Massachusetts Fleet Electrification Opportunities Study

Report for *An Act Promoting Zero Emission Vehicle Adoption* (Acts of 2016, Chapter 448)

December 22, 2017

Submitted to:
Massachusetts Department of Energy Resources

Table of Contents

Executive Summary

Massachusetts has set ambitious clean energy and emissions reduction goals and is developing policies that have made the Commonwealth a national leader in these efforts. These initiatives have led directly to the growth of a robust clean energy economy, overall economic growth, and emissions reductions. Transportation makes up a significant portion of the Commonwealth's emissions and as a result, Massachusetts has several policies in place to promote zero emission vehicle (ZEV) adoption, including the goal of 300,000 ZEVs registered in the state by 2025. Electrification of the state fleet provides an opportunity to continue leading by example in reducing the Commonwealth's emissions through electric vehicle (EV) adoption.

This report constitutes the study called for under *An Act Promoting Zero Emission Vehicle Adoption*. The report contains the results of a comprehensive review of the Commonwealth's state fleet inventories and identifies near-term opportunities for fleet electrification.

As part of this study, the Massachusetts state fleet was inventoried and opportunities for electrification were identified and evaluated. The fleet was then organized into low, medium, and high priority opportunities for electrification based upon replacement criteria including vehicle mileage and age. The study found electrification of: passenger cars presents a $1.5 million net cost savings; transit buses range from a $24 million incremental cost to a $22.8 million savings depending on federal incentive availability; and passenger trucks and vans represent a $5.8 million net cost. Passenger cars and transit buses currently present the most cost effective electrification opportunities. Passenger trucks and vans provide the largest opportunity for electrification, but require incentives to enable cost effective conversion.

Table 1 Summary of State Fleet Inventory and Electrification Opportunities

Vehicle Category	Total Vehicles per Category	Percentage of State Fleet Inventory	Electrification Opportunity Exists (X)	# Vehicles Medium or High Priority to Electrify
Motorcycle	14	0.2%	X	14
Passenger Car	970	12.4%	X	404
Passenger Truck/Van	3,505	44.7%	X	1,787
Light Commercial Truck	827	10.6%	X	0
Single Unit Short-Haul Truck	1,050	13.4%		0
Combination Short-Haul Truck	580	7.4%		0
School Bus	21	0.3%	X	3
Transit Bus	487	6.2%	X	365
Emergency	379	4.8%		0
TOTAL	**7,833**	**100%**		**2,573**

As shown in Table 1, of the 7,833 vehicles in the state fleet, 2,573 currently present opportunities for electrification. Given the opportunities for lifecycle cost savings and emissions benefits, we recommend that electrification options should be considered for all light duty passenger car and transit bus replacements. Additionally, state grants and incentives should continue to support state fleet passenger truck and van electric conversion.

I. Background

On January 13, 2017, Governor Baker signed into law *An Act Promoting Zero Emission Vehicle Adoption*, section 6 of Chapter 448 of the Acts of 2016 ("Act"). Among other ZEV policy items, the Act directs the Massachusetts Department of Energy Resources (DOER), in consultation with the Massachusetts Department of Transportation (MassDOT), to conduct a study on the opportunities for electrification of the state motor vehicle fleet and to file the study with the Legislature by October 1, 2017. Section 6 of the Act provides in full:

> *The Department of Energy Resources, in consultation with the Massachusetts Department of Transportation, shall conduct a study on the opportunities for electrification of the state fleet, including the vehicles used by the regional transit authorities; provided that the study shall include recommendations for the allowance of non-electric emergency vehicles as part of the state fleet. For the purposes of this section, 'emergency vehicle' shall mean any publicly owned or leased vehicle operated by a sworn officer in performance of their duties, any authorized emergency vehicle used for fighting fires, any publicly owned or leased authorized emergency vehicle used by an emergency medical technician or paramedic, or used for towing or servicing other vehicles, or repairing damaged lighting or electrical equipment, or any ambulance used by a private entity pursuant to contract with a public agency. The study shall be filed with the clerks of the Senate and House of Representatives and with the Senate and House chairs of the joint committee on transportation not later than October 1, 2017.*[1]

This report constitutes the study called for under section 6 of the Act. DOER retained ICF to complete the state fleet electrification opportunities study, which was carried out in four largely sequential tasks. Task 1 involved data collection and gaining a sufficient understanding of the state motor vehicle fleet. Task 2 entailed a market analysis of the EVs -- both light-duty and medium/heavy-duty -- that are currently available in the Commonwealth, or that are expected to become available within the next five years. Utilizing the data gathered in the initial tasks, ICF then set about identifying all state fleet electrification opportunities in Task 3. Finally, Task 4 consisted of a life cycle cost analysis of vehicle electrification.

[1] Acts of 2016, Chapter 448, Section 6, available at https://malegislature.gov/Laws/SessionLaws/Acts/2016/Chapter448.

II. Benefits of Vehicle Electrification and Relevant State Regulations and Programs

Benefits of Vehicle Electrification

Electrification of on-road vehicles aligns with existing state policies and programs aimed at reducing greenhouse gas (GHG) emissions from the transportation sector. In addition, electrification of vehicles can also provide significant ancillary benefits such as reduced hazardous air pollutant emissions, reduced maintenance costs, reduced fuel price volatility, reduced noise pollution, potential improved resilience to fuel supply disruption, and potential reduced cost of electricity associated with higher capacity factor utilization of the electric system. These benefits are outlined in the following bullets.

- **Emissions Reduction:** Battery Electric Vehicles (BEVs) eliminate, and Plug-in Hybrid Vehicles (PHEVs) reduce, mobile source criteria pollutant and GHG emissions. Life cycle emissions from EVs are already cleaner than their internal combustion engine counterparts. In addition, the emissions profile will continue to improve as the electricity sources of Massachusetts become cleaner. As shown in Figure 1, light-duty EVs reduce carbon dioxide (CO_2) emissions by over 50%, compared to light-duty gasoline vehicles.[2]

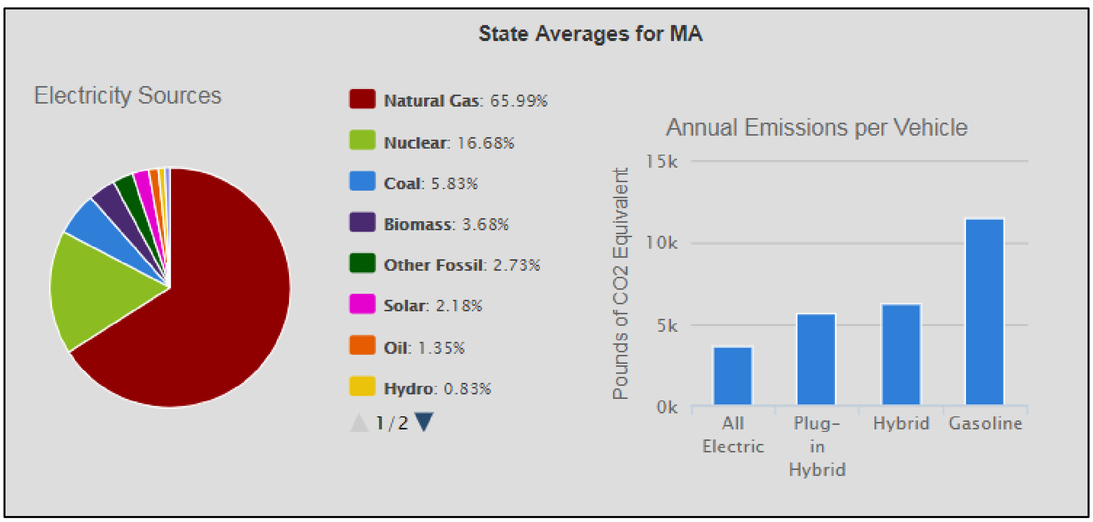

Figure 1 Comparison of CO2 Emissions: Electric vs. Gasoline

- **Hazardous Air Pollutant Reduction:** EVs can reduce hazardous air pollutant emissions, which correlates to improved air quality and reduced local negative health impacts of pollution.[3]
- **Reduce Vehicle Maintenance:** BEVs do not have an internal combustion engine, and therefore do not require such routine maintenance as oil, filter, and timing belt changes,

[2] U.S. Department of Energy Alternative Fuel Data Center, https://www.afdc.energy.gov/vehicles/electric_emissions.php
[3] U.S. Environmental Protection Agency Clean Air Act, https://www.epa.gov/clean-air-act-overview/progress-cleaning-air-and-improving-peoples-health

saving on labor and parts. Both BEVs and PHEVs utilize regenerative braking to recapture power, saving on brake wear and replacement.

