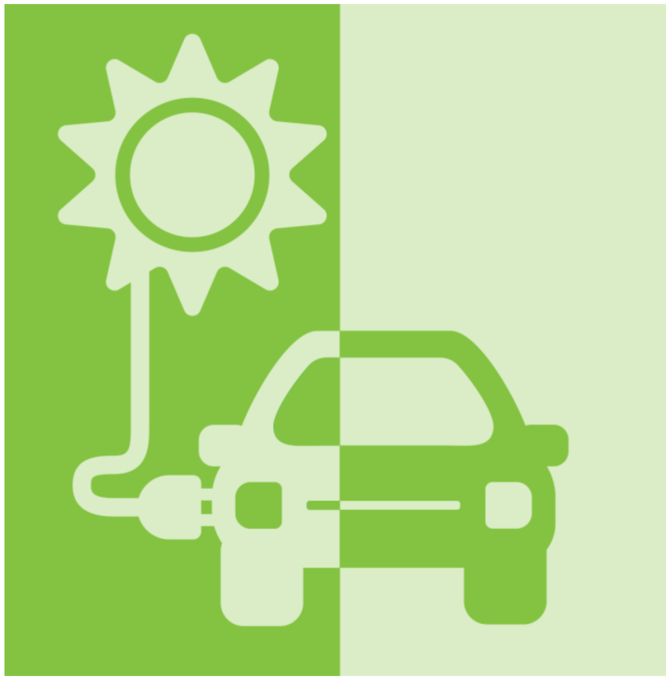

Mobility Electrification at the University of Michigan

A Report Developed for and Supported by the U-M President's Commission on Carbon Neutrality

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Creators

Juan-Jie Sun

Kamryn Hayes

Preston VanAlstine

Jason Siegel

John DeCicco

Anna Stefanopoulou, Faculty Lead

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Executive Summary

Transportation operations are a small but significant source of greenhouse gas (GHG) emissions, comprising 3% of the University of Michigan's scope 1 inventory. Much greater GHG emissions come from personal vehicles used by U-M commuters, including faculty, staff, students, and campus visitors. Although they fall in scope 3, commuting emissions amount to 120,000 metric tons CO_2 equivalent per year (tCO_2e/yr), as much as 44% of U-M's scope 1 GHG emissions.

Shifting to electric vehicles (EVs) is an important way to reduce GHG emissions. Using electricity from U-M's renewable Power Purchase Agreement with DTE Energy, we estimate GHG emission reductions of 74% for an electric bus and 73% for personal vehicles compared to their internal combustion engine vehicle (ICEV) counterparts. GHG emissions from EV use will decrease over time as the electricity grid transitions to cleaner energy, supporting a path toward carbon neutrality.

The Mobility Electrification Subgroup studied the transition potential and challenges to electric buses and commuter EVs. Key recommendations include:

- Plan the transition to an all-electric campus bus fleet, taking advantage of available subsidy programs and public-private partnerships to defray the higher up-front costs of electric buses and charging infrastructure. Electric buses and charging systems that are now commercially available can serve all Blue Bus routes, including intensively used routes, and endure cold weather conditions. The recent application for financial aid to acquire two articulated buses and charging infrastructure in the proposed bus maintenance facility is an excellent start and should be expanded.
- Invest in building a networked and equitable charging infrastructure for faculty and staff. Access to convenient charging would incentivize EV adoption for personal commuting and vanpooling. Coordinate workplace charging infrastructure for commuting vehicles and micro-mobility with area transit hubs and future rapid-transit connectors. Coordinating infrastructure deployment with the City of Ann Arbor, the State of Michigan, and industry can spur a regional transition to 20% EVs by 2030 and establish a living laboratory on e-mobility, which can be a powerhouse for economic and workforce development.
- Implement an EV educational campaign to raise EV awareness among the U-M commuting population, providing information on the benefits of EVs and on incentive programs, fuel cost savings, and charging availability.
- Commit to and assume a leadership role in Southeast Michigan on future work in e-mobility. We are in the heartland of the nation's automotive and manufacturing industry; U-M should build on its unique assets and core competencies, as well as Southeast Michigan's automotive identity, to create economic and educational opportunities in clean electric mobility solutions.

Pursuing these measures will provide significant GHG reductions. Full electrification of the U-M Blue Bus fleet will reduce GHG emissions by at least 37,000 tCO_2e (787 lifetime mtCO2/bus for 48 buses/fleet) over the typical 12-year lifetime of the buses. Expanding Ann Arbor campus charging infrastructure and promoting EV use by long-distance (20+ miles) U-M faculty and staff commuters to achieve 20% EV adoption by 2030 would reduce GHG emissions by roughly 110,000 tCO_2e over 12 years.

Overview of the Challenge

Carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions from transportation, including campus buses and other U-M managed vehicles as well as private vehicles used to commute to or visit the University's campuses, are a significant part of U-M's contribution to global warming. Ways to mitigate transportation emissions include minimizing personal vehicle use, improving fuel economy, shifting to electric vehicles (EVs), and offsetting any combustion CO_2 emissions that remain.

This report by the Mobility Electrification Subgroup of the President's Commission on Carbon Neutrality (PCCN) addresses the opportunities to shift from internal combustion engine vehicles (ICEVs) to EVs. Replacing a gasoline or diesel ICEV with an EV will zero out the direct (tailpipe) GHG emissions, that is, the emissions within the transportation sector itself. Depending on how an EV is charged, it would increase indirect (upstream) GHG emissions in other sectors, such as electric power generation. Analysis is needed to assess the net emission impacts as well as the financial impacts of a shift to EVs. Key barriers to EV adoption include the higher first cost of EVs compared to ICEVs, the up-front investment needed to provide charging infrastructure, and limited public awareness of EV options and benefits.

The U-M fleet includes the campus bus service (Blue Bus) fleet; light- and medium-duty trucks and utility vehicles used for operations and maintenance across the U-M campuses; plus cars, vans, and other vehicles available to university units for daily rental or for short- and long-term leasing. As of 2019, the U-M fleet accounted for direct GHG emissions of 7,400 metric tons of CO_2 equivalent per year (tCO_2e/yr), or roughly 3% of the University's scope 1 GHG inventory of 278,000 tCO_2e/yr.[1] U-M's Blue Buses are the largest part of fleet emissions; they are also highly visible and heavily used, making them an ideal initial focus for fleet electrification.

A much greater quantity of emissions comes from the personal vehicles used by individuals traveling to and from campus. Commuting vehicles are defined here to include cars and light trucks used by faculty, staff, and students who drive to campus as well as vehicles used by campus visitors. We estimate faculty, staff, and student commuting emissions at roughly 120,000 tCO_2e/yr (Appendix C). Although they fall into scope 3, such emissions represent a substantial aspect of U-M's overall climate impact, comparable in magnitude to about 40% of the University's scope 1 emissions. This report therefore includes analysis of ways to encourage increased EV use by individuals who commute to and park on campus.

Key Findings

Findings are summarized in two categories: namely, U-M Fleet Electrification (**eFleet**) and measures to encourage EV adoption by commuters (**EVopt**):

- **eFleet Leadership**: Transit authorities around the nation are electrifying their fleets. Peer institutions have also made significant strides transitioning to campus electric bus (eBus) fleets with successful operations and cost savings. Electrifying the campus bus fleets in Ann Arbor and Dearborn builds on U-M's unique position and core competencies as a leading research institution located near the heart of the nation's automotive and manufacturing industries.
- **eFleet GHG Reduction[2]:** An electric bus on an average route and charging from the U-M grid would save 52 tCO_2e in 2022. As elaborated below, we examined two scenarios—(1) rapid, acquiring four new eBuses per

[1] U-M (2019); sum of fossil plus renewable mobile source GHG emissions.

[2] Note that the estimates presented here are based on analyses planned before the COVID-19 pandemic and its profound impact on all U-M operations, including campus bus service. Because the results are based on bus route and usage

year, and (2) slower, acquiring two new eBuses per year—for complete conversion of the UM-Ann Arbor Blue Bus fleet. Figure 1 shows the resulting projections of cumulative GHG reductions. Rapid conversion offers cumulative abatement of about 44,000 tCO_2e by 2040, and slower conversion offers about 26,000 tCO_2e cumulatively by 2040. In both cases, abatement increases as years go on.

- **eFleet Cost:** Data from suppliers in 2019 without any subsidy assumptions shows:
  - An eBus costs about $760,000, which is $310,000 more than a diesel bus.
  - A bus depot charger has an equipment cost of about $65,000; we assume one depot charger per eBus.
  - An eBus has much lower operating and maintenance (O&M) costs than a diesel bus, saving $30,000 per year on an average route as detailed in Table B2.

  The rapid scenario for fully transitioning the Blue Bus fleet to electric in 12 years, corresponds to a cumulative net additional cost that peaks at $3.8M in 2027 as shown in Figure 2, after which the life cycle cost of operating eBuses continues to decline. A lower cost of $1.9M is projected for the slower scenario of converting the fleet in 24 years, as also shown in Figure 2. Annual net costs decline as battery prices fall and O&M savings accumulate. An analysis of electrifying the Dearborn campus buses is given in Table B7.

- **eFleet Cost-Effectiveness:** Although initially $23/$tCO_2e$, cost-effectiveness improves rapidly as eBus costs fall, O&M savings accumulate, and the electric grid becomes cleaner (Figure B7). By 2022, electric buses become more cost-effective to acquire and operate than diesel buses, and bus electrification will be a better-than-zero cost-per-ton investment.
- **eFleet Equity:** Improved intercity transit service connecting Detroit, Ann Arbor, Dearborn, and Flint as well as outlying communities such as Brighton and Toledo would better serve employees that live far from Ann Arbor for affordability reasons. Such transit solutions are best developed in coordination with regional transit agencies, and using electric buses for shuttle vans on intercity routes would provide additional GHG reductions and long-term operational cost savings.
- **EVopt Leadership**: U-M can assume a regional leadership position in workplace charging and by coordinating with national and international efforts on EV adoption. Although the analysis reported here focuses on Ann Arbor, additional opportunities to encourage EV adoption by commuters to U-M's Flint and Dearborn campuses should also be explored by teams from their campuses.
- **EVopt GHG Reduction**: Expanding the UM-Ann Arbor campus charging infrastructure to serve 20% EV adoption by long-distance (20+ miles) faculty and staff commuters by 2030 would reduce GHG emissions by about 9,200 tCO_2e annually (Table C12), for a cumulative emission reduction of roughly 110,000 tCO_2e over 12 years. Long-distance commuters create the highest amount of emissions and thus stand to see the highest emission reductions among all commuters.
- **EVopt Feasibility**: Level 2 (L2) chargers with two ports provide convenient charging capable of supporting all U-M commuting distances, and the networking capabilities of L2 chargers enable useful features such as collection of utilization data and smart power management.
- **EVopt Cost-Effectiveness**: Prioritizing charging infrastructure for long-distance commuters provides the most cost-effective GHG reductions, estimated as $116/$tCO_2e$ over 12 years, taking into account the equipment acquisition, installation, maintenance, and electricity cost. Supporting EV charging for campus commuters of all distances is less cost-effective at $191/$tCO_2e$ (Appendix C, Section 5).
  - To support 20% EV use by long-distance faculty and staff commuters by 2030, we estimate the need for 1,088 2-port L2 chargers, involving an up-front cost of roughly $3.6 million (Table C6).

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assumptions reflecting conditions prior to the pandemic, they should be taken as no more than broadly illustrative of the feasibility and benefits of bus electrification.

- The cost to the University, already included in our total cost, for providing electricity to EV commuters with this level of EV charging would be about $700,000 annually (Table C8).
- Maintenance costs for 1,088 chargers, already included in our total cost, are estimated at about $73,000 annually on average over 12 years (Appendix C).

- **EVopt Commuter Fuel Cost Savings:** Employees commuting these longer distances are projected to save roughly $14,000 in commuting fuel costs over 12 years when using an EV with free charging for their commuting miles rather than paying for gasoline, providing an additional incentive for EV adoption (App. D).
- **EVopt Culture**: Lack of information and familiarity are barriers to EV adoption. The education effort we recommend for addressing these knowledge gaps will help spur EV use by commuters and be highly synergistic with broader efforts to enhance a culture of sustainability at U-M.

Prioritized Recommendations Summary

- **Pursue the transition to an eBlueBus fleet.** U-M should transition to an all-electric campus bus fleet by 2035 with an initial 12-year cost-effectiveness of $23/tCO_2e$. Seek opportunities to collaborate with the Ann Arbor Area Transportation Authority (AAATA) in pursuing subsidies to defray the higher up-front costs of electric buses and the charging infrastructure.
- **Expand workplace charging infrastructure.** U-M should invest in rapidly building a charging infrastructure for faculty, staff, students, and visitors, aiming to support 20% EV adoption of long-distance (20+ miles) faculty and staff commuters by 2030 and coordinate with the City of Ann Arbor, the State of Michigan, and industry to lead a regional transition to EVs.
- **Implement an EV educational campaign.** U-M should develop and launch a campaign to raise EV awareness among the U-M commuting population, providing information on the benefits of EVs and on incentive programs, fuel cost savings, and charging availability. We also recommend that U-M initiate a cross-university coalition to share best practices for EV readiness and promotion among universities in Michigan, the Midwest, and the country as a whole.
- **Pursue more in-depth analysis of mobility electrification options.** The analysis reported here is best viewed as preliminary. PCCN should further examine options for mobility electrification at U-M and provide resources for more in-depth analysis to address the gaps and uncertainties that remain.

Priority Recommendations

1. Transition to an electrified bus fleet

Recent years have brought great strides in the deployment of electric buses (eBuses). Leading transit agencies in California, New York, Seattle, Chicago, and elsewhere are buying eBuses in greater numbers, with announcements implying that at least one-third of all U.S. transit buses will be electric by 2045.[3] Recent Chicago Transit Authority (CTA) plans include purchasing 20 electric buses and installing five extreme fast-charging (xFC) stations[4] as well as a commitment to a fully electric transit fleet by 2040. A number of universities have begun electrifying their campus bus fleets.[5]

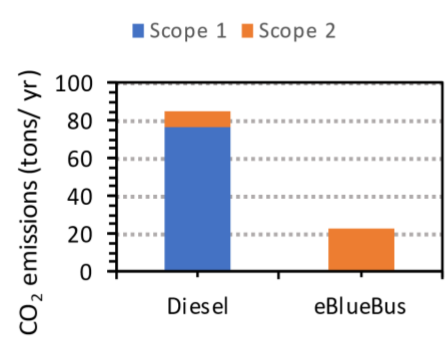

Figure 3: GHG emissions comparison

[3] EB Start (2019).
[4] CTA (2018).
[5] Sun et al. (2020).

