Electric Vehicles Research Report

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Introduction

As part of Fast Forward: MIT's Climate Action Plan for the Decade[1], published in May 2021, MIT took on the challenge to join the world in finding equitable ways to bring every sector of the global economy to net-zero carbon emissions by 2050, adapt to the effects of climate change that cannot be prevented, "going as far as we can, as fast as we can, with the tools and methods we have now". The Institute has pledged to reduce direct campus impacts on climate change by achieving net-zero carbon emissions by 2026, with a goal of eliminating direct emissions by 2050. This challenge encompassed the following electric vehicle centered goals:

- All future MIT fleet purchases of light-duty vehicles will be zero emission, subject only to availability.
- MIT will initiate the conversion of campus shuttle bus vehicles to zero-emission buses by 2026.
- MIT will increase campus car-charging stations by a minimum of 200% (from 120 to 360) by 2026.

The Electric Vehicles (EV) Research team, a group of three students who worked with MITOS to aid and further MIT's progress on the EV front, as a segment of the Carbon Footprint Working Group, addressed this challenge systemically, recognizing the integrated nature of transitioning the fleet and shuttle system with the increased demands on EV infrastructure.

By collaborating with a group of EV Co-Leads, experts in the operational field, the EV Student Researchers analyzed the current state of MIT's shuttles, Campus fleet, and charging infrastructure. Equipped with the necessary knowledge, the EV Student Researchers derived a series of recommendations for the execution of the three EV-centered goals, which will be explored throughout this report.

Mission Statement

To lead and evolve MIT towards fleet and shuttle electrification and EV infrastructure expansion as efficiently and creatively as possible, towards net-zero carbon emissions.

Buses and Shuttles Electrification

Market Trends

Market research has shown that demand for electric buses (e-buses or BEB – battery electric buses) is increasing globally. According to Bloomberg NEF's Electric Vehicle Outlook Report for 2021 (EVO2021)[2], currently there are 600,000 e-buses on the road globally, making up 39% of new EV sales and 16% of the global EV fleet. Head of electrified transport at Bloomberg NEF, Aleksandra O'Donovan, predicts that e-buses will comprise over 67% of the global bus fleet by 2040 according to Bloomberg NEF's EVO2020[3]. However, global adoption of e-buses is primarily driven by the electrification of municipal buses. Electrification of school buses or university buses and shuttles are trailing behind due to insufficient funding at the municipal, state, and federal levels and far lower utilization rates compared to municipal buses, thus deeming them less of a priority in the electrification process[4].

In recent years, however, an increasing number of universities throughout the U.S. have begun the electrification of their buses and shuttles, reducing campus-wide emissions to contribute to the global strive towards Net Zero and beyond. Many of these universities received funding from competitive government-supported programs (e.g. MassDEP grant, Georgia State Road and Tollway Authority (SRTA) grant). This indicates that funding for large-scale electrification projects may be available, but they are, nonetheless, competitive and often limited to public institutions. The following are some universities that have integrated electric buses into their fleet in recent years:

- University of Georgia – 33 e-buses (1/3 of bus fleet)[5]
- Harvard University – 4 e-buses (1/3 of bus fleet)[6]
- Columbia University – 6 e-buses[7]
- Duke University – 2 e-buses (1/12 of bus fleet)[8]

Whether it is the electrification of municipal or university buses, the high costs of e-buses seem to be the main hindrance against their widespread adoption. Approximately 40% of the cost of an e-bus is attributed to its battery. Luckily, prices for lithium-ion batteries are expected to decrease in upcoming years. Based on historical trends, BNEF's 2021 Battery Price Survey[9] predicts that by 2024 average pack prices should be below \$100/kWh. This is the price at which automakers can produce and sell EVs at approximately the same price and with the same margin as internal combustion engine vehicles (ICEVs). However, higher raw material prices mean that the point at which battery pack prices fall below \$100/kWh could be pushed back by two years to 2026. Anticipated advancements in battery technology within the next decade are also expected to drive down the cost of e-buses and EVs in general.

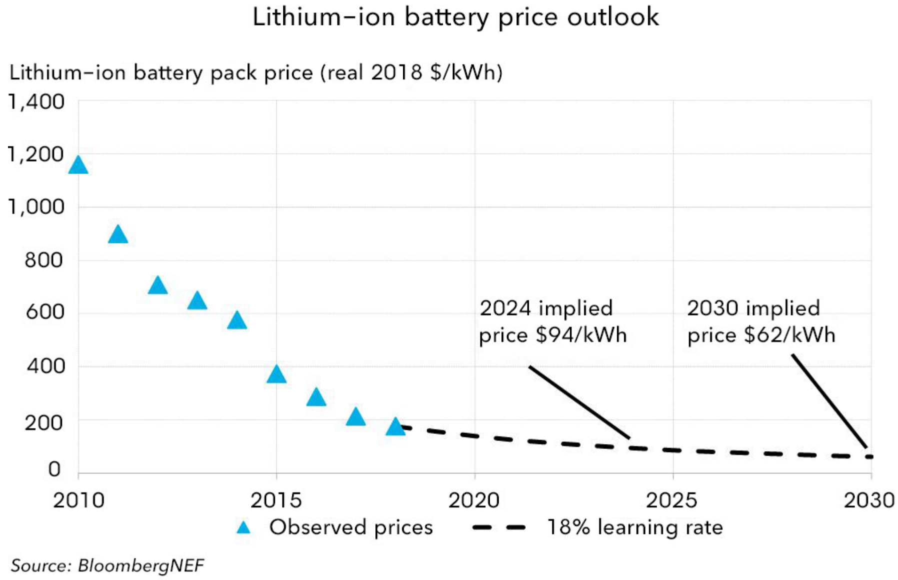

Figure 1. A plot of the actual price and projected prices for lithium-ion batteries from 2010 to 2030. Lithium-ion battery prices are expected to fall below $100/kWh by 2024.[9]

With regards to battery technology, there is ongoing research in industry and academia on replacements to commonly used lithium-ion batteries that are safer, lighter, cheaper, and minimizes charging time. Solid-state batteries are a high contender on the list of replacements for lithium-ion batteries, however, this technology is largely still experimental with key safety and battery degradation issues that have yet to be resolved. Even so, various automakers have already announced the deployment of more affordable EVs powered by solid-state batteries by 2030, to which Donald Sadoway, Professor of Materials Chemistry at the Massachusetts Institute of Technology (MIT) replied, "In their dreams."[10] Therefore, it is more likely that price reductions for electric vehicles, including e-buses, will be attributed to decreases in lithium-ion battery prices as opposed to the onset of new battery technology – at least in the short term.

The rush to adopt e-buses by municipalities and universities is justified because transportation alone accounts for 29% of U.S. greenhouse gas (GHG) emissions[11]. In a study published in 2019 by the Union of Concerned Scientists, the average 40-foot diesel bus emits 2,680 grams of CO2 per mile (g/mi), whereas an electric bus charged on the average U.S. energy mix emits 1,078 g/mi – a more than 50% reduction[12]. Therefore, to meet the emission goals stated in Fast Forward MIT, it is imperative that MIT reduce emissions associated with their buses and shuttles as soon as possible by transitioning to full electric buses.

