Boston College

Environmental Studies Senior Seminar

Zero Emissions Bus Potential Amongst Massachusetts Universities

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Abstract

Due to the pressures of fossil fuel emissions on a warming climate, it is imperative for the health of the planet to reduce the use of carbon-based energy wherever possible. One of the biggest groups of carbon emitters in the U.S. economy is the transportation sector, and a major source of fossil fuel emissions in the transportation sector is from diesel-fueled buses. There is potential to reduce the carbon emissions from buses by transitioning bus systems to electric buses. Some college campuses across the U.S. have successfully reduced their carbon emissions by developing electric bus systems for their students. However, no university in Massachusetts currently uses an electric bus system. The purpose of this study is to examine the potential for zero-emissions bus systems to be implemented on Massachusetts college campuses. The feasibility of electric bus systems was examined using a cost comparison of electric to diesel, as well as potential emissions reductions from transitioning to electric buses. These comparisons, along with criteria concerning the size of school's bus system and their commitment to sustainability, led to a recommendation for electric bus systems to be implemented at the University of Massachusetts-Amherst, Boston University, and Tufts University. The model developed in this paper also has the potential to be extended to other Massachusetts universities, and the recommendations made are universal for schools across Massachusetts.

I. Introduction

Conventional fossil fuel powered buses are costly to maintain and contribute significantly to greenhouse gas emissions in urban areas. In comparison, electric buses represent an alternative method of transportation that is both more cost effective and environmentally friendly in the long run. Transitioning away from conventional buses would represent a conscious decision to lessen greenhouse gas emissions while both lowering long term costs and improving the air quality of urban environments. There exist, however, a number of obstacles impeding the implementation of electric bus systems. Initial start-up fees are costly. Areas that wish to transition away from conventional buses need to both purchase new buses and invest in the construction of charging stations. With some modern electric buses costing an estimated $850,000 dollars each (Borison, 2014) in addition to the resources and land necessary for changing and the sunk costs associated with conventional bus infrastructure, the transition to zero emissions buses can be intimidating. Furthermore, fears exist about the reliability of electric buses and their capability to travel long distances. But several studies have shown that electric buses are significantly more efficient and cost effective than their conventional counterparts, especially in relatively compact areas such as college campuses (De Filippo, Marano, Sioshansi, 2014).

Massachusetts, with its many universities and extensive bus systems, is an ideal candidate for the implementation of electric bus systems. While other colleges across the country have implemented electric buses on their campuses, Massachusetts, a state known for its prestigious colleges has yet to implement an electric bus system on a single campus. Students at universities such as University of Massachusetts-Amherst, Boston University, and Tufts University all rely heavily on their bus systems for transportation. Though these institutions and others face obstacles such as those presented above, as well as the existence of contracted buses, they still may benefit from making the transition. It is our objective with this project to compare the potential costs and benefits of implementing electric bus systems amongst the different college campuses in Massachusetts. In doing so, we hope to identify the schools that would benefit the most from transitioning away from conventional buses. In order to do this we must assess the unique bus infrastructures in place at each of the schools while also paying attention to the different challenges they may face. The primary questions we intend to answer are as follows:

1. What are the obstacles to implementing electric bus systems in universities in Massachusetts?
2. Which schools would benefit most from the transition?

II. Literature Review

The debate in regards to the viability and effectiveness of electric buses in comparison to conventional buses has been the subject of numerous studies. And while these studies have been met with a relatively wide array of results, they ultimately show that electric buses can be both more sustainable and more cost effective than conventional buses in most situations. Furthermore, as the technology behind electric buses continues to advance and their prices continue to fall, we expect to see the sustainability and cost effectiveness of electric buses to increase immensely as well. While the scholarship in support of the viability of electric buses may only seem to currently recommend electric buses in certain contexts, it is likely that electric buses and other more sustainable bus systems that do not rely entirely on diesel have the potential to make diesel bus systems obsolete. Presently, however, we have decided to examine and compile some of the most relevant studies to our goal of assessing the feasibility and potential benefits of implementing electric bus systems throughout colleges in Massachusetts.