We recommend that U-M move expediently to transition to an all-electric campus bus fleet. UM-Ann Arbor maintains a transit fleet of roughly 55 buses with 48 40-foot buses and typically replaces four buses per year. If the U-M allocates these funds toward purchasing eBuses instead of diesels, the University could make the transition to an all-electric Blue Bus (eBlueBus) fleet by 2035. The UM-Dearborn fleet, currently three buses, can also be transitioned to electric buses. Having electric bus service on its campuses will provide U-M with a highly visible example of its leadership in moving toward a carbon-neutral future.

A step forward in this regard was a recent proposal from the Logistics, Transportation and Parking (LTP) office for a Federal Transit Administration (FTA) "Lo-No" (Low emissions/No emissions) grant to help acquire two battery-electric articulated buses. Although U-M did not receive the award, the effort positions the University to apply for other such grants as they become available.

Carbon emission reduction potential. Our analysis of GHG emissions and costs is summarized in Appendix B, referencing a technical report by Sun et al. (2020). Figure 3 compares diesel and electric bus GHG emissions on an average route. An eBlueBus would reduce combined scopes 1 and 2 emissions by 62 metric tons of CO_2 equivalent per year (tCO_2e/yr), or 74% relative to current average diesel bus emissions of 85 tCO_2e/yr.

This estimate is for U-M electricity in 2022 as supplied under the Renewable Power Purchase Agreement (PPA) with DTE. Emissions will fall further as DTE's mix becomes cleaner,[6] as shown in Fig. 4. Over a 12-year bus lifetime, the cumulative emission reduction for electrification would be 787 tCO_2e per bus on average (Table B4).

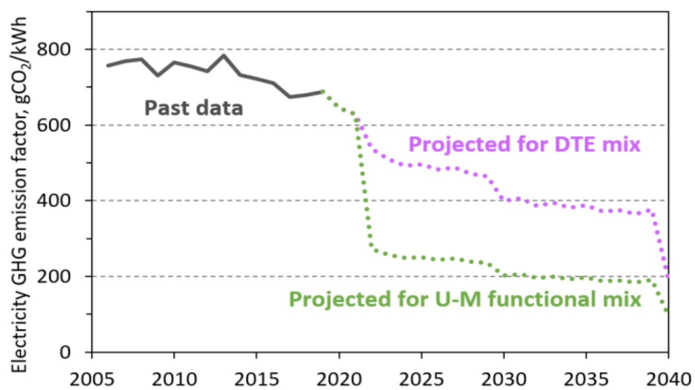

Figure 4. Carbon intensity of electricity supplied to University of Michigan

Comparable GHG reductions of roughly 60% can be achieved by electrifying the UM-Dearborn campus buses (Table B7).[7] For intercity buses, we estimate GHG reductions of 66% compared to diesel buses (Table B6), which would amplify the emission reductions from replacing the intercity car trips with bus trips.

Financial considerations. An electric bus with the basic battery warranty currently costs about \$760,000, or \$310,000 more than a diesel bus. The equipment cost of a depot charger is about \$65,000; one depot charger is needed per electric bus. (En route extreme fast charging is a possible future option for running multiple electric buses on an intensively used route; see Sun et al. 2020.)

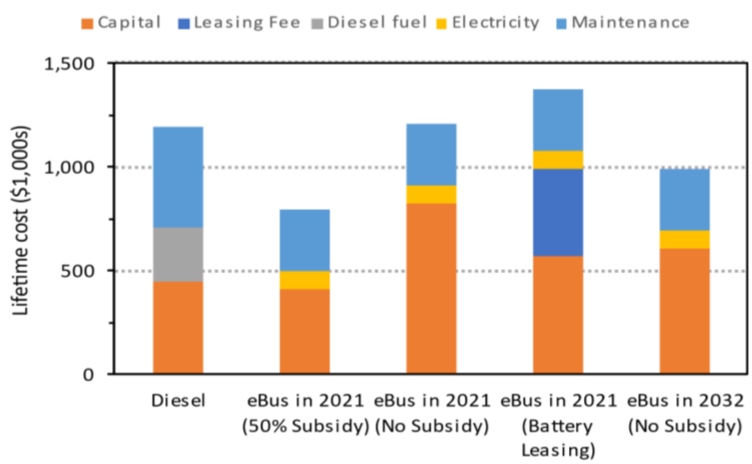

Figure 5: Diesel and electric bus lifetime cost comparisons

Electric buses have much lower O&M costs than diesel buses, for estimated savings of \$30,000 per year on an average route. Figure 5 compares 12-year lifetime costs. At present, the up-front costs of an eBus can almost be

[6] Keeler (2020).

[7] We thank Prof. Wencong Su, UM-Dearborn, for data on Dearborn campus bus routes.

recovered through lower O&M costs over a 12-year lifetime without a subsidy. The 50% subsidy offered by the Federal Transit Administration covers the extra capital cost needed for purchasing the ebus plus the charger. This immediately enables O&M savings ($30,000 per year) and results significant net savings compared to a diesel bus over a 12-year bus lifetime. U-M should therefore take advantage of available subsidy programs to defray the higher up-front costs of the electric buses and their charging infrastructure.

Metrics and tracking. Metrics for monitoring progress on this recommendation include:

- number of electric buses acquired;
- CO_2 reductions, electricity use, and diesel fuel savings;
- costs of electric buses and charging infrastructure; and
- achieved O&M costs and savings relative to diesel buses.

Organizational structure considerations. Campus bus service is a mission-critical operation; high reliability and safety are essential for getting students to class on time and providing timely connections across U-M's spatially distributed campuses. Bus electrification will entail added costs as well as new training for drivers and mechanics and new operational procedures, and thus U-M's LTP office will need adequate support as it makes the transition to electric buses.

Campus culture and individual accountability considerations. No particular issues beyond those customary for the operation and use of Blue Bus service are likely to be entailed.

Equity and justice considerations. Campus buses serve individuals from all U-M demographic groups and are particularly relied upon by individuals who lack access to automobiles. eBlueBuses will maintain the equity and social justice features of mass transit services. Because they greatly reduce local air pollution and direct individual exposures to toxic exhaust pollution from diesel buses (Table B5), electric buses will enhance welfare for those who rely on campus bus service as well as the surrounding community. In this manner, eBuses support U-M equity and environmental justice goals.

Scalability, transferability, and external engagement. Electrifying the U-M bus fleet would help increase the already growing scale of electric transit bus use in the United States as noted above. It would also position U-M as a leader in our region, providing operational experience that can be transferred to the AAATA and other regional transit agencies.

Timeline for implementation. Assuming a fixed fleet size of 48 buses, purchasing four electric buses instead of diesel buses each year starting in 2022 until 2033 would make the fleet 100% electric by 2033 (Figure B8). Electric bus costs will fall over time so that in future replacement cycles, they would be even more cost competitive with diesels without subsidies. We therefore examined a scenario of purchasing only two electric buses in the early years, resulting in a complete transition to electric buses by 2045 (Figure B10).

Potential implementation challenges. At this point in time, electric bus service has a proven track record in multiple jurisdictions of providing reliable, zero-local-emissions transit service. The major challenge is the higher up-front cost of electric buses relative to diesel buses and the investments required for charging infrastructure, including additions or modifications to the bus depot and other campus buildings. High-level commitment is needed to ensure U-M applies for all possible subsidies and partnerships that allow us to be early adopters and leaders.

Unknowns, gaps, and/or additional analysis required. Further financial and implementation planning analysis will be needed by LTP and other units as may be helpful. Electric bus costs will fall, but how fast they will fall is uncertain. Also uncertain are the availability and amount of public subsidies for defraying the added capital cost of electric buses and charging equipment. Although the GHG reduction analysis could be further refined, there is little doubt that bus electrification will lead to significant net GHG reductions that will grow over time as the electric grid is decarbonized, as is expected given DTE's stated goals of reducing CO_2 emissions 50% by 2030 and achieving net carbon neutrality by 2050.

Critical next steps to catalyze work. We recommend that U-M move expediently to pursue a transition to an all-electric campus bus fleet by applying for every possible subsidy, along with a full study for optimal routes, charging infrastructure, battery capacity, and a hybrid fleet of buses and/or shuttles.

2. Establish workplace charging infrastructure

Based on campus commuting vehicle-miles of travel (VMT) estimates compiled by the commuting team,[8] the estimated number of faculty and staff vehicles traveling to the Ann Arbor campus is roughly 38,000 per day. The Flint and Dearborn campuses also have significant commuting populations, each equal to about 3% of the Ann Arbor level of commuting travel in terms of VMT. Although we did not perform an analysis specific to those campuses, data were recently made available for Dearborn.[9]

Currently 14 Level 2 (L2) charging stations are available on the Ann Arbor campus.[10] Expanding the EV charging infrastructure will enable more widespread EV use for travel to and from campus, lowering the University's scope 3 emissions. U-M should greatly expand the availability of charging stations across all of its campuses to enable and encourage rapid EV adoption by campus commuters.

Commuter EV Adoption Target

To determine the number of EVs that U-M should target serving, we reviewed goals articulated by the City of Ann Arbor and other entities (Appendix C). Ann Arbor aims for 20% of registered vehicles used in the city to be EVs by 2030, supporting the A^2Zero goal of achieving carbon neutrality by 2030.[11] We recommend that U-M adopt this target for its long-distance faculty and staff commuters (those traveling more than 20 miles) because this population offers the highest emission reduction per dollar spent. We used this target to estimate the number of EV chargers needed, costs, and GHG reductions. We did not include an EV adoption target for students because of their relatively small share of the commuter population (about 23%) and more limited financial ability to afford electric vehicles.

The number of chargers discussed here should be taken as illustrative; further analysis engaging LTP is needed to develop a specific charging infrastructure build-out plan. Targeting 20% EV use by 2030 for long-distance commuters to the Ann Arbor campus implies a need for approximately 1,088 L2 chargers (Table C6). The Dearborn and Flint campuses also have significant numbers of long-distance commuters. As the electricity grid is decarbonized over the next few decades, U-M should consider expanding this initial charging infrastructure to support EV adoption by commuters from all distances.

Carbon emission reduction potential. Projecting the GHG reduction from substituting EVs for internal combustion engine vehicles (ICEVs) is difficult due to uncertainties involving the baseline vehicle mix, which particular ICEVs the EVs will replace, vehicle stock turnover, and the fleet averaging structure of the federal GHG emission standards for motor vehicles. We developed projections by calculating the GHG reduction an individual could see when using an EV and then aggregating over the commuting vehicle population with assumed charger utilization levels but without attempting to model net fleetwide GHG emission effects.

Under such assumptions and the above mix of charging stations, the projected GHG emission reduction for EV adoption by 20% of long-distance faculty and staff commuters would be 9,200 tCO_2e/yr in 2030 (Table C8),

[8] Commuting Internal Analysis Team (2020).

[9] Acknowledgment to Prof. Wencong Su, UM-Dearborn, for data on Dearborn campus commuting patterns.

[10] See U-M (n.d.) for a summary of current EV charging infrastructure.

[11] Stanton (2020).

equivalent to about 10% of current commuting emissions. As noted for the bus analysis, EV emission reductions will grow over time as the regional electric grid continues to decarbonize.

Financial considerations. EV charger installation costs depend greatly on the extent of civil work needed; the U-M Architecture, Engineering and Construction (AEC) office has estimated as much as $30,000 for a 4-port charging station in a location where new electrical conduit would need to be run.[12] Costs would be much lower for locations adjacent to buildings or in parking structures requiring less construction work and thus developing a strategy to minimize installation costs will be important. Charger equipment costs are relatively modest and can be under $1,500 per L2 charging port. Assuming optimized installations and costs from the literature, we projected a charging infrastructure investment of roughly $4 million for the 1,088 L2 chargers needed to support 20% EV use by long-distance faculty and staff commuters by 2030 (Table C6). The corresponding cost-effectiveness metric is $116/t$CO_2$e. Further discussion and estimation details are provided in Appendix C.

We recommend that U-M continue to cover the electricity cost for workplace charging. Our analysis implies an annual cost of roughly $700,000 for this benefit. Note that free EV charging does not imply free parking; the EV owners would still be required to purchase U-M parking permits for the lots where the chargers are located.

The only expected maintenance costs would be for damaged cords (about $200 each), a recurring cost projected to reach roughly $73,000 per year once the 1,088 L2 chargers are fully installed. Little information is available on the life span of charging equipment because of the relatively young market; researchers typically assume a 10-year life span for budgeting purposes, at which point equipment costs likely will have greatly decreased through economies of scale.

Metrics and tracking. Metrics for monitoring progress on this recommendation include:

- the number of electric vehicle charging stations installed by charger level;
- actual costs of charging equipment purchase, installation, and electricity use;
- charger utilization data including electricity consumption and session durations; and
- the implied CO_2 reductions and fuel cost savings.

Organizational structure considerations. Currently, users of L2 charging stations do not pay for the electricity, access to which is enabled with a valid U-M parking permit or purchase of a visitor parking space. There is a 4-hour charging limit, and spaces are enforced by UMPD. These policies should remain in place except for the 4-hour charging limit, which we recommend eliminating for faculty and staff to prevent the unnecessary hassle of moving vehicles in the middle of the day and to allow EVs time for sufficient charging. The L2 chargers should be networked for monitoring purposes and integrated into a smart system for efficient power management.

To target the long-distance commuters, a new permit should be created for EV owners who commute distances greater than 20 miles. Each year LTP should reserve a number of spaces equal to the number of these new permits issued to ensure that those with far commutes are guaranteed a charging spot but also allowing those who do not fit such criteria to utilize the remaining chargers. These spaces should be reserved through clear signage. Additionally, networked stations can be set up so that only a limited number of users have access to charging through either a swipe card or individual identification using an app with which chargers are synced.

Campus culture and individual accountability considerations. The University should set the expectation that commuters use the campus charging stations for top-off rather than as their main source of electricity, so as to not abuse U-M provision of the charging power.

Equity and justice considerations. Lower-income U-M staff are challenged by Ann Arbor's high cost of living. Many live in outlying communities and have a relatively long-distance commute. To ensure charging access for

[12] Stoltz, A., U-M AEC office, e-mail via A. Berki, "EV Parking Lot charger cost estimates," June 2, 2020.

these employees, we have recommended the creation of a permit described above to reserve charging spaces for those who own EVs and must commute from outside Ann Arbor.

Charging stations will remain free with the proper permits or payment for the parking space to ensure equitable access. These stations should be evenly distributed across permit types to ensure that those who can afford more costly permits are not given priority to chargers. In addition, 4% of the charging spaces need to be ADA accessible.[13]

Timeline for implementation. The COVID-19 pandemic makes a start date difficult to specify; a detailed implementation timeline will need to be developed by AEC, LTP, and the Office of Campus Sustainability (OCS). One option is to start installing new chargers in 2021 and divide the number of installations evenly over the following 9 years through 2030. In any case, U-M should monitor EV adoption rates by its commuters and regionally, updating the infrastructure development plan as needed.

Potential implementation challenges.

- A barrier to any project of this scale is cost.
- Charging station installation will temporarily disrupt parking availability, and therefore temporary supplemental parking may be needed during the process.
- Each parking lot or structure is set up and wired differently, making uniform construction methods unlikely.