Current National and State-wide Incentives

The research group could not identify any incentives that specifically target shuttle and bus electrification at the MA state or federal levels. The various MA electrification grants offered by Massachusetts Department of Environmental Protection (MassDEP)[13] are generally limited to public institutions and many do not focus on electrification of buses. However, Harvard University was able to obtain a MassDEP grant to fund the purchase of their electric buses, which indicates that there may be special programs open to private institutes as well. Harvard also received a loan from the Harvard Green Revolving Fund, a $12-million revolving loan fund that provides up-front capital for projects that reduce Harvard's environmental impact, to establish the charging system infrastructure necessary to support the new electric buses.

At this time, the research group has no knowledge of MIT having a fund similar to the Harvard Green Revolving Fund although the Parking and Transportation team will still look to the Institute to fund the purchase of e-buses and the installation of the necessary charging infrastructures.

Current State of MIT Buses

MIT's current bus and shuttle fleet is composed of five 34-seat buses, four 31-seat buses, and four 14-seat buses for a total of 13 vehicles. The ages of MIT's buses range from 5 to 12 years with lifetime mileage ranging from approximately 56,000 to 115,000 miles as of 2021. In the past, buses have been leased-to-own and operated by SP Plus Corporation, a third-party fleet management company. SP Plus manages the insurance, fuel, cleaning, and maintenance of MIT buses and shuttles, which are fully owned by MIT at the end of the 60-month lease period (Supplemental Information 1). In Spring 2022, two of the older buses have been replaced by two new diesel buses due to their deteriorating conditions.

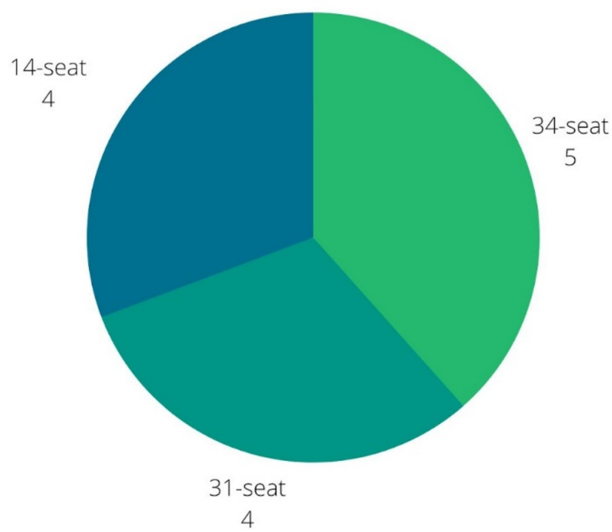

Figure 2. A breakdown of MIT's current bus and shuttle fleet by vehicle seating-capacity.

Current buses are parked on campus at an unpaved lot at 290 Albany Street. The 13 shuttles are refueled on Mondays, Wednesday, and Fridays and serve nine main routes – Boston Daytime, Boston East, Cambridge East and Somerville, Cambridge West and Brookline, Campus, Costco and Target, Trader Joe's and Whole Foods, Tech Morning/Afternoon.

Table 1 includes details regarding each route. Since the grocery routes are only active on Sundays, all values are given in terms of "Operating Day" – a day when the routes are operating

– rather than daily. More details regarding each column are given below:

- Route Length
    - Data from the Proterra route simulation performed in 2019
- Service Hours per Operating Date
    - Data from public shuttle schedules released by MIT parking and transportation
- Dispatch Frequency per Operating Day
    - How often buses arrive
    - Data from public shuttle schedules released by MIT parking and transportation
- Route Frequency per Operating Day
    - Approximately the number of times each route is traveled
    - Route Frequency = Service Hours * 60 / Dispatch Frequency
- Total Distance Traveled
    - Total Distance Traveled = Route Frequency * Route Length
- Estimated Range with 1 Full Charge
    - Data from the Proterra route simulation performed in 2019
- Number of Operating Days Sustained without Recharging
    - Days without Recharging = Estimated Range per Charge / Total Distance per Day

Route	Operating Days	Route Length (mi)	Service Hours per Operating Day		Dispatch Frequency per Operating Day (min)	Route Frequency per Operating Day	Total Distance Traveled per Operating Day (mi)	Estimated Range with 1 Full Charge (mi)	No. of Operating Days without Recharging
Boston Daytime	Weekdays	3.8	9		30	18	68.4	200	3
Boston East	Daily	3.7	6.5		30	13	48.1	191	4
Cambridge East and Somerville	Daily	4.9	4.5		30	9	44.1	188	4
Cambridge West and Brookline	Daily	5.5	4.5		30	9	49.5	216	4
Campus	Daily	4.7	4.5		35	8	36.3	177	5
Costco and Target	Sundays	14.4	3.75		75	3	43.2	178	4
Trader Joe's and Whole Foods	Wednesdays, Sundays	5.7	4.5		45	6	34.2	186	5
Tech Morning/Afternoon	Weekdays	3.5	6:15am-7:35am	80	20	4	222	197	1
			7:35am-10:35am	180	10	18			
			10:35am-4:05pm	330	20	17			
			4:05pm-5:55pm	110	10	11			
			5:55pm-10:35pm	280	20	14			
			16.33		10-20 min	64			

Table 1. Summary of key data for the nine routes served by MIT buses and shuttles. The last column "No. of Operating Days without Recharging" provides insight into the possible routes that can have an increase in frequency with the integration of electric buses.

Analysis and Recommendations for Bus Electrification

Based on the group's analysis and the information provided by the shuttle electrification Co-leads, Tom Giannino and Melissa Stopa, the group believes that initiating the conversion of campus shuttle bus vehicles to zero-emission buses by 2026 as part of Fast Forward MIT is achievable. In fact, significant strides towards laying the groundwork for the electrification of shuttles has already begun.

A key point of discussion was whether MIT should procure e-buses directly from the manufacturers themselves (e.g. Proterra), lease the e-buses long term rather than procure them, or follow a similar lease-to-own model as the one currently in effect and do so through a third-party (e.g. SP Plus). Upon consultation with Emma Homestad, an MIT procurement specialist, Tom Giannino and Melissa Stopa, the group reached the consensus to release an RFI prior to an RFP so as to acquire better insight into the options available on the market for e-buses. Therefore, the group compiled a list of firms to address the RFI to as well as aided in the drafting of the RFI itself.

Once the group identifies all viable options in the market for e-buses, the next recommended step would be to draft and release an RFP to the firms that meet MIT's requirements for e-buses. In the RFP drafting process, the group recommends keeping the following considerations in mind:

- If asking vendors to provide "Major Current Accounts" (i.e. current clients), inquire whether the vendors have worked with "preferably with universities" rather than just "preferably with private entities" – which is what Harvard included in their RFP. Private entities other than universities tend to use their buses or shuttles in different ways than what MIT and other universities intend.

- Under "Bus Performance Specs," the group recommends adding a section about noise generated by the shuttles (in decibels), since some of MIT shuttles travel at night and into small neighborhoods.

- Regarding charging ports, the group recommends installing two charging ports: one in the back of the bus and one in the front – which was also suggested by the Harvard shuttle team, who were experiencing inconveniences with parking orientation because their buses only had one charging port in the back. Therefore, the RFP should ask vendors whether it is possible to install multiple charging ports on their buses and the additional costs associated with doing so.

- The group recommends MIT include a "Sustainability Commitment" as Harvard has done for their RFP. Inquire specifically into how vendors tackle the challenge of battery recycling, since electric bus batteries are typically replaced after 6 years and there are ongoing environmental concerns with the end-of-life fate of lithium-ion batteries.