- **Lower Fuel Costs and Price Volatility:** Gasoline and diesel experience fuel supply disruptions that can increase fuel prices beyond planned operating budgets. Electricity is a much less volatile energy purchase with steadier prices for budgeting operation costs.
- **Lower Noise Pollution:** Vehicles operate much more quietly on electricity versus gasoline or diesel, providing a benefit to employees and the surrounding environment.
- **Improved Resilience to Fuel Disruption:** PEVs can be a valuable resource during disaster relief efforts, in part because many EVs can export power from their batteries to power emergency response systems, such as communication equipment, traffic lights, or fuel pumps, and because the vehicles can be charged by distributed energy resources when fuel supplies are disrupted.[4]
- **Potential Reduced Cost of Electricity:** EV charging can increase utility revenues while increasing effective utilization of the existing generation, transmission and distribution system. This has the potential to suppress future electricity price increases for all electricity customers.[5]

Relevant State Regulations and Programs

Massachusetts has a variety of regulations and programs relevant to the vehicle electrification. Several of these policies stem from the Global Warming Solutions Act (GWSA) of 2008 which requires reductions in GHG emissions from each sector of the economy summing to a total reduction of 25% below the 1990 baseline emission level by 2020 and at least an 80% reduction by 2050. Relevant policies and programs include:

- **ZEV MOU:** Massachusetts has signed onto the ZEV MOU with seven other states, which has a goal for Massachusetts of 300,000 ZEVs by 2025.
- **State Fuel Efficiency Standard**: The Leading by Example division of DOER, Operational Services Division (OSD), and Massachusetts Department of Environmental Protection (MassDEP) has developed the Fuel Efficiency Standard for the state fleet. As of September 2016, state agencies are required to meet average fuel efficiency minimums, 32 MPG for all new passenger cars and 22 MPG for trucks, vans, and SUVs, and for all new vehicle acquisitions and purchase a minimum percentage of hybrid, alternative fuel, or PEVs each year[6]. The Fuel Efficiency Standard also established the Green Fleet Committee which is comprised of representatives from DOER, OSD, and MassDEP who work directly with agency fleet managers and meets several times of year. Given the continued advancement of technologies along with diverse agency operational needs, the Green Fleet Committee may revise and update the Fuel

[4] NASEO Initiative for Resiliency in Energy through Vehicles, http://www.naseo.org/irev

[5] M.J. Bradley Analyzes State-Wide Costs and Benefits of Plug-in Vehicles, http://www.mjbradley.com/reports/mjba-analyzes-state-wide-costs-and-benefits-plug-vehicles-five-northeast-and-mid-atlantic

[6] Fuel Efficiency Standard for the State Fleet, http://www.mass.gov/eea/docs/eea/lbe/fuelefficiencystandard-final.pdf

Efficiency Standard on an annual basis to ensure that the Commonwealth continues to progress towards our fleet efficiency goals.

In the first year of the State Fuel Efficiency Standard, a total of 123 vehicles were ordered by 13 Executive Branch agencies after the release of the Standard in September 2016. During the first year of implementation, 70% of agencies that acquired vehicles (9 of 13) were in compliance with both requirements of the Standard. Those agencies that were unable to comply with the standard due to operational constraints were able to complete an Alternative Compliance Plan, allowing them to employ other creative strategies for reducing agency-wide petroleum consumption. Some highlights from the year include:

  - Of the three Category 1 vehicles (passenger cars) acquired, two of them were Alternative Fuel Vehicles (AFVs), including a Plug-in Hybrid Electric Vehicle (PHEV) and a Hybrid Electric Vehicle (HEV).
  - Of the 78 passenger and cargo vans acquired, nearly half, or 38 vehicles, underwent after-market hybrid conversions, increasing the fuel efficiency of these vehicles by up to 25%.
  - And 11% of the pick-up trucks ordered (4 of 35) included an optional engine idle shut off technology to save fuel.

- **Consumer Rebate Program:** The Massachusetts Offers Rebates for Electric Vehicles (MOR-EV) program aims to provide air pollution emission reductions for the Commonwealth by increasing the use of EVs. Funded by the DOER and administered statewide by the Center for Sustainable Energy, MOR-EV provides rebates of up to $2,500 for the purchase or lease of light-duty zero-emission and plug-in hybrid vehicles. More information can be found at https://mor-ev.org/.
- **Advanced Vehicle Technology Equipment Contract (VEH102):** OSD, in coordination with DOER, published Statewide Contract VEH102, which is a new statewide contract for Alternative Fuel Vehicles (AFV) and related equipment. VEH102 supplements VEH98 which is the statewide contract, managed by OSD, for the purchase of Light Duty Vehicles – Passenger Cars, SUVs, Trucks, Vans, Special Services Vehicles, and Police Pursuit Vehicles. VEH102 is used for the acquisition of advanced vehicle and alternative transportation equipment, hardware, software and services. Contract awards are for specialized product and service firms qualified in one or more of the following advanced vehicle or AFV technology service categories, including but not limited to:
    - EV charging station equipment, hardware and software
    - Idle reduction equipment for – heavy equipment, and heavy, medium, and light-duty vehicles (where light-duty is defined by federal regulations as gross vehicle weight rating of no more than 10,000 pounds, medium duty is 10,000-26,000 pounds, and heavy duty is greater than 26,000 pounds)[7]
    - After-market conversion technologies – all vehicle classes

[7] Light, Medium, and Heavy Duty Classification by the Federal Highway Administration, https://www.afdc.energy.gov/data/widgets/10380

- **Electric School Bus Pilot:** In May 2016, DOER launched a pilot initiative to evaluate the economic viability of electric school buses[8]. Electric school buses offer health, environmental and noise benefits as well as lower fueling and maintenance costs as compared to traditionally powered diesel or gasoline vehicles. However, the purchase price of an electric school bus is significantly higher than a diesel powered bus, and consequently, capital costs remain an impediment to advancing the technology. In addition to economic viability, the pilot also aims to test the battery storage capabilities of the bus to generate vehicle to grid (V2G) or vehicle to building (V2B) benefits (e.g. the ability to use the vehicle battery as an emergency source of power during a grid outage or to discharge the vehicle battery coincident with the site peak demand to reduce electricity demand charges) and to determine if the benefits are sufficient to encourage more widespread deployment of electric school buses.
- **Massachusetts Clean Cities Coalition**: The Massachusetts Clean Cities Coalition, housed within DOER, is part of a nationwide partnership sponsored by the U.S. Department of Energy (DOE) Clean Cities Program. Clean Cities aims to reduce petroleum consumption and GHG emissions in the transportation sector and support development of infrastructure necessary to make AFVs a viable transportation option.
- **Mass Electric Vehicle Incentive Program (EVIP):** The MassDEP EVIP grant program provides incentives to Massachusetts cities, towns, state agencies, and public colleges and universities to acquire EVs and charging stations.[9]
- **Volkswagen Partial Settlement:** California federal court approved of a partial settlement between Massachusetts and 9 other states, and Volkswagen, Audi, and Porsche concerning the OEMs' sale of diesel vehicles designed to cheat on automotive emissions tests.[10] As part of the settlement, the companies agreed, among other things, to introduce collectively in Massachusetts (and each of the other states) three new BEVs by 2020, and to offer and sell these new EVs through at least 2025.[11]
- **ZEV Commission:** The ZEV Commission is a group of public and private stakeholders, chaired by the Executive Office of Energy and Environmental Affairs (EEA), and organized to study the economic and environmental benefits and costs of increased use of ZEVs in the commonwealth.[12]
- **State Fleet Clean Energy Conversion Program:** In September 2017, DOER and Massachusetts Clean Energy Center (MassCEC) launched the $1.3 million grant program for clean transportation upgrades to 52 vehicles that serve five state agency fleets.[13]

---

[8] Baker-Polito Administration Awards Electric School Bus Grants to Four Schools: http://www.mass.gov/eea/pr-2016/electric-school-bus-grants-to-four-schools.html

[9] Massachusetts EVIP website http://www.mass.gov/eea/agencies/massdep/air/grants/massevip.html

[10] See http://www.mass.gov/ago/news-and-updates/press-releases/2017/2017-03-30-vw-settlement.html.

[11] See http://www.mass.gov/ago/docs/environmental/ecf-filed-remand-stipulation-with-executed-settlement-agreement.pdf at ¶ 11.

