and heavy duty vehicles that would result from the effects of the interaction between the ACT rule and a statewide school bus incentive program.

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[62] "Part 1039—Control Of Emissions From New And In-Use Nonroad Compression-Ignition Engines," Code of Federal Regulations, June 29, 2004, https://www.ecfr.gov/current/title-40/chapter-I/subchapter-U/part-1039#1039.101. See the row referencing emissions rates for engine outputs between 19-56 kW in Table 2 of Section 1039.101: Tier 4 Family Emission Limit Caps After the 2014 Model Year.

[63] Victor Timmers and Peter Achten, "Non-Exhaust PM Emissions from Battery Electric Vehicles," Atmospheric Environment 134 (June 2016): 10–17, https://doi.org/10.1016/j.atmosenv.2016.03.017.

4.4.2 Emissions Analysis Results

The emissions analysis results, detailed in **Table 16** in metric tons (MT), illustrate that school bus emissions would generally decline in all scenarios for almost all pollutants, but increasingly so in the ZEV Compliance and ZESB Swap scenarios. Ozone precursors NOx and VOCs, as well as PM10, would also decline in each scenario, despite the use of diesel heaters on ZESBs, as conventional internal combustion school buses operated fewer miles each year.

Table 16. Absolute Change in Scenario School Bus Emissions by Pollutant, 2023-2036 (MT)

Note that not all values will sum due to rounding.

SCENARIO	YEAR	GHGs (CO_2E)	NITROGEN OXIDES (NOx)	VOLATILE ORGANIC COMPOUNDS (VOC)	FINE PARTICULATE MATTER (PM2.5)	COARSE PARTICULATE MATTER (PM10)
Current Fuel Mix	2023	70,190	75	6.0	1.60	0.31
	2036	59,840	71	5.5	1.64	0.29
	Change	-10,350	-4	-0.5	0.04	-0.02
ZEV Compliance	2023	70,190	75	6.0	1.60	0.31
	2036	16,580	19	1.6	1.15	0.18
	Change	-53,610	-56	-4.4	-0.45	-0.13
ZESB Swap	2023	70,190	75	6.0	1.60	0.31
	2036	430	1	0.1	0.79	0.10
	Change	-69,760	-74	-5.9	-0.81	-0.21

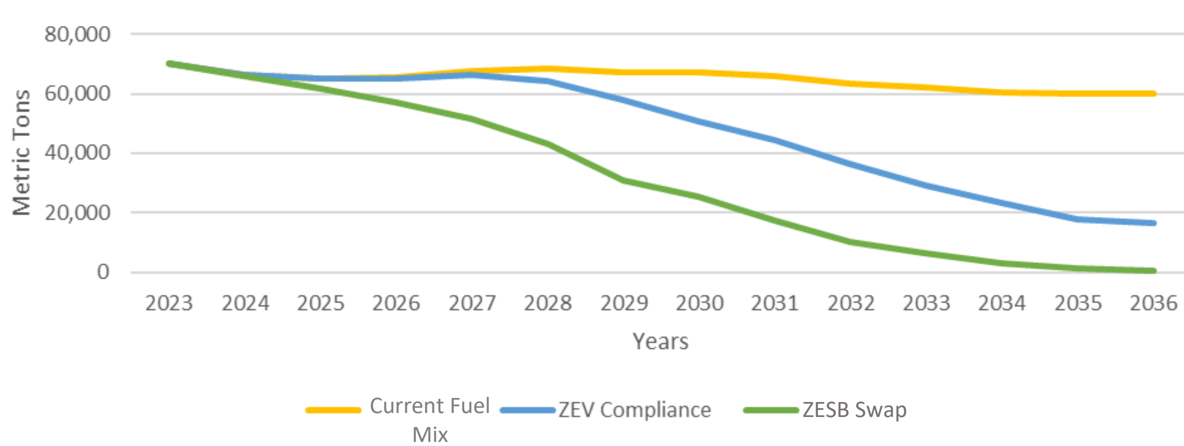
Figure 14 through **Figure 18** below show the trends in school bus pollutant emissions within the analysis horizon, which all follow the same basic trajectory. There is a small increase in school bus emissions from 2023-2028 largely because the 2022 spike in new bus purchases leads to a large cohort of fossil fuel-powered school buses that persist in the fleet and become less efficient as they age. This effect is most obvious for NOx, as most of the Massachusetts school bus fleet uses diesel fuel. This age spike results in a lower school bus replacement rate until the 2022 model year buses begin to retire more rapidly beginning in 2028. From 2028 onwards, the decline in school bus emissions for the ZEV Compliance and ZESB Swap scenarios accelerates rapidly as increasing proportions of replacement school buses entering the fleet are ZESBs. By contrast, the Current Fuel Mix scenario school

bus emissions decline only slightly, as the only improvement mechanism is older buses exiting the fleet.

School bus GHG emissions decline in all scenarios, as shown in **Figure 14**. Under the Current Fuel Mix scenario, GHG emissions from school buses decline by nearly 15 percent by 2036. The model accounts for expected improvements to vehicle fuel efficiency technology but does not anticipate major improvements to fuel economy. The reduction in school bus GHG emissions is therefore likely a result of the school bus fleet's age distribution, which rapidly becomes younger beginning in 2028. Newer vehicles are inherently more fuel efficient due to reduced wear and tear. Additionally, the retirement of older vehicles also leads to a decrease in the number of vehicles equipped with older, less fuel-efficient engines, further contributing to emissions reductions.

Significant school bus GHG emissions reductions are observed in the ZEV Compliance and ZESB Swap scenarios. In the ZEV Compliance scenario, school bus GHG emissions decrease by approximately 76 percent in 2036 compared to 2023. In the ZESB Swap scenario, almost all school bus GHG emissions are eliminated, for a total reduction of 99.4 percent by 2036. Notably, the ZESB Swap scenario exhibits less sensitivity to the spike of MY 2022 buses because every new bus following that spike would be a ZESB. In contrast, the ZEV Compliance scenario follows the ACT rule sales fractions, and thus takes longer to adopt ZESBs into the fleet.