- If appropriate, the group recommends asking vendors whether there have been instances when they were unable to meet delivery schedules, briefly describe the issue, and discuss the measures taken to ensure the delay will not occur with future clients.

- If appropriate, the group recommends inquiring into any new models or battery technologies that vendors have in store for the near future. A concern with investing in e-buses too early is that manufacturers will likely produce more efficient products at lower prices in the future. Timing of purchase is also a significant factor to consider during procurement. Waiting another year prior to procuring could mean better e-bus models to choose from.

- Regarding the charging infrastructure for the e-buses, the group recommends installing Level 3 chargers and not mix-and-matching chargers with manufacturers, which coincides with the suggestions from the Harvard fleet management team. If vendors could provide details regarding maintenance for their recommended chargers, that could be useful as well.

After the optimal option for e-bus procurement has been parsed from the RFP and the procurement of e-bus has occurred. The group recommends that the Parking and Transportation team explore the possibility of increasing the frequency of certain shuttle routes, given the likely event that the new e-buses will have a longer range per charge than current diesel buses. Current diesel buses must be refueled once every other day, whereas Table 1 reveals that e-buses can last at least twice as long without needing to recharge for the majority of the routes, with the exception of the Tech Morning/Afternoon routes. To decide on the specific routes to increase in frequency, the group recommends conducting an institute-wide survey to gather students and staffs' inputs.

Other than the logistical recommendations made above, the group also came across an innovative idea on the technological front that could further set MIT's shuttle fleet ahead of the trends – Vehicle to Grid (V2G). Firstly, Vehicle to Grid (V2G) allows electric vehicles to be energy storage units during peak hours and allows them to recharge for free or at reduced costs during quieter times. V2G works especially well with vehicles that have batteries with greater energy density, such as e-buses. Depending on whether the electricity for the e-bus lot will be provided by EverSource or MIT's Central Utility Plant (CUP), MIT's e-buses could potentially be paid by EverSource to stabilize their electrical grid at MIT's convenience. Or, idle e-buses could give electricity back to MIT's grid during peak hours, reducing MIT's need to pull energy from the CUP.

Currently, EverSource has yet to launch any V2G programs. However, there have been successful V2G projects around the U.S. with a notable example being White Plains School District in New York V2G school bus project with five Lion electric school buses linked to the Con Edison grid[14]. Regarding the feasibility of V2G, certain e-bus manufacturers such as Proterra already have directional charging systems implemented into their buses and chargers, allowing for an e-bus to charge and discharge with ease. Some drawbacks to V2G include the complexities of the partnerships involved, especially if MIT desires to be financially compensated for the service of their e-bus to EverSource's grid. Despite these challenges, it appears that Harvard University is also considering V2G, since they specifically asked vendors to provide information regarding their bus and charger compatibility with V2G in their RFP.

Recommended Timeline for Bus Electrification

The group established a recommend timeline for bus electrification based on the following assumptions and considerations:

- Replacing the oldest shuttles with new e-buses first is the best option, since older shuttles can become safety hazards for passengers due to their deteriorating conditions, as well as serve as prominent sources of GHG emissions due to low fuel efficiencies.

- Given that most e-buses on the market are 30-40 inches in length (25-30 seats), the group hypothesizes that MIT will not be able to replace their small shuttles (i.e. Chevy Glaval Vans, 18 seats) until later in the future, approximately 4-5 years from Fiscal Year 2022.

- The cost of a 40-seat e-bus is approximately $949,850.00 according to a Proterra estimate from 2019. Given the usual purchase prices of 40-seat and 14-seat diesel buses, the purchase cost of a 14-seat bus is estimated to be 26% of the purchase cost of a 40-seat diesel bus. This same proportion was applied to reach the cost of a 14-seat e-bus of approximately $253,780.59.

- Given the high upfront cost associated with purchasing each e-bus, the group recommends following a leasing schedule of 5 years (60 months) if MIT decides to pursue a lease-to-own model like the one currently in place.

- To determine the best purchase model/leasing model for e-buses, the group aimed to limit the annual lease expense to $1.3 million so that the lowest NPV of lease expenses can be achieved (Supplemental Information 1). Simultaneously, the group aimed to fully replace the bus fleet as soon as possible, resulting in the timeline shown below.

Feasibility of the recommended timeline depends on actual grants or funds received each fiscal year as well as the evolution of e-buses technology and prices on the market.

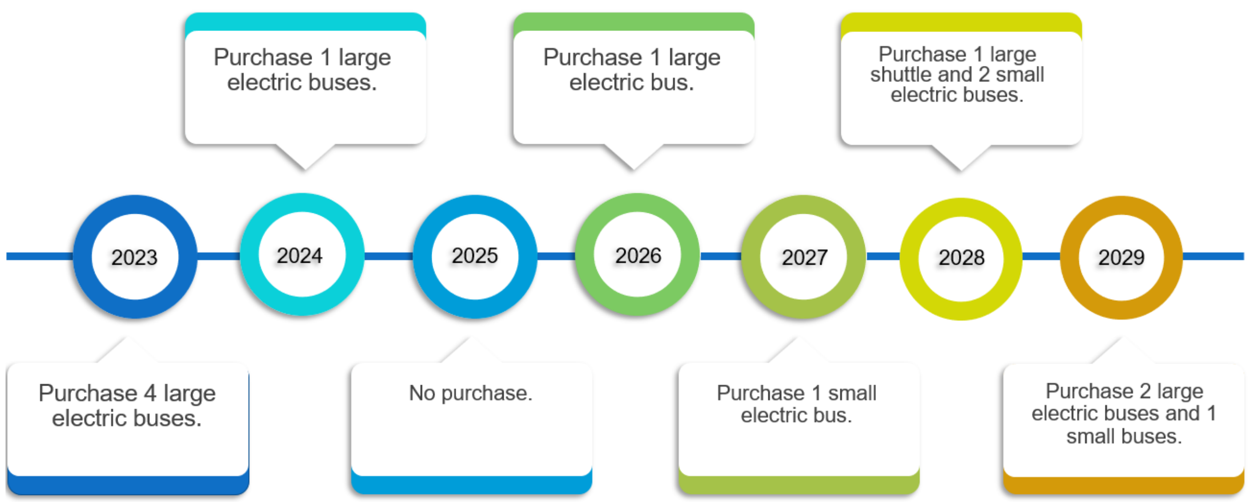

Figure 3. Timeline for the recommended purchase schedule for electric buses, to be completed over the course of 7 years starting in Fiscal Year 2023 and completing in Fiscal Year 2029.

Light-Duty Vehicles Fleet Electrification

Market Trends

BloombergNEF's 2021 Electric Vehicle Outlook publication[15] asserts that EV light-duty passenger vehicles, despite having the second largest fleet size of approximately 10 million cars (only second to 2 and 3 wheelers), are making the slowest progress towards road electrification dominance. Electric passenger cars currently have an EV sales share of 4%, second only to that of trucks and vans (1% EV share of sales). The report goes on to highlight that following current trends, buses and 2 or 3 wheeled vehicles are almost on track to reach net zero while passenger cars and light commercial vehicles are on a positive trajectory, but still require more policy support.