[12] Zero Emission Vehicle Commission http://www.mass.gov/eea/waste-mgnt-recycling/air-quality/ma-zero-emission-vehicle-commission-and-mass-drive-clean-campaign/zero-emission-vehicle-commission.html

[13] Baker-Polito Administration Launches State Fleet Clean Energy Conversion Program, http://www.mass.gov/eea/pr-2017/state-launches-fleet-clean-energy-conversion-program.html

- **Green Communities Grants:** The DOER has issued over $80 million in grants to Massachusetts designated Green Communities, with EVs and EV charging infrastructure included as eligible grant technologies.[14]
- **Other State and Federal Regulations:** In addition to state initiatives, deployment of EVs also contributes to Massachusetts maintaining compliance with the federal ozone standard, the annual AFV-acquisition requirements under the federal Energy Policy Act of 1992, as amended, the Carbon Dioxide Emission Limits for State Fleet Passenger Vehicles, and Massachusetts ZEV standards (310 CMR 7.40).

III. Developing a State Fleet Inventory

Massachusetts has a decentralized fleet management approach, with no single entity in charge of the entire state fleet. To develop a comprehensive inventory for the state fleet, each of the following departments were contacted for vehicle lists: Massachusetts Bay Transportation Authority (MBTA), MassDOT, Massachusetts Port Authority (MassPORT), Massachusetts State Police (MSP), Office of Vehicle Management (OVM), MassDEP, Massachusetts Water Resources Authority (MWRA), and University of Massachusetts Amherst (UMass) provided available fleet data. The OVM and MassDEP data covers vehicles for agencies which do not manage their own fleet. Fleet data for 17 regional transit authorities (RTA) was supplied by OVM and is included in the analysis. The compiled inventory reflects the complete state fleet.

Only on-road vehicles that are owned and operated by the Commonwealth were collected for the state fleet inventory and evaluated for electrification opportunities. The inventory excludes off-road vehicles, equipment and on-road vehicles that are registered and titled to the Commonwealth but are not procured, operated, managed, nor otherwise controlled by the Commonwealth, nor assigned to a state executive office, agency, or department (as is the case for many Municipal fleet vehicles). To supplement data collection, fleet managers were contacted for further information and electrification histories.

The following details were collected for each vehicle, where possible:

- Fleet agency (i.e., the agency the unit is assigned to);
- Make;
- Model;
- Model Year (MY);
- Current odometer reading;
- Duty cycle:
    - Days per month, miles per use, and maximum daily use
- Whether the vehicle returns to base each night;
- Assigned drivers per vehicle;
- Current vehicle replacement plan (if any):
    - Years in replacement cycle;
    - Next replacement due;
- Vehicle Identification Number (VIN);

---

[14] Baker-Polito Administration Awards Over $14 Million in Green Communities Grants, http://www.mass.gov/eea/pr-2017/over-14-million-in-green-communities-grants-awards.html

- Plate number;
- Odometer reading date;
- Vehicle class;
- Vehicle use (e.g., towing, plowing, staff transport);
- Whether vehicle carries passengers on a regular basis; and
- Whether the vehicle is primarily used for city or highway driving.

Summary of State Fleet Inventory

The state fleet currently consists of 7,833 vehicles, including passenger cars, vans and trucks, school and transit buses, motorcycles and emergency vehicles. Table 2 provides a break-down of the state fleet inventory by vehicle type.

Table 2 Summary of State Fleet Inventory

Vehicle Category	Total Vehicles per Category	Percentage of State Fleet Inventory
Motorcycle	14	0.2%
Passenger Car	970	12.4%
Passenger Truck/Van	3,505	44.7%
Light Commercial Truck	827	10.6%
Single Unit Short-Haul Truck	1,050	13.4%
Combination Short-Haul Truck	580	7.4%
School Bus	21	0.3%
Transit Bus	487	6.2%
Emergency	379	4.8%
TOTAL	**7,833**	**100%**

Approximately 5% of the state fleet already consists of PEVs, hybrid electric vehicles (HEVs), or natural gas vehicles.

IV. Market Review and Analysis

Many types of EVs are available in Massachusetts and the vehicle technology and availability are growing each year. The available EVs can be categorized into two main categories: (1) original equipment manufacturer (OEM) available models, and (2) after-market upfit and retrofit conversions. Upfit and retrofit conversions enable trucks, vans, and shuttles to be electrified. An upfit is a vehicle conversion upon purchase (new) and retrofit is performed on an existing low mileage fleet owned vehicle (used). OEMs have been continuously announcing plans to increase EV offerings. The rapid increase in market participation can be associated both with increasing public awareness and demand as well as increasingly prevalent government policies and programs to ensure a continued decrease in emissions and pollution.

Upcoming Electric Vehicle Market Trends

The EV market in the United States has undergone, and continues to undergo, tremendous change. The number of EVs available to fleet and individual buyers has increased significantly over the last several years, particularly in the light-duty sector. By virtually all accounts, the EV market will continue to grow at a rapid pace for the foreseeable future. While the light-duty sector has been the primary focus to date, the medium/heavy-duty EV market is also expected to grow markedly over the next few years. The rapid rate at which both light-duty and medium/heavy-duty vehicle manufacturers are announcing and introducing new EV models provides a bright future for the transition to an all-electric fleet.

The imminent expiration of the ZEV standard's so-called travel provision, which has allowed OEMs to earn ZEV credits in every ZEV mandate state for ZEVs that are sold in California (or any other ZEV mandate state), should increase the number of light-duty EV models offered in the Commonwealth beginning in model year 2018.[15] As the Northeast States for Coordinated Air Use Management (NESCAUM), of which Massachusetts is a member, explained in a press release earlier this year:

> *The ZEV requirements have not fully taken effect in our states due to a regulatory provision that allows automakers to concentrate early marketing efforts in California. If the California Air Resources Board accepts Staff recommendations [which CARB, in fact, did[16]], that provision will expire at the end of the 2017 model year, which will boost EV availability, marketing and sales in the Northeast ZEV states.*[17]

Aside from the travel provision, the steady escalation of the ZEV mandate's minimum ZEV floor requirements over the 2018-2025 period should also translate into an increase in the number of light-duty EV models offered in Massachusetts over the next several years.[18]

Recent announcements from several car manufacturers lend credence to this anticipated EV market trend. For example, in early July 2017, Volvo Cars declared that starting in 2019, it would no longer manufacture new conventional internal combustion engine vehicle models. Instead, all of the company's new car models will be BEVs, PHEVs, or HEVs, with 5 new BEVs to be launched between 2019 and 2021.[19] A few weeks later, Hyundai announced that EVs had moved to the "center of its product strategy," with the automaker planning to introduce up to eight new EV models between now and 2021.[20] Additional OEMs, such as BMW and

---

[15] See Voelcker, "Why Electric Cars are Rare Outside CA: Arcane 'Travel Provision' Rule" (June 1, 2015), available at http://www.greencarreports.com/news/1098525_why-electric-cars-are-rare-outside-ca-arcane-travel-provision-rule.

[16] CARB, Advanced Clean Cars Midterm Review – Resolution 17-3 (Mar. 24, 2017), available at https://www.arb.ca.gov/msprog/acc/mtr/res17-3.pdf.

[17] NESCAUM, "NESCAUM States Support Recommendations for No Changes to California Zero Emission Vehicle Standards" (Jan. 18, 2017), available at http://www.nescaum.org/documents/nescaum-states-support-california-clean-car-program-review-results-20170118.pdf/.

[18] See 13 CCR 1962.2(b)(1)(A), (b)(2)(E).

[19] See https://www.media.volvocars.com/global/en-gb/media/pressreleases/210058/volvo-cars-to-go-all-electric. These HEVs and EVs are not shown on the OEMs tab because Volvo has yet to release any details about them.

[20] See http://www.reuters.com/article/us-hyundai-motor-electric-vehicle-idUSKCN1AX039.

Volkswagen, have announced similar shifts in operations to "mass produce EVs by 2020," or "release 80 new electric cars across its multi-brand group by 2025," respectively.[21]

The BEV market has also shown a marked increase in miles that can be drive on a single charge (range), with many models now being offered with over 200 miles of range. This range capability resolves a primary barrier to adoption of EVs, namely that the driver would otherwise require frequent stops and access to electric charging infrastructure.

Fuel Cell Vehicles (FCV) are not currently available in the state, but market and infrastructure advances are anticipated to increase vehicle availability. Fuel cell vehicles will be worth monitoring as an opportunity for continued fleet electrification.

Electric Vehicle Availability

ICF performed a market survey and compiled a list of all OEM EV models available for sale in Massachusetts, summarized in Table 3.

Table 3 Summary of EV Model Availability in MA

Available EV Models	Total Vehicles per Category
BEV Models	11
PHEV Models	19
Electric Motorcycles	3
TOTAL	**33**

For each OEM EV identified, the following details were collected (where known):

- Make;
- Model;
- Technology type (i.e., PHEV or BEV);
- Electric range; and
- Price;[22][23]

In putting together this comprehensive list of EVs, ICF reviewed and consulted a wide variety of information sources. A compilation of these data sources along with a detailed list of available OEM EV makes, models, range, and price appears in Appendix A.

