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Electric Vehicle Charging Infrastructure Analysis

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Electric Vehicle Charging Infrastructure Analysis

by
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Electric Vehicle Charging Infrastructure Analysis

An Interactive Qualifying Project
submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfilment of the requirements for the
degree of Bachelor of Science

by
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Report Submitted to:

Craig Putnam
Brad Miller
Paul Mathisen
Worcester Polytechnic Institute

This report represents work of WPI undergraduate students submitted to the faculty as evidence of a degree requirement. WPI routinely publishes these reports on its web site without editorial or peer review. For more information about the projects program at WPI, see
http://www.wpi.edu/Academics/Projects.
ABSTRACT

Widespread and convenient charging infrastructure is an important catalyst for electric vehicle (EV) adoption, and colleges and universities are particularly well-suited to encourage EV ownership by offering workplace charging. However, the absence of standard procedures and the collective lack of experience, combined with future uncertainty in the EV market, makes it difficult for these institutions to ensure campus charging infrastructure keeps pace with demand. This project uses EV ownership projections, interviews, surveys and utilization data analysis to develop an evaluation model. This model is then applied to Worcester Polytechnic Institute (WPI) to produce short-term recommendations.
ACKNOWLEDGEMENTS

We would like to thank Liz Tomaszewski, WPI Associate Director of Sustainability, for her contributions as de facto project advisor. She helped connect us to other Worcester institutions, provided information on WPI’s charging station usage, capabilities, and policies, and shared WPI’s future EV infrastructure plans. She also contributed significant amounts of her time by attending nearly every weekly IQP meeting. It is safe to say the project would have been much less successful without her help.

The project also owes a debt to many people outside WPI who shared their skills and knowledge. Foremost among this group is Luba Zhaurova, Sustainability Project Manager for the City of Worcester, MA. It also includes Suzanne Wood, Sustainability Program Manager at UMass Medical School, Steve Bandarra, Sustainability Coordinator at Worcester State University, Jenny Isler, Director of Sustainability at Clark University, John Cannon, Director of Facilities at the College of the Holy Cross, and Michael Carroll at Worcester Academy. These individuals shared their institutions’ experiences with EV charging, including usage, policies, governance, and reception. Also contributing to our understanding of the subject were Mark Siegal, Ariella Cohen, Tom Chorman, and Justin Woodard at National Grid, Rachel Ackerman at the Massachusetts Clean Energy Center, and Dennis Carlberg, Director of Sustainability at Boston University.

We would also like to thank the several hundred students, faculty, and staff at WPI who responded to our survey. Their feedback played a vital role in our analysis of and recommendations for WPI’s EV charging network.

Last but not least, we express our gratitude to our advisors, Professor Craig Putnam, Brad Miller, and Professor Paul Mathisen.
EXECUTIVE SUMMARY

Electric vehicles have become increasingly popular as the variety of available models and consumer awareness has grown in recent years, but the segment still claims only a small market share. One primary issue impeding higher rates of electric vehicle (EV) adoption is the lack of charger availability. Most EV owners charge at home, but for those who have longer commutes or no access to residential chargers, public and workplace charging are necessary to make EV ownership practical and convenient. Universities and colleges are particularly well-placed to invest in workplace charging infrastructure but can face obstacles and uncertainty when making such an investment. Some feel an obligation to do their part in protecting the environment by encouraging the adoption of EVs through installing charging infrastructure, some have vocal EV-owning communities rallying for chargers, and some hope to improve the image of their institution’s sustainability efforts. Unfortunately, due to the relative recency of EV developments and thus the lack of existing examples, formulating a plan for campus charging infrastructure can be difficult. Furthermore, considerable uncertainty surrounding future developments can heighten hesitation to make a financial investment, while navigating grant programs can be confusing and time-consuming.

Worcester Polytechnic Institute (WPI), a STEM-focused university of about 7,000 students located in the midsized city of Worcester, MA, is one institution discussing future EV plans. The university installed its first charging stations in 2011 and has since seen a rate of EV adoption significantly exceeding that in the general population. By 2019, the six installed ports were largely at capacity and WPI recognized the need for continued expansion of EV infrastructure to encourage campus EV adoption. However, like at many similar institutions, university decision-makers struggled with the lack of a clear path to follow.

Project Goals

As a group of three students from WPI, we set out on a two-pronged project to serve the needs of both WPI and other universities’ sustainability offices. The two goals of this project were to provide short-term recommendations to WPI for charging infrastructure expansion and policy changes and to develop an evaluation model for EV infrastructure installation at academic institutions. The template can be used for maintaining WPI’s charging infrastructure in the long-term while also being useful to other institutions hoping to jumpstart or maintain their charging infrastructure programs.

Over the course of our project, we kept in mind issues of compatibility and upgradeability in the face of technological advancement. Aside from investing in new infrastructure, usage cost and pricing structure are perhaps the most salient policy issues. For private controlled-access chargers, like those at WPI, the price can be set lower than market rates without overloading capacity through public use. In fact, WPI as well as many other universities provide charging for free. This can be viewed both as a perk for EV owners in the WPI community or as an incentive for more community members to drive electric vehicles. We examined how this incentive affects faculty and students in order to evaluate and recommend potential changes in pricing structure.

Though the research and literature on large-scale adoption of EVs and need for Electric Vehicle Supply Equipment (EVSE) is sizable and growing, there is little published material applying this knowledge to institutional scale recommendations. This is likely attributable to the ad-hoc nature of institutional EVSE decisions at this early stage. With charging infrastructure needs growing in scale and importance,
formalizing the process is desirable. As noted, our primary goal focused on a set of recommendations for WPI, but we also hoped to address the relative paucity of recommendations for institutions, especially in the academic world. Obviously, there are many situation-specific details that preclude a completely general set of recommendations, but at least, we can provide process recommendations in the form of a general template. Creating such a template required examination of the general state of EV technology and ownership, as well as future estimates for growth in these areas. The project’s goals were to:

- Perform a literature review to determine the history and future of EV adoption trends by examining factors influencing adoption;
- Interview local universities regarding their EV charging infrastructure, their methods for managing EV charging infrastructure and expansion, and plans for future expansion;
- Survey WPI faculty, staff, and students to determine the size of WPI’s current EV community and its future expansion, and gauge opinion regarding existing EV charging infrastructure;
- Formulate short-term recommendations for WPI’s charging infrastructure expansion and policy based on survey results and comments; and
- Create a template for other universities to replicate this project’s methodology and better manage their EV charging infrastructure.

This project’s findings will inform WPI’s charging policy and infrastructure changes for the next five years.

Methodology and Process

Background Research

To develop useful and accurate guidelines for EVSE investment decisions, we conducted extensive research on EV capability and adoption trends, charging behavior, and station capabilities and protocols, among other topics. A number of organizations have produced estimates for EV adoption over the next twenty-plus years, but the only agreement between estimates is the direction rather than magnitude of adoption. There are many variables that account for this wide range, and we identify several, including government incentives and regulation, technological development, charger availability, and consumer awareness.

Assessing the Situation in Worcester-area Universities

Informational interviews were conducted to determine whether any sustainability offices at academic institutions in the area had found successful ways to manage the growth of its EV charging infrastructure. Most universities interviewed had an established EV charging infrastructure program which enabled us to analyze the effectiveness of different installation strategies and charging policies. This informed the development of our recommendations and the evaluation model.

WPI Community Survey

In Winter 2019, a survey was distributed to WPI faculty, staff, and students to measure ownership levels and trends, as well as opinion on how WPI should provide EV charging. WPI’s current EV charging infrastructure and utilization data were also examined. Before the survey, the Office of Sustainability
had no clear picture of the EV community’s size on campus. Furthermore, there were no estimates for how this community might grow in the near future, influencing demand on WPI’s EV chargers.

Survey responses were analyzed in early 2020, which revealed a much clearer picture of WPI’s EV owning community and its members’ charging habits, needs, and opinions. Non-EV owners also indicated when they expected to purchase an EV, enabling the formation of a projection estimate for growth of the EV community in the next five years. Students were also able to voice their opinions regarding EV charging policy on campus.

Evaluation Model

The evaluation model presents our guidance and recommendations for anticipating future growth in campus EV populations, deciding between potential EVSE policies and fees, and choosing the right type of chargers. These guidelines are augmented by a system dynamics-based model that aims to present rough estimates of campus EVSE needs under a range of plausible scenarios for vehicle adoption and institutional policies. Based on interviews with universities, an aggregation of successful and unsuccessful charging infrastructure policies was formed, resulting in the following evaluation model as a series of worthwhile factors to consider:

- On-campus EV population size and its approximated growth
- Charging policy options
- Installation considerations
- Types of chargers available

We encourage the use of a community survey as an effective tool for judging campus EV population as well as gathering community feedback on charging policy and installation considerations. Every institution has unique opportunities and constraints which preclude blanket recommendations, but we have identified broad dynamics and common factors for universities to consider. Because of the tradeoffs involved, we strongly urge universities to be transparent about the goals and priorities for EV infrastructure. These priorities will determine the best course of action when it comes to investment and policies.

Conclusions and Recommendations to WPI

Survey results indicate that the establishment of a charging fee at WPI would dampen enthusiasm for EV adoption. Such a result would conflict with the university’s sustainability objectives to encourage the growth of cleaner vehicles. Nevertheless, within the next decade WPI’s willingness to install new stations is likely to fall behind demand for no-cost charging, not to mention the ever-increasing utility cost as more stations are installed. Thus, we recommend eying a target date of three to five years out (2023-2025) for the imposition of a pay-by-hour fee. Hopefully, by that period electric vehicle demand will be sufficiently robust to absorb the incentive phase-out. To ease the community into this policy shift, we recommend instituting an idling fee as soon as possible for charging in the Park Avenue Garage. Charging should be kept completely free at the Gateway Garage, since the stations there are underutilized at the moment and there is no pressing need to enforce limited charging sessions to make way for other EV owners. In case of overuse at the Gateway Garage, the same charging fee policy may be applied.
In terms of additional chargers, the immediate demand for new chargers was met by the installation of five new dual-head chargers at Gateway Garage over winter break 2019. This also satisfied the significant contingent of EV owners who favored that location for new stations. Still, demand is likely to quickly absorb the increased supply. Judging from survey results, we estimate that WPI’s EV owning community will at least double in size in the next five years. By the mid-2030’s, WPI could be facing demand for more than 100 stations, although projecting that far out is always fraught with uncertainty. More immediately, preliminary data on overall charger usage after the installation of five dual-head chargers at the Gateway Garage suggest that there is still unmet need for EV chargers at the Park Avenue Garage. The Park Avenue Garage chargers are still in use most of the time when classes are in session, which suggests that location could benefit from more stations. The next most requested location for installing new chargers by the EV owning community in the survey was the Boynton Lot. As the new SmartWorld building is constructed, we want to especially emphasize the importance of including scalable infrastructure that could support the installation of many more EV chargers, as WPI’s EV community outgrows the current infrastructure. We also recommend that at least one dual-head EV charger be installed at the Visitor Lot at 60 Prescott, to take advantage of National Grid rebates that would cover the entirety of EVSE and installation costs at this location.

In order to stay abreast of charging needs on campus and the effect of these proposed policies, we suggest redistributing a slightly modified version of the survey in 2-3 years. The results from the 2020 survey can be used as a baseline value for comparison, and the validity of the predictions presented in this report can be used as a guide for making predictions based on the redistribution.
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Glossary of Terms

**BEV**: Battery Electric Vehicle. Used in this report to identify vehicles that are propelled *solely* by a battery-electric powertrain.

**CARB**: California Air Resources Board

**EJC**: Environmental Justice Community

**EV**: Electric Vehicle. Used in this report to include both BEVs and PHEVs.

**EVSE**: EV Supply Equipment

**HEV**: Hybrid Electric Vehicle

**ICE**: Internal Combustion Engine

**LEV**: Low Emissions Vehicle. Standard used in CARB regulations.

**PHEV**: Plug-in Hybrid Electric Vehicle

**ZEV**: Zero Emissions Vehicle. See LEV.
Chapter 1. Introduction

Over the last decade, electric vehicles (EVs) have gained prominence in the public discourse as a means to reduce transportation-related emissions of greenhouse gases. Nevertheless, their practical impact remains small; through 2019, EVs have yet to reach a 2% annual market share of new vehicles sales in the United States despite a 500% sales increase since 2012. Among several contributing factors, consumer surveys consistently cite poor range and lack of charging infrastructure as two of the most significant impediments to an EV purchase (Autolist, 2019; Volvo Car USA & The Harris Poll, 2019). Consequently, expanding the charging network has strong potential to spur EV adoption and make progress towards environmental objectives. While education certainly has a role to play in dispelling myths and combating lack of awareness surrounding current EV capabilities, there is little question substantial EV infrastructure investment is needed. Addressing this issue will require action from the federal government all the way down to individual institutions and property owners. Even for those who prefer to take a conservative approach, EV adoption is projected to multiply, likely making charging stations a virtual necessity for businesses, offices, landlords, and others.

Among institutional actors, universities and colleges are particularly well-placed to invest in EV charging infrastructure but can face obstacles and uncertainty when making such an investment. Most secondary institutions are large employers, tend to have communities attuned to environmental challenges, and have a unique opportunity to influence future leaders and consumers. However, there exists no standardized method for determining when a university should install EV chargers or augment capacity, how many and what type to install, and how to allocate responsibility for the new infrastructure. Currently, many universities rely on EV owners to notify them of demand for more chargers, and those looking to install their first chargers often rely on word of mouth and estimates from other universities. Considerable uncertainty surrounding future demand makes these institutions hesitant to undertake the investment. Many government agencies and utility providers offer EV charger subsidies and related incentives, but awareness of these initiatives is not universal and the often-changing program sponsors, naming, and parameters can make navigation difficult.

Worcester Polytechnic Institute (WPI), a STEM-focused university of about 7,000 students located in the midsized city of Worcester, MA, is one institution grappling with future plans for charging infrastructure. The university installed its first charging stations in 2011 and has since seen a rate of EV adoption significantly exceeding that in the general population. By 2019, the six installed ports were largely at capacity and some EV owners reported being inconvenienced by a lack of available charging spaces. Behavioral nudges can only do so much to alleviate this issue, and WPI recognized the inevitable need to continue expanding EV infrastructure if the school wishes to increase campus EV adoption. Alongside raw numbers of electric vehicles and charging stations, issues of placement and charging policy presented important areas of inquiry.

This project was targeted at providing EV infrastructure recommendations to WPI as well as developing a broader set of guidelines to assist other institutions, especially colleges and universities, in formulating an approach to these issues. To do so, we examined the current condition and predictions for electric vehicle ownership, technology and adoption initiatives, as well as protocols, capability, and deployment of charging infrastructure. For understanding the situation at WPI specifically, we evaluated utilization and usage patterns using data collected by the existing campus charging stations. Additionally, we
distributed a survey to students, faculty and staff. By asking about current vehicle ownership and potential plans to purchase an EV, we hoped to improve prediction for campus EV ownership. We also investigated the community’s attitudes towards WPI’s EV initiatives, both from the perspective of potential charging policies as well as the general community’s receptiveness to the required financial investment. By synthesizing our knowledge about EV charging issues with our appraisal of WPI’s current position, we produced predictions and recommendations to inform university administrators and Sustainability Office staff. To broaden our impact, we generalized our findings, influenced in part by issues we saw other universities dealing with. We hope our work can be useful to other institutions hoping to jumpstart or maintain their charging infrastructure programs.
Chapter 2. Background

An understanding of the characteristics and current state of electric vehicles and charging infrastructure is important background for this project. This section summarizes the general history and adoption of electric vehicles and chargers and examines the current state of WPI’s EV charging infrastructure.