In 2019, the last time vehicle sales were not influenced by Covid-19 in any way, EV sales grew by 15% globally due to the growth in BEV sales in most regions, yet the BEV market in the US fell by 2%.[16] Since then, BEV vehicle sales have only spiraled downwards but the market is expected to recover by 2030 (owing to expected battery improvements), with EVs making up 32% (approximately 4 times the 2021 7.2% total global vehicle sales comprising both PHEV and BEV) of total market share for new car sales and BEVs constituting 81% of that figure. However, growth is not to be linear or exponential, as internal combustion engine (ICE) vehicles are expected to return to growth until 2025 and then begin to decline in market penetration.

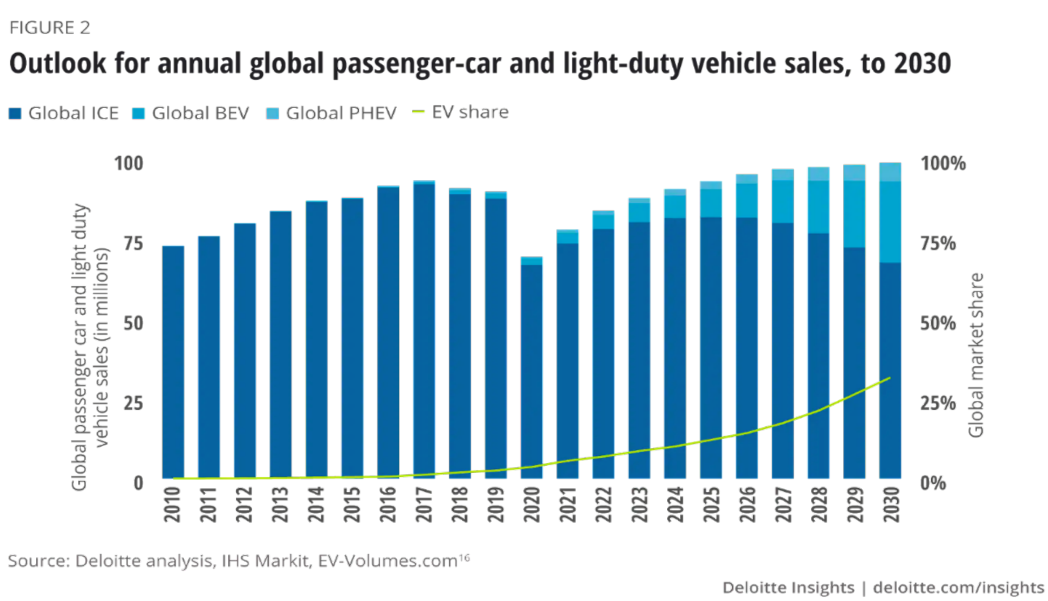

Figure 4. A plot of the trends regarding global EV adoption through 2030. EVs are expected to take up approximately 30% of the global light-duty vehicles market by 2030.[16]

It seems sensible that the Covid-19 pandemic would have a bearing on the ICE vehicle increase until 2025, as consumers who had planned to buy a car prior but ended up working from home will likely proceed with their initial plans once regulations start to ease. Similar patterns have been noted at the Massachusetts Institute of Technology (MIT), where urgent vehicle replacements post-pandemic stay-at-home regulations have been ICEs. However, the reluctance for light-duty passenger EVs and low numbers surrounding them can directly be a result of the market patterns. In an interview for "The Real Barriers to Electric Vehicle Adoption"[17], a professor at the Massachusetts Institute of Technology's Sloan Business School, David Keith, had this to say: "For all the enthusiasm for electric vehicles in the news, actual progress in the market is still taking some time to emerge." There is still much maturation to be achieved in the EV low-duty/ passenger vehicle in terms of widespread availability of non-luxury cars for specific purposes as well as pricing. This gap in availability of EVs for functionality has affected light-duty vehicle electrification in colleges, with more progress being seen in shuttle bus electrification projects instead. The following colleges have, however, taken part in programs to support the electrification of light-duty vehicles:

- University of California, Davis took on 10 BMW light-duty EVs for testing in 2018, on rental and leasing terms for faculty and staff towards their 2025 Carbon Neutrality Initiative.[18]

- Boston University has engaged in an electric fleet vehicle pilot program, for faculty to test and departments to prioritize electric models for vehicle replacement, for the currently present vehicles on the market.[19]

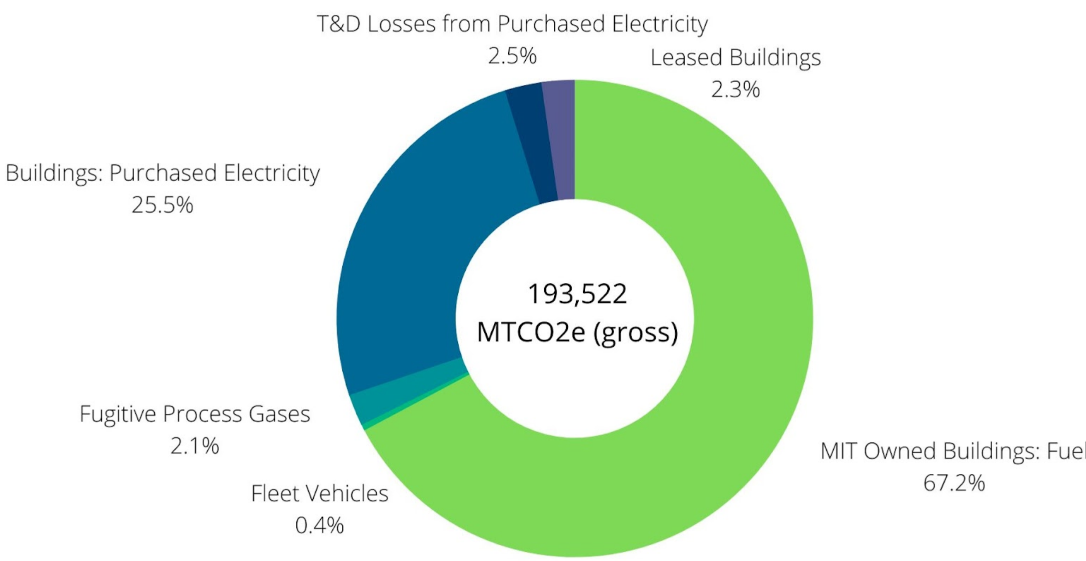

Figure 5. A breakdown of the main contributors to MIT on-campus gross greenhouse gas emissions in Fiscal Year 2021. Fleet vehicles contributed an almost negligible amount of GHG compared to GHG emissions from buildings.[20]

The Massachusetts Institute of Technology has reduced its net greenhouse gas emissions by approximately 22% from 2014 to 2021, with a 2% increase from 2020-2021[20]. However, this increase was offset through building-level energy efficiency investments, operational efficiency of the Central Utilities Plant (CUP), and improvements in the New England regional Electricity grid. More can be done on the light-duty vehicle electrification front to further reduce emissions towards MIT's net-zero goal by 2026.

Current National and State-wide Incentives

Regarding state-sponsored incentives for the purchase of light-duty EVs, the MOR-EV program[21] is the most applicable to MIT fleet replacement. MOR-EV rebate is only available for eligible vehicles purchased or leased from licensed dealerships or retail locations located in the Commonwealth of Massachusetts. As a non-profit institution, MIT can submit a rebate application for up to 10 purchased light-duty EVs at a time and will receive $2,500 in rebate for each new battery or fuel cell light-duty electric vehicle, and $1,500 for a new plug-in hybrid electric vehicle. MIT is eligible for 10 rebates per calendar year; 20 over program lifetime.