[21] See http://www.reuters.com/article/us-autoshow-frankfurt/bmw-gears-up-to-mass-produce-electric-cars-by-2020-idUSKCN1BI1LM; http://www.reuters.com/article/us-autoshow-frankfurt-volkswagen-electri/volkswagen-spends-billions-more-on-electric-cars-in-search-for-mass-market-idUSKCN1BM296.

[22] For vehicles that are offered under Statewide Contract VEH98, the price is the bid price shown in the latest Base Vehicle Price Sheet posted at https://www.commbuys.com/bso/external/purchaseorder/poSummary.sdo?docId=PO-16-1080-OSD03-SRC02-00000006279&releaseNbr=0&parentUrl=contract. For all other vehicles, it is the manufacturer's suggested retail price (MSRP).

[23] In accordance with DOER's direction, the OEMs tab is consistent with the highest rebate amount ($2,500) offered under the MOR-EV program. That is, the tab excludes light-duty EVs with an MSRP equal to or greater than $60,000.[23]

While the EV list includes light-duty and medium/heavy-duty EVs irrespective of whether they are offered under VEH98, an indication is provided to clarify whether the particular EV can be obtained through that Statewide Contract to inform due consideration of expanding the breadth of the contract (e.g., by adding light-duty EVs from OEMs not already covered such as Kia, Tesla, or Volkswagen).

After-market Conversion and Upfit Options

ICF compiled the technologies that are currently available in Massachusetts for the electrification of conventional vehicles (i.e., turning internal combustion engine vehicles into EVs, usually PHEVs), summarized in Table 4. This can be done through either conversion – the retrofitting of existing vehicles – or upfitting – typically, transforming brand new OEM vehicles into HEVs or EVs.

Table 4 Summary of Electrification Conversions Available in Massachusetts

Conversion Technology	Number of Models with Retrofit Offerings
HEV	7
PHEV	1
TOTAL	**8**

For each conversion technology listed, the following details are provided (where known):

- Make (i.e., the OEM of the vehicle eligible for conversion/upfitting);
- Model of the vehicle eligible for conversion/upfitting;
- Technology manufacturer;
- Original vehicle fuel type; and
- All-electric driving range of the converted/upfitted vehicle;

The data sources and detailed table appear in Appendix A.

The conversion technologies are all currently included on the Alternative Fuel and Technologies contract VEH 102, a ground-breaking contract which includes technologies proven to reduce fuel consumption.

Table 5 Summary of Electrification Technologies Available in MA

Vehicle Category	Total Vehicles per Category	Percentage of State Fleet Inventory	OEM Opportunity (X)	Conversion Opportunity (X)
Motorcycle	14	0.2%	**X**	
Passenger Car	970	12.4%	**X**	
Passenger Truck/Van	3,505	44.7%	**Soon**	**X**
Light Commercial Truck	827	10.6%		**X**
Single Unit Short-Haul Truck	1,050	13.4%		
Combination Short-Haul Truck	580	7.4%		
School Bus	21	0.3%	**X**	
Transit Bus	487	6.2%	**X**	
Emergency	379	4.8%		

Table 5 summarizes what vehicle categories have current OEM and conversion electrification technologies offered in Massachusetts.

Available Charging Stations

Massachusetts currently has the highest number of charging stations per capita outside of California. The state currently has 499 publicly available electric charging stations offering 1,327 individual charging plugs. [24]

Additionally, EVs now often have a charger built into the vehicle, so it is not necessary to install commercial charging stations in a fleet application. Instead, an EV only requires access to 120 or 240 volt outlet at the vehicle's home base.

[24] U.S. Department of Energy Alternative Fuel Data Center, https://www.afdc.energy.gov/fuels/stations_counts.html

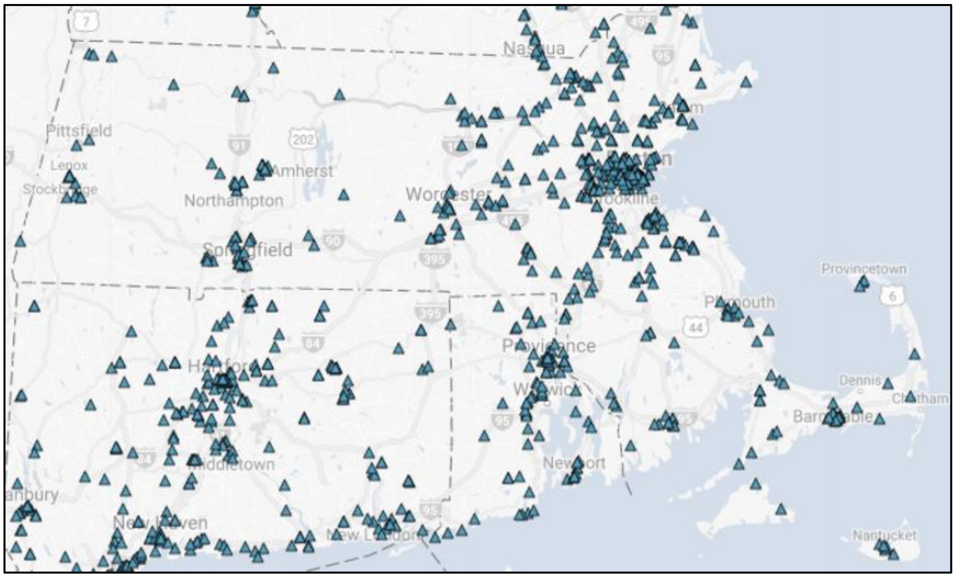

Figure 2 Map of Publicly Available EV Charging Stations

V. Opportunities for Electrification

As vehicles owned by the Commonwealth reach the end of their useful life or are phased out of use, Massachusetts has the opportunity to enhance its electric drive portfolio. Each new purchase represents an opportunity to select an EV from a rapidly diversifying range of available makes and models. Massachusetts can progress towards achievement of its emissions reduction goals by considering the supply of EV options currently available to consumers, as well as the array of new advanced technology vehicles slated for release in the near future.

How to Determine if an Opportunity Exists

In order to identify opportunities, fleet managers should understand key parameters that indicate whether or not a particular vehicle is a priority candidate for replacement or conversion to electric drive vehicle technologies. Decision makers should consider how to prioritize each vehicle’s candidacy for replacement or conversion, including setting definitions for low priority versus high priority vehicles. While each fleet will have unique attributes to take into account, the prioritization thresholds presented in this study serve as a baseline. To identify electrification opportunities for existing vehicles, factors to consider may include:

- Life cycle vehicle cost;
- When the next replacement for a particular vehicle is due (e.g., in the next few years or 20,000 miles, depending on useful life estimates);
- Average vehicle duty cycle and maximum daily driving distance;
- Vehicle maintenance costs;
- What electric drive vehicle technologies are readily available (e.g., there are no plug-in electric passenger trucks currently commercially available);
- If the alternative meets the operational needs (e.g., is this an emergency vehicle that needs to be able to operate on gasoline);

- Whether sufficient service life exists to consider retrofit (e.g., most retrofits occur under 60,000 miles per MassDOT);
- If the price differential is justifiable (e.g., must be within a few thousand dollars with available funding support); and
- Potential barriers (e.g., if no electric power is available).

Prioritization Methodology

One goal of this analysis was to identify vehicles as low, medium, or high priority for near-term electrification. High priority vehicles are those which currently present the best opportunity for electrification in the near term. Medium priority vehicles should be considered for electrification within a slightly longer timeframe, based on each individual fleet's timeline or cost priorities. Low priority vehicles are eventual contenders for electrification, but are not likely to be the strongest candidates for electrification in the near-term future.

ICF categorized each vehicle into high, medium, or low priority based on criteria that determine the efficiency and duty cycle of use of a vehicle, specifically age and total odometer reading, where that data was available.

Passenger Cars

Passenger cars were prioritized using the following thresholds:

- If vehicle age is greater than 9 years, the vehicle is high-priority
- If odometer reading is greater than 99,999 miles, the vehicle is high priority
- If vehicle age is between 5 years and 9 years, and if the odometer reading is unknown, 0, or greater than 60,000 miles, the vehicle is medium priority
- If vehicle age is between 5 years and 9 years, and if the odometer reading is unknown or less than 60,000 miles, the vehicles is low priority
- If the vehicle age is less than 5 years, the vehicle is low priority
- Any emergency vehicle is low priority

Table 6 Summary of Passenger Car Electrification Prioritization Results

Vehicle Category	Total Vehicles	Total High Priority Vehicles	Total Medium Priority Vehicles	Total Low Priority Vehicles
Passenger Car	**970**	321	83	566
% of Passenger Cars	**100%**	33%	9%	58%

As shown in Table 6, a total of 321 passenger cars were categorized as high priority and 83 as medium priority. While 566 were assigned a low priority, this is because these vehicles are not expected to be replaced in the near future. When they do reach end of life, these vehicles will present an opportunity for electrification.