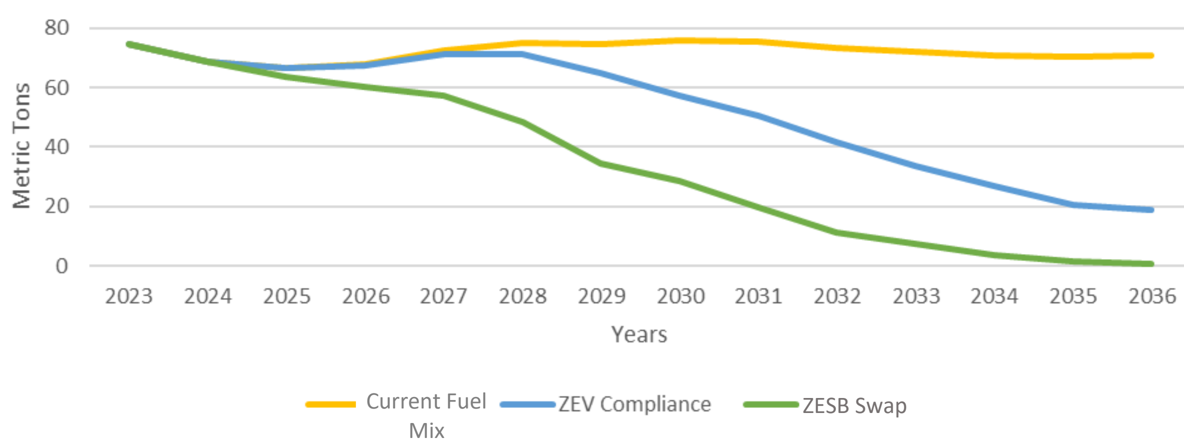
Figure 14. School Bus GHG Emissions (MT) by Fleet Replacement Scenario, 2023-2036



NOx emissions from school buses also decline across all scenarios, as illustrated in **Figure 15**. In the Current Fuel Mix scenario, school bus NOx emissions decrease by approximately 5 percent over the fourteen-year horizon. This relatively small reduction for NOx is likely due to the fleet remaining primarily diesel-powered and replacement buses using the same technology as retiring buses, as many NOx control technologies have been standard for some time.[64]

School bus NOx emissions decline in the ZEV Compliance scenario by approximately 75 percent and in the ZESB Swap scenario by 98.7 percent by 2036. This decline is primarily associated with a decline in on-road internal combustion engine activity as more ZESBs are adopted. ZESBs with diesel heaters would still emit some NOx, but the overall reduction in on-road engine fuel consumption resulting from ZESB conversion outweighs this effect.

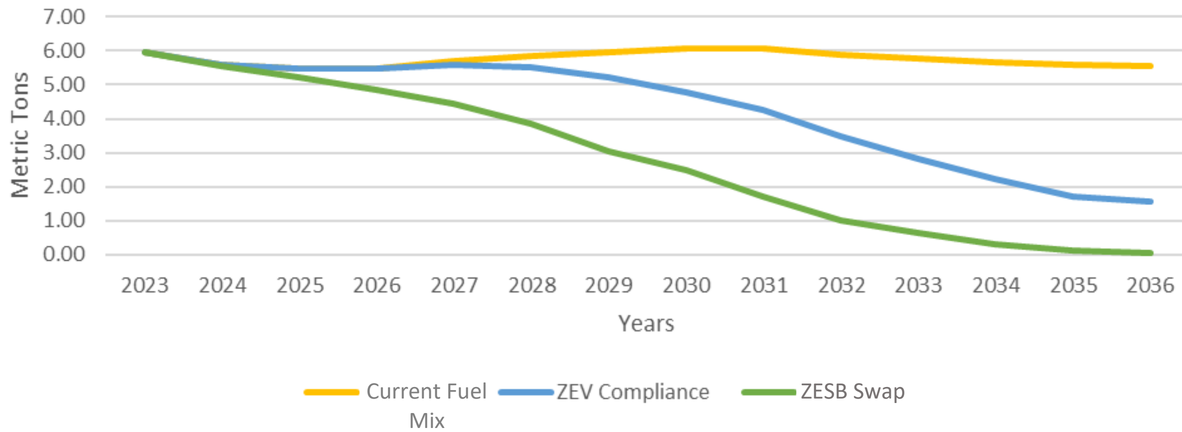
Figure 15. School Bus NOx Emissions (MT) by Fleet Replacement Scenario, 2023-2036



School bus VOC emissions decline in all scenarios, as shown in **Figure 16**. Following a similar pattern as the other pollutants, Current Fuel Mix school bus VOC emissions decrease slightly (about 7 percent by 2036) as the fleet's age distribution shifts. ZEV Compliance school bus emissions decrease by 73 percent, and ZESB Swap emissions decrease by 98 percent by 2036.

[64] Note that this analysis was conducted with MOVES3.1, which was published prior to the finalization of the EPA's final heavy duty NOx rule. See: "Control of Air Pollution from New Motor Vehicles: Heavy Duty Engine and Vehicle Standards," EPA, December 20, 2022, https://www.epa.gov/system/files/documents/2023-01/new-motor-veh-air-poll-control-hd-eng-veh-stnd-frm-2022-12-20.pdf.

Figure 16. School Bus VOC Emissions (MT) by Fleet Replacement Scenario, 2023-2036



Diesel engines are known to produce higher levels of particulate matter emissions compared to other fuel types. On-road diesel-powered vehicles such as school buses must by law be fitted with catalytic converters and particulate filters to mitigate these pollutants. However, diesel heater exhaust systems on ZESBs are not subject to the same regulations as on-road diesel engines, and therefore emit considerably higher pollution per gallon of fuel burned.

In the Current Fuel Mix scenario, PM2.5 and PM10 emissions from school buses (**Figure 17** and **Figure 18**) hardly change over the fourteen-year analysis horizon, as emissions control technology for these pollutants does not change and diesel heater proliferation does not change.

In the ZEV Compliance scenario, school bus PM2.5 and PM10 emissions both decline by 28 percent and 42 percent, respectively by 2036. In the ZESB Swap scenario, school bus PM2.5 and PM10 emissions reduce substantially by 50 percent and 67 percent, respectively by 2036. Emission reductions for both pollutants result from the elimination of running, idling, and starting exhaust emissions associated with conventional vehicle operations. These emissions savings outweigh any potential increase in emissions from the use of diesel heaters on ZESBs during winter months.