2.1. Electric Vehicles

2.1.1. Vehicle Types

Electric vehicles are grouped according to their electricity usage. There are three major types of electrified vehicles on the market: battery electric vehicles (BEV), plug-in hybrid vehicles (PHEV), and hybrid electric vehicles (HEV). Particularly in public discourse, the former two terms are frequently combined under the “EV” umbrella, although the boundaries of that term can be hazy in general use. In this report, we will use the term “EV” to refer strictly to vehicles that can be charged from an external source, which includes both BEVs and PHEVs. The more precise designations will also be used when preferable for clarity.

Traditional hybrids combine a combustion engine augmented by one or more battery-powered electric motors. In general, these vehicles can run in electric-only mode for very short periods at low speeds, if at all. Because they cannot be charged by an external source, the battery relies on the combustion engine to recharge, supplemented by regenerative braking. The regenerative braking process, which is also employed by PHEVs and BEVs, slows the vehicle by converting the kinetic energy into electric energy to charge the battery. While the Toyota Prius is the most recognizable hybrid, many manufacturers have offered hybrid models in several vehicle categories over the last two decades.

Plug-in hybrids operate on a similar concept but possess much larger batteries that accept a charge from an external electricity source. Typical electric-only range is between ten and thirty-five miles, with a couple models offering more. The Chevrolet Volt (discontinued in 2019) and the Prius Prime are popular examples, with ranges of 53 and 25 miles, respectively (Discontinued Vehicles, 2019; 2020 Prius Prime Full Specs, 2019). Additionally, a number of vehicle models, especially in the luxury segments, now have a PHEV version. Finally, battery-electric vehicles do away entirely with the combustion engine, with battery-powered motors their sole means of propulsion (BEV, PHEV, HEV, 2019).

2.1.2. EV History and Adoption Trends

While there were a handful of interesting but very limited commuter-type EVs in the 1970-80’s, the first practical electric vehicles only began to appear in the 1990’s. Production was driven by new regulatory developments, specifically the 1990 Clean Air Act Amendment, the 1992 Energy Policy Act, and new regulations from the California Air Resources Board (CARB) (The History of the Electric Car, 2014). One of the new CARB requirements mandated manufacturers sell a certain number of zero-emissions vehicles (ZEVs) relative to their overall sales (Zero-Emission Vehicle Program, 2019). Over time, some other states would adopt California’s ZEV and conceptually similar Low Emission Vehicle (LEV) requirements. To meet these new regulations, many manufacturers developed electric versions of existing vehicles such as the Ford Ranger, Chevrolet S-10, and the Toyota RAV4. These models used a mix of lead acid batteries and the more advanced but expensive nickel metal hydride (NiMH) batteries.
By the turn of the century, relaxed regulations, lower gas prices, and a strong economy pushed manufacturers and consumers away from EVs. Nevertheless, electrification took an important step forward with the 2000 release of the Toyota Prius hybrid electric vehicle. By 2005, Toyota was selling over 100,000 Priuses a year in the US (“Toyota Prius Family US Car Sales Figures,” 2019). Compare this to the earlier RAV4 EV, which sold a cumulative 1484 units between 1997 and 2003 (Motavalli, 2010). The success of the Prius helped mainstream hybrid vehicles: HEV sales peaked in 2013 at nearly 500,000 units for a market share of just over 3% (Alternative Fuels Data Center: Maps and Data, 2019). Falling gas prices have been blamed for their subsequent sales decline, although some sources also point to cannibalization of sales by PHEVs and BEVs (Josephs, 2017).

In 2006, startup Tesla Motors announced its first vehicle, the fully electric Roadster. With a range of 220 miles and a 0-60 time of less than four seconds, it marked the arrival of EVs with capabilities to rival or exceed ICE (Internal Combustion Engine) competitors. This was made possible by lithium-ion batteries. Although the Roadster’s two-door convertible body style limited practicality, more practical EVs would soon follow, both from Tesla (Model S full-size sedan, in 2012) and others, such as the 2010 Chevrolet Volt and 2011 Nissan Leaf hatchbacks.

From 2011 onward, EV sales have generally exhibited very strong year-over-year growth, as shown in Figure 1. PHEVs generally accounted for slightly less than half of overall BEV sales, excluding 2012, when the Volt and the Prius Plug-in PHEVs first achieved significant success. Just the next year, however, sharp increases in sales for the Leaf and Model S helped balance the figures. With such a small sales base, model debuts or changes in availability have the potential to significantly shift overall sales volume. Nowhere is this more evident than in 2018, when 80% year-over-year gains were achieved largely thanks to the debut of Tesla’s Model 3 compact sedan, a moderately priced option compared to the California startup’s previous models. Nevertheless, keep in mind that despite the surge in popularity, EVs accounted for barely 2% of the 17.2 million vehicles sold in the United States that year.

In the United States at least, 2019 was a setback for the segment, as EV sales dipped by 9% compared to 2018, while total new vehicle sales experienced only a 1.6% decline. Excluding the Model 3, sales decreased by an alarming 23%. While disappointing for advocates of electrified transportation, this does not necessarily portend a long-term shift in EV adoption trends. Given the ability for a single model’s performance to completely change the complexion of the total sales figure, new models arriving in the next couple years have the potential to get growth back on track.
2.1.3. Projected EV Adoption

Projections regarding the exact scope of the growth in EV ownership vary, yet most reputable sources agree that there will be a monumental increase. For example, widely quoted Bloomberg New Energy Finance (BNEF) forecasts in their “Electric Vehicle Outlook 2019” report that by 2025, global annual EV sales will rise to 10 million compared to a mere two million sold in 2018. By 2040, BNEF expects EVs to constitute the majority of global new car sales and predicts a global stock of 550 million in that year. More conservative estimates from oil companies such as BP and ExxonMobil point to 350 million and 150 million, respectively (BloombergNEF, 2019). China has a significant lead in early EV adoption, although Bloomberg predicts Europe will catch up with respect to EV market share by the mid-2020’s. The United States is expected to lag a few years behind. Nonetheless, Navigant forecasts US sales to more than double in the next five years, reaching over 2.6 million by 2030 (Funicello-Paul, 2020). In Massachusetts, Navigant projects an increase from 12,700 EVs in 2019 to 28,700 by 2025.

2.1.4. Factors Influencing EV Adoption

As the previous section hints, there is a wide range of plausible estimates for medium and long-term EV adoption. This is due to uncertainty surrounding a wide variety of factors, particularly how future EVs will compare to ICE vehicles regarding price, range, and other factors consumers value. By identifying the major factors spurring and hindering adoption, we can identify levers through which uptake rate may be increased. Furthermore, organizations like WPI should maintain basic awareness about these indicators in order to get advanced notice about possible shifts in adoption rate.

Here, we identify six major factors likely to affect future EV adoption rates: purchase incentives, government regulations, technological development which improves EV characteristics relative to ICE
vehicles, range of model choice available to consumers, charging infrastructure availability and capability, and overall consumer awareness. We also look at the more ambiguous role of gasoline prices.

2.1.4.1. Financial Incentives
Surveys and analysts frequently identify the EV purchase price premium as a significant barrier to widespread adoption. In order to offset this effect, governments around the world have provided financial incentives to EV buyers. In the US, the most significant is a federal tax credit program initiated on December 31, 2009. Depending on the vehicle’s battery capacity and the gross vehicle weight rating, the owner can get a tax credit ranging from $2,500 to $7,500 (Electric Vehicles: Tax Credits and Other Incentives, 2019). Tax credits phase out for a manufacturer’s vehicles once that company has sold 200,000 EVs.

At that point, credits gradually fall to zero over the course of roughly eighteen months (Sherlock, 2019). Tesla vehicles stopped being eligible for the full credit at the beginning of 2019, and December 31, 2019 spelled the end of any federal credit for Tesla buyers. General Motors vehicles (of which the Chevrolet Bolt is the most notable) reached the same milestones four months behind Tesla. The third-place manufacturer, Nissan, is not expected to reach the cap until at least 2021 (Gorzelany, 2019). All three manufacturers disclosed lobbying for the Driving America Forward Act, which would extend the tax credits to 600,000 vehicles with minor revisions (Cama, 2019). Nevertheless, the bill was not included in a year-end tax package, though supporters expressed optimism for future adoption (Reklaitis, 2019).

Most states have also introduced some incentives to purchase EVs. In Massachusetts, the MOR-EV program offered an incentive of up to $2,500 for purchasing or leasing EVs, and $450 for zero-emission motorcycles (MOR-EV, 2019). Although this program expired in September 2019, there is movement toward reintroducing the incentives (Shemkus, 2019).

Beyond purchase rebates, many EV drivers can take advantage of incentives throughout their vehicle’s lifespan. For instance, a number of states allow EVs to use high-occupancy vehicle (HOV) lanes irrespective of passenger count, although these privileges have recently seen increasing restrictions (Salazar, 2019; Dawid, 2018). A California study found that HOV lane access was the primary reason for purchasing an EV for up to 54% of buyers (Jansen, 2018). Eliminated or reduced exposure to gas taxes is another hidden subsidy for EVs, although electricity is also taxed.

It is important to note that these EV incentives are hardly uncontroversial. Whether the associated costs exceed the social gains from lower CO₂ emissions is beyond the scope of this report. Nevertheless, when projecting future incentives, it is vital to keep in mind the political and economic vulnerabilities. Of course, there are general concerns about the considerable monetary cost of these programs — the federal subsidies alone are projected to total $7.5 billion between 2018 and 2022. Additionally, many people are uncomfortable that EV rebates largely benefit affluent buyers; even with the credit, the most popular EVs are more expensive than the average new vehicle. Equitability concerns have manifested themselves in adjustments to California’s rebate program that cap participant income and eligible vehicle MSRP (FAQs, n.d.). Although some argue a segment of affluent consumers will still buy EVs without a rebate, the existing evidence on subsidy phase-outs makes this far from a certain proposition.

Another equity argument concerns the gas tax, which of course does not apply to fully electric vehicles. Because these taxes are generally used to fund transportation infrastructure - federal and state governments both tax fuel - it is often perceived as unfair that EVs use the roads without contributing to
maintenance. While the total lost tax revenue is currently small in most states, some, most notably California, have begun instituting annual registration fees ranging between $50 - $200 (Gorzelany, States that Charge Extra Fees to Own an Electric Vehicle, 2019). There have also been discussions and experimentation regarding a mileage fee (Harman, 2019). Expect similar debates to follow in other states, as well as potentially on the federal level.

Predicting the exact effect of subsidy changes on the EV market is difficult, but several international cases present plausible scenarios for Tesla and GM post tax-break eligibility, as well as the overall EV market if federal tax breaks are modified or eliminated. As noted, the federal tax credit on new Tesla purchases expired at the end of 2019, and new GM vehicles – as of early 2019, only the Chevrolet Bolt and leftover Volts – are only eligible for a reduced credit, which itself will expire beginning Q2 2020. While Tesla seems to have been scarcely impacted by the change, Bolt sales did decrease slightly year-over-year despite starting from a rather small base. In both cases, it will likely be several months before a clear picture emerges. More conclusive statements can be made about the effect of past subsidy cuts in Hong Kong, mainland China, and the Netherlands. Unfortunately for the purpose of predicting the US market, the evidence is somewhat contradictory.

In 2017, Hong Kong capped a tax waiver for electric vehicles, which had the effect of increasing the total price of Tesla’s Model S – by far the city’s most popular EV at that time – by over 50%. After a huge surge before the policy changed, Tesla sales plunged by over 90% the ensuing two years (Huang, 2017; Huang, 2019). Granted, this is an extreme example given the magnitude of the original tax waiver, but the sales decline is at least as severe, demonstrating the demand sensitivity even in the luxury EV market. China’s experience is perhaps more illustrative of broader subsidy cuts. In an aggressive effort to boost domestic production and sales of EVs, the Chinese government has heavily subsidized production since 2016 (Kharpal, 2019). After a glut of new manufacturers arose to take advantage of production subsidies, the government slashed the incentives in half and eliminated them entirely for vehicles with less than 250km (155mi) of range, ostensibly in an effort to promote “survival of the fittest” (Toh, 2019). One of the top Chinese EV makers, BYD, reported an 89% fall in profits for the next quarter, and other firms also attributed sales declines to the subsidy changes. Although experts and industry executives initially expressed long-term optimism, there was sufficient backlash to prompt an announced delay in further cuts (Kharpal, 2019; Sun & Goh, 2020).

Contrast Singapore and China’s experiences with that of the Netherlands, where new restrictions on EV tax breaks seem to have boosted sales (Vinkhuyzen, 2019). Beginning in 2019, the country phased out tax breaks for the portion of the EV price above EUR 50,000. This led to a surge in demand for more expensive EVs towards the end of 2018. Of course, the same incentive had been in effect for years, but the imminent changes spurred those who had been delaying a purchase to jump into the market. In December of that year, EV market share reached 30%. While demand predictably fell off in early 2019, EV sales remained higher than before. Helped once again by a wildly successful December (EV tax breaks were further reduced beginning January 1, 2020), 2019 EV market share reached 15%, nearly a 150% gain compared to the previous year (Pontes, 2020). Although definitively attributing the year-over-year gains to any particular factors is impossible, Vinkhuyzen (2019) argues that a major role was played by the late 2018 surge that helped make new EVs more visible to Dutch consumers, making them more familiar with modern EV capabilities.
2.1.4.2. Regulations

Regulation is the other side of the government intervention coin. The initial wave of “modern” EVs in the 1990’s was driven in large part by regulation on the part of the California Air Resources Board (CARB). The initial 1990 regulations, which mandated a 10% EV market share by 2003, were intended as a technology-forcing measure (McConnell, Leard, & Kardos, 2019). Although EV technology in 1990 was quite primitive, the mandate aimed to incentivize technological development by manufacturers needing to meet their EV market share targets. However, technology did not advance as quickly as the regulators hoped, and as the deadline approached, available EVs were expensive, incapable and lacked consumer interest. After being sued by a group of auto manufacturers, CARB gradually extended the deadlines and allowed the target to be met by selling hybrids (labeled as partial ZEVs, or PZEVs). McConnell et al.(2019) label 2005-2017 as “Phase 2” of ZEV program, characterized by gradually tightening but achievable targets. Despite the failure to spur pure EV adoption, the authors credit the program with increasing the rate of battery-related technological development which subsequently benefited EVs.