MORE-EV also offers rebates for the purchase of medium to heavy-duty EVs such as trucks and vans through their More-EV Trucks program. The rebate amount for the MOR-EV Trucks program depends on the Gross Vehicle Weight Rating (GVWR, lbs.) of the EV purchased with higher GVWR vehicles qualifying for a greater rebate amount than low GVWR vehicles. Furthermore, incentives follow a declining value as blocks of funding are exhausted. Currently, all medium and heavy-duty truck incentives are still in Block 1 (i.e. highest value of rebates). However, MIT can only reserve up to 10% of the number of available vouchers and rebates in a block. At this moment, the group is unsure if this limit applies annually or over the program lifetime.

Federal incentives for the purchase of EVs are not as common as state incentives. In President Biden's proposed Build Back Better Act, tax-payers can receive up to $7,500 in tax credits for the purchase of EVs with GVWR of less than 14,000 lbs. However, MIT is a non-taxable entity and thus the EV tax credit is inapplicable to the institute; nonetheless, the group believes that it is still important to recognize this $7,500 in incentives, since it is likely that more federal, state, or municipal incentives that are applicable to non-profit institutions will arise in the future which will surmount to approximately $7,500 or more.

Analysis of the MIT Campus Fleet

Given the time constraints of this project, the group conducted a thorough analysis of only the vehicles classified under "Campus Fleet," which comprises the majority of the total MIT fleet (Supplemental Information 2). Prior to analyzing the state of the fleet, irrelevant vehicles were identified and disregarded for the purpose of the group's analysis. These disregarded ("special vehicles") include snow plows, boat trailers, etc). The group narrowed down the Campus Fleet from approximately 187 vehicles to 144 relevant vehicles that have the potential to be replaced with EVs.

Figure 6 shows that approximately 70% of the Campus Fleet is composed of light-duty vehicles, with the remaining 30% composed of medium and heavy-duty vehicles. The presence of medium and heavy-duty vehicles adds a layer of difficulty in the full electrification of MIT's fleet, since their electric replacements are currently scarce in the U.S. market. It is important to note that electric replacements for certain types of light-duty vehicles are also difficult to find in the current market.

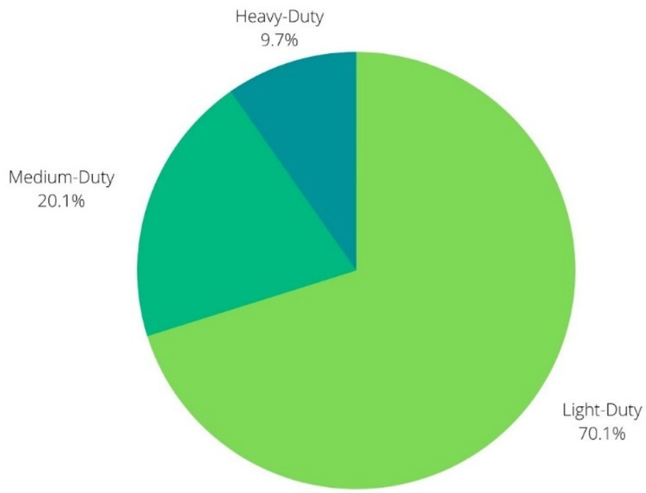

Figure 6. A breakdown of the composition of the Campus fleet, detailing the proportion of light-duty, medium-duty, and heavy-duty vehicles in the fleet.

Therefore, in Figure 7, the group dissected the composition of light-duty, medium-duty, and heavy-duty vehicles to determine their exact compositions, emphasizing the vehicle types (i.e. pickup, SUV, van, sedan) that have the greatest abundance in electric replacements. From Figure 7, it is clear that the light-duty portion of the Campus Fleet is primarily composed of pickup trucks and vans – both of which have electric replacements that will likely arrive anywhere from mid to late 2022 to 2025 as various vehicle manufacturers forecast.

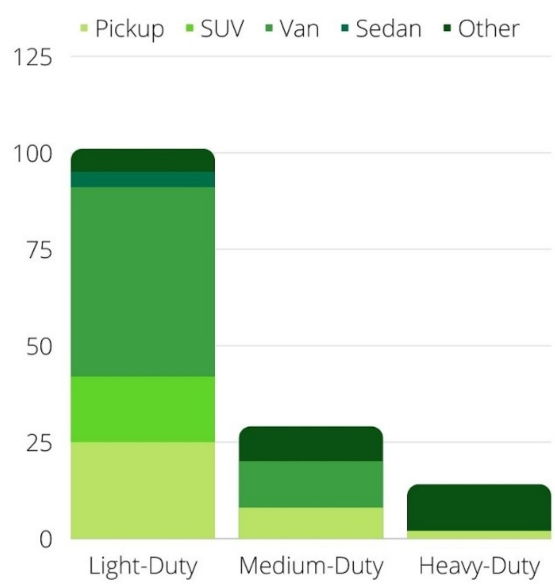

Figure 7. A breakdown of the composition of the light-duty, medium-duty, and heavy-duty vehicles in the Campus fleet, focusing on the type of vehicles that compose each.

Next, Figure 8 provides a breakdown of the specific brands or manufacturers comprising the 144 relevant Campus Fleet vehicles. From Figure 8, it is clear that over 50% of the Campus Fleet is composed of Ford vehicles, most notably Ford pickup trucks and vans. Chevrolet and GMC vehicles together take up nearly a quarter of the Campus Fleet. This information would be useful in identifying potential manufacturers, from whom to source EVs.

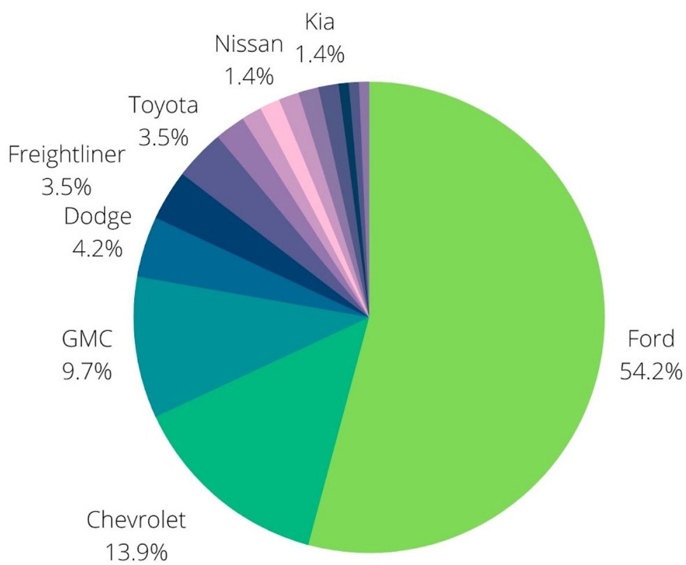

Figure 8. A breakdown of vehicle manufacturers (brands) composing the Campus fleet.

Figure 9 compares the average annual mileage for each MIT Campus Fleet vehicle with that of the U.S. average for light duty trucks, vans, and passenger cars reported in 2018 by the U.S. Department of Energy[22]. From Figure 9, it is evident that MIT Campus Fleet vehicles do not travel long distances, since their operations are mainly restricted to campus grounds. Therefore, this provides a good opportunity for a transition to EVs, since range per charge is not a drastic issue if MIT vehicles are always near the vicinity of a charger. This claim is made under the assumption that new charging infrastructure installation will be performed with the needs of Campus Fleet vehicles (most notably, maintenance and facilities vehicles) in mind.