Figure 17. School Bus PM2.5 Emissions (MT) by Fleet Replacement Scenario, 2023-2036

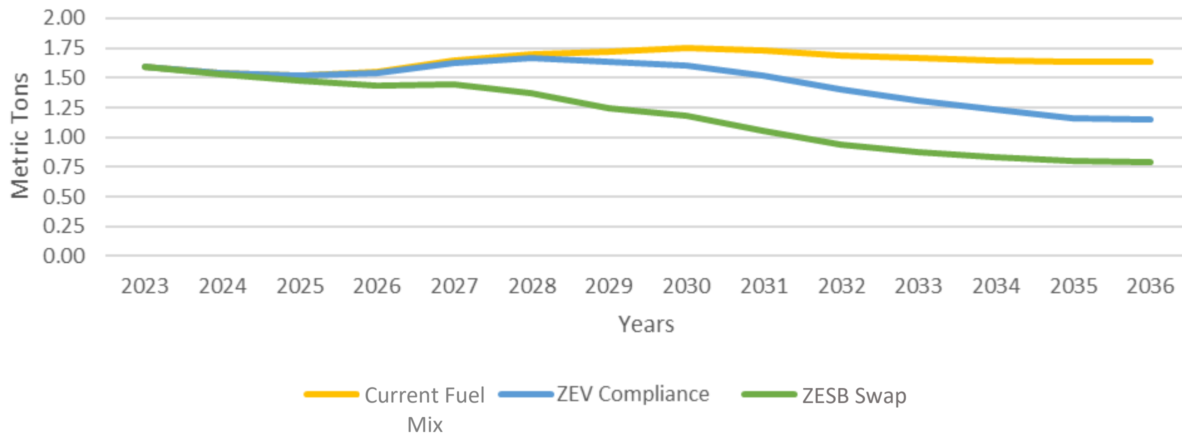
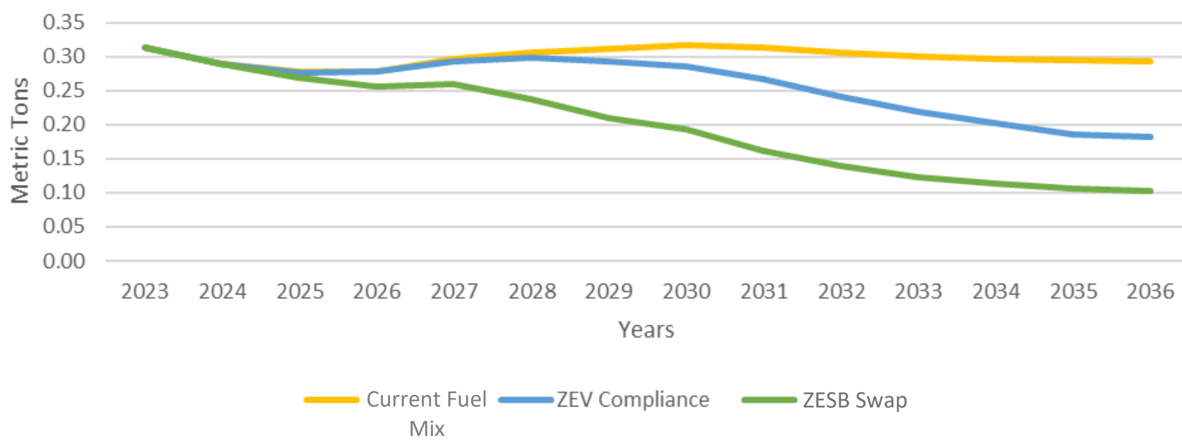


Figure 18. School Bus PM10 Emissions (MT) by Fleet Replacement Scenario, 2023-2036



To underscore the point made in the **Section 4.4.1**, these school bus emissions results are only representative of emissions from school buses under various scenarios for school bus electrification. They do not represent the impacts of a potential ZESB incentive program in the presence of the ACT rule.

4.4.3 Health Impact Analysis Results

The potential health impacts from school bus emissions on human health were estimated across the three fleet replacement scenarios using the US EPA's CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA). COBRA uses a series of health impact functions developed from the latest public health literature to estimate how a change in outdoor air quality results in incidences of a variety of health outcomes.

COBRA's health impact estimates are relative to a COBRA baseline, which is the estimated total mass quantity of an emitted pollutant (i.e., NOx) in a given year for all on-road vehicles.[65] COBRA provides upper- and lower-bound estimates of changes in incidence of specific health outcomes, and provides the median values for a selection of six health impact indicators, which are included in **Table 17**.

The COBRA results presented in **Table 17** illustrate the cumulative change in health impacts resulting from the change in school bus emissions in the ZESB Swap scenario from 2023-2036.[66] The COBRA results for the other two fleet replacement scenarios exhibit fewer changes in health outcome incidences than the ZESB Swap scenario, and are not included in the table. It should be noted that the COBRA results do not consider the incidence of school bus emissions on more vulnerable school-age people.

Most of the health outcome values have a cumulative impact of less than one over the fourteen-year analysis horizon. School buses represent a small portion of the total on-road transportation emissions inventory for the Commonwealth of Massachusetts, thus the health impacts due to a change in school bus emissions is limited.

[65] "COBRA Questions and Answers," EPA, June 7, 2023, https://www.epa.gov/cobra/cobra-questions-and-answers. The COBRA baseline utilizes data from the National Emissions Inventory (developed by the US EPA). State agencies, including the MassDEP, regularly prepare emissions inventories and submit them to be included in this national inventory.
[66] Normally, negative COBRA results indicate an increase in incidence and positive values indicate a decrease. The signs have been inverted this table for ease of reading.

Table 17. ZESB Swap Replacement Scenario: Cumulative Change in School Bus Public Health Impacts (2023-2036)

HEALTH OUTCOMES	ZESB SWAP
Deaths	-0.012
Non-Fatal Heart Attacks	-0.005
Hospital Admits	-0.004
Respiratory Symptom Incidents	-0.276
Asthma Exacerbation Incidents	-0.2
Lost Days of Work	-1

Again, it should be noted that the school bus health impact results should not be interpreted as indicative of the interactions from a potential ZESB incentive program and the ACT rule given this study did not incorporate the health impacts from all medium and heavy duty vehicles subject to the ACT rule.

4.4.4 Equitable Distribution of Air Quality Benefits from ZESBs

A transition to ZESBs will involve some fossil fuel-powered school buses being replaced with ZESBs before others, and this has implications regarding how and to whom the benefits will be distributed. As mentioned in **Section 1.3**, approximately 60 percent of low-income students take a school bus to school. Given the high capital costs of a transition to ZESBs, it is foreseeable that under-resourced school districts will be among the last to be served by this new technology.

An incentive program will influence the distribution of air quality benefits. Incorporating equity metrics into an incentive program would provide insights into the scale of this air quality impact and could be used to ensure program implementation was not creating an inequitable distribution of benefits or worsening existing inequities.

Options for defining potential beneficiaries, who are currently disadvantaged, under an equity metric include:

- Communities with school districts that rank highly on DESE's equity scale.[67]
- Communities with poor air quality, contingent on the availability of relevant data.
- Communities with high proportions of Environmental Justice (EJ) populations.[68]

Detailed air quality modeling is unlikely to be practical to inform program implementation decisions. However, potential proxies for assigning where environmental benefits are occurring include:

- The routes served by incentivized ZESBs.
- The school districts served by incentivized ZESBs.
- The garaging locations of incentivized ZESBs.