A study entitled "Multi-criteria analysis of alternative-fuel buses for public transportation" authored by researchers Gwo-Hsiung Tzeng, Cheng-Wei Lin, and Serafim Opricovic, evaluated buses with different energy sources on the criteria of energy supply, energy efficiency, air pollution, noise pollution, industrial relationship, costs of implementation, costs of maintenance, vehicle capability, road facility, speed of traffic flow, and sense of comfort (Tzeng, Lin, & Opricovic, 2005). Using these parameters, the authors ranked some of the current conventional and alternative bus systems by using a weighted average of all of their scores. The results are shown in the table below (Tzeng e. al., 2005):

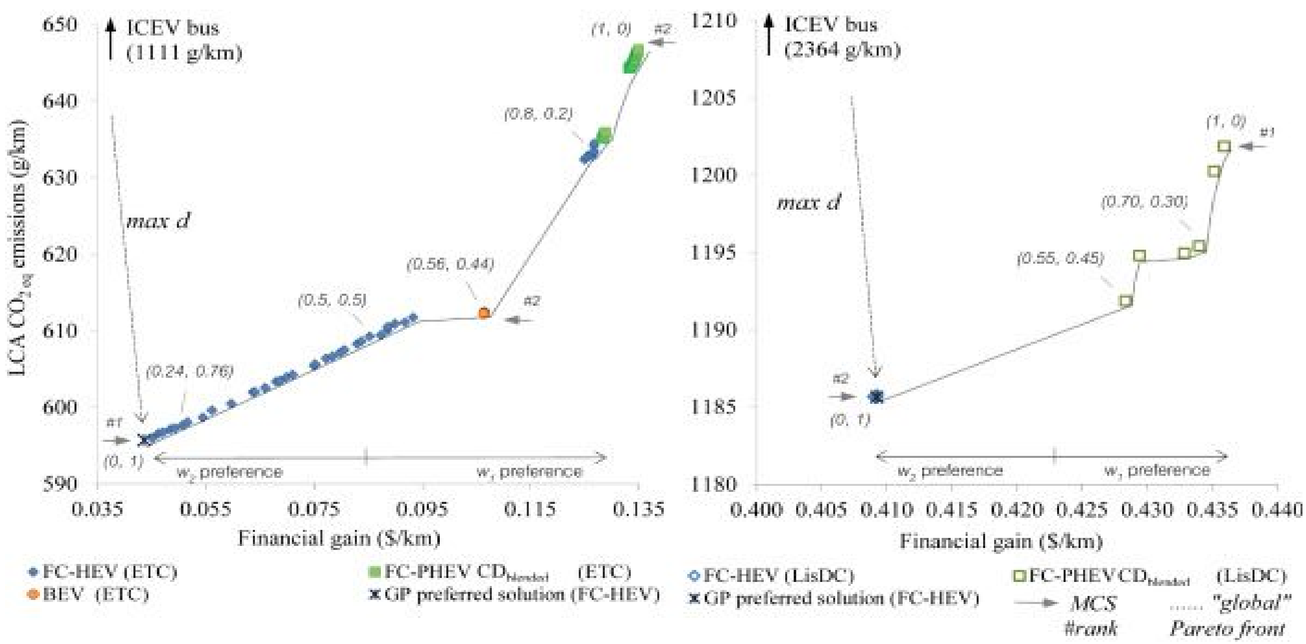
Multi-criteria ranking results						
Ranking by VIKOR	Ranking by TOPSIS					
			I	Evaluation	II	Evaluation
Rank	Alternative	Q	Rank	Index	Rank	Index
1	Hybrid electric bus gasoline engine	0.168	4	0.749	9	0.756
2	Electric busexchangeable battery	0.172	1	0.945	1	0.975
3	Electric bus opportunity charging	0.224	2	0.933	3	0.964
4	Electric bus direct charging	0.253	3	0.931	2	0.967
5	Hybrid electric bus diesel engine	0.281	7	0.7	11	0.488
6	Liquid propane gas (LPG)	0.479	11	0.345	8	0.83
7	Compress natural gas (CNG)	0.48	10	0.399	7	0.83
8	Hybrid electric bus with CNG	0.51	5	0.7	4	0.889
9	Hybrid electric bus with LPG	0.51	6	0.7	5	0.889
10	Conventional diesel engine	0.806	12	0.301	12	0.097
11	Methanol	0.852	9	0.527	10	0.698
12	Fuel cell (hydrogen)	0.925	8	0.563	6	0.865

According to the rating system used by this study hybrid electric vehicles using a gas engine are the most ideal alternative to conventional diesel engine buses. However, the truly electric vehicles all ranked very well and were only marked down due to technological limitations. The authors believe that given time, electric vehicles will score better than current hybrid models. It is also important to note that the conventional diesel engine ranked very poorly, highlighting the need to search for alternative fuel methods.