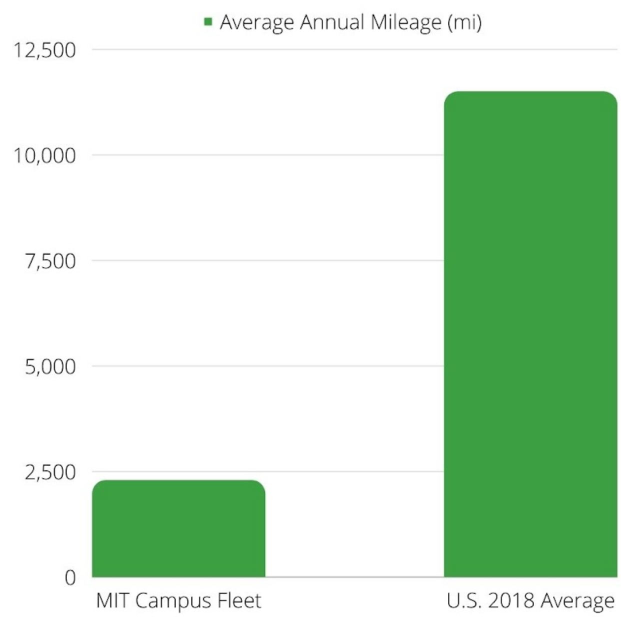

Figure 9. A plot comparing the average mileage of MIT Campus fleet vehicles with the U.S. average mileage for light-duty vehicles in 2018.

The group also analyzed environmental metrics for the Campus Fleet, most notably the average fuel economy, which is a measure of the fuel efficiency of a vehicle represented through the relationship between the distance traveled and fuel consumed (often expressed in units of miles per gallon or MPG). Vehicles with higher fuel economies are more sustainable. Every few years, the US Department of Transportation gradually increases the fuel economy requirement for newly manufactured vehicles as a part of the United States' commitment to reducing transportation emissions. Figure 10 shows a comparison between the average fuel economy per vehicle in MIT's Campus Fleet as of 2022 and the U.S. national average reported in 2020[23]. It is clear that MIT's current Campus Fleet vehicles are trailing behind in terms of fuel efficiency.

Furthermore, the Biden Administration has increased the fuel economy standard for newly manufactured light duty cars and light trucks, including pickup trucks and SUVs, to 49 mpg by 2026[24]. Figure 11 reveals that the current MIT Campus Fleet is only 42.6% of the upcoming fuel economy standard of 49 mpg. As manufacturers race to design more sustainable internal combustion vehicles by the deadline, MIT should be able to increase the average fuel economy of their fleet – whether that is achieved by replacing older vehicles with new gasoline ones with higher fuel economies, or better yet, replacing them with full battery electric vehicles.

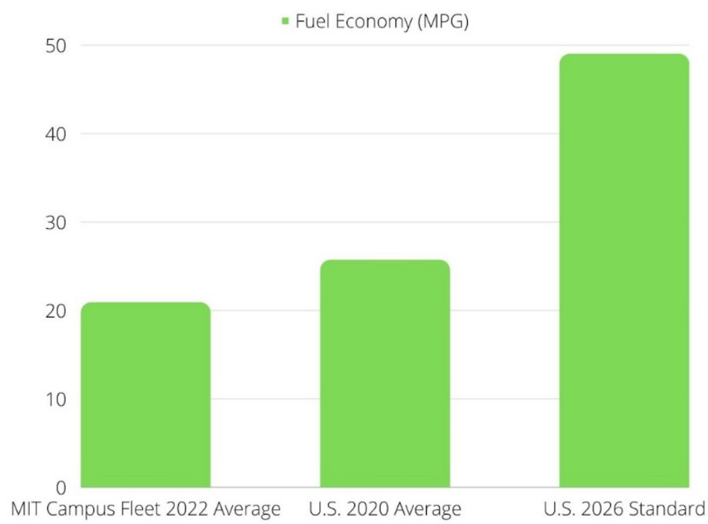

Figure 10. A plot comparing the fuel economies of the MIT Campus fleet, U.S. light-duty vehicles in 2020, and the U.S. standard in 2026.

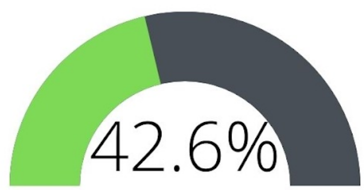

Figure 11. A figure illustrating the fact that MIT's current Campus fleet is only 42.6% of the U.S. fuel economy standard in 2026, leaving MIT with more than 50% of the way to go to reach the standard.

Recommendations for MIT Campus Fleet Electrification

Two phases of fleet electrification

The vehicles composing MIT's Campus Fleet are either managed by Maintenance and Facilities (led by EV Co-lead Martin W O'Brien), Parking and Transportations (led by EV Co-lead Tom Giannino), or other DLCs. Given that two EV Co-leads manage majority of the Campus Fleet vehicles, the group recommends Phase 1 of Campus Fleet electrification to target pickup trucks followed up SUVs managed by Maintenance and Facilities or Parking and Transportations. Phase 2 of Campus Fleet electrification would focus on informing and encouraging other DLCs (e.g. IS&T and labs) to transition to EVs.

Prioritize replacement of oldest vehicles

Regardless of the phase, the group recommends prioritizing the replacement of the oldest vehicles first due to their low fuel economies, high greenhouse gas emissions, as well as their potentially deteriorating conditions. Furthermore, the cost of maintenance and repair for the older Campus Fleet vehicles may exceed the value of the vehicle itself – in which case, purchasing new replacement vehicles, specifically electric vehicles, is not only financially beneficial but also environmentally beneficial.

Phase 1.1 – Replace pick-up trucks

Given the current EV market and the composition of MIT's Campus Fleet, the group recommends replacing current pickup trucks with electric pickup trucks to begin the electrification process. Based on the group's research, it appears that 2022 is the first year in which various automobile manufacturers have begun promoting or pre-selling new electric pickup trucks. The group recognized the new 2022 Ford F-150 Lightning as one of the best options for an electric pickup truck, since Ford vehicles constitute more than half of MIT's Campus Fleet. The Ford F-150 is also one of the most affordable electric pickup trucks introduced to the market, but the specifics of this model (i.e. vehicle size, cargo capacity, payload, etc) are also compatible with the majority of the current Campus Fleet pickup trucks.

The group also recognizes that due to global semiconductor chip shortages in the automotive industry[28], there are delays in the delivery date for EVs, including everything from pickup trucks to SUVs to sedans. Given the group's analysis of the Campus fleet composition, the group still believes replacing pickup trucks first will be more effective in reducing fleet-related greenhouse gas emissions than replacing SUVs first.

Phase 1.2 – Replace SUVs

Following the initial purchases of electric pickup trucks, the group recommends replacing current SUVs. There are relatively few SUVs in the Campus Fleet as seen in Figure 7 to replace, and there are a wide range of models at varying price ranges for electric SUVs already on the market. Electric SUVs tailored towards carrying passengers typically cost less than those tailored towards carrying cargo. Therefore, the group recommends the EV Co-leads assess the purpose of each vehicle in order to find the most suitable replacement EVs.