Unknowns, gaps, and/or additional analysis required.

- Inspection of parking lots and structures and current electrical servicing is needed to gain greater insight into accurate installation costs.
- Additional analysis is required to further understand the potential costs and emission reductions of electrifying the University's non-bus vehicle fleet.
- Additional analysis is needed on charging infrastructure for the Flint and Dearborn campuses. Data for these campuses also shows commuting emissions dominated by those driving longer distances,[14] and so similar targeting of charging infrastructure is likely to be appropriate.
- Charging infrastructure costs can vary greatly depending on the site and the uncertainties can only be narrowed through further location-specific station planning analysis.

Scalability, transferability, and external engagement. Our recommended targets for EV charging station installations are based on the City of Ann Arbor's goal of 20% EV use by 2030, ensuring that the University's investments help scale across the community. U-M should coordinate with the city in pursuing mutually reinforcing EV infrastructure build-outs and sharing the knowledge gained with other communities in the state and region. EV readiness is a key area where U-M can constructively engage with broader community and business partners in the automotive, electric utility, and related industries.

Critical next steps to catalyze work.

- The U-M AEC office should assess parking facilities to estimate the labor required for charger installation and connectivity, which will vary by site, and use this information to develop a strategy and timeline for implementation.

[13] U.S. Department of Energy (2014a).

[14] Commuting Internal Analysis Team (2020).

- LTP should begin the process of creating an additional permit for EV owners commuting more than 20 miles and a system to reserve a number of charging spaces appropriate for the number of EV permits issued to commuters. Such steps should be developed within the context of U-M's overall parking strategy revisions.
- U-M should initiate discussions with DTE about connecting this number of chargers to the grid and the potential for financial incentives similar to those of the Charging Forward Program.[15]

3. Implement an EV educational campaign

Research into the long-standing challenge of lagging consumer adoption of EVs has found that knowledge and information gaps are among the largest barriers inhibiting consumer EV use. Even in California, which has been promoting vehicle electrification for nearly 30 years, a recent policy brief highlights how lack of consumer awareness and knowledge of EVs has hindered market growth.[16] More broadly, awareness of high-efficiency vehicles, such as hybrid electric vehicles, is also needed.

Therefore, U-M needs to proactively build EV awareness by launching an educational campaign to promote EV adoption; provide information on national and utility EV incentive programs; and help commuters understand the GHG emission reductions and fuel cost savings they will see when using EVs. The campaign should enable commuters to readily learn about benefits such as U-M's employee workplace EV free charging program, EV charging rules and regulations, and the locations of charging stations. Good models, such as the Pump2Plug campaign at UC Irvine,[17] are available for guiding the design of such an effort. Further details on the type of information a campaign should cover and methods to share this information are provided in Appendix D.

We recommend that two existing U-M web resources be enhanced to better promote EVs:

- The LTP website Commute Calculator[18] should be modified to include the estimated fuel cost savings when driving an EV and taking advantage of free charging for employees.
- The transportation information provided by the U-M Mobile App[19] should be expanded to include campus EV charger locations so that employees, students, and visitors can more easily find available charging locations.

We also recommend that U-M initiate a cross-university coalition to share best practices for EV readiness and promotion among universities in Michigan, the Midwest, and the country as a whole.

Carbon emission reduction potential. Because it is a supportive information policy, attributing specific GHG reductions to an educational campaign is not possible. Such an effort is important for the success of the charging infrastructure investments and achieving the GHG emission reductions noted above. An educational campaign is a key part of a long-term strategy leading to carbon-neutral transportation through a complete transition from ICEVs to EVs in parallel to decarbonization of the electric grid.

Financial costs, savings, and considerations. Potential costs for an educational campaign are essentially composed of the cost of labor for creating and updating web pages, designing infographics and advertisements, and creating social media posts. Such costs could be minimized by carrying out the effort through undergraduate student-led projects, potential course projects, or as volunteer activities by student organizations.

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[15] DTE (n.d.).

[16] Turrentine et al. (2018).

[17] University of California, Irvine, https://sites.uci.edu/electricvehicles/.

[18] https://ltp.umich.edu/transportation-alternatives/commute-calculator/.

[19] https://its.umich.edu/computing/web-mobile/michigan-app.

Metrics and tracking. Specific progress on EV adoption could be tracked by collecting vehicle type information during parking permit registration and also with charger utilization data as noted above. Consideration should also be given to asking questions regarding vehicle choice, EV interest, and EV adoption in future Sustainability Cultural Indicators Program (SCIP) surveys,[20] which to date have not explored travel choices at that level of specificity.

Organizational structure considerations. An EV educational effort could be coordinated through OCS and LTP with assistance from other units and potentially student groups as needed.

Campus culture and individual accountability considerations. Building EV awareness in U-M commuters will contribute to strengthening the community's culture in terms of sustainability and enable individuals to better act on their environmental values.

Equity and justice considerations. Ensure that those most likely to benefit from the available EV chargers, such as low-income community members living farther from Ann Arbor, are reached by this campaign and ensure that the campaign is inclusive and comprehensive.

Timeline for implementation. It is difficult to specify a timeline without further consultation and planning among LTP, OCS, and other units. Once a plan is made and resources identified, developing the proposed campaign might take approximately one year.

[20] Graham Sustainability Institute (n.d.). https://graham.umich.edu/campus/scip.

APPENDIX A
Mobility Electrification Subgroup Scope of Work

Faculty Lead: Anna Stefanopoulou

Members: Andrew Berki, Stephen Dolen, Austin Glass, Brandon Hofmeister, Gregory Keoleian, William McAllister, Camilo Serna, Missy Stults

Staff support: Juan-Jie Sun, Jason Siegel, John DeCicco

Scope of Work

Objective: To analyze the operational, financial and environmental implications of, and identify optimal strategies for, converting gasoline and diesel internal combustion engine vehicles (ICEVs) to grid-connected electric vehicles (EVs), including cars, trucks, vans, and buses.

Background: The Vehicle Fleet Electrification subgroup of the President's Commission on Carbon Neutrality (PCCN) is analyzing the potential and developing plans for converting U-M operated motor vehicle fleets to electric vehicles (EVs). It is also examining ways for the University to facilitate and encourage EV use by staff, faculty, students, and visitors to campus.

The U-M fleet includes the campus bus service ("Blue Bus") fleet; various light and medium-duty trucks and utility vehicles used for operations and maintenance across the U-M campuses; plus cars, vans and other vehicles available to university units for daily rental or for short- and long-term leasing. As of 2018, the U-M fleet accounted for about 7,000 metric tons of CO_2-equivalent greenhouse gas (GHG) emissions, or roughly 2%, of the University's scope 1 GHG inventory.

Substituting an EV for a gasoline or diesel vehicle in the U-M fleet will zero out that portion of scope 1 GHG emissions. Depending on how the EV is charged, it would incrementally increase scope 2 emissions. Analysis is needed to assess net GHG emissions impacts as well as total cost of ownership for the fleet electrification options identified.

Also needed are analyses of opportunities for reducing scope 3 transportation emissions, which are not under the direct control of the University. For those incurred by individuals traveling to and from campus and in the surrounding community, U-M could invest in charging infrastructure for U-M parking facilities and finding other ways to encourage individual EV use. Scope 3 also includes the GHG emissions associated with goods and services purchased by the University, and the transportation aspects of those emissions could be considered as part of a broader "green procurement" strategy.

Tasks

1. Blue Bus electrification. Prior consultation with U-M Facilities and Operations has identified an opportunity for a pilot project to establish electric bus ("eBlueBus") service on key routes, replacing diesel buses that are now serving the route. Partial funding for such a project might be obtained as part of VW settlement funds administered by the State of Michigan.

    a. Analyze options for various eBlueBus pilot project choices (type and number of buses, routes served, charging system needs) to project operational, financial and environmental impacts.

  b. Write a report on eBlueBus options with recommendations for project design (December 13, 2019).

  c. Write a proposal for State of Michigan VW settlement funds to support eBlueBus acquisition (have proposal materials ready in mid-December 2019 to enable fast response when RFP is released).

2. Other electrification opportunities. Assess other U-M owned or managed vehicles and identify opportunities to encourage individual EV use by faculty, students and staff.

   a. Gather data on the existing characteristics and usage of these other U-M fleet vehicles, including those used for campus operations, renting and leasing to university units and vanpools, conferring with the Logistics, Transportation and Parking (LTP) office to understand needs and issues.

   b. Analyze options for EVs to replace additional (non-bus) fleet vehicles, identifying the types of EVs now or soon-to-be available suitable for such applications, and evaluating their costs and benefits.

   c. Analyze EV charging infrastructure requirements to serve both additional EVs in the U-M fleet and private EVs used by U-M staff, students and visitors.

   d. Explore options to encourage students, faculty and staff to switch to EVs, connecting U-M infrastructure deployment to programs offered by state, utilities and OEMs.

   e. Examine opportunities for appropriate use of e-bike and electric scooters to replace automobile use without degrading the environment for non-motorized travel.

   f. Initiate PCCN discussions on the issues associated with reducing scope 3 transportation sector GHG emissions as associated with university procurement of goods and services.

   g. Write a report summarizing additional opportunities for fleet electrification, with recommendations for EV acquisition and the development of charging infrastructure for serving both U-M owned and managed vehicles as well as private EVs in U-M parking facilities (March 2020).

APPENDIX B
Blue Bus Electrification Analysis

This appendix provides supporting analysis and information for the findings and recommendations associated with campus bus electrification. The Blue Buses are a prominent part of the U-M fleet. They are highly visible and heavily used, making them an ideal initial focus for fleet electrification. Analyzing the potential GHG emission reductions and financial impacts of Blue Bus electrification involved a series of steps, briefly summarized here and covered in more depth in a technical report on the topic.[21]

Note that the analysis presented here was planned before the COVID-19 pandemic and its major impact on all U-M operations, including campus service. Therefore, the results should be taken as merely illustrative of the general feasibility and impacts of bus electrification based on analyses of routes that were in use prior to the pandemic.

A simulation model was developed for exploring various eBlueBus operational scenarios based on data for representative electric buses and charging equipment. Analyses were performed both for an average route using depot charging and for a high-usage (intensive) route with en route extreme fast charging (xFC). The analysis demonstrates the feasibility of both cases. The financial implications were analyzed with and without bus electrification subsidies. The resulting projections are summarized below in Table B3. The simulation model can be applied for additional studies of eBlueBus deployment options, including more refined modeling as well as other bus characteristics, performance assumptions and operational conditions.

Background on Electric Buses

Many colleges and universities are moving to battery electric campus buses. Of particular relevance for Michigan because of its cold-climate location, the University of Montana[22] became the first university in the country to operate battery electric buses with en route fast charging in 2016. After 18 months of operating the two electric buses on its campus, the University of Montana benefited from the lower operational cost and better rider experience than with diesel buses. As a result, the school proceeded to acquire additional electric buses and in 2018 was awarded a $1.5 million grant from the Federal Transit Administration (FTA) to buy three more electric buses while phasing out diesel buses. Other universities phasing in electric buses include Duke University, Florida State University, Alabama A&M University, Columbia University and University of Georgia in addition to a number of California schools.

Cold climate conditions reduce the electric bus range primarily due to the energy needed for heating the cabin. The cold-weather performance experienced by transit centers and university fleets with electric buses was examined in a recent report.[23] The University of Montana avoided range problems by using en route overhead fast charging. The Southeastern Pennsylvania Transportation Authority (SEPTA) and Indianapolis "IndyGo" transit systems are addressing the cold-weather effects by installing cabin heaters and exploring overhead or wireless en route charging. A cold-weather efficiency estimate is used for our analysis, shown with comparisons to other estimates[24] in Table B1.

Based on the database of bus fleets in the United States from the American Public Transportation Association (APTA), electric bus deployment has significantly increased in this decade, as shown here in

[21] Sun et al. (2020).

[22] University of Montana (2018).

[23] Henning et al. (2019).

[24] LTI Bus Research and Testing Center (2017).

Figure B1.[25] As of 2018, there were 345 electric buses in service in the United States, of which 108 were operating in California. No electric transit buses are yet in service in Michigan, although electric school buses will soon be put into service in several public school districts including Ann Arbor.

Table B1. Efficiency comparison

	Altoona Report[a]	Blue Bus Simulation[b]	Cold Weather (18F)[c]
Efficiency (kWh/mile)	2.36	2.95	3.84
(a) Use Orange County test cycle.			
(b) The driving cycle data is collected by a GPS device on a bus running Northwood Route.			
(c) 18 degree Fehrenheit is the average low temperature at Ann Arbor in January.			

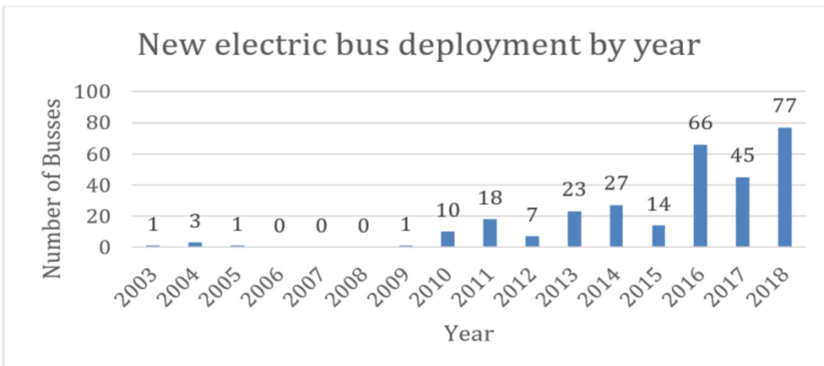

Figure B1. New electric bus deployment in the United States by year.

Modeling eBlueBus operations

In 2020, UM-Ann Arbor's in-service campus transit fleet consists of 48 40-foot buses and seven smaller, 30-foot buses.[26] All of these buses are either diesel or diesel hybrid. For purposes of analysis, we used parameters for a 40-foot diesel bus as the baseline vehicle to which eBus options are compared. For purposes of bus fleet transition analysis, we assumed a fixed fleet size of 48 buses.

In order to project the impacts of eBlueBus operation, an electric bus operation simulation model was developed. Among the key outputs of the model are energy consumption rates (kWh per mile) as well as total fuel use, the associated GHG emissions and implied fuel costs for the route under various eBlueBus scenarios.

Two cases were modeled: one for a bus operating on an average Blue Bus route and the other for an intensively used route in order to ascertain whether electric buses, given battery capacity and recharging time constraints, would be able to serve all of the campus bus route needs.

[25] APTA (2019).

[26] McAllister, William, U-M Logistics, Parking and Transportation office, document comment, May 20, 2020.

Analysis of an average Blue Bus route

Based on the Winter 2020 campus bus operations, the average Blue Bus weekday running time and distance are about 10 hours and 90 miles. We assume that the average diesel Blue Bus travels 31,250 miles and has an average fuel economy of 4.18 mpg.[27] Based on these values, we estimate current average Blue Bus GHG emissions as roughly 65 tCO_2e/year (fuel life cycle emissions, i.e., scopes 1 and 2).