In another study conducted at the Ohio State University, researchers simulated the effects of replacing the University's diesel-fueled bus system with electric buses and found that it was feasible to replace all diesel-powered bus lines with electric buses in a relatively short amount of time (De Filippo et al., 2014). Using a longitudinal dynamics model, the authors of this article created a simulation that estimated energy use based on number of chargers deployed and the queuing policy used in charging buses. The study concluded that the implementation of electric buses would include benefits of lower driving costs, higher energy efficiency, and lower overall emissions. The authors believe that all 22 buses on the Ohio State bus line could be feasibly made electric and that one 500 kW charger or two 250 kW chargers would be sufficient in powering the buses (De Filippo et al., 2014).

Further studies have sought to understand the ideal environments for electric bus systems. In a study entitled "Developing a Viable Electric Bus Service: The Milton Keynes Demonstration Project", researchers assessed the implications of the use of electric bus systems in urban environments, ultimately coming to the conclusion that, under certain circumstances, electric buses could greatly improve both the energy efficiency and air quality of an area (Miles & Potter, 2014). A study, entitled "Electric Buses: Lessons to be learnt from the Milton Keynes Demonstration Project", expands upon the work of the previous project by analyzing alternate strategies of electric bus implementation that focus on the use of wireless charging technology (Kantou & Miles, 2015). The authors of this study used the data and model utilized in the original Milton Keynes Demonstration Project to determine the feasibility and potential benefits of wireless charging that does not interrupt bus timetables. Perhaps of equal importance, this study focuses on the many factors that lessen the efficacy of electric bus systems. Routes, for example, have a noticeable effect on energy usage and must be suited to the needs of the electric bus in order to reach maximum efficiency. The performance of drivers also has a small but significant effect on energy consumption. Ultimately, however, the study found that wireless charging buses could be extremely effective alternatives to conventional diesel buses (Kantou & Miles, 2015). Using the the same demonstration method used in the Milton Keynes experiment the authors of this article showed that by tailoring routes to wireless electric buses energy usage dropped significantly.

Numerous other studies have been met with similar results. A study entitled "Fully Electric City Buses: the Viable Option" outlines the framework with which electric buses can be the most cost and energy efficient, finding that small battery electric buses with shared charging stations on reliable routes have proven to be the ideal paradigm for electric bus implementation because they show immense reductions in carbon emissions (Pihlatie, Kukkonen, Halmeaho, Karvonen, & Nylund, 2014). In another study, entitled "Reducing the Carbon Footprint of Urban Bus Fleets Using Multiobjective Optimization", authors Joao P. Ribau, Joao M.C. Sousa, and Carla M. Silva introduce an algorithm that takes into consideration many of the variables involved in the implementation of electric bus systems in order to maximize cost and energy efficiency (Ribau, Sousa, & Silva, 2015). Their results, in regards to financial and environmental benefits, can be seen below:



The conventional bus (labeled ICEV) is shown to be the least cost effective and least environmentally friendly of all the options tested. Additionally, as was shown in the previous study, hybrid electric vehicles are seen as the most economical and sustainable choice at the moment. However, this article also notes that this is likely to change as fully electric vehicles become more efficient. What this study and the studies previously mentioned show, ultimately, is that conventional bus systems are costly both financially and environmentally costly. In all models, simulations, and demonstrations they score significantly lower than most of the more sustainable alternatives. Furthermore, while the transition to more sustainable bus systems may incur heavy initial financial costs, they have been consistently shown to be financially beneficial in the long run. Based on this information, we find it necessary to further explore the potential for implementing electric bus systems in college and universities throughout Massachusetts.

The existing literature on implementing electric bus systems, while extensive, is rather shallow in regards to implementation on college campuses. Perhaps more tellingly, there are very few college campuses which utilize electric bus systems. In this paper we hope to address both of these issues in regards to colleges and universities throughout Massachusetts. By first identifying which schools are best suited for electric bus implementation and then by conducting a cost benefit analysis for each school, we hope to make clear the potential benefits of transitioning away from diesel buses. In doing so we hope to incentivize eventual adoption of electric bus systems within these schools.