EV technology has now developed to the point where regulations aim to improve the uptake rate of existing technologies. Nevertheless, because most major standards are based off sales, automakers wishing to meet increasingly strict targets will be incentivized to develop EV technology to increase consumer appeal. Thus, there is still vulnerability to concerns about a mismatch between regulatory mandates and consumer interest. While these types of regulations will generally increase EV adoption rates, the magnitude and even direction of their effect will depend on whether regulators succumb to industry pressure to weaken and/or delay mandates. Industry pressure, in turn, depends in part on outside factors like the rapid development of technology required to meet consumer expectations. On the other hand, automakers have control over factors such as deployment of existing EV technology, marketing, and dealer support. If they sense regulatory weakness, they have an incentive to discourage EV adoption, which will support a legal argument that the regulations are out of touch with market realities. In this way, regulation has potential to hinder adoption.

We start with regulatory developments close to home. In the United States, the relevant regulation is the Corporate Average Fuel Economy (CAFE) standards. As the name suggests, this legislation establishes fuel economy standards for manufacturers’ sales-weighted fleets. The standard has no EV requirement, but manufacturers can use EV sales as a credit towards their fuel economy target. The Obama administration modified the standards to make them more ambitious, but the Trump administration has proposed a significant weakening. The current administration has also targeted the stricter emissions rules put in place by California, including the ZEV mandate. Nine additional states, including Massachusetts, have joined California in adopting the ZEV regulations. Together, these ten states account for over one-third of the US auto market (Rokadiya & Yang, 2019). The latest phase of the ZEV program requires manufacturers to sell an increasing number of pure BEVs; the exact percentages are difficult to pinpoint because of intricacies regarding the ZEV credit system. The EPA is seeking to withdraw California’s ability to set its own emissions targets (and other states’ ability to join). The dispute is currently in court.

Perhaps counterintuitively, the most important regulations for US EV adoption could be those in the European Union. In 2020/2021, strict new limits on CO2 emissions phase in. While there are no requirements regarding EV sales, manufacturers who sell EVs can both lower their average vehicle emissions as well as earn “super-credits” to help them achieve compliance. And most companies will need all the help they can get: if 2021 sales followed the model composition of 2018, the total fine
levied could total EUR 30 billion, or 45% of industry net profits (Lemerle & Benz, 2019). A notable exception is Toyota, which is on track to meet the targets thanks largely to hybrid deployment, despite lagging behind other automakers in EV development (Archer & Poliscanova, 2019). Archer and Poliscanova (2019) points to the planned explosion in EV model offerings as evidence that success is possible, while Lemerle & Benz (2019) predict that manufacturers will fail in the face of consumer indifference. The latter authors further predict that the costs of (attempted) compliance will result in vehicle price hikes and job losses in the automotive manufacturing sector. If these pessimistic forecasts are borne out, the industry and political pressure on EU regulators will likely be fierce. If they stay the course, most major manufacturers will enter the mid-2020’s with significant EV offerings, having shouldered much of the initial cost of transitioning away from ICE engines. This will likely spill over into the US market, as automakers will be looking to improve the return on their EV development investment by improving US sales.

2.1.4.3. Technological Development
In part because the internal combustion engine has been subject to refinement for much longer than electric drivetrains and battery systems, the latter has considerably more remaining potential for rapid future improvement. This will likely be realized both in improved capability and lower cost. As battery prices have steadily fallen within the past decade, the price parity between EVs and ICE vehicles has also narrowed. Within five years from 2013 to 2018, battery prices fell 73% (BloombergNEF, 2019). BNEF predicts that battery prices will drop from $176/kWh in 2018 to $87/kWh by 2025, a further 50% decrease. As these prices continue to fall in the next five years, lower EV costs and increased range should result in higher rates of adoption.

Furthermore, several new and promising battery advancements were publicized in 2019. ZapGo, a UK company, recently introduced batteries that purportedly can fully charge an EV in 35 seconds, and can be used with 350-1500 kW chargers. Called C-ion cells, these batteries include “solid-state carbon-ion cells” with no lithium or cobalt (Nhede, 2019). This simultaneously lowers the cost and increases the safety of these batteries, since nothing is flammable inside the battery and the “ionic electrolytes act as a fire suppressant” (Nhede, 2019). This safety feature means that these battery cells could even be placed in a vehicle’s chassis or panels without extensive, and expensive, cooling systems.

Once these batteries are incorporated into EVs, even mainstream lower-end EVs will be able to charge just as quickly as ICE vehicles can refuel. This increased convenience would make EVs more competitive with ICE vehicles and encourage adoption.

Another battery-related innovation increases their energy density, which would mean getting more mileage out of each charge. Swiss startup Innolith claims to have made batteries with a capacity of 1000 Wh/kg, whereas industry leader Tesla’s Model 3 2170 cells are about 250 Wh/kg. This would afford EVs with this battery about 600 miles of range per charge (Hawkins, 2019). By comparison, the Toyota RAV4, the most popular non-pickup vehicle in the US, can travel approximately 435 miles on a full tank of gas. Innolith’s batteries could thus transform range from a drawback to a possible selling point for EVs. Innolith plans to make their batteries commercially available by 2022 (Toyota RAV4 Features and Specs, n.d.; Gastelu, 2019).

These types of technological advances would transform range from a drawback of EVs into a possible selling point. Therefore, the success of these and similar ventures will be important in determining the viability of EVs as mass-market vehicles.
2.1.4.4. **Model Availability**

Some analysts argue that EV adoption in the United States is constrained more by supply than demand, including lack of EV manufacturer and model segment diversity (McDonald, 2019). Crossovers are by far the country’s hottest-selling segment, while the three top-selling vehicles in the US are full-size pickups (Manzi, 2019). Despite this, among electric SUVs only the Tesla Model X and newcomer Audi e-tron sold more than 5,000 units in 2019; as of February 2020, there are no electric pickups on the market.

This concern should be alleviated as a wave of new electric models reach showrooms over the next couple years. In 2020, this includes the Tesla Model Y crossover and Toyota RAV4 Plug-in, the latter based on the best-selling non-pickup in the country. In 2020/21 they will be joined in the compact crossover segment by the Ford Escape PHEV, Volkswagen ID.4, and Ford Mustang Mach-E, among others. Startup Rivian plans to begin deliveries of its R1T pickup by the end of 2020, with potential competitors in the Tesla Cybertruck and an all-electric Ford F-150 slated to arrive in 2021.

Excluding Tesla, all these manufacturers have significant room remaining under their tax credit threshold, which should help drive consumer demand. The sales performance of these models will be a strong indicator as to the medium-term success of EVs in the US. Success would likely encourage other legacy manufacturers to increase investment in EV platforms, while piquing consumer interest and serving as technological “ambassadors.” Relative failure would not kill the electrification movement, but it may signal that truly widespread adoption is still several years away for the United States.

2.1.4.5. **Consumer Awareness**

Surveys find a large gap between EV users and the general public regarding EV capability and ease of ownership. A 2019 AAA survey found that 57% of Americans who are unlikely to buy an EV are scared to run out of charge while driving and 57% cited range anxiety, that is, concern about EVs having too little range for longer commutes or trips (Edmonds, 2019). Furthermore, 59% of Americans responded that they were unsure “under which driving conditions the charge of an electric vehicle’s battery will last longer, on the freeway or in stop-and-go traffic” (Edmonds, 2019). Still, these percentages have been dropping in recent years, indicating increased consumer awareness about EV capabilities. The percentage of respondents concerned about a lack of chargers is down 11 percentage points from 2017, as well as the concern about “running out of charge when driving” (Edmonds, 2019). As EVs grow more popular, word of mouth promotion and the increased public visibility will augment educational and promotional content. The resulting reinforcing feedback is well-recognized in marketing theory. As charging companies expand their networks in public stations and the workplace, consumer concerns about lack of charging will gradually decrease. Overall, as consumer awareness about EVs and availability of charging increases, previous roadblocks to EV adoption will slowly be lifted, resulting in continuing EV adoption growth.

2.1.4.6. **Charging Infrastructure Availability**

BNEF indicates that “access to home or workplace charging” is a significant factor in whether a customer chooses an EV over an ICE vehicle (BloombergNEF). A 2019 AAA survey found that 58% of Americans who are unlikely to buy an EV are concerned about the lack of charger availability (Edmonds, 2019). When it comes to charging, convenience is key. Depending on range and usage, most EVs need to be charged at least once a week. Therefore, sparse EV charging networks pose a significant hurdle for prospective EV owners.
There are several ways EV owners could access charging: publicly-owned stations (i.e. those owned by municipalities), privately-owned stations (similar to gas stations), home chargers, and workplace chargers. According to the US Energy Department, more than 80% of EV charging is done at home (Charging at Home, n.d.) When prospective EV owners do not live in a single-family home, such as an apartment or condo, it might not be possible to install a charger so that the EV can be plugged in to charge overnight. If prospective customers do not have a charging station near their place of work, then EV owners must rely on access to charging near their home. Though there have been steady advances in the availability of charging stations and fast chargers, not enough has been done to tip the scales.

2.1.4.7. Price of Gasoline
It seems logical that higher gas prices would correlate with increased rates of BEV and PHEV adoption. However, sources seem conflicted on whether gas prices have a significant effect on PHEV and BEV sales, if any.

In 2008, gas prices in the US rose above $4.00 per gallon. According to the US Department of Transportation, this resulted in increased interest in PHEVs (Brand, 2009). More recently, in 2018, experts like Anil Goyal, the executive vice president of operations for Black Book National Auto Research, stated that “There is good demand for hybrids with gas prices going up” (Hoffman, 2018). In April and May of 2018, Canada experienced significantly increased gas prices, which some analysts correlated with higher EV sales across the board—Chevrolet Volts, Teslas, Nissan LEAFs (Rufiange, 2018). Edmunds analysts posited that higher gas prices shortened the amount of time it took to make an EV purchase worthwhile (Krebs, 2012).

On the other hand, a 2014 Plug In America report showed that gasoline prices and EV sales had very little correlation from December 2010 – November 2014. At this time, gasoline prices ranged from $3.00 to $4.00. While EV sales had very weak correlation with gas prices ($r = 0.01), auto sales had a higher correlation ($r = 0.44), which was likely due to people purchasing autos instead of trucks. The report concluded that the data for that time period showed that the PHEV sales and gasoline prices were independent (Kelly, 2014).

2.2. Charging Infrastructure
This section examines the types of EV charging infrastructure, technological developments in charging, and the financial incentives available to institutions like WPI.

2.2.1. Types & Levels of Chargers
Charging solutions are grouped into three levels based on their voltage and rate of charge. Charge rate is expressed in terms of miles of range added per hour charged, sometimes shortened to range per hour (rph) or miles per hour (mph). The latter syntax will be used in this report. Also, note that even within the same level, charge rate can vary depending on the vehicle model.

Level 1 chargers use a standard 120V electrical plug and do not require significant installation. However, they are quite slow compared to other chargers. Level 1 chargers can generally charge at 2-5mph. Level 2 chargers operate through a 208V or 240V plug. While it is possible to simply plug in an adapter to a dryer outlet, Level 2 chargers generally require an equipment installation. Standard charging speeds are
generally 10-25mph, although some cars can reach charging speeds of 50mph with higher current (How Long Does it Take to Charge an Electric Car?, 2019).

DC fast chargers, also known as Level 3 chargers, require significant equipment investment but offer much higher charging rates. DC refers to direct current, which is how DC chargers deliver power straight to the battery; in contrast, AC chargers (level 1 and 2) supply alternating current which must be converted to DC by an onboard converter. Charging rates among fast chargers are more complex, largely because rate can vary drastically with ambient temperature and battery level, with speeds slowing down as the battery fills. Additionally, different vehicles accept different max rates of electricity transfer. In general, however, most EVs using DC stations can reach an 80% charge in 30-60 minutes, with likely decreases in the future as technology and infrastructure develop (Kane, All-Electric Car Peak DC Fast Charging Comparison, 2019).

ChargePoint offers a DC Fast Charger (DCFC), the ChargePoint Express Plus. The system promises to be able to deliver 165-500 kW to a single vehicle depending on the number of power modules installed (ChargePoint, 2017). The fastest-charging EV, the Tesla Model 3 Long Range Dual Motor, can only accept 250 kW of power. Newer EVs will likely be able to accept more and more charge, and even ChargePoint anticipates that the Express Plus will only be able to serve EV charging needs for 10 years (Quartier, 2019).

Charging connectors also vary. All EVs sold in the US from 2000 onward are equipped with a J1772 plug receptacle or adapter, and all Level 1 and 2 stations use this connector. When it comes to DC fast charging, compatibility concerns emerge. A J1772 variant called the CCS Combo 1 compatible with DC chargers can be found on cars such as the Chevrolet Bolt, Hyundai Kona EV, and Porsche Taycan. Other cars, notably the Nissan Leaf and Mitsubishi i-MiEV, use the CHAdeMO for fast charging while retaining the J1772 port for AC stations. Tesla vehicles can also charge on CHAdeMO through the addition of an adaptor. Although CHAdeMO had an early adoption lead, CCS vehicles are now being sold at a much faster rate and have virtually closed the gap in cumulative sales (Kane, U.S. BEV Sales By DC Fast Charging Capability: 2019, 2020). This may portend a dim future for CHAdeMO, at least outside Japan. Of course, Tesla’s proprietary plug, used on their vehicles and Supercharger stations, is the third major plug type for DC fast charging in the United States. Figure 2 displays some of the existing plug standards.
In the EU and China, there are a couple other plug types. As the industry matures, manufacturers may standardize plug types, though it seems plausible that some brands may retain proprietary equipment for the foreseeable future, at least while charging technology advances rapidly. Finally, there are wireless charging stations that charge compatible vehicles without requiring physical contact. While there are level 2-equivalent wireless chargers on the market, the segment is currently in its infancy. Nevertheless, they offer the appealing prospect of a more convenient charging process.

### 2.2.2. Public vs. Private Stations

There is currently a wide array of setups with regards to charger ownership and access. This is partly a result of a rapidly growing and innovating industry, but it also reflects the diversity of charging needs in the general EV community.

Around the world and in the US, the vast majority of EV charging is done at home. A McKinsey & Company analysis projects that home charging will account for 73% of EV energy demand in 2020 and 64% in 2030, given a home-centered infrastructure scenario (Engel, Hensley, Knupfer, & Sahdev, 2018). This is sensible because most vehicles remain parked there overnight, and overnight charging allows some owners to take advantage of off-peak electricity rates. However, charging at home presents difficulties for EV owners who live in multi-family units or apartments, as well as the minority of single-family homes without a driveway. This type of housing arrangement forces owners to rely on public chargers. This may take the form of restricted-access chargers in parking lots or garages requiring fees or memberships to access. A few cities have also experimented with street side chargers, including those mounted to streetlight poles (De Blasio Administration, 2018). Given the dorm or apartment-based living arrangements of most college students, there is a strong opportunity for post-secondary institutions to encourage adoption by providing EVSE to their school community.

Ensuring access to charging infrastructure requires a localized response to account for the wide variety of parking situations between different areas. In general, however, the US is more hospitable to home-centered charging compared to Europe and especially China (Engel, Hensley, Knupfer, & Sahdev, 2018).
As the EV user base diversifies, there will be a greater need for charging infrastructure outside of individual homes. This need can be filled in part by employers and institutions like WPI. It also highlights the need for public charging stations, both Level 2 and DC fast chargers (Wood, Rames, Muratori, Raghavan, & Melaina, 2017).