To examine the feasibility of electrification, we assumed a route somewhat longer than the average, selecting an illustrative bus that serves three weekday shifts: 06:45–10:45, 13:55–17:45 and 22:10–02:10. A bus assigned to this route would have a running time of 12.1 hours and be driven a daily distance of 136 miles.

We used data for a commercially available 40-foot eBus with a 440 kWh battery and assumed the use of a 125 kW depot charger for recharging the electric bus during the breaks between each shift. The bus's electric drive component characteristics were modeled and compared to data available in the Altoona test.[28] Using these characteristics and other physical parameters for the eBus running the Northwood route (selected for its applicability to the intensive use case described below), the simulation model calculated an energy consumption rate of 2.95 kWh/mile. To account for the additional energy needed for heating loads and lower efficiency in winter, we applied a 30% safety factor based on a published analysis of how eBus performance changes with ambient conditions,[29] yielding the 3.84 kWh/mile value shown in Table B1, above. This is considered to be the worst-case scenario when the temperature in Ann Arbor is as low as 18°F. This is used to ensure the reliability of the electric bus. To look at lifetime operation, 2.62 kWh/mile is used based on simulations from the National Renewable Energy Lab (NREL) and can be considered as the effective vehicle efficiency which accounts for the local annual temperature profile.

The simulation showed that such a bus was capable of running this route with ample time to fully charge the bus during the breaks between shifts. The bus would be parked at the depot during scheduled breaks that were at least three hours long. As shown in the figure below, the battery state of charge would not fall below 50 percent.

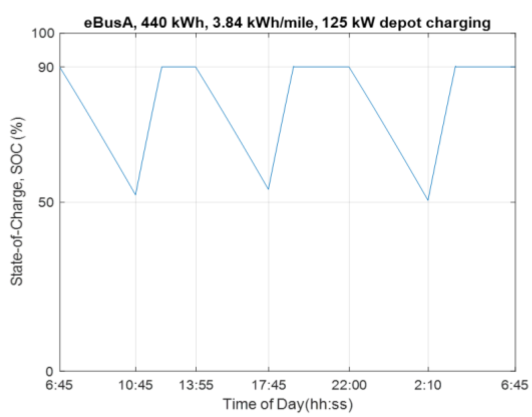

Figure B2. The status quo schedule simulation

[27] Approximate values based on inspection of recent data from U-M FTP office.

[28] LTI Bus Research and Testing Center (2017).

[29] Henning et al. (2019).

Route selection for an intensive use case for cost-effectiveness and return of investment

Although it is not possible to know at this stage how eBus service would be phased in at U-M, it is useful to analyze a scenario of intensive eBus use in order to demonstrate the feasibility of serving heavily used routes in addition to an average route as examined above. An intensive route use case was selected for simulation based on several considerations. Factors include a route that sees high utilization; traverses sites suitable for locating a fast charging station; overlaps with several other routes so that the same charging station can serve additional eBuses (either campus or city buses) in the future; and operates in locations convenient for research as part of the Electrify M living laboratory.

High utilization maximizes the GHG reduction, fuel cost and maintenance cost saving benefits of electrification. It is also important for cost-effectiveness in terms of the charging facility investment so that charger capital costs are spread over as much bus operation as possible. To support the research objectives of the Electrify M Living Laboratory, to be situated near U-M's engineering departments, the route should be one that serves North Campus, for which Bonisteel Boulevard is the major thoroughfare. Bonisteel Boulevard also has Ann Arbor city bus routes (22, 66), so placing a bus charging station along it would allow for future expansion to serve the city as well as additional campus bus routes that might be electrified in the future. Currently, three Blue Bus routes traverse Bonisteel Boulevard: Northwood, Commuter North/South, and Diag-to-Diag. Of these routes, Northwood has the highest bus utilization, operating for about twenty hours on weekdays and eighteen hours on weekends.

Based on such factors and discussions with the LTP office, the Northwood route was selected for the study. GPS data collected for the Northwood route include the location, velocity, and altitude with a 10 Hz sampling frequency. The route as traced by the GPS data is shown in Figure B3. The velocity data are used as the driving cycle input for the model and the altitude data are used to calculate the grade force for representing vehicle dynamics. Roughly speaking, the 8-mile long Northwood route is repeated 23 times on weekdays, resulting in 184 miles per day.

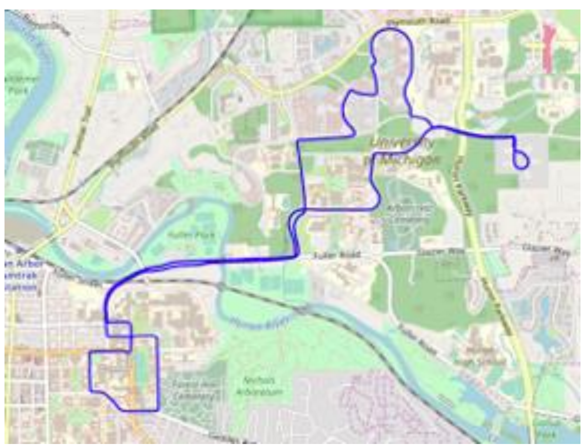

Figure B3. Northwood campus bus route

The current schedule for the Northwood route has four buses always running for the service between 6:55 AM to 9:55 PM and two buses running for the service between 9:55 PM to 2:55 AM. The drivers of these buses take a 20-minute break about every 2 to 3 hours at Central Campus Transportation Center (CCTC). During the breaks, another bus and driver run the route. In other words, five buses are needed between 6:55 AM to 9:55 PM: four of them are running while the other is on break. This pattern is called the "five-bus rotation schedule."

In fact, the fleet schedule has different groups of five buses running the Northwood route in the morning, afternoon and evening because no bus is dedicated to a single route. Although the current operational schedule involves many different buses, it could in principle be served with five buses dedicated to the route, so that five eBuses would see intensive use that maximizes the utilization of the charger and the potential GHG reductions as shown in Figure B4.

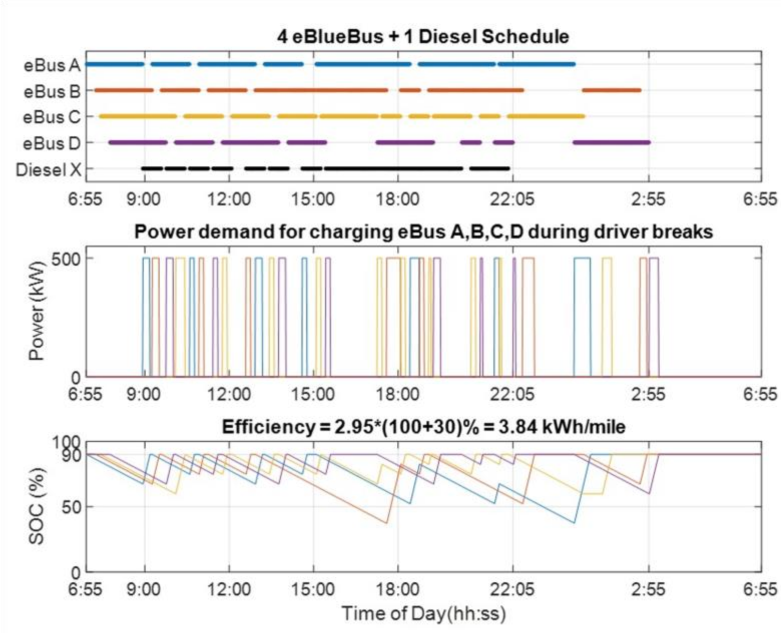

Figure B4: 4 electric and 1 diesel bus Northwood schedule

Cost and emissions comparison with diesel buses

In this section we provide a snapshot of the 2020 cost and emission abatement for purchasing one bus with depot charging or purchasing four buses with en-route charging as potential one-time pilots for learning purposes. As more and more communities and universities electrify their bus fleet, data and experience is documented and shared, making such an isolated pilot project not entirely necessary. This section is provided for completeness and in the case that such a pilot is deemed necessary. The analysis of a systematic fleet electrification transition is analyzed in the next section.

For use on an average route, the cost of a single electric bus plus the equipment

Table B2: Annual operating and maintenance costs

Assumptions	Source	UM Values
Annual Miles (mi/vehicle)	UM LTP	31,250
Electric Vehicle Assumptions		
Vehicle Cost ($/vehicle)	Proterra	$ 760,000
Vehicle Efficiency (kwh/mi)	UM/NREL	2.62
Maintenance ($/mile)	FTA	$ 0.79
Electricity Rate ($/kWh)	UM LTP	$ 0.09
Charger and Infrastructure ($)	DTE	$ 65,000
Diesel Vehicle Assumptions		
Vehicle Cost ($/vehicle)	UM LTP	$ 450,000
Vehicle Efficiency (mpg)	UM LTP	4.18
Maintenance ($/mile)	UM LTP	$ 1.29
Diesel Fuel ($/gal)	UM LTP	$ 2.90
Notes	(a) Annual fuel costs are about $7,000 for an eBus and $22,000 for a diesel bus, yielding an annual savings of $14,000. (b) Annual maintenance costs are about $25,000 for an eBus and $40,000 for a diesel bus, yielding an annual savings of $16,000.	

cost of a depot charger would be roughly $825,000, or $375,000 more than a new diesel bus. An electric bus has lower operating and maintenance (O&M) costs than a diesel bus, with estimated savings of $30,000 per year.[30]

The annual O&M saving includes the fuel saving and the maintenance of about $14,000 and $16,000, respectively. The cost comparison between a diesel bus and an electric bus running 31,250 miles annually is shown as Table B2. These single-bus, average-use estimates scalable for multiple units and would likely involve minimal changes to fleet management.

NREL Foothill Report (data period)	Average mileage per bus per month	Average mileage per bus per year	Maintenance cost ($/mile)
4/2014-7/2015	2,333	27,996	0.16
8/2015-12/2016	2,456	29,472	0.14
1/2017-12/2017	1,953	23,436	0.12
1/2018-6/2018	2,152	25,824	0.71
7/2018-12/2018	2,183	26,196	0.78
1/2019-6/2019	2,443	29,316	0.68
7/2019-12/2019	2,054	24,648	0.84

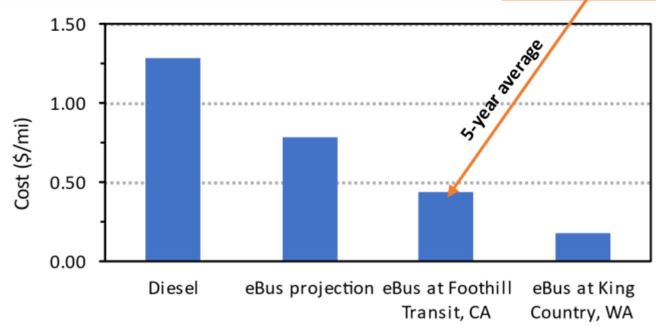

Figure B5: Maintenance cost

The fuel cost of diesel buses is calculated by assuming the diesel price at 2.90 $/gal and the efficiency of 4.18 MPG provided by U-M LTP department. For the electric buses, we use the electricity price at 0.089 $/kWh as suggested by the U-M Facilities and Operations and the simulated average annual efficiency of 2.62 kWh/mile as discussed earlier and shown in Table B1.

The maintenance cost of diesel buses is calculated based on the average historical data at 1.29 $/mile provided by the U-M LTP department. The maintenance cost of electric buses is calculated based on the estimation at 0.79 $/mile.[31] In fact, the value of 0.79 $/mile is reasonable compared to the real-world operation data from the Foothill Transit agency in the Greater Los Angeles area. Their series of progress reports[32] for 2014–2019 provides some of the most comprehensive operational data for electric buses in the United States. From these reports, we extracted the average distance traveled and maintenance cost data shown in Figure B5.

A 50% capital cost subsidy would more than cover the additional up-front cost of $375,000. If available, such a subsidy would change the lifetime (12-year) financial impact from unfavorable (an extra cost of $15,000) to favorable (a savings of about $400,000).

For an intensive use case, we analyzed the Northwood route, which connects central campus, north campus and Northwood housing area. This route includes a location suitable for siting an en route xFC station. Our analysis shows that the Northwood route could be served by four electric buses running a staggered schedule with xFC stops of roughly 10 minutes duration during driver breaks plus a single diesel bus for filling schedule gaps. As shown in Table B3, the additional capital cost compared to four diesel buses would be roughly $1.5 million including both electric buses and the installed xFC station. This high-usage case would have more favorable lifetime economics than incrementally adding electric buses on average routes with depot charging, but would also require modest adjustments to fleet management and driver schedules. As shown in Table B3, with a 50% subsidy for the four buses and the xFC equipment cost, the additional cost would fall to a savings of $143,000.

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[30] Sun et al. (2020).

[31] Proterra (2016).

[32] NREL, https://www.nrel.gov/transportation/fleettest-electric-foothill.html.

Table B3: Summary of eBlue Bus cost and emissions analysis

Case analyzed	Bus and charger ($1,000s) Total Cost	Additional cost: Without subsidy	Additional cost: 50% subsidy	Emission reductions (mtCO2): Per year	Emission reductions (mtCO2): 12-year lifetime	12-year net cost ($1,000s): Without subsidy	12-year net cost ($1,000s): 50% subsidy	Lifetime cost-effectiveness ($/mtCO2): Without subsidy	Lifetime cost-effectiveness ($/mtCO2): 50% subsidy
Single electric bus on average route in 2022 (scalable to any number of buses)	825	375	-38	62	787	15	-398	19	-506
Four electric buses on intensive route with on-route extreme fast charging	3,315	1,514	-143	335	4,230	-422	-2080	-100	-492

Costs include electric buses with extended battery warranties.
Additional costs are relative to a new diesel bus cost of $450,000.
The average route assumes 31,250 miles per year; the high-usage (intensive) route is about 42,000 miles per year.
Values in this table are rounded.

The emission reductions for a single bus on an average route would be roughly 62 metric tons of CO_2 per year, amounting to 787 tons over a 12-year bus lifetime (Table B4) with projected U-M grid mix from 2022 to 2033.[33] For four electric buses on an intensive route, the projected CO_2 reductions are 335 metric tons annually, adding up to 4,200 $tCOe_2$ cumulatively over an assumed 12-year lifetime. The assumptions used for making these estimates are detailed in Table B4. Scope 1 emissions from diesel buses are calculated using the expected annual mileage, efficiency (MPG) and a GHG emission factor for diesel fuel.[34] Scope 2 emissions for diesel buses and electric buses are calculated using the annual mileage and the upstream GHG emission factors for producing diesel fuel and generating electricity.[35] Note that there are no scope 1 emissions for electric buses.