III. Background and Existing Zero-Emission Bus Systems at Universities

Founded in 2004, Proterra strives to greatly reduce emissions released by vehicles through development of the "bus of tomorrow" (Proterra "About Proterra", 2016). The company envisions a shift from buses powered by diesel fuel to electric buses that will not contribute to the concentration of greenhouse gases already present in the atmosphere. The target areas are primarily cities and institutions with a significant population and ridership. Following the introduction of its first electric model called the EcoRide, Proterra found success in the vehicle that was fuel efficient, quiet, and compatible with local and federal regulatory standards (Proterra "About Proterra", 2016).

Building upon the EcoRide model, Proterra introduced its current model the Catalyst, which is "up to 500% more fuel efficient than a typical diesel or CNG bus" (Proterra "About Proterra", 2016) and is gaining popularity in California, where the company has its headquarters, and other areas of the nation that have a reputation for exploring and implementing initiatives promoting sustainability. Fast charge technology allows the Catalyst to be considered a reliable mode of transportation because the bus does not have a limited range in which it can travel. With the help of fast charge stations installed on the routes, a Catalyst bus has the potential to travel over 700 miles in a 24 hour period following a single charge (Proterra "About Proterra", 2016).

Proterra has found that since introducing its zero-emission bus, its customers have reaped several benefits. By shifting from diesel buses to the Proterra zero-emission bus, consumers have saved a collective $1,258,238 and prevented 8,493,154 pounds of emissions from being released into the atmosphere (Proterra "Homepage", 2016), a benefit that not only helps the direct consumer but also everyone in that region who can enjoy cleaner, less polluted air. Proterra attributes these cost savings not only to fuel but also to costs for maintenance. There are no necessary oil changes and 75% fewer brake repairs compared to conventional bus models (Proterra "Advantages", 2016). In addition, because there are 30% fewer parts in a Proterra zero-emission bus, there are fewer objects and parts that would require maintenance and attention (Proterra "Advantages", 2016). Thus, there may be significant upfront costs for implementing a zero-emission bus system, but consumers would save money in the long run due to non-existent fuel costs and lower maintenance costs.

Proterra buses will make their debut on university campuses at the University of Montana, a mid-sized university with a population of just over 9,000 students located in an urban setting (US News and World Report, 2016). The buses have recently been purchased by the university and are expected to join the fleet in the summer of 2016 (University of Montana [UM] News, 2016). Because the zero-emission buses are not yet in use, it is difficult to determine the ultimate costs and benefits the university will experience as a result of this shift within the bus system. However, according to a recent article, the University of Montana will mitigate the upfront costs by slightly increasing tuition fees for its students and also by utilizing a grant by the United States Environmental Protection Agency (UM News, 2016). This grant of $163,191 was given to the university through the Montana Department of Environmental Quality for the purposes of "[improving] public health by reducing emissions and particulate matter" (UM News, 2016). Thus, government subsidies and grants can potentially play a large role in promoting the implementation of sustainable initiatives and programs such as a zero-emission bus system.

The purpose for purchasing zero-emission buses was driven by a steady increase in ridership at the university and a commitment to sustainability and climate action. Since 1999, the number of students, faculty, and visitors utilizing the buses for transportation has increased to about 15,000 people per week, and in 2015, the university bus system provided more than 400,000 rides (UM News, 2016). Due to continually increasing ridership and the large number of rides provided by the service, the university would inevitably spend a greater amount of money each year on fuel and maintenance costs for diesel or even hybrid buses. Thus, the purchase of zero-emission buses may have a large upfront cost, but the benefits will outweigh the costs in the long term because of the lack of fuel and maintenance costs tied to zero-emission buses.

In addition to the cost reduction, the University of Montana also took on this initiative so that it may remain consistent with its commitment to environmental protection and sustainability. The implementation will help the university reach its goal of carbon neutrality because no fuel will be burned to produce carbon dioxide and other greenhouse gases during the operation of university-owned buses. The shift from conventionally fueled buses to zero-emission buses would prevent 123,500 gallons of fuel from being burned and 1,392 tons of greenhouse gas emissions from entering the atmosphere throughout the projected 12 year lifespan of these buses (UM News, 2016). It is likely that the University of Montana will experience positive externalities including health benefits from the reduction in pollution from transportation in addition to long term cost savings that will make funds available for other programs and initiatives.