Phase 1.3 – Replace sedans and vans (when available)

The group recommends replacing current vans and sedans (i.e. small passenger vehicles) operated by Maintenance and Facilities or Parking and Transportations last. Most electric sedans on the market are designed to be luxury vehicles with brands such as Tesla and Mercedes leading the way. Furthermore, sedans are the least common vehicles in the Campus Fleet (Figure 7), and thus, do not contribute much to the GHG emissions of the overall Campus Fleet. Therefore, there is less of an urgency to replace them.

The replacement of vans is hindered by current technologies available in the market in the short-term as manufacturers focus on perfecting the batteries and mechanics of light-duty EVs before tackling the challenge of designing larger vehicles such as vans and trucks. However, Ford is expected to release their 2022 Ford E-Transit All-Electric Van in early 2022 but given this one of the only electric vans already available on the market and its relatively low range of 126 miles per charge, the group believes it is more pragmatic to wait and observe the evolution of the market for electric vans in the next 3-5 years before investing in them.

Phase 2 – Encourage the replacement of light-duty vehicles managed by other DLCs

During Phase 2, the group recommends reaching out to the other DLCs that manage vehicles in the Campus fleet and inform them of MIT's EV-related commitments and encourage them to join the cause.

Explore a partnership with Ford

Given MIT fleet managers' evident trust in Ford vehicles, especially for maintenance and utilities applications, the group recommends establishing a formal business partnership with Ford with assistance from the procurement office. A formal partnership may make MIT eligible to receive special discounts on EV purchases from Ford as well as test-drive new Ford EVs – such as the 2022 Ford E-Transit All-Electric Van – to decide whether to invest in them. This partnership could also entail maintenance and repair training for MIT's mechanics, who can specialize themselves in Ford EV models (and perhaps one or two other EV brands based on necessity).

Utilize a fleet replacement model to compare total lifetime cost of replacements

To estimate the total cost of replacing current fleet vehicles with specific electric replacement currently in the market, the group created a fleet replacement model (Supplemental Information 2) and have summarized the main findings below. Due to limitations in available public data for medium-duty and heavy-duty vehicles, only the light-duty vehicles in the categories of "Light Duty Pickup," "Light Duty Van," "SUV," and "Passenger Car" were considered for the model. Since every vehicle in the aforementioned categories have varying resale values and annual mileage, the exact replacement cost will differ between vehicles. Keeping in line with the previous recommendations of replacing the oldest vehicles in the fleet first, the oldest vehicles in each of the four categories will be considered for the purpose of this summary.

- For the category of "Light Duty Pickup," the current 2005 Ford Ranger Utility was considered.
    - Gasoline Replacement: 2022 Ford F150
    - Electric Replacement: 2022 Ford F150 Lightning

- For the category of "Light Duty Van," the current 2003 Chevrolet Express 2500 Van was considered.
    - Gasoline Replacement: 2022 Ford Transit Connect
    - Electric Replacement: 2022 Ford E-Transit

- For the category of "SUV," the current 2011 Ford Explorer Limited was considered.
    - Gasoline Replacement: 2022 Ford Explorer
    - Electric Replacement: 2022 Hyundai Ioniq 5

- For the category of "Passenger Car," the current 2012 Ford Focus SE was considered.
    - Gasoline Replacement: 2022 Toyota Camry
    - Electric Replacement: 2022 Chevrolet Bolt EV

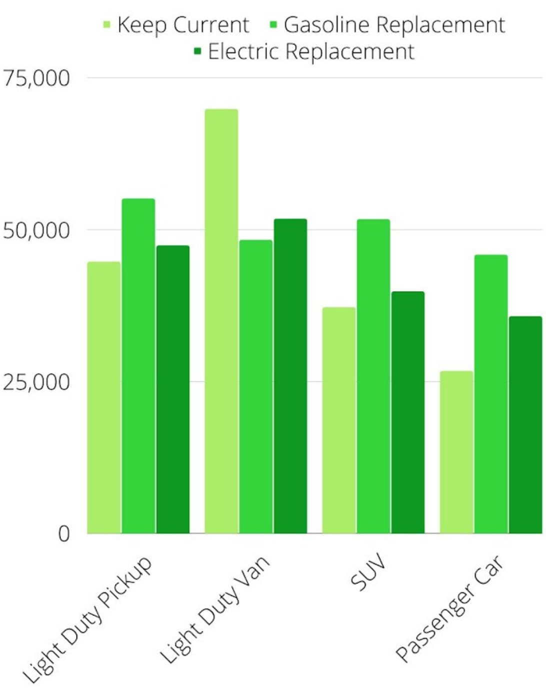

Figure 12. A plot comparing the total lifetime cost over 10 years for three scenarios – keep current fleet vehicle, sell current vehicle and purchase a gasoline replacement, or sell current vehicle and purchase an electric replacement.

It is evident from Figure 12 that EV replacement for current light duty pickup trucks, SUV, and passenger cars are generally lower in total cost of ownership over a 10 year period than gasoline replacements. The total cost of ownership may vary depending on the specific model or brand of replacement vehicle chosen, but the general trend is that EV replacements will likely cost approximately the same – and in some cases, less than – gasoline replacements. The results of the model supports the group's recommendation to take priority in replacing the oldest fleet vehicles first, starting with the light-duty pickup trucks.

Analysis and Recommendation of MIT Police Vehicles Fleet

The MIT Police Department owns 21 relatively new vehicles, with 2 being motorcycles, 2 being hybrid electric vehicles, and 3 being more than 10 years old. Half the fleet (10 vehicles) is made up of SUVs, with the remaining being cargo vans (2) and sedans (7).

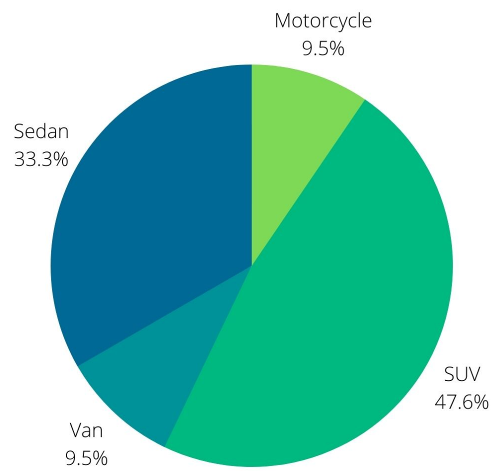

Figure 13. A breakdown of the police vehicles fleet.

Phase 1 – Replace SUVs

The group recommends the replacement of the SUVs first, given the availability of a suitable substitute on the market. The Mustang Mach-E has passed Michigan State Police tests[25], gaining recognition for its trunk accessibility, top acceleration and sturdy braking systems, and has been purchased in hundreds by the NYPD. Furthermore, SUVs are the predominate vehicle types in the police fleet; therefore, replacing them first would allow the police vehicles fleet to most effectively reduce their GHG emissions.

Phase 2.1 – Replace sedans based on availability of suitable model

While the sedan market grows, the Tesla Model 3[26] can also be considered for sedan replacement, given its use by several police departments, such as the NYPD. However, the group recognizes the Tesla EVs are often more costly than EVs from other manufacturers, so the group recommends pursuing Tesla EVs as police vehicles only if no better alternative can be identified in the next 3-5 years.

Phase 2.2 – Replace motorcycles based on availability

The Harley Davidson Electric LiveWire motorcycles are also worth exploring as a replacement, as they have been used by police departments such as the Vermont DMV[27].

Phase 2.3 – Replace vans based on availability

Finally, while van options like the 2022 E-Transit exist, they have not been tested or piloted, and the group recommends waiting and watching the growth of the EV market and police department vehicle tests for possible cargo van replacements for the MIT police.