Table B4: GHG emissions reduction estimation for electric buses

	Annual Values: Travel miles	Diesel Scope 1+2 tons CO2	eBus Scope 2 tons CO2		Reduction Scope 1+2 tons CO2
Intensive use	42,000	114	30		84
Average use	31,250	85	22		62
	Efficiency		CO2 Emission Factors		
	mile per GGE	kWh per mile	Customary unit		kgCO2 per mile
Diesel bus	4.18	9.08	11	kgCO2/gal	2.71
eBus	14.48	2.62	0.27	kgCO2/kWh	0.71

(a) Metric tons on a CO2-mass basis, per bus per year
(b) The diesel fuel emissions factor is based on 10.24 kgCO2/gal tailpipe (Scope 1) and 1.09 kgCO2/gal upstream (Scope 2
(c) GGE = Gasoline Gallon Equivalent
(d) Diesel to electricity conversion = 37.95 (kWh/gallon)

In addition to the GHG emission reduction, replacing diesel buses with electric buses also reduces air pollution that is directly harmful to health. Using the Environmental Protection Agency (EPA) Diesel Emissions Quantifier (DEQ), we estimated the air pollutant reductions shown as Table B5.

[33] Keeler (2020).

[34] ANL (2018).

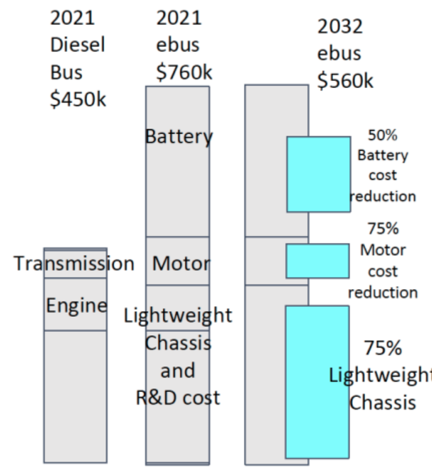
[35] See ANL (2018) for diesel and Keeler (2020) for electricity. It should be noted that the U-M electricity emissions factors include only combustion emissions from U-M and DTE generating facilities and so do not include all upstream GHG emissions from natural gas or other fossil fuel extraction and processing.

Table B5. Reduction of air pollutants through Blue Bus electrification

	Reduction of air pollutants per bus	
	Annual reduction (metric tons)	Lifetime reduction (metric tons)
NOx	0.32	3.83
PM2.5	0.01	0.13
HC	0.03	0.35
CO	0.11	1.36

Cost projection for battery electric vehicles

To project the future price of electric buses, we assume that the higher cost of an electric bus compared to a diesel bus mostly comes from battery. With recently quoted prices at $760,000 for an electric bus and at $450,000 for a diesel bus, the implied extra battery cost is $310,000. We assume that this extra cost will decrease by half over the next decade primarily due to the declining cost of the battery. Therefore, the price of an electric bus is projected to be $560,000 after 2030 assuming a battery pack cost of $110/kWh.[36]



For a 125-kW depot charging station, the recent hardware cost is $65,000. We assumed the hardware cost would drop one-third by 2032[37] and then remain at $43,330 after 2032. The charging stations should be networked in order to enable demand response control.

Cost-effectiveness prediction

Figure B7 shows the cost-effectiveness in $/ton of CO_2 reduced over a bus lifetime for Scenario 1. Although initially $23/tCOe₂, cost-effectiveness improves rapidly through the combination of falling eBus costs, accumulating O&M cost savings and a cleaner electric grid. By the second year, the $/ton metric drops below zero, indicating that using electric rather than diesel buses saves money while reducing emissions and implying a better-than-zero net-cost investment.

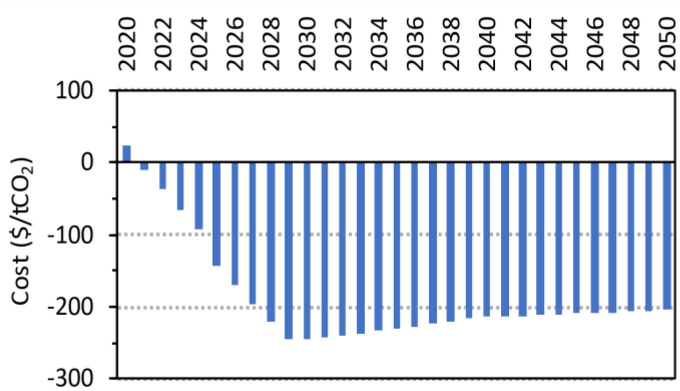


Figure B7: Lifetime cost-effectiveness per bus

Two transition scenarios for U-M campus bus fleet electrification

We examined scenarios of both a rapid and a slower transition to an all-electric Blue Bus fleet for the Ann Arbor campus as follows.

[36] U.S. Department of Energy (2020); battery pack market prices continue to decline for high volume manufacturers from $500/kWh in 2013 to $200/kWh in 2018 and scheduled to reach an average of $100/kWh in 2025, thus lowering the price of electric vehicles purchased after 2030.

[37] ICCT (2019).

For a rapid transition (Scenario 1), starting in 2022, we assume that U-M would buy 4 eBuses instead of the 4 diesel buses purchased each year until the fleet is all-electric. The stacked column chart shown in Figure B8 visualizes the fleet transition under Scenario 1, which would see the fleet fully converted by 2033. Figure B9 (same as Figure 2 in the main text) shows annual and cumulative net costs, indicating that in the early years, electric buses are more costly than diesel buses. However, after the fleet is fully converted by 2033, operating electric buses becomes less costly because of their lower fuel and maintenance costs, so that cumulative costs then decline over time.

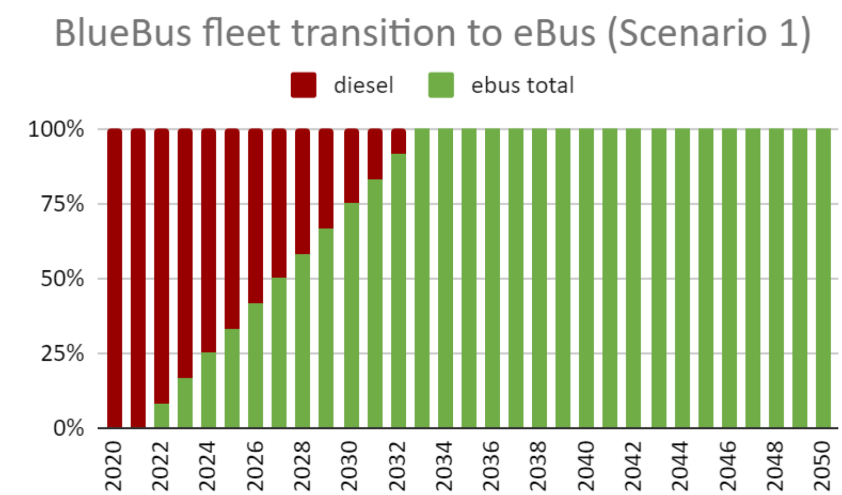


Figure B8. Fleet transition under Scenario 1

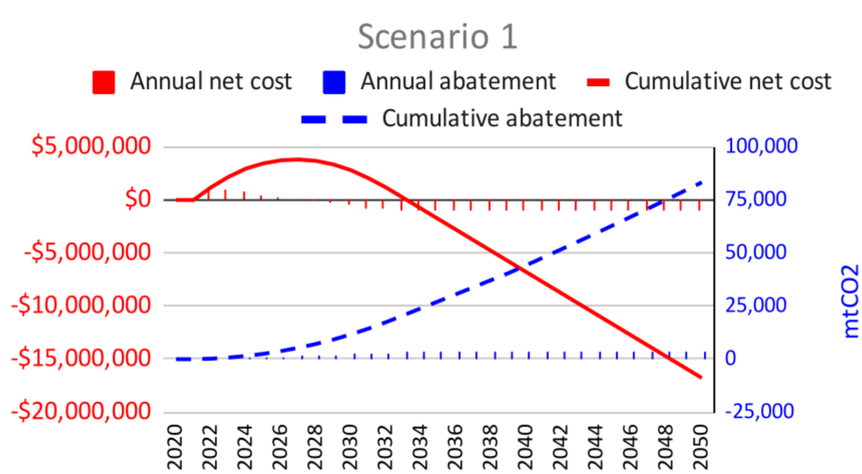


Figure B9. Fleet transition net cost for Scenario 1

Scenario 2 starts with a slower initial transition and assumes that, from 2022 through 2033 (over the first 12 years), U-M buys 2 eBuses instead of 2 diesel buses while continuing buying 2 new diesel buses as needed for replacements. After the first 12 years, we assume that U-M stops purchasing new diesel buses and purchases instead eBuses at the rate of 4 per year until the fleet is all-electric. This scenario reduces the up-front costs by waiting until eBus prices fall before speeding up the rate of fleet electrification. The fleet is expected to be fully converted by 2045 as shown in Figure B10. The cumulative cost of Scenario 2 in Figure B11 is lower than that of Scenario 1 in Figure B6 because it partly avoids the higher eBus costs of the early years, but it also has a much lower CO2 abatement.

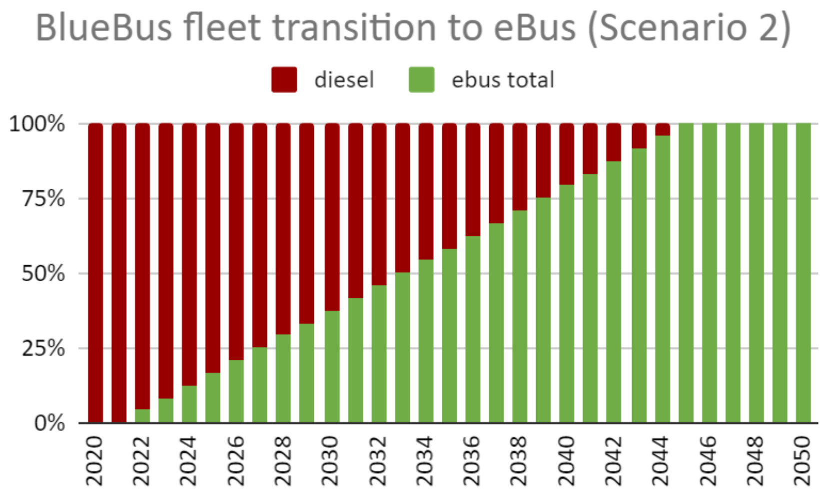


Figure B10. Fleet transition under Scenario 2

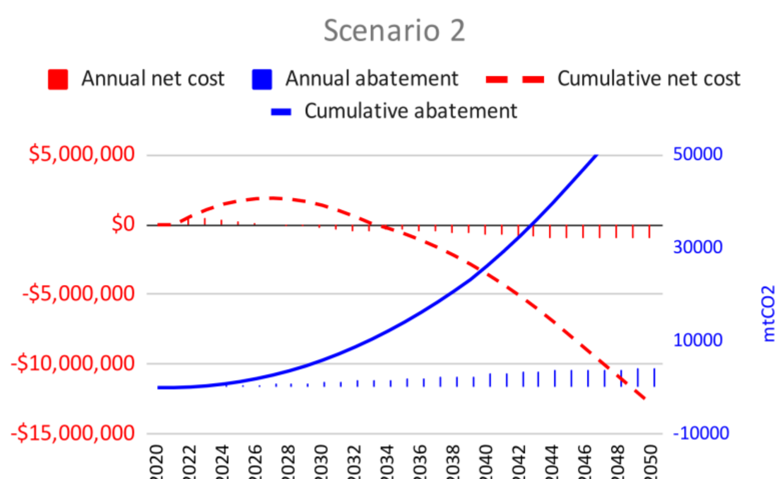


Figure B11. Fleet transition net cost for Scenario 2

Intercity electric bus analysis

U-M currently provides a shuttle bus connecting Detroit Center, UM-Dearborn, and the Central Campus Transit Center (CCTC) in Ann Arbor. If shuttle bus or vanpool service were expanded to reach outlying bedroom communities such as Brighton, Flint, Jackson and Toledo, additional GHG reductions would be achieved by electrifying those new routes beyond those due to reduced vehicle miles traveled (VMT). A preliminary analysis with intercity route characteristics and intercity electric bus performance data from the literature is given in Table B6, implying an average 66% GHG emission reduction compared to diesel intercity buses.

Based on the eBus energy consumption estimates in Table B6, round trips on these intercity routes would consume at most 275 kWh when temperature in Ann Arbor is as low as 18°F, and therefore well within the range of an eBus with a 440 kWh battery pack. The longest charging time would be a bit more than 2 hours using a 125 kW charger. An electric bus serving any of these intercity routes would be able to make a round trip without charging, so that charging can be done when a bus finishes its round-trip run and comes back to the Ann Arbor campus. Therefore, the emission reductions in Table B6 are calculated by assuming these intercity buses would be charged from the U-M grid.

Table B6. Intercity electric bus routes

Connector Route	Diesel (a)(b)			EV		Emission reduction
Route	One way distance (mile)	Energy consumption (gal)	Emission (kgCO2)	Energy consumption (kWh)	Emission (kgCO2)	(kgCO2/trip)
AA-Brighton-Flint	57.5	8.3	94.5	105.8	28.8	65.7
AA-Jackson	36.7	5.3	60.3	67.5	18.4	41.9
AA-Dearborn-Detroit	46.9	6.8	77.1	86.3	23.5	53.6
AA-Toledo	53.9	7.8	88.6	99.2	27.0	61.6
Note	(a) Diesel efficiency of 6.89 MPG, based on LTI (2001) report on GILLIG Model G21D102N4 (b) Emission factor of 11.325 kgCO2/gal, based on Argonne National Lab GREET model (2018). (c) eBus efficiency of 2.62 kWh/mile, based on LTI (2017) report on Proterra Catalyst E2. (d) Winter extra energy consumption of 30%, based on Henning et al. (2019).					

UM-Dearborn campus buses

Compared to the bus system on the Ann Arbor campus, the system on Dearborn campus is much simpler. There are three buses serving the three routes: Maize, Blue and Wolverine. Each bus is dedicated to each route and circulates from around 7:40 a.m. to 9:50 p.m. Based on the energy consumption estimated in Table B7, an electric bus with a 440 kWh battery pack should be able to serve the route Blue or Wolverine in daytime with a single overnight charging. Serving the Maize route without an en route charging stop would require a bus with greater battery capacity.

Table B7. UM-Dearborn shuttle routes

U-M Dearborn Shuttles	Diesel (a)(b)			EV		Emission reduction
Route	Daily mileage (mile)	Energy consumption (gal)	Emission (kgCO2)	Energy consumption (kWh)	Emission (kgCO2)	(kgCO2/day)
Maize	150.9	36.1	408.8	395.4	107.7	301.2
Blue	110.4	26.4	299.1	289.2	78.8	220.3
Wolverine	93.8	22.4	254.1	245.8	66.9	187.2
Note	(a) Diesel efficiency of 4.18 MPG, based on BlueBus data on Ann Arbor campus. (b) Emission factor of 11.325 kgCO2/gal, based on Argonne National Lab GREET model (2018). (c) eBus efficiency of 2.62 kWh/mile, based on a simulation given the route on Ann Arbor campus. (d) Winter extra energy consumption of 30%, based on Henning et al. (2019).					