While the University of Montana is still in the beginning stages of zero-emission bus implementation, Stanford University has a more established system of which the university has been able to experience the long term benefits. With a population of 7,019 students and suburban setting (US News and World Report, 2016), Stanford University must accommodate transportation for its large number of students, faculty, and visitors who do not have the ability to travel around the area with the same ease as those with access to the public transportation services at universities in urban settings. Thus, Stanford has developed an extensive bus system that not only takes riders around campus but also provides transportation to shopping and entertainment hubs, metropolitan bus and train stations, and airports (Stanford University "Transportation Initiatives", 2016).

According to a director of Parking and Transportation services at Stanford University, the university currently owns thirteen zero-emission buses, and it recently purchased ten more zero-emission buses that will join the existing fleet in the near future. The implementation has been gradual due to the size of the fleet (between 40 and 50 buses), but the university hopes to complete the shift and be 100% zero-emission in terms of transportation within the next five to ten years. The director highlighted some of the costs, such as the expected large upfront costs for new infrastructure and a new operational model, and some of the benefits, such as reduced fuel and maintenance costs, reduced downtime for disabled buses, and a substantial reduction in greenhouse gas emissions. In addition, there were challenges to this implementation, which included successfully having the institution change the way it views expenditures, determining and obtaining the appropriate amount of charging infrastructure, and training and changing the driving habits of the bus drivers since zero-emission buses run differently than conventional buses.

While there were some challenges in making the shift from conventional fuels to electricity in terms of the bus system, there is evidence that the project has been successful when paired with other sustainable transportation initiatives. Stanford University has reduced its carbon footprint, especially in regards to transportation. Most notably, “from 2002 to 2014, the percentage of Stanford employees driving alone to campus dropped from 72 to 49 percent” (Stanford University “Transportation Initiatives”, 2016). Not only is the university replacing conventionally fueled buses with electric buses that produce no emissions, but it is also actively influencing students and faculty to utilize carpooling and public transportation to reduce individual carbon footprints. Thus, Stanford University presents a sustainable model that other universities can follow in order to reduce their institutions’ carbon footprints and total amount of emissions.

IV. Methods

To follow these examples of other universities with electric bus systems, like University of Montana and Stanford University, we sought to model electric bus systems on three Massachusetts colleges and see if implementing electric bus systems would be feasible for these schools. Our methods in choosing schools and creating our model are detailed below.

4.1 Choosing Schools

To identify potential schools, the top fifteen schools in Massachusetts in terms of student population were found. This metric was used because these are the schools that have the most expansive bus systems because they serve the most students. Schools in this list without bus systems, like Northeastern University, were eliminated. From the remaining schools, three schools were chosen based on the type of campus, diversity in bus system size, their history of sustainable initiatives, and funding available for environmental projects. The three schools that fared the best from these criteria were University of Massachusetts - Amherst, Boston University, and Tufts University.

University of Massachusetts - Amherst is the largest school in Massachusetts in terms of student body (22,252 students), and it is a rural campus (US News and World Report, 2016). The administration has an expansive climate action plan that includes a goal of achieving carbon neutrality by 2050 (Small, 2012). UMass has a very expansive bus system, and it has already taken action to reduce greenhouse gas emissions in its bus fleet. It recently reduced its campus fleet by 84 buses, resulting in a 20% reduction in carbon emissions (Small, 2012). Additionally, UMass Amherst has already shown its interest in implementing an electric bus system. In May, 2012 the University was awarded a $10,000 Alternative Fuel Feasibility Study by the American Fueling Systems (AFS) Cooperative Agreement Program, which will analyze UMass's current fleet and provide a feasibility study that determines potential savings and emissions reductions (Small, 2012). Implementing electric buses has the potential to reduce the carbon footprint of millions of people. According to Glenn Barrington, the General Manager of UMass Transit Services, 3.39 million passengers used UMass's buses last year (Glenn Barrington, personal communication, April 13, 2016). UMass Amherst is leading a $7.5 million federal grant to address climate change with a consortium of seven other universities and has also won the following awards for environmental leadership: 2014 ACUPCC's Climate Leadership Award, 2015 AASHE's STARS Gold Designation, and the White House's 2012 Campus Champions of Change Challenge (UMass, 2016).

Boston University (BU) was the school we picked for an urban campus. It is the second largest school in Massachusetts in terms of student population with 18,017 students (US News and World Report, 2016). Boston University, as a private university, has significant funding potential for a new bus system. BU has a $1 million revolving loan fund for sustainable projects (BU "What We're Doing", 2016). It has a history of commitment to sustainability, and it is the first university to achieve a STARS Silver rating five times from AASHE (BU "Annual Report", 2016). Boston University's bus system, while not as expansive as UMass Amherst's, carries 1.9 million passengers each year (BU Today Staff, 2016), so implementing a zero emissions bus system has the potential for large emissions reductions per capita. It is an urban school, so students have more public transportation options, which is why it is a smaller bus system than UMass.