5.0 Recommendations for a Statewide Incentive Program

5.1 Background on Incentive Structures

Incentive programs designed to support the adoption of ZEVs can be structured in various forms. Background information on financial incentive program types can be found below:

- ***Grant*** programs involve interested candidates developing applications and making financial awards to the applicants based on evaluation against a set of criteria. Grant awards can be customized based on the applicant's needs and the awardee typically pays the full upfront capital cost before getting reimbursed by the grant award. Grants sometimes provide some personalized technical assistance to

[67] DESE has an existing equity framework that stratifies school districts into 12 categories based on the percentage of residents that are eligible for state assistance, such as the Supplemental Nutrition Assistance Program or MassHealth. Category 12 represents the districts with the greatest share of residents eligible for state assistance.
[68] See for the Executive Office of Energy and Environmental Affairs (EEA) definition of an EJ population: "Environmental Justice Policy of the Executive Office of Energy and Environmental Affairs," Mass.gov, June 24, 2021, https://www.mass.gov/doc/environmental-justice-policy6242021-update/download.

awardees because the program administrator learns about the applicant's specific fleet and needs in their application.

- ***Voucher*** programs apply a discount immediately at purchase to lower the upfront costs for the purchaser. While an application to receive a voucher may be required, vouchers can also be automatic. Vouchers are typically at a flat rate and not customizable to the purchaser.

- ***Rebate*** programs are similar to vouchers but typically involve a post-purchase reimbursement, thus requiring the purchaser to pay the full upfront capital of the approved purchase. Rebates can also be structured to be provided at the point-of-sale, which would lower the sticker price of the purchase and not involve a reimbursement.

- ***Use-based*** incentive programs pay the user a set amount based on their usage rate, such as a payment per every mile driven on a ZEV. This type of incentive could reduce net operating costs and encourage the use of ZEVs after their purchase.

Desirable attributes for a ZEV incentive program would typically include those in **Table 18** below.

Table 18. Desirable Program Attributes

ATTRIBUTES	DEFINITION
Scalability	Incentive amounts can be adjusted to hit sales or fleet share targets.
Financial Effectiveness	Reduces the need for school bus operators to bear the full upfront capital for ZEVs and associated charging infrastructure.
Ongoing Utilization	Incentivizes the ongoing use of ZEVs not just their purchase.
Administrative Burden	Creates a low or reasonable administrative burden for the state and recipients of incentives.
Demographic Equity	Incentive structure allows flexibility to focus on those who are disadvantaged and/or underserved if desired.
Equity Across Operating Models	Incentive structure allows for all fleets to benefit, regardless of service provision model.
Efficiency	Allows incentive amounts to be adjusted on a case-by-case basis.

Table 19 below presents an evaluation of the incentive structures against the criteria defined above.

Table 19. Evaluation of Incentive Structures

ATTRIBUTES	DISCUSSION
Scalability	Grants, rebates, vouchers, and use-based program incentive amounts can all be adjusted to help meet program targets.
Financial Effectiveness	Grants and rebates generally require the applicant to pay for the full upfront cost and then reimburse the applicant post-purchase. Vouchers, on the other hand, typically apply at the point-of-sale to alleviate the upfront costs required for purchase. Use-based incentives reduce operational costs and do not typically reduce the purchase cost.
Ongoing Utilization	Grants, rebates, and vouchers promote the purchase of ZEVs, but they don't necessarily promote the use of the vehicle. Use-based incentives promote the use of a ZEV by providing payments on a per-use basis.
Administrative Burden	Grant applications are often extensive and require time and resources from the applicant. Use-based incentives also require detailed data collection and documentation in order to provide the basis for payment. Rebates and vouchers, on the other hand, might require applications but are generally the least burdensome for applicants.
Demographic Equity	Each incentive structure allows the program design to prioritize disadvantaged and/or underserved, if desired.
Equity Across Operating Models	Each incentive structure allows for both privately and publicly owned fleets to benefit.
Efficiency	Rebates, vouchers, and use-base amounts are typically flat, while grant amounts are often customizable to meet the individual applicant's needs.

5.2 Existing State and Federal Regulations and Programs Relevant to ZESBs

There are existing regulations relevant to and incentive programs available to potential purchasers of ZESBs in Massachusetts. The presence of these existing programs, outlined below, has important implications for decisions about providing additional statewide incentives.

THE ADVANCED CLEAN TRUCK RULE (ACT RULE)

As previously discussed in **Section 4.0**, the ACT rule is a medium and heavy duty ZEV sales requirement that applies to OEMs that certify vehicles for sale in Massachusetts in weight classes 2B through 8. OEMs can accumulate credits for ZEV sales and will incur deficits for each non-ZEV sold in Massachusetts starting in MY 2025.[69] OEMs are considered compliant when the credits they purchase or generate through ZEV or near-zero-emission

[69] MassDEP, "Background Document on Emergency Regulation Amendments to 310 CMR 7.40."

vehicle (NZEV) sales equal their deficits within a reporting year per regulatory class.

If a manufacturer does not meet the ACT rule sales percentage requirements, they have one model year to make up their deficit or else be subject to a continued penalty until compliant. The penalty is approximately $20,000 per vehicle.[70] Due to the high penalty cost and high cost of medium and heavy duty ZEVs, it is anticipated that OEMs will collectively meet but not exceed the sales percentage requirements.

EPA CLEAN SCHOOL BUS PROGRAM (CSB)

The Infrastructure Investment and Jobs Act (IIJA) of 2021 authorized the EPA to administer the Clean School Bus (CSB) Program, which totals $5 billion in funding available for the replacement of diesel school buses with zero and low emission school buses through Federal Fiscal Years (FFYs) 2022-2026.[71]

The first iteration of the CSB was the 2022 CSB Rebate program, which provided funding for both the full cost of a zero-emission or clean school bus (up to $375,000) and the cost of an L2 charger (up to $20,000).[72] The 2022 CSB Rebate program structure allowed recipients to access funding quickly, via a streamlined application process and website.

In the first round of the 2022 CSB Rebate program, five Massachusetts entities received funding as shown in Error! Reference source not found.. The 2022 CSB Rebate awards in Massachusetts amount to $29,535,000 for 75 ZESBs. Of note, none of these awards included propane or CNG-powered buses, which were an option for funding.[73]

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[70] "Final Regulation Order - Advanced Clean Trucks Regulation," California Air Resources Board, June 2023, https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2021/hdim2021/hdi-mfroatta-1.pdf.
[71] "Clean School Bus Program," EPA, accessed September 1, 2023, https://www.epa.gov/cleanschoolbus.
[72] "2022 Clean School Bus (CSB) Rebates Program Guide," EPA, May 2022, https://nepis.epa.gov/Exe/ZyPDF.cgi/P1014WNH.PDF?Dockey=P1014WNH.PDF. Eligible school buses for the 2022 rebate program operate on a battery electric, CNG, or propane drivetrains.
[73] "Awarded Clean School Bus Program Rebates," EPA, accessed September 1, 2023, https://www.epa.gov/cleanschoolbus/awarded-clean-school-bus-program-rebates.