2.2.3. Public Station Interface and Cost

There are various charging station providers and unit manufacturers leading to a variety of capabilities and protocols. ChargePoint offers several administrative options to limit charger overuse. For the present, the WPI EV community has elected not to use any of these features; they could be explored in the future. One feature allows EV owners to be charged an hourly fee once they exceed a set time limit, such as four hours. ChargePoint also offers a feature where EV owners can join a waitlist. According to ChargePoint, the amount of time drivers have to get to the charging station and plug in after receiving notification that a spot has opened up can be customized (ChargePoint, 2020).

2.2.4. Financial Incentives

National Grid is a utility company serving Massachusetts, New York, Rhode Island, and the UK (National Grid, 2020). In Massachusetts, National Grid offers rebate programs for EV charging infrastructure. National Grid must apply for approval from the Massachusetts Department of Public Utilities to run these programs (interview with Mark from National Grid). In recent years, National Grid has received funding for its approved programs as part of the VW settlement.

As part of National Grid’s 2018 Charging Station Market Development Program, institutions hoping to install more EV chargers can apply to have 100% reimbursement of the electrical infrastructure cost and a significant percentage of equipment costs from National Grid. The electrical infrastructure cost includes all of the rewiring needed to provide power to the charging station, and 100% of this is covered for approved projects. Equipment costs include the cost of the stations themselves.

If the chargers are only accessible to the institution’s employees, National Grid covers 50% of the equipment costs. If the chargers are publicly accessible, National Grid will cover 75% of the equipment costs. If the chargers are publicly accessible in an environmental justice community (EJC), National Grid will cover 100% of the equipment costs. A community can meet the EJC criteria due to low average income, a high proportion of minorities, or a high proportion of non-English speakers. According to results from the 2010 census, Worcester has 106 EJ block groups, including all colored areas on the map in Figure 3 (MassGIS, 2010). The X on the left side of Figure 3 denotes WPI’s Park Avenue Garage, and the X on the right side of Figure 3 denotes WPI’s Gateway Garage, WPI’s two main parking garages.
WPI also owns smaller lots in the surrounding neighborhoods, such as the Hackfeld Lot, Einhorn Lot, Boynton St Lot, Dean St Lot, Institute Lot, Lancaster Lot, West St Lot, and Schussler Road Lot (WPI Map, Appendix A). Correspondence with National Grid revealed that this program is only valid if an area can be categorized by at least two of the criteria represented in Figure 3. According to National Grid representatives, National Grid will reimburse the institution for 100% of the EVSE and installation costs if the chargers are installed in an EJC and made open to the public for at least five years. It appears that the Gateway Garage would qualify for this program, but it is unclear whether National Grid retroactively reimburses, since WPI did not pursue this program when installing the five new chargers at Gateway Garage. National Grid would cover 100% of the installation and EVSE costs, making this a very attractive option for future chargers in this location. However, since the garage is currently exclusive to WPI community, it would require policy changes to get the chargers to be publicly available in order to take advantage of National Grid’s incentive.

2.2.5. Technological Developments in EV Charging

Companies such as ChargePoint, CHAdeMO, Electrify America, and Tesla are continually developing chargers that can deliver more power and charge more rapidly than prior models. With the advent of these DC Fast Chargers, EV owners can cut down their overall charging duration significantly. There have been steady, incremental advances in charging technology as EVs are also increasingly able to accept higher rates of charge. For example, Tesla’s newly released V3 Superchargers claim to give a Model 3 “up to 75 miles of charge in five minutes and charge at rates of up to 1,000 miles per hour” (Tesla, 2019). What would have taken a Level 2 charger approximately one hour to do, the V3 Supercharger purports to do in five minutes. However, fast chargers are often wildly more expensive than Level 2 chargers. No doubt similar incremental improvements will continue to be made.
On the other hand, some startups are attempting to shake up the EV charging industry with more creative innovations. Wireless EV charging promises increased convenience over wired charging. One US-based company, Plugless, boasts that its customers have charged more than a million hours with its technology. Essentially, a Plugless charging attachment is added onto the EV between the two front wheels on the undercarriage, and drivers simply need to pull up to a Plugless charger to initiate charging. This technology is currently only compatible with Tesla Model S, BMW i3, Nissan LEAF, and Chevrolet Volt (Plugless Questions, 2020). According to the company, these models can charge at a rate of 20-25 mph, which is the average speed of a Level 2 charger.

Other companies have attempted this technology, but it does not seem to be gaining traction. As part of an experiment to encourage Oslo’s taxi drivers to switch to electric, a company called Momentum Dynamics developed a wireless charger that can deliver a claimed 50 kW (Momentum Dynamics, 2018). This would be the equivalent of an older Level 3 charger (Nelder, 2019). Momentum Dynamics specially retrofitted buses and taxicabs to accept this wireless charging, but were stalled by a lack of EV manufacturers willing to commit, when they were already too concerned with the production of standard EVs (Deign, 2019). With faster and faster standard wired chargers, it is unlikely that the convenience of wireless charging will outweigh the convenience of the speed of new wired chargers.

Volkswagen revealed plans and a prototype for a robot coupled with battery wagons that would navigate to EVs needing to be charged, plug the battery in, and scuttle off to charge other EVs. Once charging is completed, the robot will decouple the battery from the EV and bring the battery to be recharged (Szymkowski, 2019). However, this is in a highly experimental stage and will not likely hit the market in the near future.

One company had tried to start an EV battery swapping service in 2007, but the EV market was still too nascent to make it viable. Now, in 2020, Chinese company NIO seems to have made it work. NIO customers say that without NIO’s 6-minute battery swap service, they would not have purchased their EV, since they do not have access to charging at home and are concerned about the amount of time it takes to charge and battery degradation over time. With NIO’s service, owners can simply switch with a new battery when their charge is running low. This service would probably not be viable in the US or Europe, and will perhaps only be sustainable in China for a few more years, as conventional chargers get faster and EV battery range increases (Moloughney, 2020).

2.3. Current Situation at WPI

2.3.1. History

WPI first installed a dual-port charger in 2011, funded through a MA Department of Energy grant jointly awarded to WPI and Clark University (WPI to Unveil Electric Vehicle Charging Station, 2012). In 2014, the school added two more dual-port chargers at the Park Avenue Garage. All units are ChargePoint Level 2 with the standard J1772 plug. After the beginning of this project, WPI decided to install five additional chargers (i.e. 10 ports) in the Gateway Parking Garage. They were installed over winter break 2019 and were opened for business in January 2020. Due to the limited sample size for the new stations, the data presented in this report only reflect the three initial chargers, unless otherwise noted, although our analysis and recommendations consider the likely impact of the recent increase in capacity.
2.3.2. Price and Charging Policies

All charging is currently free and there are no immediate plans to change this policy. Prior to the installation of the Gateway Garage chargers, the electricity cost to WPI was relatively minor – less than $600/month for the six Park Ave charging ports - and charging EV owners for electricity was deemed more trouble than it is worth (WPI Sustainability Manager E. Tomaszewski, interview, 2019). There is an informal four-hour courtesy limit to leaving one’s car plugged in, and chargers are currently first-come, first-serve. There is an EV owner mailing list for drivers to communicate regarding charger usage and issues.

All dual-port chargers at WPI are operated by ChargePoint, and WPI has an administrative ChargePoint account to monitor usage and be notified of performance issues. The account also provides data regarding usage, users, and electricity costs.
Chapter 3. Methodology

To form our recommendations, we needed to combine our background research with an assessment of current EVSE utilization, project EV ownership trends at WPI among faculty, staff, and students, and gather input on future initiatives. All these objectives were addressed in a survey distributed to the WPI community, and our understanding of existing infrastructure usage was strengthened by the analysis of data collected by WPI’s ChargePoint account, which tracks individual charging sessions as well as overall usage. Interviews with other Worcester colleges granted us useful perspective about the range of constraints and difficulties facing other institutions. Finally, we synthesized this information to present a general framework of institutional charging recommendations, applied with particular focus on specific guidance for WPI. The general course of the project is depicted in flowchart form in Figure 4.

![Figure 4: Project Flowchart](image)

3.1. Assessing the WPI Situation

Worcester Polytechnic Institute (WPI) is a private university with approximately 4700 undergraduate and 2200 graduate students located in the midsized city of Worcester, MA. WPI is known for its focus on engineering and project-based learning, with faculty research centered on robotics, sciences, and manufacturing (WPI Research, n.d.). According to WPI’s 2018-2019 Common Data Set report, 51% of all degree-seeking students live off campus and commute (do not live in college-owned, -operated, or -affiliated housing) (WPI, 2019). However, probably only a small percentage of these students live more than a mile from campus and regularly drive a car to WPI. There is currently no way to determine this exact figure.
Through web research and conversations with WPI’s Office of Sustainability, we familiarized ourselves with the history and usage of WPI’s existing charging infrastructure. We hoped to understand what policy steps need to be taken to install more chargers. Additionally, we hoped to gauge how WPI’s EV-owning population correlated to the utilization of the chargers. The proportion of chargers to the size of WPI’s EV-owning population can be used in the future to ensure that WPI keeps pace with demand.

3.1.1. ChargePoint Data Analysis

Taking advantage of the data aggregation tools available through WPI’s ChargePoint account, we examined the current utilization of the six initial charging ports. We focused on the semester immediately before the 10 new charging ports were installed in the Gateway Garage, from August 23-December 14, 2019.

The ChargePoint administrative account offers real-time data regarding current number of ports in use and the amount of power flowing to all of the ports at that time. Furthermore, other graphs can easily be generated to show the following information over time (up to station lifetime): number of unique drivers, number of sessions, average session length, how much the electricity for charging has cost, and the total amount of energy dispensed to the stations.

As seen in Figure 5, the administrative ChargePoint account dashboard offers a quick view of a few select graphs such as the Station Status, Station Usage, Real Time Power, and Unique Drivers.
In the Reports/Analytics page, administrators can further customize the station data analysis. The types of graphs that ChargePoint can generate are depicted in Figure 6. These graphs can be filtered according to port location, vehicle make, and charging duration, to name a few. Because WPI does not utilize the queueing feature nor charge a fee, several fields are of little use currently. Nevertheless, the information is available if these capabilities are utilized in the future.
Figure 6: Detail view of options for ChargePoint analysis graphing.

Figure 7 depicts a partial screenshot of the Sessions Details Table. The table includes user and session information for every charging instance. Information includes account number, zip code, time spent plugged in, and time spent charging. A complete list of table columns is depicted in Figure 8. We used this table to cross-reference commute length and charging time, group users by yearly charging frequency, and determine average idling time, among other uses.

<table>
<thead>
<tr>
<th>Transaction Date (Pacific Time)</th>
<th>Total Duration (hh:mm:ss)</th>
<th>Charging Time (hh:mm:ss)</th>
<th>Energy (kWh)</th>
<th>GHG Savings (kg)</th>
<th>Gasoline Savings (gallons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020-02-22 02:03:18</td>
<td>04:46:33</td>
<td>03:10:34</td>
<td>18.365</td>
<td>7.713</td>
<td>2.305</td>
</tr>
<tr>
<td>2020-02-21 21:12:37</td>
<td>00:07:35</td>
<td>00:06:53</td>
<td>0.281</td>
<td>0.118</td>
<td>0.035</td>
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<tr>
<td>2020-02-21 21:04:08</td>
<td>00:02:50</td>
<td>00:02:13</td>
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<td>0.000</td>
<td>0.000</td>
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<tr>
<td>2020-02-21 21:00:35</td>
<td>00:59:57</td>
<td>00:03:02</td>
<td>0.001</td>
<td>0.001</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Figure 7: Session Details Table
We used the average utilization graph (Figure 9), session length histogram (Figure 10), and sessions graph (Figure 11: Sessions Graph, last 30 days). We wanted to investigate exactly how much WPI’s existing stations were used, and the general usage patterns for charging. We also wanted to examine how quickly the charger utilization had increased over the charger lifetime, in order to search for a way to predict when newly installed chargers would similarly reach capacity.
The ChargePoint resources also enabled us to examine usage on timescales as small as one day, all the way up to one year. However, there are some limitations. Data can be viewed on a “Custom” timescale, but to filter out every weekend and school holiday requires analyzing the data on a five day scale. With more than five years of data and multiple data sets to analyze, this did not seem like a good use of time. (Only for the average utilization graph, which shows a percentage of overall station usage, can weekends be filtered out through a setting on ChargePoint itself.) Since there is no easy way to filter out times when most WPI EV owners do not come to campus, the calculations for overall usage are artificially decreased. Therefore, it would be best to slightly overestimate the number of chargers needed to ensure that the infrastructure can handle peak demand on weekdays.

3.1.2. WPI Community Survey

In order to formulate a prediction for future EV adoption on campus, we decided to survey the WPI community. The survey was sent to students, faculty and staff. By surveying the undergraduate and graduate students, we obtained a rough estimate of how many students would bring EVs to campus in
the next four years and we were able to determine the different variables that affect the students’ decisions to purchase an EV.

By knowing these factors, we could better project the students’ future EV adoption rates. Even though the students form the majority of the school, our main focus was on faculty and staff since they are financially stable and will most likely stay at WPI for many years. Therefore, they are more likely than students to purchase an EV during their time at WPI, affecting demand for the chargers. With this survey, we aspired to obtain a general idea on the EV’s range, how much the chargers were in use, if the cost of charging affected their decision to purchase an EV, and opinions and complaints about the current chargers on campus. (For a full list of survey motivations, see Appendix D)

3.1.2.1. Survey Design
The survey sent out to the WPI community included questions about members’ current and future charging needs as well as their opinions and knowledge about WPI’s EV charging policies. The survey was separated into two different sections: EV users and non-EV users. Some questions shown to the EV owners, such as frequency of charging at WPI, are not shown to non-EV owners, in order to decrease the rate of incomplete responses.

EV users are asked to give information about their vehicles, their commute range, and access to residential charging. On the other hand, non-EV users are asked about their awareness of WPI’s charging infrastructure, and their future plans for purchasing an EV. Both parties are asked to give brief personal information, current vehicle age, opinions about WPI’s charging policies, and feedback about WPI’s perspective on EVs and future infrastructure needs on campus. With this survey design, we are able to collect data on current and future charger usage on campus. Also, we are able to make predictions about the potential EV population on campus based on the survey takers’ future plans for purchasing an EV. The general flow of the survey is depicted in Figure 12. A full list of survey questions can be found in Appendix E: WPI Community Survey. In order to analyze the survey results easily, we preferred to use Qualtrics as our framework. Qualtrics offers a variety of analysis tools. Since WPI provides a free Qualtrics subscription to its students, we decided to take advantage of this.
3.1.2.2. **Drawbacks and Potential Biases**

Despite our efforts to limit bias in the wording of the questions, there are many unavoidable variables that introduced potential bias in survey responses. WPI’s community mostly consists of engineers and people in a STEM field. Since we did not track each survey participant’s field, we are unsure of the distribution of majors and departments for survey respondents. We suspect that a large portion of our undergraduate respondents are students studying Robotics Engineering (RBE). This means that our survey results would not be as representative of the WPI population as a whole, since RBE is not one of the largest majors on campus.