For a suburban school, Tufts University in Medford, MA was chosen. Tufts is the 14th largest school in Massachusetts in terms of student population with 5,177 students (US News and World Report, 2016). While there are larger suburban schools in Massachusetts that could have been studied, Tufts is a suburban school with a smaller bus system that both UMass and BU. In order to truly examine the feasibility of electric bus systems, a comparison between schools with large, medium, and small bus systems was needed. This is why we selected Tufts as the suburban choice. It also is a private school with a history of a commitment to sustainability, which means that it has the potential to being open to implementing an electric bus system. The Sierra Club ranked Tufts University as the 86th most "green" university in the country (Sierra Club "Cool Schools", 2015). Historically, Tufts has been a leader in university sustainability, especially by developing the first university environmental policy (Tufts University "About", 2016). Tufts also signed the Second Nature Climate Commitment on April 21, 2016. This creates an opportunity for a zero emissions bus system to be proposed. The Commitment says that Tufts must create a comprehensive Climate Action Plan within the next two months, and the plan must contain a target date for carbon neutrality (Tufts University "Second Nature", 2016). Because Tufts is planning to become climate neutral, they have the potential to implement a zero emissions bus system.

To determine the feasibility of implementing electric bus systems at these three schools, the financials were examined. The metrics used were the initial costs of both diesel and electric buses, the yearly maintenance costs of each type of bus, the yearly fuel costs of both bus systems, and the yearly externalities associated with using diesel power and electric power. These criteria were modeled after a University of Delaware study of electric school buses versus diesel school buses and are explained in-depth below (Noel & McCormack, 2014). To determine the specific costs for each school, the logistics of each school's bus system was obtained from each school's sustainability director. This information included the number of buses in each school's fleet and the distance that the fleet travels. Once the costs were computed for each school, present-value depreciation was used to compare the lifetime costs of an electric bus system at each school compared to a diesel bus system.

4.2 Cost Metrics

Bus Costs

The average cost of a diesel bus was found to be $300,000 (MacKechnie, 2015). For this study, the electric bus examined was the Proterra Catalyst, which costs $500,000 per bus as of October 2015. (Casey, 2015). In addition, each charger for these buses costs $600,000 as of 2014 (Redden, 2014). More updated costs were unavailable. For this analysis, it was assumed that two chargers would be needed for UMass's bus system, and one charger would be needed for both BU and Tufts based on the Ohio State University study (De Filippo et al., 2014). As a result, it was estimated that an initial $1.2 million outlay was required for charging stations at UMass and $600,000 at BU and Tufts.

Energy costs

According to the most recent Department of Energy figures, the national average cost of diesel is $2.23 per gallon, and the national average cost of electricity is $0.13 per kilowatt hour (United States Department of Energy, 2016). A more useful metric for measuring electricity costs is cost per gallon equivalent because Proterra reports fuel efficiency in these terms. According to the Sierra Club, the cost of electricity is $1.29 per gallon equivalent (Sierra Club "Zero-Emission", 2015). The average inflation rate for diesel over the last two decades was 8.5%, and it was 1.9% for electricity (U.S. Energy Information Administration, 2016).

Maintenance costs

For diesel buses, maintenance costs are $1 per mile, in addition to a yearly maintenance cost of $9,075. For electric buses, maintenance costs are $0.20 per mile, in addition to a yearly maintenance cost of $1,770 (Sierra Club "Zero-Emission", 2015).

Externalities

Two types of externalities were looked at in the useage of both types of buses. The first type is the average social cost of carbon. On average, a diesel bus emits 22 pounds of carbon per gallon of diesel that it burns (EPA Office of Transportation and Air Quality, 2005). Even though electric buses are not directly emitting carbon as they travel, emissions from the production of the electricity they use need to be taken into account. As electricity sources are transferred from coal and natural gas toward renewables, the electricity used to power electric buses will lessen in emissions. Eventually, electric buses will truly be zero-emissions. Currently, however, the average emission rate is 1.18 pounds of carbon per kilowatt hour for electricity (Noel & McCormack, 2014). To monetize the externality of releasing carbon into the atmosphere, the average social cost of carbon was used. The average social cost of carbon is $36 per metric ton of carbon dioxide (Interagency Working Group on Social Cost of Carbon, 2013).