Table 20. 2022 EPA Clean School Bus Rebate Program Funding - Massachusetts[74]

SCHOOL DISTRICT	APPLICANT	# OF ELECTRIC BUSES	AMOUNT AWARDED
Lower Pioneer Valley Educational Collaborative	Andco, Incorporated	25	$9,875,000
Lawrence	New England Transit Sales, Inc.	25	$9,875,000
New Bedford	Dattco Inc	14	$5,530,000
Fall River	City Of Fall River	10	$3,860,000
Upper Cape Cod Regional Vocational Technical	Upper Cape Cod Regional Vocational Technical School District	1	$395,000

MASSCEC ACT SCHOOL BUS PROGRAM

The Massachusetts Clean Energy Center (MassCEC) operates the Accelerating Clean Transportation (ACT) School Bus program. This program was designed to complement the EPA's CSB program and is deploying $23.3 million in funding for school bus electrification in the Commonwealth. ACT School Bus provides two opportunities for support: advisory services and fleet deployment.[75]

The advisory services program component offers free ZESB electrification planning services. This opportunity does not provide funding to purchase a ZESB, but rather to help public school districts and private school bus fleet operators prepare for future funding opportunities, perform feasibility studies and financial modeling, and develop vehicle and charging station procurement plans.

The first round of the 2022 fleet deployment services program component offered selected school bus fleets up to $2 million in flexible funding for ZESBs and associated infrastructure, as well as consulting services to assist with procurement, data collection, and future electrification planning. **Table 21** below displays the 2022 ACT School Bus Deployment first round funding

[74] "Awarded Clean School Bus Program Rebates," EPA.
[75] "Accelerating Clean Transportation (ACT) School Bus: Overview," Massachusetts Clean Energy Center (MassCEC), accessed January 11, 2023, https://www.masscec.com/accelerating-clean-transportation-act-school-bus-overview.

awardees. Notably, the first round of the ACT deployment funding awardees mirrored the Massachusetts awardees of the EPA CSB program, with the addition of Quincy Public Schools. The advisory services program selection and project launch commenced in Summer 2023. Meanwhile, the application window for Round 2 of the fleet deployment funding closes in January 2024.

Table 21. 2022 ACT School Bus Program Fleet Deployment Awards[76]

SCHOOL DISTRICT	AMOUNT AWARDED
Lower Pioneer Valley Educational Collaborative	$2,000,000
Lawrence	$1,675,000
New Bedford	$1,970,000
Fall River	$2,000,000
Upper Cape Cod Regional Vocational Technical	$1,480,490
Quincy Public Schools	$355,000

DOER MOR-EV TRUCKS PROGRAM

The Massachusetts Offers Rebates for Electric Vehicles (MOR-EV) Trucks Program is a statewide ZEV program funded by DOER and administered by the Center for Sustainable Energy (CSE). The program offers rebates for both purchase and lease of qualifying ZEVs, including eligible ZESBs.

The rebate values, shown in **Table 22**, are designated by vehicle class and follow a declining value as rebate blocks are exhausted. School bus purchasers can apply to the MOR-EV Trucks program to reserve a rebate through a voucher system prior to purchasing or leasing. This reservation system ensures that funding is available for up to 12 months once applicants are approved. After the purchase or lease is finalized, a rebate of up to $90,000 can be claimed.[77] Of note, this program cannot be used in combination with any other Massachusetts provided or managed funding.

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[76] Erika McCarthy, "Baker-Polito Administration Announces Over $100M Commitment to Clean Energy and Transportation," Massachusetts Clean Energy Center (MassCEC), December 23, 2022, https://www.masscec.com/press/baker-polito-administration-announces-over-100m-commitment-clean-energy-and-transportation.

[77] "Trucks: Class 3-8," Massachusetts Offers Rebates for Electric Vehicles (MOR-EV), accessed September 14, 2023, https://mor-ev.org/trucks-3-8.

Table 22. 2023 DOER MOR-EV Values[78]

CLASS	GVWR (LBS.)	TOTAL NUMBER OF REBATES PER BLOCK	REBATE VALUE, BLOCK 1	REBATE VALUE, BLOCK 2	REBATE VALUE, BLOCK 3
3	10,001 – 14,000	200	$15,000	$12,750	$10,838
4	14,001 – 16,000		$30,000	$25,500	$21,675
5	16,001 – 19,500		$45,000	$38,250	$32,513
6	19,501 – 26,000		$60,000	$51,000	$43,350
7	26,001 – 33,000		$75,000	$63,750	$54,188
8	33,001+		$90,000	$90,000	$65,028

MASSEVIP

MassDEP administers the Massachusetts Electric Vehicle Incentive Program (MassEVIP) Workplace & Fleet Charging Incentives, which currently provides funding to cover up to 60 percent of the cost of L1 and L2 EV charging stations. The maximum allowed incentive amount is $50,000 per street address for hardware and installation costs.[79] MassEVIP will not fund installation costs for projects funded through the utility programs described below but will cover equipment costs.[80]

INVESTOR-OWNED UTILITY PROGRAMS

In Massachusetts, certain utilities offer "make-ready" electric charging programs, covering the costs on the utility side of the electric meter. On December 30, 2022, DPU approved EV programs for the following regulated electric companies: National Grid with a budget of $206 million, Eversource with a budget of $188 million, and Unitil with a budget of $998,000.[81] Both

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[78] Ibid.

[79] "Apply for MASSEVIP Workplace & Fleet Charging Incentives," Massachusetts Department of Environmental Protection (MassDEP), accessed August 29, 2023, https://www.mass.gov/how-to/apply-for-massevip-workplace-fleet-charging-incentives.

[80] "Massachusetts Electric Vehicle Incentive Program (MassEVIP) Charging Station Programs," Mass.gov, May 10, 2023, https://www.mass.gov/doc/matrix-of-massevip-grant-programs/download.

[81] Mass.gov, "Electric Vehicle Charging."

National Grid and Eversource have developed their approved programs, while Unitil has yet to do so at the time of writing. The DPU ruling requires that eligible entities apply for other available and eligible state and federal funding opportunities prior to seeking utility program funding. The following utility programs are currently available for school bus fleets:

National Grid

National Grid administers the Fleet EV Charging Program that provides up to 100 percent of utility-side L2 and DCFC costs, up to $6,700 for customer-side costs, and provides charger rebates for public fleet charging stations.[82] Additionally, their Fleet Advisory Service Program offers complementary assistance to public fleets, including electrification planning.[83] The incentive amounts are highest for Environmental Justice (EJ) communities and eligible applicants must be National Grid customers, including municipal, school bus, public transit, and state and federal government fleets.