Furthermore, survey respondents were self-selecting, which means that those who responded are more likely to feel very strongly about EVs, whether positively or negatively. Since it is a rather long survey, we expect that most respondents who completed the survey have a positive opinion towards EVs. Those who own EVs or are planning to purchase one in the near future would be more interested in taking the survey since they would be directly affected by any resulting policy changes.

3.1.2.3. **Method of Distribution**

To send out the survey to faculty and staff, we used the *dl-potpourri* list recommended to us by our project advisors. Using this list, our advisor forwarded our survey to approximately 1000 members of
faculty and staff. We received fewer than 100 responses from faculty and staff, and approximately 50 more after sending it to the faculty mailing list a few weeks later.

There is an undergraduate mailing list at WPI, but it is moderated by student government, which has a policy of not distributing surveys. Furthermore, a list of names of distribution lists by major does not exist, and they are not included in the WPI global contact list, to protect confidentiality. Therefore, we had to call up approximately 30 academic departments to ask administrators to send our survey along to undergraduate and graduate majors in their department using their own mailing lists. An email with instructions on how to send out the survey was sent out early in C term (January, 2020). We had to follow up with several large majors, such as mathematical sciences, after a week to ensure that as many students saw our survey as possible.

In total, we received 675 responses, with about 60 of those incomplete, where the respondent did not finish the survey.

3.2. Assessing Other Universities

In order to broaden our perspective on EV charging needs and practices, we met with representatives from the sustainability offices at Clark University, Worcester State University, and UMass Medical School, as well as the Director of Facilities at the College of the Holy Cross. All these schools had existing charging infrastructure, but the time since first station installation ranged from two weeks for Holy Cross to eight years at Clark. We inquired about their history, current usage, charging policies and pricing, the process by which they decided to install or expand their infrastructure, and the attitudes of campus community members towards the stations. All interviews were conducted in September 2019. We also followed up in February 2020 and were informed of relevant updates.

3.3. Working with the City of Worcester

As a further effort to expand the impact of our project, we reached out the City of Worcester to offer assistance with any potential municipal initiatives to expand local EVSE. The city had previously cooperated with the utility provider National Grid to install four EV charging stations in public parking garages, but otherwise had not formulated any programs for increasing EVSE investment either public or private (L. Zhaurova, personal communication, November 12, 2019). Still, the city was in the process of drafting a sustainability master plan – the “Green Worcester Plan” – and was receptive to working with our team to incorporate an EV component. Specifically, the city Sustainability Project Manager hoped we could investigate the desirability of installing EV charging stations at one or more Worcester public high schools, particularly by gauging interest in such an investment in each school community.

With this goal in mind, we modified the WPI community survey to investigate similar questions among teachers, administrators, and possibly students at a high school level. Several questions were removed in an effort to shorten the survey and increase response rate, while the question text was altered to address the modified setting. We also incorporated feedback from city contacts and produced a final, approved version of the survey. Unfortunately, a number of delays and setbacks meant that this survey had not been distributed by the time we submitted our report. Nevertheless, we remain hopeful that it will be helpful in the future.
3.4. Formulation of Recommendations and Evaluation Model

In order to craft recommendations and create the evaluation model, we combined the background information we gained from readings, articles, and studies with the firsthand information we gathered from our interviews, survey, and data analysis. An important piece of our evaluation model is a system dynamics model of institutional EV adoption and charging requirements. This tool can be used to gain a sense of plausible adoption estimates as well as test the impact of various charging policies. A causal loop diagram (CLD) displaying the model structure is shown in Figure 13. Arrows signify causal relationships between variables; they are labeled with a plus sign if an increase in the causal variable results in an increase in the effected variable or a minus sign if the variables move in opposite directions; all relationships are assessed ceteris paribus. A (+) loop icon indicates a reinforcing feedback loop while a (-) loop icon denotes a balancing loop.

In the model, the desired charging amount per electric vehicle is positively related to average commute length and the provision of fee-free charging but negatively related to EV range, meaning that a longer average EV range will reduce the average desired charging amount. Charging amount per EV is multiplied by the number of EVs on campus to calculate the number of desired charging stations. The ratio of desired to existing charging ports determines the EVSE usage rate. A higher campus EVSE usage rate makes EVs less attractive for faculty and staff members (students are assumed to make vehicle...
purchase decisions without reference to campus conditions). Logically, if EVs are more attractive, the adoption rate among the school population will be higher, which translates over time to more EVs being driven to campus. As the EV population grows, the installation of more charging stations balances the supply and demand, creating a balancing or negative feedback loop (labeled Loop 1). On the other hand, installing more stations makes the infrastructure less crowded, making EVs more attractive and driving further growth. This creates a reinforcing or positive loop (Loop 2).
Chapter 4. Findings and Results

Our results comprise interviews with other universities, data analysis through WPI’s ChargePoint administrative account, and survey results from the WPI community survey. Interviews enabled us to explore the outcomes of different charging policies. Survey results and ChargePoint utilization analysis illuminated the charging situation and general opinions regarding EV charging at WPI.

4.1. WPI Survey Results and Analysis

From our survey results, we project the growth of EVs at WPI and analyze the community’s support of certain policy changes regarding charger usage. 403 undergraduate students, 43 graduate students, 94 faculty members, and 61 staff members completed the survey, totaling 601 respondents. Approximately 10% of the undergraduate student population of WPI responded to the survey.

For frequency-related questions that are multiple choice, we followed the scheme outlined in Table 1. When referring to survey results and analysis, we also utilize the same vocabulary.

<table>
<thead>
<tr>
<th>Table 1: Frequency-related vocabulary</th>
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<tbody>
<tr>
<td>Always</td>
</tr>
<tr>
<td>Often</td>
</tr>
<tr>
<td>Rarely</td>
</tr>
<tr>
<td>Never</td>
</tr>
</tbody>
</table>

4.1.1. General Opinion towards EVs and EV Chargers

As expected, the general opinion towards EVs from all respondents was overwhelmingly positive (Figure 14). Ostensibly, this would translate to support for EV chargers on campus. Further, as shown by Table 2, among the four demographics surveyed, all groups prioritized the same benefit that comes with having EV chargers on campus: cost savings. While more than half of the undergraduate and graduate student respondents, and staff expressed that cost efficiency is far more important than any other benefit, our largest group of respondents, faculty, was split up very closely between cost savings, need of charging for their commute, and extending their PHEV’s electric-only range. Keeping in mind that students usually live closer to campus compared to faculty, needing a charge to complete their commute is highly expected of faculty members. Faculty members that chose the “Other” option indicate that the most important benefit for them is either their appreciation for WPI’s sustainability efforts or the convenience of having chargers on campus.
When asked for the top two reasons behind their EV purchases, EV owners ranked multiple-choice options in the following order of importance:

1. Sustainability
2. Fuel/maintenance savings
3. Owning cutting-edge technology

At least based on these self-reported reasons, it seems that most EV owners are motivated by environmental concerns. At a technically focused institution like WPI, it is rather surprising to see “owning cutting-edge technology” at the bottom of the list. To further spur EV adoption on campus, it appears that any educational outreach efforts should stress the environmental benefits of EVs and the cost savings in addition to the “novelty” factor.

4.1.2. Benefits of WPI’s Chargers

Among the four demographics we have surveyed, all groups prioritized the same benefit that comes with having EV chargers on campus: cost savings. While more than half of the undergraduate and graduate student respondents, and staff expressed that cost efficiency is far more important than any
other benefit, our largest group of respondents, faculty, was split up very closely between cost savings, need of charging for their commute, and extending their PHEV’s electric-only range. Keeping in mind that students usually live closer to campus compared to faculty, needing a charge to complete their commute is highly expected of faculty members. Faculty members that chose the “Other” option indicate that the most important benefit for them is either their appreciation for WPI’s sustainability efforts or the convenience of having chargers on campus.

4.1.3. EV Adoption Projection

The survey illuminates several factors that affect EV adoption on campus, including when respondents expect to buy an EV, the age of their current vehicle, the amount they are willing to pay for an EV, the effect of WPI charging infrastructure on such a purchase, and EV range and their commute distance.

4.1.3.1. Self-reported Predictions for Next EV Purchase

The distribution of responses for expected EV ownership from the entire WPI community is shown in Figure 15. However, we suspect that many of the undergraduate students do not expect to be on campus when they purchase their EV. Their responses mostly reflect their expected increase in income after they graduate and ostensibly get a high-paying tech job. Therefore, we also isolated responses from faculty and staff because these individuals are more likely to still be on campus when they purchase their vehicle (most predict a purchase in 5-10 years). This subset of responses is shown in Figure 16.

![Figure 15: Survey response to question “When, if ever, do you expect to own/lease an EV?”](image_url)
To compare our estimates for future EV ownership on campus, we also aggregated the responses to determine the growth in total number of EV owners on campus, which is depicted in Figure 17. One weak point of the survey was that for this question, the multiple choice options encompassed multiple years, such as “5-10 years”. Additionally, the year intervals are not consistent (“0-2 years” versus “5-10 years”). If one were to re-design and redistribute the survey, it may be advisable to at least standardize these year intervals.
Another important note about Figure 17 is that since we did not survey the entire population of WPI, the responses to this question do not perfectly predict on-campus EV adoption. Furthermore, not everyone who responded to the survey will purchase an EV or purchase an EV in the time frame indicated by their response. We posit that responses past the five year mark are likely less accurate, since most people’s futures are not so clearly planned out in advance that they would know exactly when they would purchase their next vehicle. Still, since it is more likely that those who are anticipating an EV purchase in the next five years choose to fill out our survey, we assume that the responses to this question capture the majority of those who will actually purchase an EV in the next five years.

4.1.3.2 Extrapolating from Past Data
Just because an individual says they plan to purchase an EV in X number of years is hardly a guarantee they will actually do so, nor did the survey reach every prospective EV buyer. Thus, it is helpful to supplement the self-reported predictions with past data gathered from WPI’s ChargePoint account. Figure 18 shows the number of people who charged at least 30 times in the given year. This roughly corresponds to once per week during the school year.
Although 47 survey takers indicated they owned an EV, the most recent data show 36 frequent users of WPI’s charging stations. The discrepancy largely agrees with the count of those who report never (5 individuals) or rarely (8) for charging on campus. To account for these less frequent users, we can use ChargePoint data to determine the share of charging sessions belonging to occasional users or visitors. Over the past few years, these categories of users, collectively including those who charge less than thirty times per year, have accounted for approximately 20% of charging sessions, as shown in Figure 19. Due to the stability of this number, it seems reasonable to assume similar behavior in the near future.
In light of this data, the nine faculty and staff survey takers expecting to purchase an EV seems quite low. As Figure 18 shows, the last three years have averaged over eight new EVSE users per year. This apparent contradiction may be a consequence of the 10% survey response rate. Given a projected increase in EV market share, we would only expect this number to grow. Therefore, we would recommend looking at nine new users in the next two years as the floor for likely adoption. Double or even triple that growth would not be surprising.

4.1.3.3. Price Difference

On average, EVs cost about $55,600 and ICE vehicles cost $36,718. The price ratio of EVs to ICE vehicles is therefore approximately 1.5 (Coren, 2019) (Hecht, 2019). This means that EVs are currently 1.5 times as expensive as ICE vehicles. Along with the EV price premium, this ratio also reflects the reality that sales-weighted EV purchases skew towards the premium and luxury vehicle segments; for example, the Tesla Model 3, by far the best-selling EV, is generally considered a luxury compact car. In the survey, we asked how much more respondents were willing to pay for an EV if they were purchasing a $30,000 ICE vehicle. The distribution of responses is depicted below.

Table 3: Distribution of Amount non-Undergraduate Respondents are Willing to Pay Extra for an EV (dollars)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>$4,150</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>$3,540</td>
</tr>
<tr>
<td>Sample size</td>
<td>163</td>
</tr>
<tr>
<td>Confidence interval</td>
<td>$540</td>
</tr>
</tbody>
</table>
On average, non-EV owning faculty, staff, and graduate students were willing to pay $4,145 more for an EV. This translates to an EV/ICE price ratio of approximately 1.13. If the price of EVs drops significantly or if the price of ICE vehicles increased, then perhaps there would be an increased rate of adoption. However, as it stands now, the majority of the WPI community seems to think that EVs are still too expensive compared to ICE vehicles.

4.1.3.4. Influence of having EV chargers at WPI
Responses from current EV owners was a fairly normal distribution of responses, with only 7 out of 42 respondents (16.67%) saying that their decision to purchase an EV was not at all influenced by WPI’s chargers. Everyone else was at least slightly encouraged to purchase an EV because of the presence of chargers at WPI. About 36% of respondents said that WPI’s EV chargers influenced their decision to purchase an EV “a lot” or “a great deal”.

![Figure 20: Survey response to question “How much influence, if any, did the presence of EV chargers at WPI have on your decision to purchase your current EV?”](image)

Among 101 non-EV owning faculty and staff, only 12 said that WPI’s EV chargers would have no influence a future EV purchase, while 48 say that an EV purchase decision would be influenced “a lot” or “a great deal.” Note that these figures do not include the 18 people who never expect to own an EV. As shown in Figure 21 the vast majority of faculty and staff who expect to own an EV in the next ten years report that WPI’s chargers would influence such a decision by at least a moderate amount. Furthermore, 61% of students (both graduate and undergrad) who expect to purchase an EV within the next two years answered in the same manner. However, so did 30% of students who do not expect an EV purchase in the next decade. This result is rather nonsensical, considering that nearly all of these people will have left campus long before they expect to purchase an EV. Perhaps they interpreted the question to be
asking whether WPI’s EVSE made them more willing to buy an EV, such as by increasing awareness. Whatever the reason, it suggests that the student responses to this question should be treated with a healthy amount of skepticism.

Regardless, the overall figures offer compelling evidence that WPI’s forward-thinking EVSE investment encourages EV adoption among the entire community, particularly faculty and staff. Given that “Incentivizing EV adoption” was the second-most cited institutional benefit of WPI’s chargers according to the survey, this means the outcome is in line with community goals. It also suggests a viable strategy for other institutions who wish to accelerate the adoption of EVs.

4.1.3.5. Commute Distance and EV Range
This section only considers the commuting distance of faculty and staff, who are more likely to purchase an EV during their time at WPI. The distributions of commute distance between non-EV owners and EV owners were similar, with a right skew indicating that most respondents live close to WPI. The average commute for non-EV owning, non-undergraduate respondents is 16.58 +/- 3.78 miles (confidence interval of 95%). The average commute for EV owners was 23.51 miles +/- 5.00 miles (95% confidence interval).

At minimum, this demonstrates that a long commute is not a significant factor inhibiting further EV adoption at WPI. It was hypothesized that non-EV owning respondents were concerned about having to frequently charge an EV after a long commute, but most EVs can comfortably make a roughly 30-mile round trip without charging for an entire week. Instead, the results suggest that those who are more likely to have a longer commute are also those who are more likely to consider purchasing an EV. This is supported by a McKinsey survey, which indicates that EV owners tend to have 32% longer commutes than non-EV owners (Berman, 2020).
Figure 22: Histogram of Faculty/Staff Commute Distances

Figure 23: Histogram of EV Owner Commute Distance
4.1.4. Policy-Related Analysis

4.1.4.1. Usage Fees

Another salient question is whether to charge a fee for electricity. On this issue, respondents both with and without EVs are overwhelmingly opposed to instituting a fee, as seen in Figure 24. Evidently, most non-EV owners are willing to subsidize their EV-owning counterparts. We did not disclose to survey takers the cost to WPI of this subsidy, and it is impossible to determine whether most people had a realistic estimate of this expense.