The other externality examined was public health externalities. The estimated health externalities for a Class 7 Heavy Duty diesel vehicle is $0.08 per mile (National Research Council, 2010). The estimated health externalities for electricity is $0.0149 per mile (Noel & McCormack, 2014).

4.3 Formulas Used

To determine the Net Present Value of the cost savings from switching to electric buses over the 12 year lifetime of a bus, present-value depreciation of the costs of each system was used. $NPV = PV_D - PV_E$, where $PV_D = \frac{C_{D_1}+M_D+E_D+B_D}{(1+r_d)^1} + \frac{C_{D_2}+M_D+E_D}{(1+r_d)^2} + \ldots + \frac{C_{D_{12}}+M_D+E_D}{(1+r_d)^{12}}$ and $PV_E = \frac{C_{E_1}+M_E+E_E+B_E}{(1+r_d)^1} + \frac{C_{E_2}+M_E+E_E}{(1+r_d)^2} + \ldots + \frac{C_{E_{12}}+M_E+E_E}{(1+r_d)^{12}}$.

C_D is the cost of diesel, which was calculated for year 1 as $2.23 * yearly miles traveled. For each subsequent year, the cost of diesel is the cost of the previous year inflated by 8.5%, which is the average rate of inflation of diesel. C_E is the yearly cost of electricity, which was calculated for year 1 by $1.29 per gallon equivalent * (1 gallon equivalent/21.4 mi) * yearly miles traveled. The ratio of 21.4 miles per gallon equivalent is the Proterra Catalyst's fuel efficiency rating (Proterra "Product Portfolio", 2016). For each subsequent year, the cost of electricity is the cost of the previous year inflated by 1.9%, which is the average rate of inflation of electricity. For UMass, yearly miles traveled was about 1,000,000 miles last year (Glenn Barrington, personal communication, April 13, 2016). For BU, yearly miles traveled was determined by using the size of the bus routes (6.9 mile weekday route and 3.7 mile weeknight and weekend route) and the bus schedule to determine how many miles are covered each week during the school year and in the summer (BU "About", 2016). Then, each week was summed to find the total yearly miles traveled, which came out to 137863.5 miles. For Tufts, yearly miles traveled was determined by the size of each bus route, which was provided by Andrea Breault, Tufts' Fleet/Transportation Manager, and the number of trips per route per day. The Davis Square route is 4 miles roundtrip, the Boston Avenue route is 5 miles roundtrip, and the SMFA/NEC route is 14 miles roundtrip (Andrea Breault, personal communication, May 2, 2016). Based on the daily bus schedules for each route (Tufts University "Shuttle Services", 2016), the yearly miles traveled for the Tufts system is 107,744.

M_D is the maintenance cost of the diesel buses. Maintenance costs were calculated by \$1* yearly miles traveled + \$9,075. Maintenance costs were the same for each of the 12 years. M_E is the maintenance cost of the electric buses, calculated by \$0.20 * yearly miles traveled + \$9,075.

E_D is the external cost of diesel buses. Yearly diesel externalities were calculated by (\$36/ton CO_2) * (1 ton CO_2/2000 lbs CO_2) * (22 lbs CO_2/gallon diesel) * (yearly gallons of diesel consumed) + yearly miles traveled * 0.08. E_E is the external cost of electric buses. Yearly electric externalities were calculated by (\$36/ton CO_2) * (1 ton CO_2/2000 lbs CO_2) * (1.18 lbs CO_2/KWH electricity) * (1.7 kWh/mi)* (yearly miles traveled) + yearly miles traveled * 0.0149. The value of 1.7 kWh/mi is the fuel economy of a Proterra Catalyst (Proterra "The Proterra Catalyst", 2016). For UMass, yearly gallons of diesel consumed was about 200,000 gallons, (Glenn Barrington, personal communication, April 13, 2016). For Boston University, the average fuel efficiency of a diesel bus was used, which is 2.75 miles per gallon (Maynard, 2009). Yearly gallons of diesel was then calculated by 137863.5 miles per year / 2.75 miles per gallon, which came out to 50132.18182 gallons per year. For Tufts, the average fuel efficiency of a diesel bus was also used, and yearly gallons of diesel was calculated by 107,744 miles per year / 2.75 miles per gallon, which came out to 39,179.64 gallons per year.