APPENDIX C

Commuter Electrification Analysis

This appendix describes the analysis used to project the investment in EV charging infrastructure needed to support 20% EV use by UM-Ann Arbor faculty and staff commuters. It presents baseline estimates for the current number of commuter vehicles and their GHG emissions. It also gives information on the current number of EV charging stations and utilization on the Ann Arbor campus. It then develops estimates of the number and type of EV charging stations needed to support the targeted level of EV use; projects the resulting GHG emission reductions; and estimates the costs and cost-effectiveness of the recommended charging infrastructure investment. Details of the analysis described here are available in an online workbook.[38]

1. Current Commuting Emissions

Our analysis builds upon data gathered by the PCCN Commuting Internal Analysis Team (IAT)[39] giving vehicle-miles of travel (VMT) by commuters to UM-Ann Arbor by campus area (Central, North, South, Medical, and East Medical) broken down by commuting distance band. We used these data to estimate the number of commuting vehicles as shown in Table C1. In addition to the estimated 37,800 faculty and staff commuting vehicles, the Commuting IAT provided an aggregate estimate of roughly 11,200 student commuting vehicles for Ann Arbor, for a total of roughly 49,000 vehicles used by regular commuters (excluding campus visitors[40]) under the then-recent conditions (2019, pre-pandemic).

Table C1. Estimated numbers of commuting vehicles by UM-Ann Arbor campus area (faculty and staff only)

Distance Band	Central	North	E.Medical	Medical	South	Total
< 1 mile	788	330	5	49	73	1,245
1-2 miles	1,603	694	12	605	193	3,108
2-4 miles	2,311	1,196	52	1,960	0	5,518
4-6 miles	1,178	665	86	1,465	294	3,688
6-10 miles	1,387	638	233	1,858	559	4,675
10-15 miles	934	596	230	1,812	531	4,102
15-20 miles	1,045	512	169	2,197	663	4,586
20+ miles	2,654	1,269	364	5,303	1,287	10,877
Totals	**11,900**	**5,900**	**1,150**	**15,250**	**3,600**	**37,800**

[38] Mobility Electrification Subgroup, Infrastructure Cost Calculations.

[39] Commuting Internal Analysis Team (2020).

[40] Data are not readily available for estimating GHG emissions from campus visitor vehicle use, so those emissions are excluded from this analysis, and estimating them can be considered for future work.

To estimate baseline emissions, we worked from the Commuting IAT's estimates of average daily round-trip commute distances by distance band, which were multiplied by the estimated numbers of vehicles in each band to calculate daily total VMT. We assumed 200 average commuting days per year, reflecting vacation and sick days, the likelihood that faculty and students may not commute every day, particularly in the summer, and the fact that not all staff are full-time or everyday commuters. We also assumed that existing EV or other alternative fuel use is statistically negligible, so that a typical gasoline internal combustion engine vehicle (ICEV) GHG emission factor is representative of the current commuter vehicle population. We used an average light-duty vehicle fuel economy of 23.8 mpg[41] and a gasoline life cycle (tailpipe plus upstream, i.e., scopes 1 and 2) emissions factor of 10.449 gCO_2e/gallon,[42] implying a fuel cycle GHG emissions rate of 439 gCO_2e/mile for commuting vehicles on average.

The results are given in Table C2, yielding a baseline commuting GHG emissions estimate of roughly 120,000 tCO_2e/yr. As noted in the main text, this value is comparable in magnitude to about 40% of U-M's total scope 1 GHG emissions. Figure C1 shows the GHG emission estimates by distance band, illustrating how they are dominated by drivers commuting 20 or more miles each way. Long-distance drivers represent about 30% of the commuting population (based on estimated vehicle counts) but account for 60% of the emissions.

Table C2. Commuter vehicle usage and GHG emissions for UM-Ann Arbor (faculty, staff and students)

Distance Band	Average round-trip commute, miles	Vehicles per distance category	Daily VMT by distance band	ICEV gasoline use (gallons/day)	GHG emissions (metric tons CO_2e/day)
< 1 mile	0.8	1,468	1,145	48	1
1-2 miles	2.6	3,490	9,005	378	4
2-4 miles	4.4	5,587	24,692	1,037	11
4-6 miles	9.5	4,550	43,407	1,824	19
6-10 miles	15.7	6,899	108,032	4,539	47
10-15 miles	23.9	6,324	151,021	6,345	66
15-20 miles	33.5	6,363	212,916	8,946	93
20+ miles	58.2	14,300	832,273	34,969	365
Totals		48,981	1,382,491	58,088	607
			Annual total (metric tons CO2e)		**121,392**

[41] U.S. Energy Information Administration (2020), Table 7, on-road light-duty vehicle stock estimate for 2019.

[42] ANL (2018).

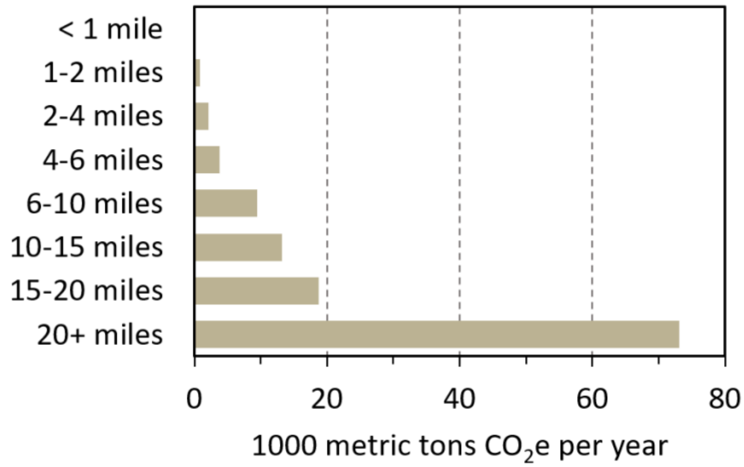


Figure C1. GHG emissions from commuters to U-M Ann Arbor by distance band

2. Current EV Charging Station Availability

By way of background, Table C3 provides basic information on the three standard charging station levels from DOE's Alternative Fuels Data Center (AFDC).[43] L1 chargers can be set up where the vehicle owner provides their own charging cord or can be in the form of a wall mount or pedestal charging with its own chord. Costs vary greatly depending on which of these types is selected.[44] L2 chargers are typically installed as a wall-mount or pedestal with equipment that conforms to an Electric Vehicle Supply Equipment (EVSE) protocol to ensure safe control of the charging process. Direct Current Fast Charging (DCFC) equipment is usually installed in high traffic areas on a pedestal.

Table C3. Types of EV Chargers

Charger Level	Voltage	Miles of Range Added	AC/DC	Port Type
Level 1 (L1)	120V	2-5 per hour	AC	J1772
Level 2 (L2)	208V, 240V	10-20 per hour	AC	J1772
DCFC	208V, 480V	60-80 per 20 mins	DC	Varies depending on vehicle

At present, UM-Ann Arbor campus parking facilities have 14 L2 chargers, provisioned by ChargePoint. The locations are given in Table C4 and indicated on a map in Figure C2. Chargers are free to use with a valid permit (Gold, Blue, Yellow, or Orange for faculty/staff; Student Orange or Student Yellow/After Hours for students). Some are available to visitors with payment for the parking space.

[43] AFDC (n.d.).
[44] U.S. Department of Energy (2015).

Table C4. Existing EV Charging Station Locations at UM-Ann Arbor

Location	No. of Chargers	Cost	Additional Notes
Ross Athletic Campus Lot SC32 (Hoover & Greene)	2	No cost for permit holders.* Visitors pay normal parking rate.	Enforced 6 AM - 6 PM Monday - Friday
Ann Street Parking Structure M86, Medical Campus	2	No cost for permit holders.* Visitors pay normal parking rate.	Enforced 6 AM - 6 PM Monday - Friday
Wall Street Parking Structure M93, Medical Campus	4	No cost for permit holders.* Not available for visitors.	Enforced Monday 6 AM - Saturday 1 AM
North Campus Lot NC27 (Murfin Street)	2	No cost for permit holders.* Visitors pay normal parking rate.	Enforced 6 AM - 6 PM Monday - Friday
North Campus NCRC Parking Structure NC100	4	No cost for permit holders.* Not available for visitors.	Enforced Monday 6 AM - Friday 5 PM
*Valid permits include: Faculty/Staff: Gold, Blue, Yellow, or Orange Student: Student Orange, Student Yellow, After Hours, or Student Yellow/After Hour			

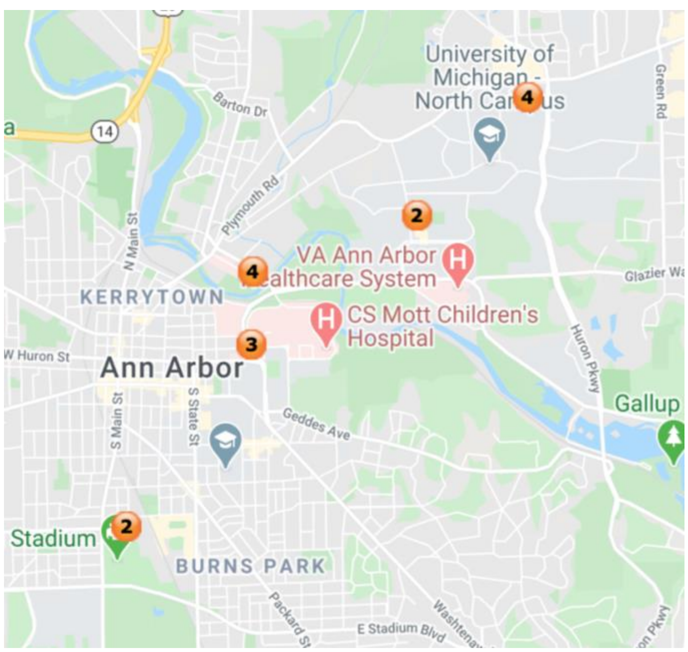


Figure C2. Existing EV charging stations at the UM-Ann Arbor campus (number of chargers shown in circles; all are Level 2)

The parking spaces with charging stations may only be used for those charging EVs. A 4-hour time limit is enforced, generally meaning that EV users must move their vehicles after 4 hours.[45] This arrangement is inconvenient because many employees must park all day and finding an available parking spot can be difficult midday; moreover, the locations of the lots with EV chargers are not necessarily a short walk from many employees' office buildings.

Existing charger utilization

We obtained a data set[46] collected from the campus charging stations and accessed the ChargePoint dashboard, which provides real-time data on electricity usage, occupied stations, and a variety of other items. The average EV charging session length was 2:16 and the median length was 2:10. These durations may be shorter than actual session lengths because many of the recorded sessions were extremely short, likely due to connectivity interruptions that would result in a given user session being recorded as a set of shorter charging intervals.

We also found that the data for both charging session start and end times were bimodal with an intermodal interval of approximately 4 hours, as illustrated by the histogram of session end times shown in Figure C3. These observations suggest that EV owners were likely to have moved their vehicles during the day and that different EVs occupied the charging spots as they became available.

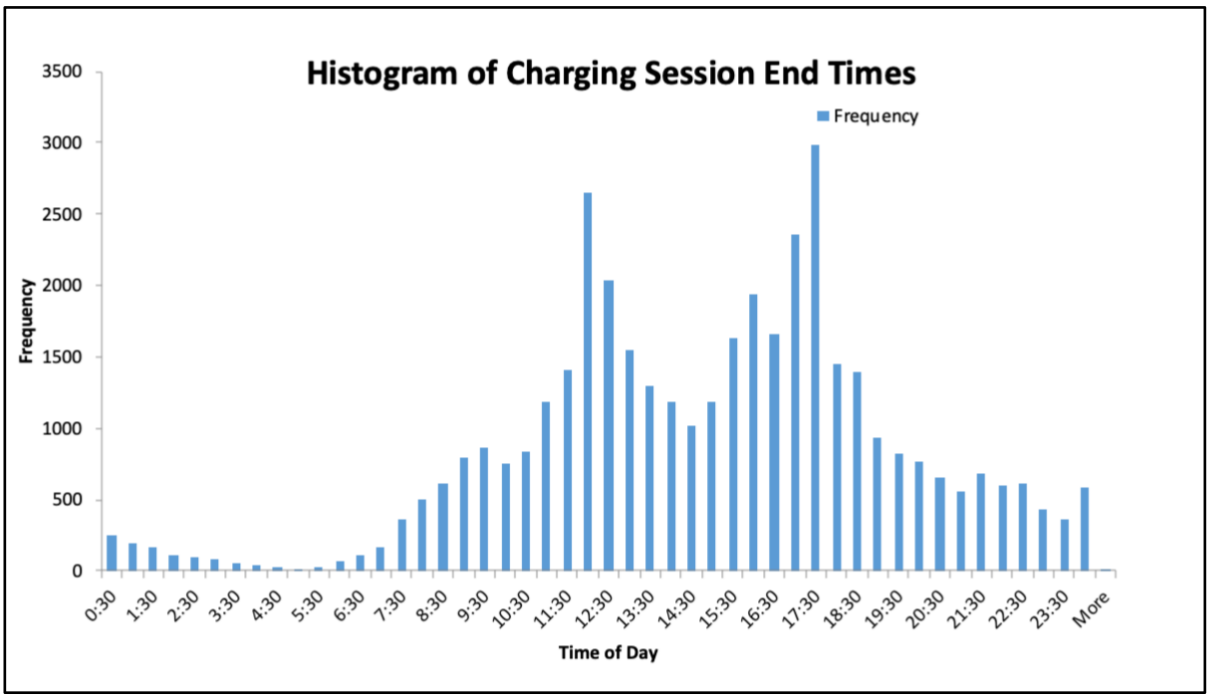


Figure C3. Distribution of Charging Session End Times for L2 Chargers at UM-Ann Arbor

[45] U-M (n.d.).

[46] ChargePoint (2020).

3. EV Adoption Target

Electrification investments offer many advantages for universities, including ways to reduce commuter emissions, provide employee and student benefits, enable fleet charging, offer research opportunities for faculty and students, and signal the University's environmental leadership.[47] To develop a target for the number of EVs that U-M should seek to serve for its commuter population, we reviewed the electrification goals articulated by the City of Ann Arbor, the International Energy Agency (IEA) and the State of California.

The IEA "EV30@30" campaign aims for a global share of 30% EVs in the new vehicle market by 2030.[48] The State of California has set a goal of 5 million registered vehicles being EVs by 2030,[49] in this case referring to all vehicles in use (the "car parc"), not just new vehicles. According to California Department of Motor Vehicles' records, approximately 31 million light-duty vehicles were registered in California as of 2019, counting those classified as automobiles plus light trucks as classified by the state's and Non-Commercial Vehicle Registration Act.[50] If this number remains flat, it implies that California's goal corresponds to approximately 16% of the state's registered vehicles being EVs by 2030.