Buses

Buses were prioritized using the following thresholds:

- If vehicle age is 15 years or greater, the vehicle is high-priority
- If odometer reading is greater than 99,999 miles, the vehicle is high priority
- If vehicle age is between 5 and 15 years, and if the odometer reading is unknown, or less than 99,999 miles, the vehicle is medium priority
- If the vehicle age is less than 5 years and/or the mileage is under 99,999 miles, the vehicle is low priority

Table 7 Summary of Bus Electrification Prioritization Results

Vehicle Category	Total Vehicles	Total High Priority Vehicles	Total Medium Priority Vehicles	Total Low Priority Vehicles
School Bus	**21**	3	0	18
Transit Bus	**487**	44	321	122
% of Buses	**100%**	10%	63%	28%

A total of 3 school buses and 44 transit buses were categorized as high priority and 321 transit buses as medium priority while 140 buses were low priority.

The MBTA has begun an extensive study of electrification of their transit fleet. The study will provide detailed analysis of their specific vehicles and routes, and is anticipated to be complete in 2018.

Passenger Trucks and Vans

While passenger trucks (including vans and transit shuttles) represent the largest portion of the fleet vehicles, 44.7%, there are not OEM EV models currently available for purchase. Therefore conversion via upfitting and retrofitting are the only current options for electrification. As such, there are two categories of vehicles to prioritize for electrification: 1) vehicles approaching replacement which can be replaced with an upfitted new vehicle, and 2) relatively new vehicles with low miles that can be retrofitted

Passenger trucks and vans were prioritized using the following thresholds:

- Less than 5 years of age and less than 60,000 miles, the vehicle is medium priority and is considered for retrofit.
- Greater than 9 years of age with over 150,000 miles, the vehicle is medium priority and is considered for replacement with an upfit.

Many state fleet passenger trucks and vans did not have vehicle mileage information available. In cases where the vehicle make/model had a conversion technology available but mileage was not available, it was included in the medium priority list.

Table 8 Summary of Passenger Truck Electrification Prioritization Results

Vehicle Category	Total Vehicles	Total High Priority Vehicles	Total Medium Priority Vehicles	Total Low Priority Vehicles

Passenger Truck/Van	**3,505**	0	1,787	1,718
% of Passenger Trucks	**100%**	0%	51%	49%

Passenger trucks and vans were considered medium priority as opposed to high priority because there are currently no zero emission conversion opportunities, there are only low emission conversion technologies available. The electrification opportunity is limited to regenerative braking with electric motor propulsion assist hybridization, as compared to other vehicle categories which include plug-in electric opportunities (e.g. the passenger truck and van hybrid solution never runs on electricity only). Table 8 shows the number of passenger trucks/vans recommended for electrification.

Additional Vehicle Categories

Motorcycles were also considered for electrification, with any cycles over 6 years old considered a high priority and all others a medium priority.

Additional medium- and heavy-duty fleet vehicles, such as street sweepers, tractor-trailers, trash trucks, and more are included in the fleet list, but at this time they are considered a low priority for electrification due to limited EV model availability and the prohibitive costs of converting these vehicles. A rapid market transformation is undergoing and these vehicle types may soon have electrification opportunities.

While off-road equipment was not considered as a part of this study, electrification opportunities are increasing in the market today.

Electrification Prioritization Results

The fleet electrification prioritization resulted in 5% of the fleet presenting a high priority opportunity for electrification, 28% representing a medium priority opportunity for electrification, and 67% as a low priority for electrification, as summarized in Table 9.

Table 9 Summary of Fleet Prioritization Results

Vehicle Category	Total Vehicles	Total High Priority Vehicles	Total Medium Priority Vehicles	Total Low Priority Vehicles
Motorcycle	**14**	6	8	0
Passenger Car	**970**	321	83	566
Passenger Truck/Van	**3,505**	0	1,787	1,718
Light Commercial Truck	**827**	0	0	827
Single Unit Short-Haul Truck	**1,050**	0	0	1,050

Combination Short-Haul Truck	**580**	0	0	580
School Bus	**21**	3	0	18
Transit Bus	**487**	44	321	122
Emergency	**379**	0	0	379
TOTAL	**7,833**	374	2,199	5,260
TOTAL as a Percent	**100%**	5%	28%	67%

While 67% of the fleet was assigned a low priority, this is because these vehicles are either not expected to be replaced in the near future or do not currently have viable electrification opportunities. When these vehicles do reach end of life, these vehicles may at that time present an opportunity for electrification.

VI. Costs of Electrification

ICF developed a lifecycle cost analysis for vehicle electrification, as compared to conventional vehicles. The lifecycle costs combine acquisition, operation, and maintenance costs to determine the total costs over a vehicle's useful-life, to calculate the financial displacement of the higher capital costs required to purchase EVs.

Methodology and Tools

ICF utilized the DOE Argonne National Laboratory's (ANL) most recent Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool to estimate lifetime costs for each category of heavy- and light-duty vehicle.[25] AFLEET Tool allows users to compare cost differences between conventional vehicles and AFVs. Users can rely on default data built into the model for the specific vehicle categories of interest, or can input in real-world data from the particular fleet being analyzed.

To make prioritization recommendations for Commonwealth fleet data, ICF categorized fleet vehicles into AFLEET Tool vehicle types. The light- and heavy-duty AFLEET Tool vehicle types included in the analysis are defined below:[26]

AFLEET Tool Vehicle Type Definitions

- Light-Duty Vehicles
    - Passenger car: four wheel, two axle vehicle whose primary function is passenger transport;
    - Passenger truck: four wheel, two axle vehicle whose primary functional design is for cargo, but are used primarily for passenger transport; and

[25] Argonne National Laboratory. AFLEET Tool 2017. August 2017. https://greet.es.anl.gov/index.php?content=registration&from=afleet

[26] Argonne National Laboratory. User Guide for AFLEET Tool 2016. May 2016. https://greet.es.anl.gov/publication-afleet-tool-2016-user-guide.

  - Light commercial truck: four wheel, two axle vehicle used primarily for cargo transport.
- Heavy-Duty Vehicles
  - School bus: passenger vehicle with a capacity of 15 or more persons used primarily for transport of students for school;
  - Transit bus: passenger vehicle with a capacity of 15 or more persons primarily used for transport within cities;
  - Refuse truck: truck primarily used to haul refuse to a central location;
  - Single unit short-haul truck: single unit truck with more than four tires with a range of operation of up to 200 miles; and
  - Combination short-haul truck: combination tractor/trailer truck with more than four tires with a range of operation of up to 200 miles.

Acquisition Costs

Today, the current acquisition cost – the purchase price – of an EV is higher than that of a conventional internal combustion engine vehicle powered by gasoline of diesel. This is the case both for government (and other) fleet buyers and for the general public.

According to Kelley Blue Book, the transaction price of a new EV was, on average, approximately $38,000 in July 2017, compared to, on average, approximately $17,000/$20,000/$25,000/$35,000 for a subcompact/compact/mid-size/full-size conventional car.[27] The primary reason that EVs are more expensive to buy is the high cost of their key component, the battery. Yet, lithium-ion battery costs have dropped sharply since 2009,[28] and they continue to decrease. Some analysts now predict that the purchase price of a EV will reach parity with and actually fall below that of a gasoline vehicle as early as 2025.[29]

Operation Costs

Vehicle operating costs – what it costs to fuel the vehicle – present a starkly different picture. In late August 2017, AAA released the 2017 edition of its annual *Your Driving Costs* study. AAA included BEVs in the national evaluation for the very first time, and found that "[b]y relying on electricity instead of gasoline, fuel costs [for BEVs] are significantly lower than average [gasoline-powered vehicles], at under four cents per mile" compared to over 10 cents per mile.[30] Thus, nationwide, operation costs for BEVs are about 1/3 of what they are for conventional vehicles. This means that acquiring a BEV instead of an internal combustion engine vehicle will

---

[27] See Kelley Blue Book, "New-Car Transaction Prices Rise Nearly 2 Percent Year-Over-Year in July 2017, According To Kelley Blue Book" (Aug. 1, 2017), available at http://mediaroom.kbb.com/2017-08-01-New-Car-Transaction-Prices-Rise-Nearly-2-Percent-Year-Over-Year-in-July-2017-According-To-Kelley-Blue-Book.