Eversource

Eversource offers the EV Charging Rebate program for Massachusetts fleets, including school bus fleets, which provides up to 100 percent of utility-side costs to install EV chargers, up to $6,700 for customer-side costs, and charger rebates for L2 and DCFC charging station equipment costs.[84] Incentive amounts are highest for EJ communities. Eligible applicants must be Eversource customers. Eversource has developed a fleet advisory service offering that is currently limited to public fleets.

5.3 Incentive Structure Recommendations

1. OBJECTIVE OF INCENTIVE

If the underlying objective is to increase overall numbers of zero emission heavy duty vehicles or to maximize total GHG and other emissions reduction, an incentive program for ZESBs may not have the intended effect.

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[82] "Fleet Electric Vehicle Charging Program," National Grid, August 2023, https://www.nationalgridus.com/media/pdfs/bus-ways-to-save/ev/ev-infrastructure-brochure-fleet_ada.pdf.
[83] "About the Program," National Grid MA Fleet Advisory Services Program, accessed September 5, 2023, https://fleetadvisoryma.nationalgrid.com/about-program.
[84] "Eversource - Massachusetts Electric Vehicle Charging Rebate," Eversource, May 2023, https://www.eversource.com/content/docs/default-source/save-money-energy/electric-vehicle-make-ready-application.pdf?sfvrsn=85cdcd62_4.

If the ACT rule is effective at driving ZEV sales up to the specified sales percentages, an incentive is likely to shift the balance of ZEV sales within the regulated vehicle classes in favor of school buses and away from other ZEVs, resulting in more ZESB sales but fewer sales of other types of ZEVs in Massachusetts. This is because the extra ZEV credits enabled by a ZESB incentive can be purchased by other OEMs to satisfy their ACT rule sales percentage obligations in lieu of producing additional ZEVS. There is a risk that an incentive would create no additional ZEV sales.

While modeling the net emissions outcomes across all classes of vehicles regulated by the ACT rule falls outside the scope of this report's analysis, adding a new incentive in the presence of the ACT rule carries the theoretical possibility of emissions increases, if selling more ZESBs results in fewer sales of other ZEVs, depending on the relative miles traveled and emissions control technologies between the fossil fuel school buses replaced and the fossil fuel vehicles whose replacement is forgone.[85]

Given the large opportunity cost of a program that financially supports the adoption of ZESBs, the legislature may wish to consider using these resources for other initiatives that would reduce emissions without these policy interactions (i.e., sources not subject to regulated sales requirements).

However, if the priority is to ensure emission reductions and/or ZEV sales occur specifically in school bus fleets and foregone emission reductions from other medium and heavy duty vehicles are not a concern, an incentive program for ZESBs could be used to achieve this. This would result in the benefits of medium and heavy duty vehicle electrification being somewhat more targeted at the people and areas currently impacted by emissions from fossil fuel-powered school buses.

[85] Older diesel-powered vehicles typically emit more pollutants compared to their newer counterparts. For example, MOVES3.1 estimates that a Class 7 MY 1993 diesel vehicle emits nearly nine times more NOx per mile (0.0219 kg/mi) than a Class 7 MY 2023 diesel vehicle (0.00237 kg/mi).

2. EQUITY

If a ZESB incentive is established, the associated program should monitor awards and adjust as needed to ensure that disadvantaged school districts are being awarded at or above the same rate as other school districts.

It is recommended that a ZESB incentive program adopts an equity framework based on school district population metrics. If school buses are being prioritized for electrification to reduce school children's exposure to school bus air pollutants, then using a school district population-based equity framework is in alignment with that program's objective.

3. BUDGET REQUIREMENTS

If an incentive program were to be introduced to support a transition to ZESBs, it would need access to a significant budget over multiple years because the additional costs to transition Massachusetts' school bus fleet are high relative to conventional technologies. For example, if a program was designed to fund the incremental capital cost and every school bus was replaced on its normal replacement cycle by a ZESB starting in 2023, this program would require approximately $5.4 billion, leading to a 99.4 percent fleet transition by approximately 2036.[86]

Moreover, the amount of expenditure in a given timeframe would most likely increase with a more aggressive speed of fleet transition. If the fleet transition goal was targeted for 2030, for example, the program may require a greater annual budget compared to a scenario with a later targeted transition date to motivate school bus owners to accelerate adoption.

4. PROGRAM SCALABILITY

If a new ZESB incentive is developed, the program should have a scalable structure for adjusting incentive amounts to accommodate changes in the school bus vehicle and charging market, such as evolving technology costs, school bus purchase price sensitivities, and changes in federal incentives.

[86] It is a common practice for incentive programs to fund incremental costs, however this does not guarantee a particular level of sales. Notably, the 2022 EPA Clean School Bus Rebate Program provided funding amounts for the school bus and associated charging infrastructure that covered more than the incremental cost.

5. ADMINISTRATIVE SIMPLICITY

If a ZESB incentive was introduced, consideration should be given to delivering all state support for ZESB adopters via a single mechanism, whether it is derived from existing or newly developed interventions. This would streamline the application process for school bus operators, enabling them to access both financial and technical support through a unified administrative structure and coordinate with a single point of contact.

There is already a relatively complex landscape of programs that are targeted at or available to ZESB purchasers in Massachusetts. Adding an additional program would increase the compliance burden for applicants, causing applicants interested in various programs to navigate through multiple sets of eligibility criteria, application processes, and performance requirements. Applicants would also need to understand and make tradeoffs between different funding sources where they were “non-stackable” or require separate approvals before starting a project in cases where they were stackable.

Moreover, introducing a new ZESB incentive program within the current policy environment would further diffuse government interventions supporting ZESB adoption and increase the challenge of determining which programs are effective and how to improve individual programs.

6. AGE-BASED INCENTIVE

If a ZESB incentive is created, to minimize unintended consequences associated with interactions with the ACT rule, it is recommended to include a scrappage requirement targeting the oldest and most polluting school buses as a condition for a ZESB incentive program.

7. PRIVATE AND PUBLIC ELIGIBILITY

If a ZESB incentive is developed, it is recommended that the program be accessible to both public and private entities who undertake the activity that confers eligibility for receiving an incentive (i.e., purchasing a school bus to provide transportation service in Massachusetts).

Works Cited

"2022 Clean School Bus (CSB) Rebates Program Guide." United States Environmental Protection Agency (EPA), May 2022. https://nepis.epa.gov/Exe/ZyPDF.cgi/P1014WNH.PDF?Dockey=P1014WNH.PDF.

"2023 Clean School Bus (CSB) Grant Program." United States Environmental Protection Agency (EPA), April 2023. https://www.epa.gov/system/files/documents/2023-04/2023-csb-grant-nofo-4-20-23.pdf.