The most ambitious goal is Ann Arbor's, with a stated community-wide target that 20% of vehicles registered by individuals living in the city be electric by 2030.[51] This target supports the city's overall A^{2}Zero goal of achieving carbon neutrality by 2030. For 20% of in-use vehicles to be electric by 2030, a very rapid increase in EV purchases by Ann Arborites would be needed within the next few years.

To develop a similar goal for U-M commuters, we focus on the long-distance commuters who account for the bulk of emissions (Figure C1, above) and for whom electrification will be most cost-effective (as discussed below). We also focus on faculty and staff rather than students. Student vehicles comprise just about 23% of the regular commuting fleet, and the University offers them limited parking availability during workdays. Only graduate students and junior and senior undergraduate students can purchase any form of parking permit (Student Orange Permit). Therefore, many students are not typical U-M commuters in that they are restricted from a majority of the parking areas where EV charging would be installed. Moreover, students generally have more limited financial resources, making it more difficult to afford EVs. We therefore propose that U-M target 20% of long-distance (20+ miles each way) faculty and staff commuters for EV adoption by 2030.

4. Cost Analysis

We examined two scenarios for campus EV charging infrastructure investments, one to support 20% EV adoption by the entire faculty and staff commuting population and the other for 20% EV adoption by on long-distance (20+ miles one-way) faculty and staff commuters.

Type of chargers

We assume use of L2 chargers because they can be readily networked, which enables monitoring, control and data collection as well as smart power management, which can minimize the need for major upgrades of campus connections to the electric grid. Networking also facilitates charger use by EV owners because charging station information can be integrated into mobile apps to provide information

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47 U.S. Department of Energy (2016b).

48 IEA (2019).

49 California Public Utilities Commission (n.d.).

50 State of California Department of Motor Vehicles (2019).

51 Stanton (2020).

such as maps of charger locations and the real-time availability of charging ports.[52] Stations should also be installed following ADA guidelines[53] to ensure fair and equitable access to charging.

Although L2 chargers are assumed for the analysis reported here, we also received location-specific installation cost estimates for L1 chargers from U-M's Architecture, Engineering and Construction (AEC) office, which were $24,000 for a single L1 charging pedestal and $30,000 for two adjacent pedestals.[54] These estimates reflect the substantial civil work needed to run circuits to charger locations in existing surface lots or on-street parking spots. Unit costs would fall significantly for multiple chargers in a given location or for locations in parking structures or adjacent to buildings. Comparable civil work would be involved for installing L2 chargers in similar locations.

We assumed L2 charging stations with two charging units per pedestal and two ports per unit, so that each charging unit can serve two vehicles over the course of a day. We assumed equipment costs of $1,550 for each charging unit[55] and $1,895 per pedestal,[56] values that are representative of products currently on the market. For installation costs, we assumed $2,305 per unit, a value that includes labor, materials, permits and electricity capacity upgrades.[57]

Number of chargers

Working from the number of faculty and staff vehicles by distance band (the Total column of Table C1, above) we calculated the number of charging ports needed to serve 20% of the vehicles. For example, the number of vehicles in the long-distance (20+ miles) band is 10,877; 20% of those implies 2,175 EVs to be served, which in turn implies half that number of chargers, i.e., 1,088, assuming two ports per charger. This is the value used for our recommendation of supporting EV use by 20% of long-distance commuters; a scenario of supporting 20% of all (not just long-distance) faculty and staff commuters entails a similar calculation over all distance bands. In both cases, we subtracted $67,235 from the resulting installed cost estimates to account for the 14 chargers already installed on campus.

These calculations are summarized in Tables C5 and C6, below. The total installed (fixed) cost to support EV use by 20% of all faculty and staff commuters would be $18 million and it would be $3.9 million for EV use by only the long-distance subset. Although U-M does not generally qualify for rebates such as those provided by DTE's Charging Forward program,[58] as a major customer, the University is generally able to negotiate cost reductions on major electrical work involving the utility. To reflect the likelihood of such cost savings, subtracting $250,000 (the DTE program's maximum rebate) from the estimate would then reduce the investment needed to support 20% EV adoption by long-distance commuters to roughly $3.6 million, as given in the last line of Table C6.

Little information is available on the life span of charging equipment due to the relatively young market, but industry experts typically assume at least a 10-year life span for budgeting purposes. For the purpose of our analysis, we have assumed a charger life span of 12 years, after which hardware will need to be replaced. Maintenance costs consist of damaged cord repairs and are estimated to be

[52] Doyle (2017).

[53] U.S. Department of Energy (2014a).

[54] Stoltz, A., U-M AEC office, e-mail via A. Berki, "EV Parking Lot charger cost estimates," June 2, 2020.

[55] ClipperCreek (2020a).

[56] ClipperCreek (2020b).

[57] Nicholas (2019).

[58] DTE (n.d.).

around $200 per charger every 3 years.[59] For 1,088 L2 chargers, this cost amounts to $220,000 every three years, for an ongoing average cost of roughly $73,000 annually.

Table C5. EV Charging Infrastructure Costs, All Faculty and Staff Commuters

Distance	Quantity Level 2 Chargers
< 1 mile	125
1-2 miles	311
2-4 miles	552
4-6 miles	369
6-10 miles	468
10-15 miles	410
15-20 miles	459
20+ miles	1088
Total	3780
Total equipment cost (chargers + pedastals):	$9,440,300
Total installation cost:	$8,712,670
Total fixed cost:	$18,085,735

Table C6. EV Charging Infrastructure Costs, Long-Distance Faculty and Staff Commuters Only

Commuting distance band	Quantity Level 2 Chargers
20+ miles	1088
Total equipment cost (chargers + pedastals):	$2,716,488
Total installation cost:	$1,253,554
Total fixed cost:	$3,902,807
Total fixed cost w DTE incentive	$3,652,807

As previously noted, charging infrastructure costs are rather uncertain and difficult to estimate without location-specific evaluations of the planned installation sites. However, we expect that further cost reductions could be obtained through negotiations with DTE and charger manufacturers.

Electricity cost

We estimated the cost to the University for supplying free electricity to on-campus EV chargers based only on the energy rate ($/kWh), as described below. As the amount of EV charging rises, it may be necessary to consider demand charges (based on power draw, $/MW), which will need to be addressed in future analysis based on discussions with DTE.

To calculate aggregate university costs for electricity usage, we began with the estimated total faculty and staff commuting vehicles per distance group (Table C1) and applied a the 20% EV adoption target to these numbers, resulting in estimates of the number of EVs per distance band shown here in Table C7. It is difficult to know how much charging commuters will do on campus; for estimation purposes, we

[59] Chang et al. (2012).

assumed that the commuters would charge up enough to cover their daily round-trip commute distance, as given in Table C2; the implied annual EV mileage by distance band is shown in Table C7.

We assumed an average EV electricity consumption rate of 0.28 kWh/mile, a value typical of currently available midsized electric cars as listed in the U.S. DOE/EPA 2020 Fuel Economy Guide.[60] The resulting electricity use estimates were scaled up to account for charging losses, for which a factor of 1.135 was assumed.[61] The cost was then calculated based on U-M's recent average electricity rate of 8.6 cents per kWh, yielding the results shown in Table C7.

Table C7. Electricity cost for on-campus EV charging by 20% of UM-Ann Arbor faculty and staff commuters

Distance Band	Number of EVs	EV VMT 1000 mi/yr	Electricity use MWh/yr	Electricity cost $/year
< 1 mile	249	39	12	1,062
1-2 miles	622	321	102	8,766
2-4 miles	1,104	976	310	26,665
4-6 miles	738	1,407	447	38,464
6-10 miles	935	2,929	931	80,040
10-15 miles	820	3,918	1,245	107,088
15-20 miles	917	6,137	1,950	167,736
20+ miles	2,175	25,321	8,047	692,050
Totals	7,560	41,048	13,045	1,121,870

The annual cost to the University to provide free workplace charging for Ann Arbor faculty and staff commuters from all distances would be $1.1 million. For only the long-distance (20+ miles) commuters as recommended in this report, the annual cost would be roughly $700,000 at the targeted level of 20% EV adoption by faculty and staff commuters.

5. Emission Reductions

To project the GHG emission reductions associated with investments in EV charging infrastructure, we compared emissions from the electricity use for the on-campus EV charging to the emissions from the internal combustion engine vehicles (ICEVs) replaced by the EVs. Consistent with values previously used, we assume that a typical EV rated at 0.28 kWh/mile replaces an average gasoline ICEV rated at 23.8 mpg. These calculations are summarized in Table C8, below, for all commuting distance bands.

ICEV emissions were calculated by distance band working from the values in Tables C1 and C2. For EVs, the electricity use values in Table C7 were multiplied by an emission factor of 0.223 $kgCO_2e/kWh$, based on the average GHG intensity projected over the next 12 years for electricity from U-M's renewable PPA

[60] U.S. Department of Energy and EPA (2020), p. 39.

[61] Sears et al. (2014).

with DTE (Figure 4 in main text). GHG abatement was calculated as the difference between EV emissions and 20% of baseline ICEV emissions (reflecting the 20% of ICEVs replaced by EVs).

Table C8. GHG emissions and abatement for 20% EV adoption by UM-Ann Arbor faculty and staff commuters

Distance Band	ICEVs tCO_2e/yr	EVs tCO_2e/yr	Abatement tCO_2e/yr
< 1 mile	85	3	14
1-2 miles	704	24	117
2-4 miles	2,142	72	356
4-6 miles	3,089	104	514
6-10 miles	6,429	217	1,069
10-15 miles	8,601	290	1,430
15-20 miles	13,472	454	2,240
20+ miles	55,584	1,875	9,242
Total	90,107	3,039	14,982

For the targeted EV adoption by 20% of long-distance (20+ miles) Ann Arbor faculty and staff commuters, the resulting annual GHG emission reduction estimate is roughly 9,200 tCO_2e/yr (metric tons CO_2-equivalent per year). If EV use was adopted by 20% of all faculty and staff commuters, the estimated GHG reduction would be roughly 15,000 tCO_2e/yr. These abatement levels represent a 17% reduction relative to current faculty and staff commuter GHG emissions.

Cost-Effectiveness

We evaluated the cost-effectiveness of GHG reduction for two scenarios, one that targets EV adoption by only the long-distance commuters and the other for all faculty and staff commuters, using undiscounted benefits and costs over an assumed 12-year time horizon. Also note that cost-effectiveness is evaluated here for U-M as the investor; that is to say, these estimates do not reflect commuters' own costs (e.g., EV purchase price premiums) and benefits (fuel savings) for EV adoption. However, the consumer fuel cost savings for EV use are discussed below in Appendix D as relevant to an educational campaign.

Because they have the highest vehicle use, long-distance commuters have the highest GHG reduction potential and can make the best use of the infrastructure investments. Aggregate costs included charger equipment and installation, electricity and maintenance as estimated above. The resulting cost-effectiveness is \$116/tCO_2e for the investment level needed to support 20% EV use by the long-distance faculty and staff commuters. A similar calculation for EV use by 20% of all commuters results in \$191/tCO_2e. Note that these estimates assume a fixed grid emissions factor of 0.223 $kgCO_2e/kWh$; cost-effectiveness would improve over time as the grid decarbonizes and equipment costs continue to fall as time goes on.

APPENDIX D

EV Education and Promotion

Literature Review

Previous research has found that an information gap is perhaps the largest barrier to EV adoption among consumers. University of California (UC) Davis research has highlighted the fact that lack of consumer awareness and knowledge of EVs hinders market growth, and that positive correlations exist between EV awareness and purchases.[62] Kurani et al.,[63] Singer,[64] and Wolinetz and Axsen[65] (among a broader academic consensus) all agree that consumer awareness, knowledge, and experience with EVs are low and create a barrier to EV purchases. An education and awareness campaign is therefore crucial to closing this information gap and expanding EV ownership among commuters.

While it may be thought that governments and institutions should prioritize investment in financial incentive programs over educational campaigns, the UC Davis team emphasizes that educational campaigns are likely more cost-effective than financial purchase incentives for increasing EV sales. Some studies also find that socioeconomic standing is not a significant factor in EV purchases. Kurani suggests that income is a smaller factor than context and attitudes for EV adoption.[66] Likewise, Li et al. find in a comprehensive literature review that whether a consumer purchases an EV is not significantly influenced by income.[67]

Li et al. also note that one important inhibitor of EV purchases is uncertainty about "long charging time and insufficient charging infrastructures." Therefore, it is crucial that University of Michigan expands available infrastructure and simultaneously promotes this expansion to commuters. While the 20% EV adoption target recommended in this report reflects hoped-for market growth by 2030, U-M can foster EV purchases by being proactive in expanding its charging infrastructure because when commuters are confident in the infrastructure, they will be more likely to purchase an EV. Hardman and Turrentine support this proposition, explaining that a lack of workplace charging infrastructure is a proven deterrent to employees from purchasing EVs.[68] Designating employee use of this expanded EV charging infrastructure as free of cost and advertising this program will only help to catalyze EV adoption among the commuting population.

A U.S. Department of Energy (DOE) report on university campus charging suggests many tools that universities can utilize to effectively promote EV adoption, including the utilization of a web page that includes information on the locations and rules of available charging stations, and the sharing of this information with new employees through human resources departments.[69] This report also emphasizes the role of charging stations and their promotion as a visible display of a school's commitment to sustainability. Another DOE report on workplace charging is relevant to EV promotion among university employees, suggesting that visual communication tools such as posters and infographics are an effective

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[62] Turrentine et al. (2018).

[63] Kurani et al. (2016).

[64] Singer (2016).

[65] Wolinetz and Axsen (2017).

[66] Kurani (2019).

[67] Li et al. (2017).

[68] Hardman and Turrentine (2017).

[69] U.S. Department of Energy (2016b).

way to educate employees about EVs. Social media and internal newsletters can also be used to share information on EV benefits among employees.[70]

Besides logistical information on chargers, a large part of the information to be shared in the recommended educational campaign is individual cost savings and emission reductions. Li et al. (2017) discussed the effectiveness of educating consumers on cost savings by showing consumers how to calculate fuel and maintenance cost savings over the ownership period. Consumers tend to disregard EVs as an affordable vehicle due to the high up-front cost. However, especially for long-distance commuters, the fuel cost savings can outweigh the up-front price; but because consumers tend to make purchases with short-term costs in mind, these long-term savings are overlooked. This observation highlights the potential impact of a virtual, interactive cost calculator for promoting EV adoption. Sanguinetti et al. (2019) demonstrated the effectiveness of the UC Davis online vehicle cost calculator ("EV Explorer") for educating and persuading consumers about EVs supported by a study with 108 participants.[71]

The advertisement of relevant incentive programs through an official university web page has been done by multiple universities, such as University of California San Diego and San Diego State University as part of their electric vehicle programs. The UC Davis International EV Policy Council also lists the advertisement of incentive programs and how to access them as an important component of an EV education and awareness campaign.[19]

In conclusion, academic research shows that the EV information gap among consumers is significant and that it can be overcome through educational interventions, but such campaigns need to be backed by an expanded infrastructure to support EV use. Official university websites and social media channels can be utilized to share information on charging logistics, cost savings and emission reductions, and relevant incentive programs.