[28] See DOE, "Fact #914: Plug-in Vehicle Sales Climb as Battery Costs Decline" (Feb. 29, 2016), available at https://energy.gov/eere/vehicles/fact-914-february-29-2016-plug-vehicle-sales-climb-battery-costs-decline.

[29] See https://about.bnef.com/blog/electric-vehicles-accelerate-54-new-car-sales-2040/.

[30] AAA, "Your Driving Costs" (Aug. 23, 2017), available at http://newsroom.aaa.com/auto/your-driving-costs/; http://exchange.aaa.com/wp-content/uploads/2017/08/17-0013_Your-Driving-Costs-Brochure-2017-FNL-CX-1.pdf at 9 (3.68 cents for EVs, 10.26 cents for gasoline vehicles on average).

yield, over the vehicle's lifetime, a roughly 65% savings in fuel costs. According to the latest figures on the DOE eGallon tool, the savings appear to closer to 18% in Massachusetts.[31]

Maintenance Costs

Maintenance costs are the costs to maintain and repair a vehicle, and include such things as the cost of parts and labor associated with routine maintenance as specified by the OEM (e.g., oil changes and fluid replenishment), the cost to repair and replace wear-and-tear items that require service (e.g., brake pads, spark plugs, and timing belts), and the cost of replacement tires. Maintenance costs decrease as a vehicle becomes more electrified. As explained in DOE's *PEV Handbook for Fleet Managers*:

> *Because PHEVs have [internal combustion engines], maintenance requirements for this system are similar to those in conventional vehicles. However, the EV electrical system (battery, motor, and associated electronics) likely will require minimal scheduled maintenance. Because of regenerative braking, brake systems on EVs typically last longer than on conventional vehicles. In general, BEVs require less maintenance than conventional vehicles do, because there are usually fewer fluids to change and far fewer moving parts.*[32]

Therefore maintenance is less expensive and laborious for BEVs and PHEVs as compared to the average gasoline vehicle. The 2017 AAA study calculated the maintenance costs for a BEV at 6.55 cents per mile compared to almost 8 cents per mile for the average gasoline vehicle. Assuming 12,400 miles per year, this equates to $982.50 versus $1186.50 in annual maintenance costs, or a slightly more than 17% difference in favor of the BEV.[33] AAA thus confirmed that "[w]ithout a gasoline engine to maintain, [BEVs] have the lowest annual maintenance and repair costs." Overall, AAA concluded that "[a]lthough [BEVs] can have higher up-front costs, lower fuel and maintenance costs make them a surprisingly affordable choice in the long run."[34]

Total Cost of Ownership

To uniformly capture the lifecycle cost of owning an EV versus a gasoline or diesel vehicle, ICF relied on the AFLEET Tool's Total Cost of Ownership (TCO) Calculator, which "evaluates the

---

[31] See https://www.energy.gov/articles/egallon-what-it-and-why-it-s-important (showing that as of late June 2017, $1.88 worth of electricity would enable a PEV driver to go the same distance as a gallon of gasoline that cost $2.29, which equates to an 18% savings).

[32] DOE, Plug-In Electric Vehicle Handbook for Fleet Managers, at 10 (Apr. 2012), available at https://www.afdc.energy.gov/pdfs/pev_handbook.pdf.

[33] http://exchange.aaa.com/wp-content/uploads/2017/08/17-0013_Your-Driving-Costs-Brochure-2017-FNL-CX-1.pdf at 9.

[34] AAA, "Your Driving Costs" (Aug. 23, 2017), available at http://newsroom.aaa.com/auto/your-driving-costs/.

net present value of operating and fixed costs over the years of planned ownership of a new vehicle, as well as lifetime petroleum use, GHGs, and air pollutant emissions."[35]

Passenger Cars

The passenger car prioritization analysis resulted in 404 medium and high priority vehicles identified for electrification, detailed in Table 10. An analysis was then performed to determine the cost-benefit of fleet electrification by comparing the total cost of ownership of an electrified vehicle versus a gasoline powered vehicle. The analysis determined the net savings (or cost) of switching to an electrified vehicle after factoring in the up-front capital cost to purchase the vehicle, as well as the fuel and maintenance savings over the vehicle lifetime. For passenger vehicles the savings included relevant *Drive Green with Mass Energy*[36] negotiated EV pricing, and ranged from $768 to $11,817 per vehicle as seen in the below table.

Table 10 Medium and High Priority Passenger Car Net Cost Savings as a Result of Electrification

Passenger Vehicles	BEV-Short Range	PHEV-Long Range	BEV-Long Range	PHEV-Short Range	TOTAL
Number of High Priority Vehicles Recommended per Model	107	257	33	7	**404**
Total Cost of Ownership Savings Compared to a Conventional Fuel Vehicle	$11,817	$769	$1,833	$5,886	
Estimated Total Cost Savings	$1,264,419	$197,633	$60,489	$41,202	**$1,563,743**

These 404 high and medium priority passenger cars represent a potential net lifetime cost savings of over $1.56 million for the Commonwealth. Electrification should be considered in most cases when a passenger car is up for replacement, as the opportunity exists and electrification provides a positive lifecycle cost benefit.

Buses

The school and transit bus prioritization analysis resulted in 368 medium and high priority vehicles for electrification. Federal Transit Administration funding is currently available for up to 80% the incremental costs of urban transit fleet electrification[37], resulting in Massachusetts lifetime transit bus cost savings of $126,894 per vehicle. Rural transit fleet electrification funding is also available at 50% the incremental costs of rural transit fleet electrification.

Table 11 Medium and High Priority Bus Individual Cost Savings as a Result of Electrification

	EV Transit Bus	EV School Bus

[35] Argonne National Laboratory. User Guide for AFLEET Tool 2016. May 2016. https://greet.es.anl.gov/publication-afleet-tool-2016-user-guide.

[36] Prices subject to change based on terms and conditions found at Drive Green with Mass Energy http://massenergywebservices.com/drivegreen/table-all.php#volt

[37] Urbanized Area Formula Grants – 5307, Federal Transit Administration, U.S. Department of Transportation, https://www.transit.dot.gov/funding/grants/urbanized-area-formula-grants-5307

Lifetime Cost Savings of Electrification ($/bus), (no incentive)	-$64,409	-$163,858
Cost Savings with FTA 5307 80% Urban Incremental Incentive ($/bus)	$126,894	$15,342
Cost Savings with FTA 5311 50% Rural Incremental Incentive ($/bus)	$55,156	-$51,858

Table 12 Medium and High Priority Bus Fleet Cost Savings with and without Federal Incentives

Buses	Transit Bus (Rural)	Transit Bus (Urban)	School bus (Rural)	TOTAL
Number of Medium and High Priority Buses	330	35	3	
Lifetime Cost Savings of Electrification (no incentive)	-$21,254,970	-$2,254,315	-$491,574	**-$24,000,859**
Lifetime Cost Savings of Electrification (with federal incentives)	$18,201,480	$4,441,290	$165,468	**$22,808,238**

If it is assumed that the federal funds will be available for electrification of this entire selection, then these 368 buses represent a lifetime cost savings of $22.8 million. If, however, it is assumed that the federal funds will not be available to incentivize the electrification of this entire selection, then these 368 buses represent a total incremental cost of $24 million. It is likely that federal funds would be available for at least a portion of the state fleet's electrification. In cases where federal funds are available, there is a net positive lifetime cost savings associated with electrification. This makes clear that federal incentive availability makes a decisive difference in the lifecycle cost of electrifying a bus. As with the other EV markets, the incremental price of an electric bus over a traditional is expected to decrease.

In the near term, electrification of buses should primarily be considered when federal incentives are available. As the cost of electric transit buses continues to decline, replacement with electric buses will become more achievable.

Passenger Trucks and Vans

The only current opportunities for electrification of passenger trucks and vans are through an after-market upfit or retrofit. The lifetime cost savings associated with an after-market upfit or retrofit depend highly on annual miles driven by the vehicle and length of time it is driven. In many cases, after-market upfits and retrofits cost more than their lifecycle benefits.

Table 13 Medium and Priority Passenger Truck Cost Savings as a Result of Electrification

Passenger Trucks and Vans	F-150 Plug-In Electric Conversion	Ford Transit Van Hybrid Conversion	Chevy Express Van Hybrid Conversion	TOTAL

Number of Medium Priority Vehicles Recommended per Model	296	1,304	187	**1,787**
Total Cost of Ownership Savings Compared to a Conventional Fuel Vehicle	-$14,189	-$1,095	-$963	
Estimated Total Cost Savings	-$4,199,944	-$1,427,880	-$180,081	**-$5,807,905**

It should be noted that, currently, hybrid conversions available for a passenger or cargo van are not plug-in electric, but rather a regenerative braking system. The plug-in electric conversion available for the F-150 currently has a significant negative lifetime cost savings. The negative lifetime cost savings in Table 12 are based on the assumption that no incentive or grant program is available to offset the cost of conversion.