Challenges Regarding Fleet Electrification and Recommended Solutions

The group recognizes that a key challenge in the full electrification of MIT's approximately 250 vehicle fleet is inciting DLCs beyond Maintenance and Facilities to join the electrification cause. Other DLCs have full autonomy over the type of vehicles they purchase but may not be aware of the cost and environmental benefits of EVs or be able to afford or coordinate a transition to EVs. In response to this main challenge, the group presents the following two solutions.

Solution 1: "Mind and Heart" Campaign

Utilize a "Mind and Heart" campaign to convince DLCs that are not led by EV co-leads (such as Martin or Tom) to consider transitioning to EV or only purchasing EV vehicles from now on if they decide to add to their fleet. The campaign can include test-drives or car loans where DLC leads drive EVs under Maintenance and Facilities as a means of encouraging them to transition. Other ideas are crafting EV transition pledges that individual DLCs can sign once they have decided to transition, at whatever pace they decide to. DLCs with very low annual mileage could also be introduced to lower-cost creative solutions, whenever feasible, such as the possibility of 2 DLCs sharing a single electric vehicle.

Solution 2: EV Leasing Program

A second, perhaps more ambitious, solution the group recommends is for MIT's Parking and Transportation or Facilities groups to establish an EV leasing program. This may be attractive to DLCs that own gasoline vehicles with low annual mileage and wish to adopt EVs into their operations but do not wish to commit to purchasing and maintaining their own EVs. The EV leasing program will allow such DLCs to rent EVs owned by Parking and Transportation or Facilities for a fee (similar to renting an MIT-owned shuttle), which will help cover the initial purchase cost of these EVs. By making the EV adoption process more convenient and affordable for DLCs, the group believes there will be less resistance to fleet electrification.

Recommended Timeline for Campus Fleet Electrification

The group based the following timeline for Campus Fleet electrification on the amount of state incentives from the MOR-EV light-duty vehicles program and the MOR-EV Trucks program. MIT's access to these incentives is subject to the availability of funding, which can be quickly depleted over the next few years. Therefore, the recommended timeline takes maximum advantage of the MOR-EV rebates while they last.

With the following timeline, the group aims to replace approximately 101 light-duty vehicles and 43 medium or heavy-duty vehicles in the Campus fleet over the next 12 years from Fiscal Year 2023 to Fiscal Year 2034.

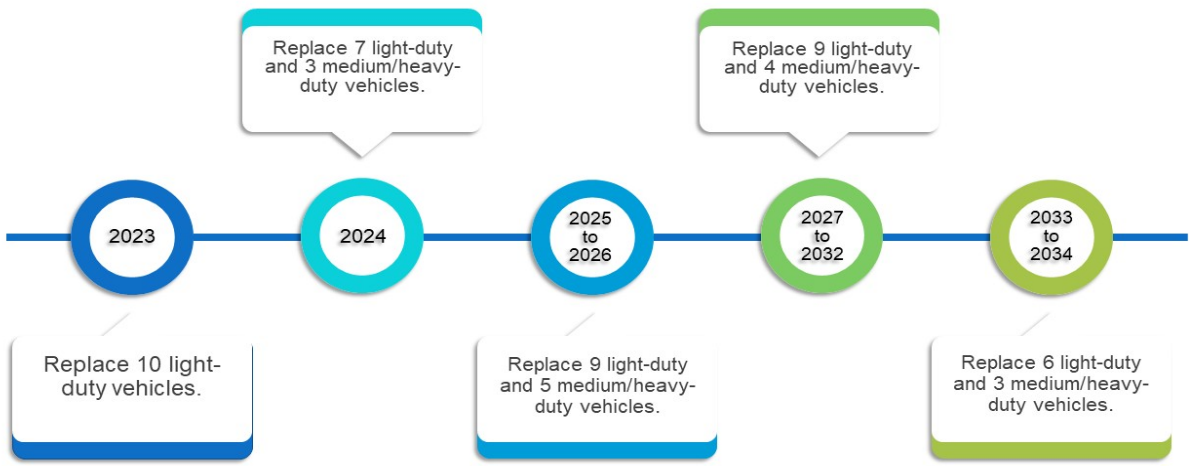

Figure 14. Timeline for the recommended EV purchase schedule for 144 relevant vehicles in the Campus fleet, to be completed over the course of 12 years starting in Fiscal Year 2023 and completing in Fiscal Year 2034.

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References

1. https://climate.mit.edu/climateaction/fastforward
2. https://about.bnef.com/electric-vehicle-outlook/
3. https://about.bnef.com/electric-vehicle-outlook-2020/
4. https://dspace.mit.edu/bitstream/handle/1721.1/115600/1036985839-MIT.pdf?sequence=1
5. https://tps.uga.edu/transit/electric-buses/
6. https://news.harvard.edu/gazette/story/2021/10/harvard-adds-four-electric-shuttle-buses-to-fleet/
7. https://transportation.columbia.edu/content/our-electric-buses
8. https://today.duke.edu/2021/01/new-electric-buses-roll-campus-roads
9. https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/
10. https://www.forbes.com/sites/neilwinton/2021/11/28/solid-state-batteries-promise-electric-car-popularity-boost-but-technical-mountains-await/?sh=c37d342632fa
11. https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions
12. https://www.ucsusa.org/sites/default/files/attach/2019/04/Electric-Utility-Investment-Truck-Bus-Charging.pdf
13. https://www.mass.gov/lists/massdep-waste-recycling-grants-assistance#:~:text=MassDEP%20Programs,-Sustainable%20Materials%20Recovery&text=An%20open%20source%20set%20of,of%20recycling%20in%20your%20community.&text=Grants%20of%20up%20to%20%245%2C000,short%2Dterm%20waste%20reduction%20projects
14. https://cleantechnica.com/2020/12/11/new-york-v2g-project-using-5-electric-school-buses-is-live/
15. https://about.bnef.com/electric-vehicle-outlook/
16. https://www2.deloitte.com/us/en/insights/focus/future-of-mobility/electric-vehicle-trends-2030.html
17. https://mitsloan.mit.edu/ideas-made-to-matter/real-barriers-to-electric-vehicle-adoption
18. https://www.ucdavis.edu/news/carbon-neutrality-initiative
19. https://www.bu.edu/sustainability/projects/electric-vehicles/
20. http://sustainability.mit.edu/ghginventory#!2021%20ghg%20update
21. https://mor-ev.org/
22. https://afdc.energy.gov/data/10309
23. https://www.energy.gov/eere/vehicles/articles/fotw-1177-march-15-2021-preliminary-data-show-average-fuel-economy-new-light#:~:text=Preliminary%20data%20for%20EPA's%202020,miles%20per%20gallon%20(MPG).
24. https://www.cnn.com/2022/04/01/energy/fuel-economy-rules/index.html
25. https://media.ford.com/content/fordmedia/fna/us/en/news/2021/09/24/tough-enough-for-law-enforcement-mustang-mach-e.html
26. https://electrek.co/2021/12/30/nypd-buys-184-ford-mustang-mach-e-approves-option-buy-250-tesla-model-3/
27. https://www.wcax.com/2022/03/29/vermont-dmv-gets-first-its-kind-motorcycle/

28. https://www.consumerreports.org/buying-a-car/global-chip-shortage-makes-it-tough-to-buy-certain-cars-a8160576456/