![Figure 24: Survey response to question “Should WPI charge a fee for using the charging stations or should charging be provided free of cost?” classified by EV ownership status](image)

If WPI were to institute a fee for charging, the majority of respondents who were EV owners preferred a pay-per-hour policy, which is a feature of the ChargePoint app that could be activated (Figure 25). Other universities we interviewed, such as UMass Medical, have a broader portfolio of chargers. In these situations, adding a fee to the parking pass would be a more realistic option.
Because the WPI Office of Sustainability as well as many community members believe WPI should be encouraging the adoption of electric vehicles, it is important to examine the effects of a fee on EV adoption. Figure 26 shows that the introduction of a fee would significantly impact many potential EV purchases. Therefore, if incentivizing adoption is of primary importance to WPI, this result suggests the school should delay the introduction of charging fees until financial or demand constraints cannot be satisfied otherwise.
Figure 26: Survey response of non-EV owners to question, "If WPI added a fee for EV charging, how much influence, if any, would this policy change have on your hypothetical EV purchase decision?" - Faculty & Staff responses only

4.1.4.2. Four-Hour Courtesy Limit

WPI’s EV community has an unwritten policy to keep charging sessions to a maximum of four hours. Since there are no strict written rules, the policy is enforced by respect and oral communication. The users communicate with each other through an email alias. As seen from Figure 27, the majority of users conform to this policy. Only 34.34% of the sessions exceeded the four-hour limit. The average charging duration in the Fall 2019 semester was 3 hours and 47 minutes.

Figure 27: Distribution of Charging Session Length
According to ChargePoint data, the majority of sessions exceeding four hours were after 4 pm. Although there are some rare extension cases during the day (7am – 2pm), the majority are during after work hours. This idling does not have a high effect on the EV users for now. In case of a member of the community is in need of charging, and someone else is occupying the port for an extended amount of time, the member can notify the EV user email alias so that a charger can be vacated as soon as possible. Auditing the EV users email alias for seven months, we observed that this is a rare event.

The following graph depicts the range of BEVs and PHEVs on campus for 28 BEVs and 18 PHEVs. The average electric range for BEVs on campus is 257.1 mi +/- 21.4 mi (95% confidence interval) with a standard deviation of 57.7 mi. The average electric range for PHEVs on campus is 28.7 mi +/- 2.9 mi (95% confidence interval) with a standard deviation of 6.2 mi. The average one-way commute for all EV owners was 23.51 miles +/- 5.00 miles (95% confidence interval). Therefore, most EV drivers should be able to get a full charge in a 4-hour charging session, and not have to charge every day.

![Range of BEVs and PHEVs on campus](image)

Out of the 28 EV owners who responded to how frequently they followed the 4-hour limit with their own vehicle, 26 of them said that they always or often do, which is about a 93% adherence rate to the current policy. A couple users did admit to frequently ignoring the guideline. 37 out of 38 EV owners responded that they were aware of the 4-hour charging limit, while only one responded “Sounds familiar...”. Although respondents are less likely to admit non-adherence to the charging policy, it is safe to say that the charging policy is widely known among the community and the ChargePoint data show that few EV users violate the policy during peak charging hours.

Although it is rare, there are occasions in which EV users were not able to find an available port. This occurs due to various reasons such as ICE vehicles parking at the charger spots, an EV’s extended
parking time at the port, and the limited number of chargers the institution has. Installing the 10 new ports at Gateway Garage should decrease the frequency of this event. Although the location of the new chargers is inconvenient to some users, currently the available resources sufficiently offset the increased demand due to these issues. Current EV owners were also asked about charging an idling fee once charging has finished. This anti-idling policy is used at some public charging stations. The response of the WPI EV community was skewed negatively (Figure 29), though not nearly as strongly as the reaction to a general fee.

![Should WPI Charge a Steeper Idling Fee?](image)

*Figure 29: Survey response to question “Some public stations discourage idling by billing users at a relatively high rate to remain plugged in once charging has finished. Should WPI adopt a similar policy?” – presented only to current EV owners*

4.1.4.3. Expanding WPI Charging Infrastructure

What about installing new stations? The community is quite enthusiastic about doing so, at least if someone else is paying. When asked if WPI should install more stations funded by grants and rebates, the response was overwhelmingly in favor. However, there is a major shift when it comes to using school funds to install more stations. Perhaps predictably, undergraduates are least supportive, with only 30% somewhat or strongly agreeing with such an action, compared to approximately half of graduate students and staff, and nearly two-thirds of faculty.
Should WPI install more chargers if funded mostly by grants and rebates?

Figure 30: Survey response to question "Should WPI install more chargers if funded mostly by grants and rebates (from government or utilities)?"

Should WPI install more chargers if funded mostly by school funds?

Figure 31: Survey response to question "Should WPI install more chargers if paid for mostly by school funds?"
When cross-referenced with opinions about EVs, the results are predictable: those who view EVs more favorably are more in favor of using school funds to install stations (Figure 33). If nothing else, this is a good reality check for our survey, indicating that people were giving rational responses. Furthermore, the primary benefit respondents saw for having charging stations had little effect on opinions on installing more (Figure 34).

Figure 32: Survey response to question “Should WPI install more chargers if paid for mostly by school funds?” classified by respondent category
Figure 33: Survey response to question, “Should WPI install more chargers if paid for by school funds?” classified by respondent’s answer to question “What is your general opinion of electric vehicles?”

Figure 34: Survey response to question, “Should WPI install more chargers if paid for by school funds?” classified by respondent’s answer to question “Please choose the most important institutional or social benefit of WPI’s EV chargers, in your opinion”
4.1.5. Summary of Results

In total, 601 survey responses were recorded. Most respondents were undergraduate students, while most faculty and staff respondents tended to own EVs. Overall, the WPI community has an overwhelmingly positive view of EVs. Many faculty and staff members indicated that they expected to purchase or lease an EV in the next five years, which would at least double the number of EV owners on campus.

Most respondents believed that charging should be free, while EV owners indicated that should a fee be implemented, it should be on a pay-per-hour basis. EV owners were polarized on whether WPI should charge an idling fee. While most respondents overwhelmingly agreed that WPI should install more chargers if funded by grants and rebates, there was no clear support for or opposition against installing chargers funded by the school.

4.2. Interviews with Other Universities

Through interviews with other universities, we sought to understand how WPI could improve its own policies to encourage EV adoption and better regulate charging. We also wanted to understand the process these organizations went through when deciding to install chargers. Through these new contacts, we also aggregated data and reports regarding how other universities determined how many chargers to install, and other institutions’ projections for EV ownership. The universities included Clark University, Worcester State University, College of the Holy Cross, and University of Massachusetts Medical School.

4.2.1. Clark University

Clark, which alongside WPI opened its first EV chargers in Spring 2012, has held steady with two dual-head stations for a total of four charging ports, with no immediate plans for expansion. Clark EV drivers also take advantage of an adjacent public station. While a Clark parking pass is nominally required to use the stations, enforcement is minimal. Despite a strong community culture of environmental sustainability, EV adoption has not been particularly swift. When we visited the campus in September 2019, the Director of Sustainability relayed that the stations were rarely full and that users would park at a charger all day without problem. However, in February, data indicated that the stations were at capacity during 75% of work hours. Over the 2019/2020 school year, the university has also put together a more formal EV user group. Headed by an EV-owning physics professor, the group now boasts twenty-five members, though only half that number currently own an EV (J. Isler, personal communication, February 19, 2020). Still, considering Clark has about half the population of WPI, they are not too far behind in adoption. The group is developing a pricing policy that will keep stations free except if a car has been idle (i.e. finished charging) for greater than one and a half hours. One difficulty Clark has faced is that no office has the authority to oversee the EV charging infrastructure. For example, the Office of Sustainability’s budget does not allow for sufficient resources to do this. When their stations needed to be replaced, the lack of a definitive authority meant that grant applications were not submitted and the university shouldered the full cost (J. Isler, personal communication, September 23, 2019).
4.2.2. College of the Holy Cross

Holy Cross installed four dual-port chargers in their faculty and staff garage over Summer 2019. Currently, only about five unique users utilize the eight available spots. The director of facilities also noted a significant decrease in demand during the coldest months. Holy Cross charges approximately 15 cents per kilowatt hour. About 10% goes to ChargePoint, and the remaining 13 cents exactly covers the electricity cost. Charging at home would cost about 20 cents per kilowatt hour.

Since parking is very limited at Holy Cross, demand for additional chargers would need to be balanced with the fact that only EVs can park in those spots, so if they are not well used, they serve only to deprive an ICE vehicle of a parking spot.

To determine how many chargers to purchase, Holy Cross relied solely on word-of-mouth from other Worcester-area universities (J. Cannon, personal communication, September 18, 2019). When they saw how WPI’s three dual-head chargers were being used at capacity, they decided to purchase four dual-head chargers, which seems to be more than enough for the present demand. It allows room for growth in EV ownership on campus and saves them money and effort, since they installed all chargers at the same time through one rebate.

4.2.3. UMass Medical School

The UMass Medical School has five Level 2 chargers (three Tesla and two Eaton-branded J1772), and six Level 1 outlets in the West Garage on their main campus. These chargers are heavily used, although precise figures for usage and energy consumption are unavailable because of the chargers’ lack of data collection. Due to the high demand at existing chargers, in May 2019 UMM installed four new dual-port stations in their Plantation St garage located slightly off-campus. Originally opened in 2013, the garage was built with EVSE compatibility in mind. All four new chargers are connected to the ChargePoint network. Although the university currently offers free charging, financial considerations are a potential concern given that the UMM parking facilities are funded by a trust and therefore must be income-neutral (S. Wood, personal communication, September 18, 2019).

The EV community at UMass Medical has been very vocal about the need for more charging stations, and previous charger installations were largely the result of individual EV owners petitions. UMass Medical is in the process of creating a universal alias that everyone, including those not in the UMass community, can join. Due to the demographics of UMass Medical’s EV owners, the university will most likely pursue installing more Tesla chargers.

Of the schools we interviewed, UMM certainly has the most developed set of charging guidelines. These have been influenced by meetings and communication with current EV drivers as well as a sustainability survey conducted in Fall 2018. All drivers who want to use the charging stations must have a UMMS parking pass. However, the school has a tiered parking system, with some parking locations costing more than others. When West Garage was the only EV charging location, all UMM EV owners could access the garage to charge, even if they normally did not have parking rights there. Upon charging completion, the driver was required to return to their normal parking location. Several months after the addition of the Plantation St. Garage chargers, users were split according to pass type, and assigned to chargers at one of the garages. Drivers must still return to their designated location when not charging. To provide some flexibility, West St. Garage has ten EV-only parking spots for its seven 1st-floor chargers.
(the remaining four Level 1 ports are on other floors). School guidelines also allow EV users to unplug another user’s vehicle if fully charged (Level 2 only). Single-head Level 2 chargers have a four-hour limit, and administrators encourage morning users to leave by noon to allow for a second set of vehicles to charge during regular hours (S. Wood, personal communication, February 18, 2020). Dual-head units have an eight-hour limit to account for slower charging speeds if both heads are occupied. Level 1 locations are also subject to an eight-hour limit. Enforcement is limited, and the system relies on self-policing and courtesy to maintain smooth operation. In service of this goal, charging guidelines and FAQs are organized in a PDF and posted to the university website (see Appendix C).

4.2.4. Worcester State University

Worcester State (WSU) had two dual head Level 2 chargers when we visited in September 2019. Only one of these chargers is connected to the ChargePoint network, which means that the data collected is only a small representation of all charger use on campus. The non-network charger is in the school’s garage, which is not open to visitors. Data collected from the exterior charger showed a daily usage rate of 89% and 31 unique users for September 2019. Since then, the school has added two more and plans on installing a further four (S. Bandarra, personal communication, March 2, 2020).

In fall 2019, there were only two students on campus that owned EVs, which is low considering that 62% of the student body commutes. The chargers are cost-free as an initiative to encourage the WSU community to switch to electric vehicles. In order to unify the EV owner community, Worcester State University has formed an email alias. By observing the community, the sustainability department has come up with various policies and they are in the process of writing an EV usage policy.

4.2.5. Summary

These interviews revealed the diversity of EV infrastructure programs at different universities. We appreciated the profound impact of a vocal EV owning community and an Office of Sustainability that can provide sufficient support to maintain the institution’s EV charging infrastructure. WPI and UMM appear to have the most vocal and consolidated EV owning communities, with a centralized mailing list where EV drivers can air grievances and advocate for more chargers.

In terms of charger management, the best system seemed to be for all chargers to be from the same company, if possible, enabling universities to monitor their usage and know when to install more. Still, UMM proves that a non-homogeneous charging infrastructure can work.

There is also no standardized way universities regulate EV charger usage. Some charge a fee to cover electricity costs, while others, like WPI, offer it for free. Of the universities who charge a fee, some charge by an hourly rate and others add a fixed fee to the parking pass. Some chargers are available to the public, while others are only available to faculty and staff. Some have a minimally enforced charging session limit, while others lack demand for their chargers and have no policy at all.

We also saw that there is no standardized, reliable method to determine the number of EV chargers to install, or when to install them. Therefore, from the beginning of the project, we resolved to formulate a basic procedure an institution could follow to embark on a journey to install EV chargers. We also hoped to determine which charger usage policy would best fit WPI’s user profiles and resources. For each institution, the circumstances are different, so there is no one-size-fits-all solution to any of these challenges.
Chapter 5. Conclusions and Recommendations

In this chapter, we outline a general evaluation model based on the results described in Chapter 4 that can be used by universities starting or maintaining their EV charging infrastructure. The evaluation model consists of several factors we found most impactful when analyzing WPI’s EV charging infrastructure. These factors include: on-campus EV population size and its approximated growth, charging policy options, installation considerations, and types of chargers available. We recommend certain tools to those who hope to analyze their institution’s EV charging infrastructure, such as the community survey and the system dynamics model we developed during this project. This template could also be used by WPI as a general way to ensure its charging infrastructure is keeping pace with demand. Then, we describe specific short-term recommendations for WPI informed by survey results.

5.1. Evaluation Model

This evaluation model presents our guidance and recommendations for anticipating future growth in campus EV populations, deciding between potential EVSE policies and fees, and choosing the right type of chargers. These guidelines are augmented by a system dynamics-based model that aims to present rough estimates of campus EVSE needs under a range of plausible scenarios for vehicle adoption and institutional policies. In many ways, the template generalizes the steps our team took to analyze WPI’s EV charging infrastructure and to formulate our recommendations. For this reason, reading Section 5.2 on WPI-specific recommendations gives an example of how to apply these recommendations.