However, as Passenger Trucks and Vans are the largest vehicle category in the state fleet there is an opportunity for significant emissions reduction benefits by electrifying passenger trucks and vans. While currently operations savings alone may not cover the full incremental cost of electrification, emissions savings and potential extended life of the vehicle should be considered. State grants and incentives are a valuable tool to offset the differential cost, such as the State Fleet Clean Energy Conversion Program, which recently funded the conversion of 52 state fleet vehicles.

Additional Vehicle Categories

Motorcycles were found to have a lifetime cost savings of $7,383 associated with replacement with electric OEM options.

Additional medium- and heavy-duty fleet vehicles, such as street sweepers, tractor-trailers, trash trucks, and more are included in the fleet list, but as this time they are considered a low priority for electrification due to limited EV model availability and the prohibitive cost margins of converting these vehicles without incremental funding.

Emissions Reductions

The AFLEET tool outputs estimated annual emissions reductions along with the cost savings. Electrification of the 2,573 medium and high priority vehicles represents an annual GHG emissions reduction of 34,473 metric tons, as detailed in Tables 16 and 17 in Appendix A.

VII. Conclusion

Of the 7,833 vehicles in the State Fleet, 2,573 currently present opportunities for electrification. The ongoing rapid EV market transformation will increase beneficial fleet electrification opportunities in the future. The pace of market transformation makes up-to-date informed procurement methods more difficult but more valuable, as EVs continue to overtake traditional vehicles as the lowest lifecycle cost of ownership fleet option. To further ease the fleet manager's ability to electrify the fleet, the statewide contract for vehicle acquisition, VEH98, could continue to be reviewed to ensure EV makes and models are included when new options come onto the market.

In addition to the financial benefits of fleet conversion, there are emission reduction benefits not fully analyzed in this study. Emission reduction goals of the Commonwealth are bold and forward looking, however, these goals cannot be achieved without a transformation of the transportation sector. As such, the emissions savings associated with electrification should be considered in the evaluation of all state fleet vehicle purchases.

All state fleet passenger car purchases could be electrified and the majority of these purchases could provide net cost savings and reduced emissions. However, there are other factors that should be considered such as vehicle application, battery range, and charging infrastructure availability.

All transit bus purchases eligible to receive federal funds for urban and rural transit fleet electrification would provide net cost savings and reduce emissions.

State grants and incentives should continue to support state fleet passenger truck and van electric conversions.

The Commonwealth has an opportunity to lead by example through electrifying a significant portion of the state fleet and decreasing the total cost of ownership of hundreds of fleet vehicles in the process.

Appendix A - Relevant Documentation

Original Equipment Manufacturers

Table 13 provides a list of light duty OEM makes and models currently available in MA, along with their range and manufacturer suggested retail price (MSRP).

Table 14 OEM Light Duty EVs Currently Available in MA

OEM Make	Model	Technology	All-electric Range (miles)	Price
Alta Motors	Redshift SM	BEV	50	Unknown
Audi	A3 Sportback e-tron	PHEV	16	MSRP: $38,900
BMW	330e	PHEV	14	MSRP: $44,100
BMW	i3 BEV (60 amp-hour battery)	BEV	81	MSRP: $42,400
BMW	i3 BEV (94 amp-hour battery)	BEV	114	MSRP: $44,450
BYD Motors	e6	BEV	Up to 250	Unknown
Chevrolet	Bolt	BEV	238	$34,567-$36,795
Chevrolet	Volt	PHEV	53	$30,812-$32,770
Chrysler	Pacifica Hybrid	PHEV	33	$40,490-$40,932
Energica	Ego	BEV	Unknown	Unknown
Energica	Eva	BEV	Unknown	Unknown
Ford	C-MAX Energi	PHEV	20	$27,103-$28,843
Ford	Focus Electric	BEV	115	$26,743-$28,049
Ford	Fusion Energi	PHEV	21	$28,532-$29,444
Hyundai	Ioniq	BEV	124	MSRP: $29,500 - $32,500
Hyundai	Sonata	PHEV	27	$33,874
KIA	Optima	PHEV	29	MSRP: $35,210
KIA	Soul	BEV	93	MSRP: $32,250 - $35,950

Mercedes-Benz	B250e	BEV	87	MSRP: $39,900
Mercedes-Benz	C350e	PHEV	Up to 10	MSRP: $46,050
Nissan	Leaf	BEV	107	$22,750-$33,300
Quantya	Strada	BEV	2.5 hours	MSRP: $10,985
Smart	Electric Drive	BEV	58	MSRP: $25,000
Toyota	Prius Prime	PHEV	0-25	$26,230
Victory	Empulse TT	BEV	Unknown	MSRP: $$19,999
Volkswagen	e-Golf	BEV	125	MSRP: $28,995 - $36,265
Zero Motorcycles	Zero DS	BEV	47-138	MSRP: $10,995-$13,995
Zero Motorcycles	Zero DSR	BEV	95-138	MSRP: $15,995
Zero Motorcycles	Zero FX	BEV	24-62	MSRP: $8,495-$10,495
Zero Motorcycles	Zero FXS	BEV	26-68	MSRP: $8,495-$10,495
Zero Motorcycles	Zero S	BEV	54-153	MSRP: $10,995-$13,995
Zero Motorcycles	Zero SR	BEV	54-153	MSRP: $15,995

Passenger car replacement with EV selection was based upon vehicle annual mileage, with annual mileage of under 4,000 miles replace with a Ford CMAX (PHEV- Short Range), 4,000 – 10,000 miles annually replaced with a Nissan Leaf (BEV- Short Range), 10,000 – 12,000 miles replaced with a Chevy Bolt (BEV- Long Range), and greater than 12,000 miles annually replaced with a Chevy Volt (PHEV- Long Range).

Data Sources

a. FuelEconomy.gov Find a Car (https://www.fueleconomy.gov/feg/findacar.shtml)

b. U.S. Department of Energy's (DOE) Alternative Fuels Data Center Alternative Fuel and Advanced Vehicle Search (https://www.afdc.energy.gov/vehicles/search/)

c. DOE's Model Year 2017: Alternative Fuel and Advanced Technology Vehicles (https://www.afdc.energy.gov/uploads/publication/model-year-2017-vehicles.pdf)

d. California Air Resources Board (CARB)
   a. Heavy-Duty Certification Program - Approvals (https://www.arb.ca.gov/msprog/cihd/approvals/approvals.htm)
   b. On-Road New Vehicle & Engine Certification Program (https://www.arb.ca.gov/msprog/onroad/cert/cert.php)

   c. Draft - Technology Assessment: Medium- And Heavy- Duty Battery Electric Trucks And Buses (https://www.arb.ca.gov/msprog/tech/techreport/bev_tech_report.pdf)
   d. Draft - Technology Assessment: Heavy-Duty Hybrid Vehicles (https://www.arb.ca.gov/msprog/tech/techreport/hybrid_tech_report.pdf)
   e. California's Advanced Clean Cars Midterm Review Appendix B: Consumer Acceptance of Zero Emission Vehicles (ZEVs) and Plug-in Hybrid Electric Vehicles (https://www.arb.ca.gov/msprog/acc/mtr/appendix_b.pdf)[38]
   f. Advanced Clean Cars Summary (https://www.arb.ca.gov/msprog/clean_cars/acc%20summary-final.pdf)[39]

e. Argonne National Laboratory Light Duty Electric Drive Vehicles Monthly Sales Updates (https://www.anl.gov/energy-systems/project/light-duty-electric-drive-vehicles-monthly-sales-updates)

f. Industry association lists
   a. Multi-State ZEV Task Force - Vehicles (https://www.zevstates.us/vehicles/)
   b. Plug In America - Vehicles (https://pluginamerica.org/vehicles/)
   c. Plug In Cars - Cars (http://www.plugincars.com/cars)
   d. EV Obsession (https://evobsession.com/)

g. Manufacturer websites, press releases, and representatives

h. Commonwealth of Massachusetts resources
   a. Operational Services Division - Master Blanket Purchase Order (https://www.commbuys.com/bso/external/purchaseorder/poSummary.sdo?docId=PO-16-1080-OSD03-SRC02-00000006279&releaseNbr=0&parentUrl=contract)
   b. Massachusetts Offers Rebates for Electric Vehicles (https://mor-ev.org/)

i. U.S. General Services Administration Alternative Fuel Vehicle Guide (https://www.gsa.gov/portal/content/104224)

j. Stories from news outlets on vehicle availability and recent electric drive vehicle pilot programs
   a. Green Car Reports (http://www.greencarreports.com/)
   b. Business Insider (http://www.businessinsider.com/)
   c. Autotrader (https://www.autotrader.com/)
   d. Car and Driver (http://www.caranddriver.com/)
   e. HybridCars.com (http://www.hybridcars.com)
   f. CleanTechnica (https://cleantechnica.com/)
   g. School Bus Fleet (http://www.schoolbusfleet.com/)
   h. Electrek (https://electrek.co/)

k. Vehicle lists from other state programs
   a. Drive Clean CA (https://www.driveclean.ca.gov/)