"About the Program." National Grid MA Fleet Advisory Services Program. Accessed September 5, 2023. https://fleetadvisoryma.nationalgrid.com/about-program.

"Accelerating Clean Transportation (ACT) School Bus: Overview." Massachusetts Clean Energy Center (MassCEC). Accessed September 1, 2023. https://www.masscec.com/accelerating-clean-transportation-act-school-bus-overview.

"Apply for a School Bus Learner's Permit." Mass.gov. Accessed September 19, 2023. https://www.mass.gov/how-to/apply-for-a-school-bus-learners-permit.

"Apply for MASSEVIP Workplace & Fleet Charging Incentives." Massachusetts Department of Environmental Protection (MassDEP). Accessed August 29, 2023. https://www.mass.gov/how-to/apply-for-massevip-workplace-fleet-charging-incentives.

Arora, Mitul, Dan Welch, and Fred Silver. "Electric School Bus Market Study." CALSTART, November 2021. https://calstart.org/wp-content/uploads/2021/12/Electric-School-Bus-Market-Report-2021.pdf.

"Awarded Clean School Bus Program Rebates." United States Environmental Protection Agency (EPA). Accessed September 1, 2023. https://www.epa.gov/cleanschoolbus/awarded-clean-school-bus-program-rebates.

"Background Document on Emergency Regulation Amendments to 310 CMR 7.40." Massachusetts Department of Environmental Protection (MassDEP), December 30, 2021. https://www.mass.gov/doc/310-cmr-740-background-document/download.

Blue, James. "Subtle Shifts in School Transportation Industry's Fuel Mix." School Bus Fleet, May 23, 2018. https://www.schoolbusfleet.com/10009615/subtle-shifts-in-school-transportation-industrys-fuel-mix.

"Chapter 179 - An Act Driving Clean Energy and Offshore Wind." Massachusetts Legislature, August 11, 2022. https://malegislature.gov/Laws/SessionLaws/Acts/2022/Chapter179.

"Chapter 70 Program." Massachusetts Department of Elementary and Secondary Education (DESE). Accessed September 7, 2023. https://www.doe.mass.edu/finance/chapter70/.

"Circuit Breaker Transportation FAQ." Massachusetts Department of Elementary and Secondary Education (DESE), July 9, 2020. https://www.doe.mass.edu/finance/circuitbreaker/transportation-faq.html?section=eligibility.

"Clean School Bus Program." United States Environmental Protection Agency (EPA). Accessed September 1, 2023. https://www.epa.gov/cleanschoolbus.

"COBRA Questions and Answers." United States Environmental Protection Agency (EPA), June 7, 2023. https://www.epa.gov/cobra/cobra-questions-and-answers.

"Commercial Electric Rates (MA)." Unitil, August 1, 2023. https://unitil.com/electric-gas-service/pricing-rates/rates.

"Competitive Supply Glossary." Mass.gov. Accessed September 19, 2023. https://www.mass.gov/info-details/competitive-supply-glossary.

"Control of Air Pollution from New Motor Vehicles: Heavy Duty Engine and Vehicle Standards." United States Environmental Protection Agency, December 20, 2022. https://www.epa.gov/system/files/documents/2023-01/new-motor-veh-air-poll-control-hd-eng-veh-stnd-frm-2022-12-20.pdf.

"Demand Charge Alternative Program for Massachusetts." National Grid, August 2023. https://www.nationalgridus.com/media/pdfs/bus-ways-to-save/ev/cm9464-demand-charge_one-pager.pdf.

Duran, Adam, and Kevin Walkowicz. "A Statistical Characterization of School Bus Drive Cycles Collected via Onboard Logging Systems." *SAE International Journal of Commercial Vehicles* 6, no. 2 (2013): 400–406. https://doi.org/10.4271/2013-01-2400.

"Electric School Buses." Lightning eMotors. Accessed December 19, 2023. https://lightningemotors.com/electric-school-buses/.

"Electric Vehicle Charging." Mass.gov, June 6, 2023. https://www.mass.gov/info-details/electric-vehicle-charging.

"Ensuring Educational Stability for Students in Foster Care - Guidance." Massachusetts Department of Elementary and Secondary Education (DESE), January 18, 2018. https://www.doe.mass.edu/news/news.aspx?id=24765.

"Environmental Justice Policy of the Executive Office of Energy and Environmental Affairs." Mass.gov, June 24, 2021. https://www.mass.gov/doc/environmental-justice-policy6242021-update/download.

"EPA Clean School Bus Program - Second Report to Congress Fiscal Year 2022." United States Environmental Protection Agency (EPA), February 2023. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1016LN0.pdf.

"Eversource - Massachusetts Electric Vehicle Charging Rebate." Eversource, May 2023. https://www.eversource.com/content/docs/default-source/save-money-energy/electric-vehicle-make-ready-application.pdf?sfvrsn=85cdcd62_4.

"Final Regulation Order - Advanced Clean Trucks Regulation." California Air Resources Board, June 2023. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2021/hdim2021/hdi-mfroatta-1.pdf.

"Fleet Electric Vehicle Charging Program." National Grid, August 2023. https://www.nationalgridus.com/media/pdfs/bus-ways-to-save/ev/ev-infrastructure-brochure-fleet_ada.pdf.

"Flipping the Switch on Electric School Buses: Cost Factors: Module 1 (Text Version)." Alternative Fuels Data Center. Accessed September 7, 2023. https://afdc.energy.gov/vehicles/electric_school_buses_p8_m1.html.

"Flipping the Switch on Electric School Buses: Cost Factors: Module 3 (Text Version)." Alternative Fuels Data Center (AFDC). Accessed September 7, 2023. https://afdc.energy.gov/vehicles/electric_school_buses_p8_m3.html.

"Fulfilling the Promise of Local Aid by Strengthening State-Local Partnerships." Mass.gov, October 13, 2022. https://www.mass.gov/report/fulfilling-the-promise-of-local-aid-by-strengthening-state-local-partnerships.

"General Law - Part I, Title III, Chapter 30B, Section 5." Massachusetts Legislature. Accessed September 7, 2023. https://malegislature.gov/Laws/GeneralLaws/PartI/TitleIII/Chapter30B/Section5.

"General Law - Part I, Title XIV, Chapter 90, Section 7A." Massachusetts Legislature. Accessed September 7, 2023. https://malegislature.gov/Laws/GeneralLaws/PartI/TitleXIV/Chapter90/Section7A.

"How Regenerative Brakes Work." Energy.gov. Accessed November 11, 2023. https://www.energy.gov/energysaver/how-regenerative-brakes-work.

Huntington, Alissa, Jessica Wang, Emmett Werthmann, and Eleanor Jackson. "Electric School Bus U.S. Market Study." WRI, August 2023. https://files.wri.org/d8/s3fs-public/2023-07/esb-us-market-study-2023.pdf.