Educational Program Elements

Based on our review of other EV campaigns and suggestions from the literature, a U-M education program to support EV adoption by campus commuters should consider several elements.

At minimum, it should include the creation of an official U-M web page that connects commuters to relevant EV incentive programs such as the U-M employee free workplace charging program, utility rebates and discounted electricity rates, and federal EV tax credits.

Such information could be added to U-M's existing Electric Vehicle Charging web page.[72] Currently, this web page only includes information on charger locations, costs, and rules; it could be expanded to include a list of relevant incentives that will highlight the potential affordability of EVs. Both of these options should also mention the individual commuter GHG emission reduction and fuel cost savings from EV use. A more thorough web page along these lines would highlight the environmental benefits of EVs and encourage EV use while enhancing the visibility of U-M's climate action commitments.

To specifically highlight EV benefits to individual commuters, the U-M "Commute Calculator" web page[73] should be modified to include estimated daily, monthly, and annual fuel cost savings when driving an EV and taking advantage of free charging for employees. In addition, it could include estimated daily,

[70] U.S. Department of Energy (2014b).

[71] Sanguinetti et al. (2019).

[72] https://ltp.umich.edu/transportation-alternatives/electric-vehicle-charging/.

[73] https://ltp.umich.edu/transportation-alternatives/commute-calculator/.

monthly, and annual GHG emission reductions after switching to the currently listed transportation alternatives, as well as EVs (see Table D2 below).

Another avenue of information-sharing is the official UM mobile application. Currently, the application includes a map of on-campus parking lot locations and lists of individual lot features, including permit types allowed, hours of enforcement, and the presence of EV chargers (see "U-M Mobile Application" below). This functionality could be expanded to include the spatial location of chargers across campus and information on types of chargers, number of chargers, and time constraints for each charging location. While real-time usage data is available on the third-party ChargePoint application, ChargePoint only supports L2 chargers, making information on L1 charging locations and regulations difficult to locate. The presence of charging information on the UM phone application brings visibility to U-M staff, students, and faculty of the feasibility of EV ownership and operation.

In addition, the creation of shareable infographics officially branded by UM to be distributed through official UM social media channels such as Facebook, Twitter, and Instagram will help to include UM students and a broader public audience in this campaign. These infographics would share basic information on EV ownership in a condensed, visually appealing format, encouraging sharing among U-M social media followers. By commissioning students to create these infographics, the utilization of official UM social media channels is one way to provide student engagement opportunities in this campaign as well as in the broader work of the PCCN.

Finally, U-M should provide EV charging information to new employees through the Human Resources department during New Employee Orientation (NEO) sessions, including charging station locations, rules and regulations, and the free employee charging option.

Relevant Incentive Programs

Table D1 lists federal and local utility EV incentive programs relevant to University of Michigan faculty, staff, and students. This list should be added to an official University of Michigan web page, including links to applications. Note that there is potential for this list to expand through university negotiations with EV manufacturers for employee and student discounts.

Commuter Fuel Cost Savings and GHG Emission Reductions

Shown below in Table D2 are the estimated fuel cost savings per commuter. Average daily commute VMT was multiplied by an estimated gasoline cost per mile of 10.10 cents[74] to yield the total daily gasoline cost. The cost for commuting an equivalent distance in an EV and charging at home was found by multiplying average daily VMT by an efficiency parameter of 0.28 kWh/mile and then multiplying the resulting kWh by the average DTE electricity cost rate of 16.89 cents/kWh (for a household that uses 1000 kWh).[75] Daily commute fuel cost savings for driving an EV and charging at home was found by taking the difference of gasoline cost and electricity cost.

Daily commute fuel cost savings with free employee charging are equivalent to the daily cost of gasoline. One way to estimate these savings involves assumptions similar to those of the preceding paragraph based on the generic assumptions cited, which would imply fuel cost savings for switching from an ICEV to an EV of $375 for a 200-day work year (not accounting for non-commute driving). Employees with a 20+ mile commute have a large potential for fuel cost savings, at an average of $1,175 annually, and a total 12-year EV lifetime savings of approximately $14,000.

[74] AAA Exchange (2017).

[75] MPSC (2020).

Table D1. EV Incentive Programs

National		
U.S. Department of Energy	**IRC 30D New Qualified Plug-In Electric Drive Motor Vehicle Credit**[76]	Federal income tax credit for all EV and PhEV purchases. Amount depends on battery capacity; base credit is equal to $2,500, plus $417 for a vehicle with a battery with at least 5 kWh capacity, plus an additional $417 for each kWh in excess of 5 kWh. Limit is $7,500; does not apply to leased vehicles.
Utility		
DTE	**Charging Forward Residential Rebate**[77]	$500 rebate for DTE customers who purchase an EV, install a qualified Level 2 charger, and enroll in a year-round Time-of-Use rate.
DTE	**Discounted Time-of-Use Rates**	Three discounted nighttime electricity pricing plans for EV owners with flexible charging schedules: EV Plan, Time-of-Day Plan, and Dynamic Peak Pricing Plan.
Consumers Energy	**PowerMIDrive™ Home Charger Rebate**[78]	$500 rebate for Consumers Energy customers who purchase an EV and install a qualified Level 2 charger.
Consumers Energy	**Residential Time of Day Rate**[79]	Discounted nighttime electricity pricing plan for EV owners with flexible charging schedules.

[76] IRS (2020).
[77] DTE (n.d.).
[78] CMS/Consumers Energy (n.d.-a).
[79] CMS/Consumers Energy (n.d.-b).

Table D2. Fuel Cost Savings per Commuter

Another approach is based on fuel economy and gasoline price projections from the EIA (2020) *Annual Energy Outlook,* which foresees a national on-road fuel economy of roughly 28 mpg and gasoline price

Fuel Cost Savings per Commuter

Daily commute distance	Average daily VMT	Daily fuel cost to drive alone, non-EV	kWh equivilent	Home charging cost for daily commuting kWh	Daily fuel cost savings with EV	Annual fuel cost savings with EV	Daily fuel cost savings with free UM charging	Annual fuel cost savings with free UM charging
< 1 mile	0.8	$0.08	0.224	$0.04	$0.04	$8.59	$0.08	$16.16
1-2 miles	2.6	$0.26	0.728	$0.12	$0.14	$27.93	$0.26	$52.52
2-4 miles	4.4	$0.44	1.232	$0.21	$0.24	$47.26	$0.44	$88.88
4-6 miles	9.5	$0.96	2.66	$0.45	$0.51	$102.05	$0.96	$191.90
6-10 miles	15.7	$1.59	4.396	$0.74	$0.84	$168.64	$1.59	$317.14
10-15 miles	23.9	$2.41	6.692	$1.13	$1.28	$256.72	$2.41	$482.78
15-20 miles	33.5	$3.38	9.38	$1.58	$1.80	$359.84	$3.38	$676.70
20+ miles	58.2	$5.88	16.296	$2.75	$3.13	$625.16	$5.88	$1,175.64
Average	18.575	$1.88	5.201	$0.88	$1.00	$199.53	$1.88	$375.22

of $2.70 per gallon on average over the next twelve years. Commuters driving a 58-mile round trip 200 days per year would tally 11,600 miles per year, consuming an average of 414 gallons of gasoline at a cost of roughly $1,100 per year. That implies 12-year savings on the order of $13,000. This value is quite close to the $14,000 value noted above.

Per-commuter GHG emission reductions were calculated using the same parameters as the aggregate university GHG emission reductions calculation. On average, an employee that switches from an ICEV to an EV and uses free employee charging will reduce their daily commute emissions by roughly 73%.

Table D3. Daily GHG Emission Reductions per Commuter

Daily GHG Emissions Reductions per Commuter:

Daily commute distance	Average daily VMT	Commute emissions, non-EV (kgCO2e/day)	Commute emissions, EV (from grid) (kgCO2e/day)	GHG emissions reductions (kgCO2e/day)	Annual emissions reductions (kgCO2e)
< 1 mile	0.8	0.35	0.09	0.26	51
1-2 miles	2.6	1.14	0.31	0.84	167
2-4 miles	4.4	1.93	0.52	1.41	283
4-6 miles	9.5	4.17	1.12	3.05	611
6-10 miles	15.7	6.89	1.85	5.05	1,009
10-15 miles	23.9	10.49	2.81	7.68	1,536
15-20 miles	33.5	14.71	3.94	10.77	2,153
20+ miles	58.2	25.55	6.84	18.71	3,741
Average	18.6	8.15	2.18	5.97	1,194
				Percentage Reduction:	73.21%

Enhancing the Commute Cost Calculator

To specifically highlight EV benefits to individual commuters, the Commute Calculator[80] on the U-M LTP website should be modified to include estimated daily, monthly, and annual fuel cost savings when driving an EV and taking advantage of free employee charging. In addition, as part of the "Transportation Alternatives" section of the website, the Commute Calculator should be updated to include estimated daily, monthly, and annual GHG emission reductions after switching to the currently listed transportation alternatives, as well as EVs.

Shown below is the current Commute Calculator as of May 2020, which already includes annual fuel costs for the options of Drive Alone, Carpool and Vanpool.

[80] https://ltp.umich.edu/transportation-alternatives/commute-calculator/.

Image D1. U-M Commuter Cost Calculator

How many days per month do you commute to work (22 is full time)?

22

How far is your round-trip commute to work? (in miles) Google Maps

20

How many miles per gallon does your vehicle average? Federal Fuel Economy Guide

25

How much per gallon do you pay for gas?

2.75

Which U-M Parking Permit do you purchase?

Blue

CALCULATE

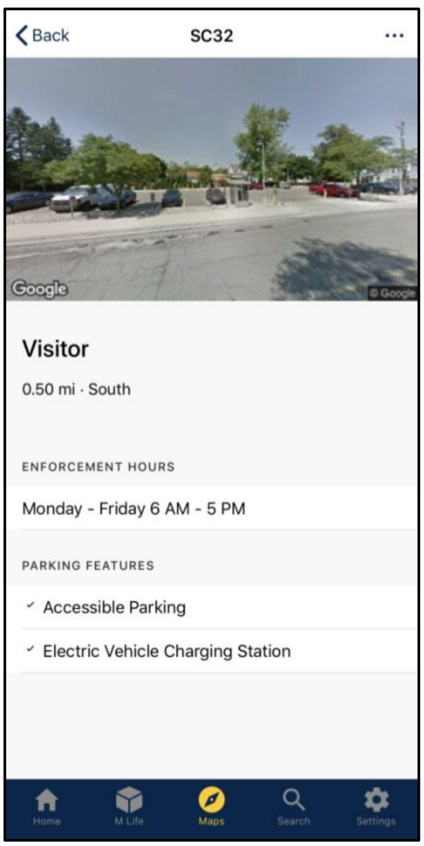
Results	Daily	Monthly	Yearly
Drive Alone[1]	$6.82	$150.04	$1800.48
Carpool with 1 other person	$3.41	$75.02	$900.24
Vanpool (University of Michigan) with 6 people[2]	$1.69	$37.18	$446.16
Transit Options			
AAATA (Ride FREE with your University of Michigan MCard)	$0	$0	$0
Express Ride (Canton and Chelsea)[3]	$2.84	$62.50	$750.00
Detroit Connector[4]	$12.00	$264.00	$3168.00

Enhancing the U-M Mobile App

Another avenue of information-sharing is the official U-M mobile application.[81] Currently, the application includes a map of on-campus parking lot locations and lists of individual lot features, including permit types allowed, hours of enforcement, and the presence of EV chargers. Shown in the screen shot here, for example, is the current display for the SC32 lot on South Campus, which highlights Accessible Parking and the presence of an Electric Vehicle Charging Station.

This functionality should be improved to show the specific locations of chargers available on campus, so that employees, students or visitors searching for one can do so without opening the information for each parking lot until they find a lot with charging capability. The Parking Features section, rather than listing only the presence of EV chargers, should be updated to include information on types of chargers (i.e., L1 versus L2), number of chargers present, charging costs (for non-employees) and time constraints for each charging location. While real-time usage data is available on the third-party ChargePoint mobile app, ChargePoint only supports L2 chargers, making information on L1 charging locations and regulations difficult to locate. Having more detailed charging information on the U-M Mobile App would improve the convenience of EV use by making charger information and benefits more visible to users.

Image D2. U-M Mobile App Screen Shot



[81] https://its.umich.edu/computing/web-mobile/michigan-app.

APPENDIX E

Peer Benchmarking

The research we have performed indicates that the University of Michigan would be among the first in the Midwest to make a large-scale effort to lower its scope 3 GHG emissions through the installation of electric vehicle charging infrastructure for its commuters. Although many other universities currently have small numbers of EV charging stations (typically less than 30 per campus with some exceptions), very few have publicly announced efforts on the scale that we are proposing for U-M. It is possible that other institutions are engaging in internal discussions and efforts of a similar scope but the large majority of the contacts to whom we reached out were unresponsive (perhaps due to COVID-19). The institutions we contacted were primarily those of similar faculty sizes and student enrollment to U-M and those that have publicly declared a carbon neutrality goal or other climate action plan.

The University of California (UC) system's goals for zero-emission vehicle (ZEV) numbers are laid out in its Policy on Sustainable Practices.[82] This document sets a goal of 4.5% of the commuters to the individual UC schools driving ZEVs by 2025 and 30% by 2050. Working toward these system-wide goals, a number of UC schools have established programs for increasing EV use by commuters to their campus. We heard the most detail from David Karwaski, Senior Associate Director of Transportation at UCLA. Their efforts include a plan to install chargers at 4.5% of the university-owned parking spaces, implying approximately 990 chargers (UCLA currently has installed over 100). They have found that installing mostly L1 chargers works well because employees arrive, plug in, and trickle charge all day with the expectation that this is a top-off site and not a primary source of charging. Mr. Karwaski also noted that UCLA has found L1 installation much easier and cheaper than L2. UC Irvine also has a strong program, seen in their Pump2Plug website and campaign.[83]

Lisa Tornatore, the Sustainability Director at Boston University explained that Boston University was moving forward with a Climate Action Plan[84] and have hired a consultant to aid in EV fleet transition. Their Parking and Transportation Services are currently working on evaluating the need for an expanded charging program. The University of Maryland also has a Climate Action Plan and has specifically laid out numbers for EV charging stations goals. Their aim is for 43 parking spaces with L2 Chargers by 2020, 64 by 2025 and 93 by 2040.[85]

Other institutions we contacted about charging infrastructure expansion that either provided no relevant information or did not respond include Washington University in St. Louis; George Washington University; University of Minnesota–Twin Cities; University of Colorado Boulder; University of California, Davis; University of California, Berkeley; and the University of California, San Francisco. Many other institutions' efforts were researched online.

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[82] University of California (2019).

[83] University of California, Irvine (n.d.), https://sites.uci.edu/electricvehicles/.

[84] Boston University (2017).

[85] University of Maryland (2018).

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