In order to best ensure success in EVSE management, an institution should make their goals explicit. These are likely to be influenced by the value placed on sustainability – by the general campus community and especially the administration – as well as financial constraints, campus vehicle ownership rate, and other institution-specific factors. Do they want to make the bare minimum investment and take a reactive approach to infrastructure? At the other end of the spectrum, an institution can proactively invest in charging stations as a means to encourage EV adoption among its community and thereby promote sustainability. The latter method is potentially costly, not only due to the larger initial investment, but because it creates a reinforcing feedback loop by encouraging faster EV adoption, which in turn require even more infrastructure. Such a plan requires strong commitment from school administration and a formalized assignment of responsibility for EVSE policy, expansion, and maintenance. It would also benefit from outreach initiatives to ensure the entire campus community is aware of and hopefully enthusiastic about the plan.

5.1.1. EV Population and Growth

For universities that are aspiring to increase the number of EV users on campus, we recommend creating an email alias of all the EV users or members who are interested in EVs. The invitation to this alias can be emailed to the school with a general distribution list. Users who are not a part of the community can self-identify and be included in the EV alias. This alias can be used as a focus group to ask for input regarding infrastructure expansion and charging policy.

Another simple way to gauge the EV population and its potential growth would be to send out a survey to ascertain alias members’ thoughts on EVs and existing infrastructure at their institution. The survey
used during this project is included in Appendix E and can be used as a starting point. From the survey, community members can also express their opinions about the institution’s current EV policies and get informed of current policies. This would engage the community’s interest and provide beneficial data to the administration. The data gathered can also be used to help parameterize the model presented in Section 5.1.5.

5.1.2. Charging Policy Options

Institutions have several options when deciding whether to charge a fee for EV charging. Some institutions keep charging free, either as publicity for newly installed chargers or to encourage the community to adopt EVs as part of its sustainability efforts. If the electricity bill becomes too hefty, some institutions choose to impose a fee to minimally cover these utility costs. Depending on whether the chargers can record session length and driver ID, some institutions impose either a pay-by-hour fee or simply a fixed add-on fee to the parking pass.

In the interest of sustainability, we recommend offering free charging (with the possible exception of an idling or overuse fee) for at least the next two to three years as a means to encourage EV adoption. Free electricity also encourages PHEV owners to charge and thus operate more in electric-only mode, thus reducing emissions. The time window for offering free charging may be longer or (slightly) shorter depending on general market conditions. However, once EVs gain significant momentum, a fee will likely be necessary both to cover costs as well as limit charging demand to meet limited available supply. The magnitude of any fee should balance sustainability, financial, and demand concerns. In the more distant future, it is not implausible to imagine above-market electricity rates being required to balance station supply and demand at institutions where a large EVSE network is infeasible. Especially at non-profit and public institutions, such a policy may be seen as a way to unfairly profit off drivers. As always, image and public relations will be contributing decision-making factors.

In order to track charger usage, we urge universities to license a charging software if possible. This way, they will be able to track the current utilization and decide whether they are reaching capacity. By analyzing this data, the administration can decide the purchase date of future chargers as well as how many and what type to get. Another instance charging software would be beneficial is while tracking the energy usage. In case the institution wants to charge people for EV charging on campus, they can confirm their energy usage and determine a reasonable price point. However, the charging stations need to be compatible with one another in order to obtain accurate data.

Another consideration is enforcement of charging policy. Technically, ICE vehicles cannot park in EV charging spots. Depending on the location and the scarcity of parking spots, however, the enforcement of this policy can be lax. If this becomes or is anticipated to become a significant issue, we encourage dialogue and collaboration with the campus entity in charge of parking enforcement. Some institutions have an informal charging etiquette of limiting charging sessions to some set time, such as four hours. Again, there is often little to no enforcement of this policy. An option for institutions with software licenses for the chargers involves the imposition idling fees. This can encourage efficient charger use without consuming parking enforcement resources.
5.1.3. Installation Considerations

Some factors to consider before installing chargers would be the cost and the location of the installation. The universities that want to install new chargers should check if they have the wiring ready for chargers before purchasing the product because the electrical preparation for the installation might be more expensive in some locations than others or would need to be rewired from scratch. Something beneficial to keep in mind during construction would be to prepare the electrical foundation for future charger installations. It is cheaper to install chargers with a pre-made correct electrical infrastructure than preparing the infrastructure at the time of installation.

While deciding on charger locations, institutions should consider convenience of access as well. A survey can be conducted in order to measure the community's needs. For users, convenience is extremely important and would increase the utilization of the chargers.

Currently, the state and many energy companies offer various incentives for charger installations. Universities interested in commencing or expanding their EV community on campus may highly benefit from these incentives. Also, the state has special incentives for environmental justice community (EJC) locations. The institute may check if any of their property is located within an EJC area. This way the cost of the charger installations may be reimbursed. To get more information about the current possible incentives, reference Section 2.2.5.

Another possible path to follow may be contacting private companies, alumni, and administrators directly. Some companies are willing to donate chargers to educational institutions. This way the university would only need to pay for the installation cost. Also, many alumni are willing to donate to the school. Whether the donation is financial help or charger donation, the university will benefit from it.

Institutions should keep in mind that EVSE installation incentives will eventually be withdrawn as momentum builds and they are no longer necessary to spur installation, not to mention with cost ballooning as volume increases. Given the very high likelihood that most universities will eventually benefit from having several tens of chargers, it would certainly be prudent to take advantage of current incentives covering much of the electrical infrastructure cost, if not the charging stations themselves.

A downside of being proactive in EVSE investment is the possibility that the investment becomes obsolete before it is heavily used, but we believe the risks are small. Innovation could take the form of a robot that delivers a battery to an EV’s location and retrieves it when charging completes – VW has shown such a concept – or vehicles that are able to self-park and rotate themselves into and out of charging spaces. These types of innovations would make traditional chargers less attractive, but existing units could likely coexist successfully. Alternatively, imagine a major battery breakthrough that tripled the range of the average EV. This could cause charging demand to decrease as those with home charging capabilities eschew the hassle of workplace charging. Nevertheless, there remain those without access to charging infrastructure at home; this population is especially significant at a university, given the number of students who live in dorms or apartments. Combined with the inevitable delay between technological breakthrough and adoption that would allow institutions to put further EVSE projects on hold, this scenario would not entail significant wasted investment. Similarly, a fast-charging breakthrough would reduce demand for Level 2 stations, but given the likely price differential, the latter would still fulfill a role. The only development that would make EVSE a wasted investment would be a
A rapid shift in the outlook for electric vehicles. This could result from a move towards other alternative energy vehicles: hydrogen fuel cell or natural gas, for instance. However, we judge this possibility extremely unlikely.

Additionally, the need for more EV chargers should be balanced with the concern of non-EV owners over a lack of parking spaces. Since EV charging spots are strictly reserved for EVs, each charging spot for an EV owner takes one parking spot away from a non-EV owner. If the institution has limited parking, they may face opposition from ICE drivers. As long as EV spaces are added in rough alignment with actual EV adoption, the need for parking spaces should remain relatively constant: a charging EV is not taking up a regular space, after all. Keep in mind, however, that Level 2 EV spaces will not be filled 100% of the time due to cars swapping in and out. Additionally, an EV owner is less likely to move from a charging spot – and less likely to charge in the first place – if they do not expect to be able to quickly find a new place to park. Of course, there are many other factors contributing to parking availability, but we believe institutions should keep in mind the impact of EVSE on parking and vice versa.

5.1.4. Types of Chargers Available

For easiest charging infrastructure management, we recommend that a university’s chargers all be in the same brand ecosystem. For example, all of WPI’s chargers are from ChargePoint, and their software (which universities can choose to license) enables closer monitoring of station usage. Some universities, like UMass Medical, have a mix of chargers, and are unable to properly track usage and to enforce pay-by-hour charging.

Depending on the number of existing chargers, and the length of commute and size of the EV owning population, a school’s EV charging solution can vary. It is important to consider the capabilities in addition to the number of chargers to be purchased. Schools with fewer than five EV owners, especially ones who have not yet made requests for better charging infrastructure, should be able to accommodate EV charging with several wall outlets (Level 1), where EV owners can bring their own cable, plug in and stay for the day. Even for institutions with more developed EV communities, we recommend using this method to supplement faster stations at a smaller cost. In our survey of WPI, multiple EV drivers expressed interest in this solution; UMass Medical School offers an example of Level 1 plugs successfully augmenting charging capacity.

If there are sufficient funds and demand for better charging infrastructure, a university might consider installing Level 2 chargers. At the time of writing this report, a Level 2 ChargePoint charger costs approximately $7,000 in addition to installation costs. (ChargePoint chargers are among those on the list of approved chargers for the National Grid rebate program, and therefore are used for these hypotheticals.) One dual-head Level 2 charger can fully charge at least four EVs per day, if each charging session is limited to four hours. Since it is unlikely that the average EV owner will imperatively need to charge every day, a good rule of thumb is to have at least one plug per five EV owners, or one dual-head charging station per 10 EV owners. One example is WPI’s 2019 EV charging situation. With at least 40 EV drivers and only three dual-head Level 2 chargers, the chargers were constantly operating at capacity.

With a DC Fast Charger (DCFC), each EV could theoretically cycle in and out within 30 minutes or less, meaning that a single DCFC charger (single head) could potentially service up to 16 drivers per day. The payoff: a DCFC costs $35,000, five times as much as a dual-head Level 2 charger (Green Ways 2Go, 2019). Therefore, institutions hoping to purchase a DCFC would most likely need to charge a fee for
charging, as a DCFC station would also draw significant power. An institution considering installing DCFCs should consider how they will enforce short charging sessions. ChargePoint’s waitlist feature might be helpful in letting people “schedule” a charging time, although ChargePoint does not offer any such reservation-making features.

DC Fast Chargers are probably not a good general solution for EV charging at a university. We recommend that DCFC only be purchased mainly for use in visitor parking lots. A cost-equivalent five dual-head Level 2 chargers would be able to service up to 20 vehicles per day, whereas a DCFC could service at the most 16 per day. Therefore, the only justification for the increased cost for DCFCs would be the convenience of quick charging. Visitors and those who need to charge quickly for their commute home might benefit from a DCFC, but since most faculty, staff, and students plan to be on campus for extended periods of time, Level 2 charging is the optimal solution—they can fully charge their vehicle, while not having to worry about frequently going to move their EV in between classes.

5.1.5. System Dynamics Model

In order to provide a rough estimate of the amount of EV infrastructure needed at an institution, we built a system dynamics computer simulation model using the Stella software. As with any tool, predictions should be taken with a healthy degree of skepticism. This is especially true in this case given the wide variance in plausible EV adoption estimates. To account for this uncertainty, the model design allows users to adjust the general EV adoption curve to test any number of scenarios. The general adoption rate variable is defined graphically with respect to time; two possible time shapes for the function are shown in Figure 35. The horizontal scale is years since start of simulation, parameterized as 2020. The vertical scale is EV market share; it is important to emphasize that this measures the share of new vehicle sales, not the composition of vehicles on the road. In the specification on the left, EV market share grows slowly before picking up in the late 2020’s. By 2040, ICE vehicles still outnumber EVs in yearly sales. By contrast, the parameterization on the right maps a much more aggressive view of EV adoption, as the category surpasses 50% market share in the early 2030’s.

There are a number of other parameters that can be adjusted to fit either future expectations or institutional specifics. The former category includes the rate of growth in average EV range, while the
latter includes number of faculty and student vehicles, average commute length, and average vehicle age on campus, among several other factors. The user can also test the effect of a charging fee. Figure 36 and Figure 37 display the user interface and adjustment options.
Faculty and staff EV purchase decisions are based off the general rate of adoption modified by several factors. Lower charger usage increases adoption because new buyers expect to be able to take advantage of institutional chargers, while adding a fee to charge does the opposite. There is also an “institution base attraction factor” variable to represent all other institution-specific factors. At WPI, for instance, the EV adoption rate has generally kept well ahead of the rate for society at large, so this parameter is specified to be greater than 1. Students, because they generally own older vehicles and/or ones passed down from family members, adopt EVs more slowly and are also unaffected by institutional specifics.

In the default model specifications, the growth in desired number of chargers slows and eventually goes negative despite a continued growth in campus EV population. This is because average EV range also increases over time, and a greater range is assumed to decrease individual demand for charging. The decrease in demand is particularly pronounced if EVSE users must pay for electricity. To see an example of the model applied to WPI, please see Section 5.2.5.

5.2. Short-Term Recommendations for WPI

In this section, we combine our general guidelines with our analysis from WPI’s ChargePoint account and the feedback we received from the community survey. In part because of long-term uncertainty in the EVSE sphere, most of our recommendations pertain to the next five years. After that time, WPI will surely want to revisit these issues, and the general evaluation guidelines in Section 5.1 will be of use at that time.

5.2.1. Charging Policy

As of February 28, 2020, charging in the past month cost $841, and we estimate that at this rate, the annual cost of electricity to all 16 plugs will approach $10,000. This cost will only rise as more WPI community members purchase EVs and need to charge, and especially if WPI is able to maximize the efficiency of charger usage by discouraging idling. If idling time is reduced, assuming near-constant charger usage, the amount of time actually dispensing electricity – and hence cost – will rise. The “WPI Forward” cost-cutting initiative may increase pressure on this expense.

Therefore, we believe that in the long run a charging fee, coupled with an idling fee, is necessary to ensure financial sustainability and channel demand towards those who need it most strongly. According to our survey results, members of WPI’s current EV community would prefer the fee for charging to be on a pay-per-hour basis. However, this will inevitably be an unpopular policy move. The majority of survey respondents (both EV owners and non EV owners) were highly averse to starting to charge a fee for charging. There was also a sizable cohort who responded that a charging fee would significantly affect an EV purchase decision. The latter finding is problematic given WPI’s goal to incentivize adoption. Several current EV owners said that they would completely stop using the WPI stations if a fee was added. This, on the other hand, would not necessarily be a negative development. Because neither WPI’s financial resources nor parking availability are limitless, it is unreasonable to expect enough charging spots (which take away an all-purpose parking space) to allow all campus EV users to charge all the time. Thus, we need to incentivize those users with-long range EVs and convenient home charging to plug in less. A less saturated charging network also makes the perk more appealing for potential new EV owners.
Weighing the competing objectives, we recommend delaying fee implementation for two or three years if possible to wait for EV adoption to gain more momentum. We nonetheless recommend easing EV owners into the idea by instituting an idling fee as soon as possible. An idling fee will also produce valuable data regarding users’ sensitivity to charging cost, a valuable insight when evaluating the levy of further fees. We favor adopting Clark University’s planned idling policy allowing EV owners to stay plugged in for up to an hour and a half before idling fees begin. This would give EV owners ample time in which to move their vehicle once it is done charging, since most undergraduate classes are 50 minutes long and graduate classes are not more than 1.5 hours long.

WPI could choose to keep charging free at Gateway Garage where demand is significantly lower, while charging a fee at the busier Park Ave Garage. This policy could be combined with higher fees during peak station hours, such as from 8am – 5pm. Several faculty members mentioned that they felt it was acceptable to stay plugged in for longer in the evening, when there is no longer as much demand for the charging stations.