Jbaily, Abdulrahman, Xiaodan Zhou, Jie Liu, Ting-Hwan Lee, Leila Kamareddine, Stéphane Verguet, and Francesca Dominici. "Air Pollution Exposure Disparities Across US Population and Income Groups." *Nature* 601, no. 7892 (January 12, 2022): 228–33. https://doi.org/10.1038/s41586-021-04190-y.

Kay, Michael, Michael Clark, Catherine Duffy, Scott F Lian, and Melissa Laube. "Bus Lifecycle Cost Model for Federal Land Management Agencies." United States Department of Transportation, September 30, 2011. https://rosap.ntl.bts.gov/view/dot/9548.

Lazer, Leah, and Lydia Freehafer. "A Dataset of Electric School Bus Adoption in the United States," Dataset – Version 6. WRI, June 2023. https://wri-dataportal-prod.s3.amazonaws.com/manual/electric_school_bus_adoption_dataset_v6_2023-08Aug.zip.

Lazer, Leah. "Electric School Bus Data Dashboard: Electric School Bus Initiative." WRI, September 1, 2023. https://electricschoolbusinitiative.org/electric-school-bus-data-dashboard.

Lee, Bryan, and Rachel Chard. "The Electrification of School Buses Assessing Technology, Market, and Manufacturing Readiness." CALSTART, April 2023. https://calstart.org/wp-content/uploads/2023/04/WRI-ESB-TRL-MRL-Manufacturing-Report_Formatted-APRIL-2023.pdf.

Levinson, Michelle, Phillip Burgoyne-Allen, Alissa Huntington, and Norma Hutchinson. "Recommended Total Cost of Ownership Parameters for Electric School Buses: Summary of Methods and Data." World Resources Institute, January 30, 2023. https://www.wri.org/research/recommended-total-cost-ownership-parameters-electric-school-buses-methods-data.

"The Longer Route to School." Bureau of Transportation Statistics, January 12, 2021. https://www.bts.gov/topics/passenger-travel/back-school-2019.

"Massachusetts Electric Vehicle Incentive Program (MassEVIP) Charging Station Programs." Mass.gov, May 10, 2023. https://www.mass.gov/doc/matrix-of-massevip-grant-programs/download.

"Massachusetts School and District Profiles." Massachusetts Department of Elementary and Secondary Education (DESE). Accessed August 21, 2023. https://profiles.doe.mass.edu/general/generalstate.aspx.

"MassDEP Files New Regulations to Reduce Emissions, Advance Market for Clean Trucks in the Commonwealth." Massachusetts Department of Environmental Protection (MassDEP), December 30, 2021. https://www.mass.gov/news/massdep-files-new-regulations-to-reduce-emissions-advance-market-for-clean-trucks-in-the-commonwealth.

McCarthy, Erika. "Baker-Polito Administration Announces Over $100M Commitment to Clean Energy and Transportation." Massachusetts Clean Energy Center (MassCEC), December 23, 2022. https://www.masscec.com/press/baker-polito-administration-announces-over-100m-commitment-clean-energy-and-transportation.

"McKinney-Vento Homeless Education Assistance Act." Massachusetts Department of Elementary and Secondary Education (DESE), August 23, 2023. https://www.doe.mass.edu/sfs/mv/default.html.

Miller, Yaron, and Brian Watts. "States and School Districts Clear the Air with Electric School Buses." The Pew Charitable Trusts, September 19, 2023. https://www.pewtrusts.org/en/research-and-analysis/articles/2023/09/19/states-and-school-districts-clear-the-air-with-electric-school-buses.

Moura, Maria Cecilia Pinto de, Cecilia Pinto, and Daniel Gatti. "Inequitable Exposure to Air Pollution from Vehicles in Massachusetts: Who Bears the

Burden?" Union of Concerned Scientists, 2019. http://www.jstor.org/stable/resrep24098.

"Part 1039—Control of Emissions From New And In-Use Nonroad Compression-Ignition Engines." Code of Federal Regulations, June 29, 2004. https://www.ecfr.gov/current/title-40/chapter-I/subchapter-U/part-1039#1039.101.

"Pupil Transportation Guide: A Guide for Massachusetts School Administrators." Massachusetts Department of Elementary and Secondary Education (DESE), August 1, 1996. https://www.doe.mass.edu/finance/transportation/guide.html.

"School Bus Safety Fact Sheet." Mass.gov. Accessed August 21, 2023. https://www.mass.gov/info-details/school-bus-safety-fact-sheet.

Shapiro, Jeffrey S. "The Chapter 30B Manual; Procuring Supplies, Services, and Real Property." Mass.gov, May 2023. https://www.mass.gov/doc/the-chapter-30b-manual-procuring-supplies-services-and-real-property-legal-requirements-recommended-practices-and-sources-of-assistance-9th-edition/download.

Steward, Darlene. "Critical Elements of Vehicle-to-Grid (V2G) Economics." National Renewable Energy Laboratory (NREL), September 2017. https://www.nrel.gov/docs/fy17osti/69017.pdf.

Tessum, Christopher W., Joshua S. Apte, Andrew L. Goodkind, Nicholas Z. Muller, Kimberley A. Mullins, David A. Paolella, Stephen Polasky, et al. "Inequity in Consumption of Goods and Services Adds to Racial–Ethnic Disparities in Air Pollution Exposure." *Proceedings of the National Academy of Sciences* 116, no. 13 (March 26, 2019): 6001–6. https://doi.org/10.1073/pnas.1818859116.

Timmers, Victor, and Peter Achten. "Non-Exhaust PM Emissions from Battery Electric Vehicles." *Atmospheric Environment* 134 (June 2016): 10–17. https://doi.org/10.1016/j.atmosenv.2016.03.017.

"Trucks: Class 3-8." Massachusetts Offers Rebates for Electric Vehicles (MOR-EV). Accessed September 14, 2023. https://mor-ev.org/trucks-3-8.

"Understanding Your Electric Bill: Saving Money on Demand Charges and Power Factor." Mass.gov, April 1, 2019. https://www.mass.gov/doc/understanding-your-electric-bill-saving-money-on-demand-charges-and-power-factor-0/download.

Wang, Jessica. "Electric School Bus U.S. Buyer's Guide." World Resources Institute (WRI), March 2023. https://electricschoolbusinitiative.org/buyers-guide.

Yang, Zifei, Peter Slowik, Nic Lutsey, and Stephanie Searle. "Principles for Effective Electric Vehicle Incentive Design." International Council on Clean Transportation (ICCT), June 2016. http://theicct.org/sites/default/files/publications/ICCT_IZEV-incentives-comp_201606.pdf.