[38] Figure 11: Annual California ZEV new registrations by model CY2011-2015 and Table 2: Top ZEV and PHEV new registrations by region
[39] Table 8: Future ZEVs and PHEVs Announced by Manufacturers

b. Hybrid and Zero-Emission Vehicles (http://www.californiahvip.org/docs/HVIP_EligibleVehicles.pdf)
c. New York State Electric Vehicle - Voucher Incentive Fund (https://truck-vip.ny.gov/NYSEV-VIF-vehicle-list.php)
d. High-Efficiency Truck Users Forum (http://www.calstart.org/Projects/htuf/Vehicle-List.aspx)

Retrofits and Upfits

Table 14 provides a list of electric conversion makes and models currently available in MA, along with their original fuel source and range.

Table 15 Electrification Conversions (Upfits and Retrofits)

Make	Model	Original Fuel	Manufacturer	All-electric Driving Range (miles)
Chevrolet	1500 Silverado Pick-Up Truck 4.3 liter	Gasoline	VIA Motors	40-45
Ford	F-150	Gasoline	XL Hybrids	Unknown
New Flier 35 ft and 40 ft	Transit Bus	Diesel	Complete Coach Works	150
International	ProStar Day Cab Tractor	Diesel	Magmotor Technologies, Inc. (US Hybrid)	80
Utilimaster	Aeromaster FT 1261 Walk-In	Diesel	Magmotor Technologies, Inc. (US Hybrid)	75
Freightliner	M2 106/108SD, 114SD, MT55	NA	Odyne Systems	Unknown
International	4300/4400, 7300/7400/7500	NA	Odyne Systems	Unknown
Kenworth	T370	NA	Odyne Systems	Unknown
Ford	F750	NA	Odyne Systems	Unknown
Chevrolet	G2500 Express Van 4.8 liter	Gasoline	VIA Motors	40-45
Thomas Built Buses	Type C and D School Bus	Diesel	TransPower	80

a. CARB
    a. Aftermarket Parts Database of Executive Orders (https://www.arb.ca.gov/msprog/aftermkt/devices/amquery.php)
    b. Select Device Type: Off-vehicle charge capable system and Engine Modification/Engine Change
b. U.S. Environmental Protection Agency (EPA)

   a. Lists of EPA-Compliant Alternative Fuel Conversion Systems (https://www.epa.gov/vehicle-and-engine-certification/lists-epa-compliant-alternative-fuel-conversion-systems)
   b. Transportation and Air Quality Document Index System (https://iaspub.epa.gov/otaqpub/)
c. Conversion company and upfitter websites, press releases, and representatives

Table 16 Annual GHG Reductions by Electrification

Medium and High Priority Emission Reductions	Light-Duty OEMs (404 EVs)	XL Hybrids (1,787 HEVs & PHEVs)	Buses (368 EVs)	TOTAL
Annual GHG Emissions Reduction (metric tons)	1,033	3,649	29,791	**34,473**

Table 17 Annual Air Pollutant Emissions Reductions by Electrification

Medium and High Priority Emission Reductions	Light-Duty OEMs (404 EVs)	XL Hybrids (1,787 HEVs & PHEVs)	Buses (368 EVs)	TOTAL
CO (lbs)	13,628	6,247	16,510	**36,385**
NOx (lbs)	1,038	1,299	38,852	**41,189**
PM10 (lbs)	66,063	16	746	**66,825**
PM2.5 (lbs)	66,064	16	637	**66,717**
VOC (lbs)	1,069	1,981	1,574	**4,624**

Appendix B – Data and AFLEET Tool Assumptions

ICF used the assumptions detailed below to populate the TCO Calculator and generate cost savings estimates. The AFLEET 2016 Tool allows users to specify the state and county in which vehicles will be used. As county-specific data is only pertinent to emissions reductions modeling, which is beyond the scope of this analysis, the geography assumed for all vehicles modeled was Suffolk County, Massachusetts. The AFLEET Tool also allows, and recommends, that users change the default assumptions for a number of other inputs. In this analysis, ICF used data specific to Massachusetts and particular vehicle makes and models to inform assumptions wherever possible. However, as noted in the State Fleet Inventory section, because of data gaps in the fleet inventory, ICF was not able to modify the default inputs for all variables, and thus used the AFLEET Tool's default values when required.

Each run in the AFLEET Tool relied on an electricity mix specific to the Northeast region. ICF also assumed private charging stations for each scenario, and assumed that no loan would be required for any of the vehicles purchased. This analysis assumes a 10 year useful life for all light-duty vehicles and a 12-year useful life for all heavy-duty vehicles. As Commonwealth fleets do not have uniform vehicle replacement requirements, ICF referred to Oak Ridge National Laboratory's Transportation Energy Data Book and the Massachusetts ZEV Action Plan to estimate useful life of light-duty vehicles, and applied this assumption across multiple light-duty categories in the AFLEET Tool. [40,41] The heavy-duty estimate is based on bus fleet data provided anecdotally by MassDOT, which indicated a 12-year and 500,000-mile lifetime. This was the only concrete, Massachusetts-specific data point available to ICF regarding vehicle lifetime.

The table below describes some of the key assumptions used as inputs in the AFLEET Tool for a BEV, a PHEV, and a comparable vehicle from the same manufacturer for all vehicle categories. ICF selected two EVs, the Chevrolet Bolt and Nissan Leaf, and two PHEVs, the Ford C-Max Energi and Chevrolet Volt, to compare to a conventional vehicle. From the range of available electric drive vehicles, ICF selected these makes and models that represent an average BEV and PHEV on the market, based on incremental acquisition cost and fuel economy. The corresponding conventional vehicles entered into the AFLEET Tool were the Chevrolet Malibu, Nissan Altima, and Ford Fusion.

---

[40] The Commonwealth of Massachusetts. Massachusetts Zero Emission Vehicle Action Plan. August 2015. http://www.mass.gov/eea/docs/doer/clean-cities/massachusetts-zero-emission-vehicle-action-plan2015.pdf.

[41] Oak Ridge National Laboratory. Transportation Energy Data Book, Edition 35. October 2016. http://cta.ornl.gov/data/index.shtml.

Table 18: AFLEET EV and PHEV Assumptions

Category	Technology	Make/Model	Incremental Acquisition Cost[42]	Fuel Economy	Annual Mileage	Useful Life (years)
Light Duty – Passenger Car	BEV	Chevrolet Bolt	$14,940	119 MPGe	12,400	10
Light Duty – Passenger Car	BEV	Nissan Leaf	$8,180	112 MPGe	12,400	10
Light Duty – Passenger Car	PHEV	Ford C-MAX Energi	$27,120	39 MPG gas only	12,400	10
Light Duty – Passenger Car	PHEV	Chevrolet Volt	$11,540	42 MPGe	12,400	10
Light Duty – Passenger Truck	PHEV	XL Hybrid Upfit	$25,000	20.5 MPG	11,400	10
Heavy Duty – School Bus	BEV	Motiv Power Systems Ford E450	$364,000	21.2 MPGe	15,000	12
Heavy Duty – Transit Bus	BEV	New Flyer	$239,129	9.8 MPGe	41,667	12

Data Disclaimers

Due to the inconsistent and irregular data collection and maintenance methodologies across Commonwealth fleets, the above details are not available for each vehicle. In particular, data sources did not provide information regarding current odometer reading, duty cycle, whether the vehicle returns to base each night, and current vehicle replacement plan for a majority of vehicles included in the analysis. These data fields are particularly helpful in differentiating recommendations for BEVs and PHEVs in the Electrification Analysis. Gaps in data may also be attributed to specific fleets' legal ability to share fleet data with a contractor. As such, ICF notes as a disclaimer that incomplete data limits its ability to conduct a fleet electrification study. Individual Commonwealth fleets may refer to this electrification study to complete their own analysis as more fleet data and vehicle models become available. The Electrification Analysis includes recommendations and solutions to further categorize fleet data and complete the electrification study.

[42] Acquisition cost before applicable local or federal incentives