5.2.2. Financial Incentives

WPI should continue to take advantage of the financial incentives offered by National Grid’s Lead by Example program. National Grid covers 100% of the installation costs for approved projects, and a certain percentage of EVSE costs depending on location of chargers and accessibility. If WPI installs private “workplace” chargers, National Grid offers a rebate of 50%. If WPI installs publicly accessible charger in a non-EJC area (such as the Park Avenue Garage), National Grid will reimburse 75% of EVSE costs. The best deal is for WPI to install publicly accessible chargers in an EJC fulfilling two of the criteria, in which case National Grid would reimburse 100% of EVSE costs, as long as they are kept public for at least five years.

WPI’s Visitor Lot at 60 Prescott would be a prime candidate for this program, since it is located in a qualified EJC and could be made available to the public without endangering the security of the WPI community (as opening the Gateway Garage to the public might do). We recommend that WPI explore this possibility before 2021. The current EJCs are designated based on 2010 census data, and 2020 census results which are used for state and federal redistricting will be released on March 31, 2021, which could affect whether that parking lot is still in a qualified EJC (Wang, 2019).

5.2.3. Installation Considerations

When the majority of faculty and staff responded to the survey, it was before the five dual-head Gateway Garage chargers were installed. At that point in time, most respondents indicated that they would like the Park Avenue Garage, Gateway Garage, and Boynton Lot to have priority for new chargers. Therefore, we recommend that the new SmartWorld building have the electrical infrastructure to support the installation of at least five dual-head chargers in the future as needed.

Of course, the need for more EV chargers should be balanced with the concern of non-EV owners over a lack of parking spaces. Since EV charging spots are strictly reserved for EVs, each charging spot for an EV owner takes one parking spot away from a non-EV owner. If the institution has limited parking, more chargers will engender increased opposition from ICE drivers. As long as EV spaces are added in rough alignment with actual EV adoption, the need for parking spaces should remain relatively constant: a charging EV is not taking up a regular space, after all. However, Level 2 EV spaces will not be filled 100%
of the time due to cars swapping in and out. Additionally, an EV owner is less likely to move from a charging spot – and less likely to charge in the first place – if they do not expect to be able to quickly find a new place to park. Of course, there are many other factors contributing to parking availability, but we believe institutions should keep in mind the impact of EVSE on parking and vice versa.

5.2.4. Types of Chargers

Several EV owners expressed interest in being able to charge their vehicle at a Level 1 plug (EV owner supply their own cable), especially if they did not have to move the vehicle all day and could simply stay there to charge. While spots near Level 1-friendly plugs should not be reserved for EVs so as not to incur the wrath of ICE vehicle owners, this would be a viable way to slightly reduce the demand for the Level 2 chargers. Level 1 charger electricity usage would also be more difficult to track than for “smart” Level 2 chargers connected to the ChargePoint software. It would be a much smaller expense, though, making the inability to charge a fee for using a Level 1 charger acceptable.

5.2.5. Model Output

ChargePoint data and survey responses helped us parameterize the System Dynamics model to fit WPI’s experience. Figure 38 and Figure 39 show four scenarios for desired charging ports and the total number of EVs on campus, respectively. The label Free-High corresponds to a high EV adoption scenario where charging is free, Paid-Low a situation with low EV adoption and a charging fee, and so on. Based on the research laid out in this report, we expect actual adoption rates to fall somewhere between the High and Low scenarios presented here.

![Figure 38: Desired campus charging ports under four scenarios](image)
The EV number is based off a daily vehicle population of 3000, with 1000 belonging to faculty and staff and the rest to students. Determining the number of student vehicles regularly driven to campus is difficult but given that WPI has approximately 2400 parking spaces and there is considerable street side parking, the estimate of 3000 seems reasonable. Especially after 5-10 years, the exact predictions are likely to be quite unreliable, but it is still valuable to examine the dynamics. For instance, note that growth in desired charging ports slows earlier than that of EV adoption due to the negative relationship between EV range and charging needs. Also, instituting a fee does harm EV adoption efforts, but the effect on charging needs is far more pronounced. This supports our recommendation to charge a fee in the future.
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Appendix A: WPI Map

https://www.wpi.edu/sites/default/files/docs/About-WPI/WPI_CampusMap.pdf
## Appendix B: College Comparisons Chart

<table>
<thead>
<tr>
<th>University</th>
<th>WPI</th>
<th>Clark University</th>
<th>College of the Holy Cross</th>
<th>UMass Medical Worcester State University</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of Charging Ports</strong></td>
<td>16</td>
<td>4</td>
<td>8</td>
<td>13 Level 2 (8 ChargePoint, 3 Tesla, 2 others) 6 Level 1 outlets 8</td>
</tr>
<tr>
<td><strong>Approximate Date of Installation</strong></td>
<td>2011 - present</td>
<td>2011; replaced 2019</td>
<td>Summer 2019</td>
<td>Over past 5 years First station 2011/12; most recent 2020</td>
</tr>
<tr>
<td><strong>Method for monitoring usage</strong></td>
<td>ChargePoint</td>
<td>ChargePoint; Went without monitoring for several years</td>
<td>ChargePoint</td>
<td>ChargePoint for Plantation St. Garage; none for West Garage ChargePoint (1); None (1); Unspecified (2)</td>
</tr>
<tr>
<td><strong>Charger Usage</strong></td>
<td>High</td>
<td>24 unique users; chargers full 75% of time</td>
<td>5 unique users; drop in cold months</td>
<td>West: High, always in use Daily usage rate: 89%, 31 unique users (before recent expansion)</td>
</tr>
<tr>
<td><strong>Charging Fee</strong></td>
<td>Free</td>
<td>Free with $40 parking permit; working on idling pricing</td>
<td>15 cents/kWh</td>
<td>Free with parking permit Free</td>
</tr>
<tr>
<td><strong>Open to Public?</strong></td>
<td>Some stations</td>
<td>No; minimal enforcement</td>
<td>No; faculty garage</td>
<td>No No</td>
</tr>
<tr>
<td><strong>Other Charging Policy Details</strong></td>
<td>Email alias, courtesy four-hour limit</td>
<td>Proposal needs to be drafted by EV owners focus group</td>
<td>Overseen by Facilities</td>
<td>Charging rules and FAQ PDF Email alias, currently drafting usage policy</td>
</tr>
<tr>
<td><strong>Method for Planning Expansion</strong></td>
<td>Office of Sustainability</td>
<td>EV User group: 25 members (12 own EVs)</td>
<td>Word of mouth from other colleges, rebates</td>
<td>Vocal EV owners, Office of Sustainability</td>
</tr>
<tr>
<td><strong>Plans for Expansion</strong></td>
<td>Two more with SmartWorld building; two or three more in Park Ave</td>
<td>None</td>
<td>None</td>
<td>More Tesla chargers? 4 more</td>
</tr>
</tbody>
</table>
Appendix C: Charging Policy Examples


Appendix D: Survey Motivation Questions

- What is the projected EV ownership on campus and in Worcester? (5 years)
  - Student opinion regarding chargers (%), student opinion on EVs in general?
  - How likely are people to get an EV in the next 5 years?
  - Does WPI’s free charging affect the above statistic?
  - How far do people commute? (Compare with EV ranges?)
  - Research on batteries, advancements, and sales: see paper
- How is the current infrastructure being utilized?
  - How long their commute is
  - How often EVO drive EV to campus
  - How often EV owners charge
  - How long EVO charge
  - How often they are unable to charge
    - Complaints about the current system. Include suggestions?
  - Data from CP: How often are the users on there longer than 4 hours?
  - How many EV owners are there on campus?
  - Data from Liz, ChargePoint
- What changes need to be made?
  - Suggestions?
  - Where do EVO think new chargers need to be put?
    - Should inform them where the new charging stations will be
Appendix E: WPI Community Survey

Notes:

A * symbol denotes question validation. This means that respondents were either required or highly encouraged to answer before moving on (the latter triggers a popup stating: “There are X unanswered questions on this page. Would you like to continue?”).

A ▶ symbol denotes that some or all of the answer options were presented to the respondent in randomized order. If the question listed an “Other” or “None” option, this was always listed as the last option and not randomized.

Start of Block: ID questions

Q27 This project aims to provide recommendations for electric vehicle (EV) charging infrastructure expansion and policy changes at WPI. Your responses to this survey will help us investigate the present and future of EV charging infrastructure utilization and EV ownership on campus.

There are currently 6 charging spots at the Park Ave garage. The average utilization of these chargers over the past month was 78%.

Q2 Are you a(n)...

- Undergraduate Student (1)
- Graduate Student (2)
- Faculty Member (3)
- Staff Member (4)

Display This Question:
If Are you a(n)... = Faculty Member
Q32 What department are you primarily associated with?
________________________________________________________________

Q33 What is your general opinion of electric vehicles (EVs)?

- Extremely positive (1)
- Somewhat positive (2)
- Neither positive nor negative (3)
- Somewhat negative (4)
- Extremely negative (5)

Q40 If you have a vehicle on campus, what is its age?

- 2 years old or newer (1)
- 3-5 years old (2)
- 5-10 years old (3)
- 10-15 years old (4)
- 15+ (5)
- No vehicle on campus (6)
Q28 Note: If you drive a hybrid that cannot be plugged in to charge, please answer "No" to the following question.

Q1 Do you currently drive an EV (battery electric or plug-in hybrid)?

- Yes (1)
- No (2)

End of Block: ID questions

Start of Block: EV Owners Only

Q3 What is the make and model of your car?

- BMW i3 (8)
- Chevy Bolt (4)
- Chevy Volt (5)
- Nissan Leaf (6)
- Tesla Model 3 (1)
- Tesla Model S (2)
- Tesla Model X (3)
- Toyota Prius Plug-in (aka Prius Prime) (7)
- Other (Please Specify) (9) ________________________________________________
Q4 What is the electric-only range of your vehicle in miles?

________________________________________________________________

Q6 What is the distance of your commute to WPI (one-way) in miles?

________________________________________________________________

Q7 Do you have access to a charger at your place of residence?

☐ Yes (1)

☐ No (2)

☐ It's complicated (please explain) (3) ____________________________________________

Q5 How regularly do you drive this vehicle to WPI?

☐ Always (4-5 times/week) (1)

☐ Often (2-3 times/week) (2)

☐ Rarely (1/week or less) (3)

☐ Never (4)
Q9 With what frequency do you use or attempt to use the charging stations at Park Ave?

- Always (4-5 times/week) (1)
- Often (2-3 times/week) (2)
- Rarely (1/week or less) (3)
- Never (4)

Q11 Are you aware that WPI offers free EV charging?

- Yes (1)
- No (2)
Q19 How frequently are you unable to charge because all chargers are occupied?

- Always (4-5 times/week) (1)
- Often (2-3 times/week) (2)
- Rarely (1/week or less) (3)
- Never (4)

Q14 Are you aware of the informal 4-hour limit on charger use?

- Yes (1)
- Sounds familiar... (2)
- No (3)

Q20 How often do you follow this limit with your own vehicle?

- Always (1)
- Often (2)
- Rarely (3)
- Never (4)
Q25 How much influence, if any, did the presence of EV chargers at WPI have on your decision to purchase your current EV?

- A great deal (1)
- A lot (2)
- A moderate amount (3)
- A little (4)
- None at all (5)

Q31 What were your primary reasons for purchasing your current EV? (Max 2 responses)

- Fuel/Maintenance Savings (1)
- Sustainability (2)
- Owning cutting-edge technology (3)
- Other (4) ________________________________________________

Q36 If you were buying a new $30,000 car, how much more would you be willing to pay for an EV equivalent?

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<tbody>
<tr>
<td>0</td>
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Amount in thousands of dollars ($) (): [Graphical visualization]
Q13 Are you aware that WPI offers free EV charging at the Park Ave garage?

- Yes (1)
- No (2)

Q21 When, if ever, do you expect to own/lease an EV?

- Within next 2 years (1)
- In 2-5 years (2)
- In 5-10 years (3)
- 10+ years (4)
- Never (5)

Q23 What is the distance of your commute (one-way) to WPI, in miles?

_________________________________________________________________

_________________________________________________________________
Q35 If you were buying a new $30,000 car, how much more would you be willing to pay for an EV equivalent?

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<th>3</th>
<th>6</th>
<th>9</th>
<th>12</th>
<th>15</th>
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End of Block: Non-EV Owners Only

Start of Block: General Questions

Q25 Should WPI charge a fee for using the charging stations or should charging be provided free of cost?

- Charge money (1)
- Free charging (2)
- Neutral/ no opinion (3)

Display This Question:
If When, if ever, do you expect to own/lease an EV? ! = Never
Q24 How much influence, if any, would the presence of WPI’s EV chargers have on a future decision to purchase an EV?

- A great deal (1)
- A lot (2)
- A moderate amount (3)
- A little (4)
- None at all (5)

---

Display This Question:

If When, if ever, do you expect to own/lease an EV? != Never
And How much influence, if any, would the presence of WPI’s EV chargers have on a future decision to... != None at all

Q38 If WPI added a fee for EV charging, how much impact, if any, would this policy change have on your hypothetical EV purchase decision?

- A great deal (1)
- A lot (2)
- A moderate amount (3)
- A little (4)
- None at all (5)
Q21 Some public stations discourage idling by billing users at a relatively high rate to remain plugged in once charging has finished. Should WPI adopt a similar policy?

- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)
Q22 Should WPI install more chargers if funded mostly by grants and rebates (from government or utilities)?

- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

Q23 Should WPI install more chargers if paid for mostly by school funds?

- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (4)
- Strongly disagree (5)

Display This Question:

If Do you currently drive an EV (battery electric or plug-in hybrid)? = Yes
And Are you aware that WPI offers free EV charging?, Yes Is Not Displayed
Q24 Please choose the **most important** personal benefits (up to two) of WPI's EV chargers:

- [ ] Cost savings (1)
- [ ] Cannot get home without a charge (2)
- [ ] No charger at home (3)
- [ ] Extending my PHEV's electric-only range (6)
- [ ] No benefit (4)
- [ ] Other (Explain if desired) (5) 

Q26 Please choose the **most important** institutional or social benefit of WPI's EV chargers, in your opinion:

- [ ] Image/publicity (1)
- [ ] Incentivizing EV adoption (2)
- [ ] Setting an example (3)
- [ ] Supporting WPI's sustainability goals (4)
- [ ] No benefit (5)
- [ ] Other (please explain): (6) 

---

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Q29 (Optional) Which WPI location should have the highest priority for additional chargers? Please choose up to 2 options.

- [ ] Park Ave garage (1)
- [ ] Boynton Lot (2)
- [ ] East Hall garage (3)
- [ ] Gateway garage (4)
- [ ] No more chargers (5)

Q35 Please share any other thoughts you would like us to consider:

________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________

End of Block: General Questions
## Appendix F: Authorship

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<thead>
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<th>Editor</th>
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<td>All</td>
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<td>SL/JM/JM</td>
<td>ZS</td>
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<td><strong>Background</strong></td>
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<td>Charging Infrastructure</td>
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<td>Current Situation at WPI</td>
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<td>ZS</td>
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<td>WPI Survey Results and Analysis</td>
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<td><strong>Conclusions and Recommendations</strong></td>
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<td>Evaluation Model</td>
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<tr>
<td>Short-term Recommendations for WPI</td>
<td>All</td>
<td>JM</td>
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