B_D is the upfront cost of the diesel bus fleet. This was calculated by total number of buses in fleet * $300,000. This determination was made under the assumption that all buses in the fleet would need to be replaced every 12 years, so for ease of calculations replacements for all buses were done in the first year. B_E is the upfront cost of the electric bus fleet. This was calculated by total number of buses in diesel fleet * $500,000 + number of chargers required * $600,000. This value was likely an overestimate, as the cost of chargers have likely gone down since 2014. The total number of buses in UMass's fleet is 35 (Glenn Barrington, personal communication, April 13, 2016). The total number of buses in BU's fleet is ten (BU "Advertising", 2016). The total number of buses in Tufts' fleet is four (Andrea Breault, personal communication, May 2, 2016).

The discount rate is given by r_d. A standard discount rate of 4% was applied to this model (Scheuren, 2011). The discount rate is used to account for the fact that money saved 12 years from now is worth less to a person than money saved today because money has time-value. The Net Present Value calculation tries to account for the time value of money. It sums up the discounted costs each year to determine the present value of these future costs. This model finds the present value of the costs of the diesel bus system and the present value of the costs of the electric bus system. If the present value of the diesel bus system is higher than the present value of the electric bus system, then the electric bus system is a good investment.

V. Results

For each school, the present value of the electric bus system's lifetime costs was lower than the present value of the diesel bus system's lifetime cost, making electric bus systems a good and feasible investment. This was even with the initial cost of charging infrastructure. Table 1 shows the results of the net present-value calculation. The summation columns show the summation of the various costs, but they do not apply a discount rate, so they are not the present value of each individual cost. The discount rate was applied to the total cost each year in order to get an overall present value at the end of 12 years.

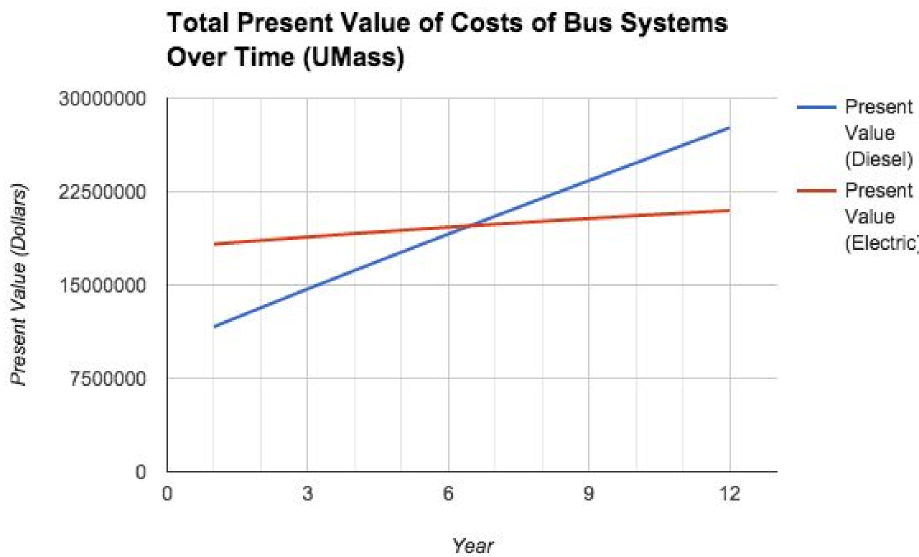
Table 1.

	$\sum_{i=1}^{12} C_D$	$\sum_{i=1}^{12} M_D$	$\sum_{i=1}^{12} E_D$	$\sum_{i=1}^{12} B_D$	PV_D	$\sum_{i=1}^{12} C_E$	$\sum_{i=1}^{12} M_E$	$\sum_{i=1}^{12} E_E$	$\sum_{i=1}^{12} B_E$	PV_E	$NPV\ savings$
UMass	$8,718,965.41	$12,108,900	$1,910,400	$10,500,000	$27,626,427.34	$803,954.57	$2,421,240	$612,096	$18,700,000	$20,976,377.25	$6,650,050.08
BU	$2,185,503.80	$1,763,262	$370,577.09	$3,000,000	$6,199,289.58	$110,835.99	$352,112.40	$84,385.70	$5,600,000	5,811,921.84	$387,367.74
Tufts	$1,708,029.47	$1,401,828	$289,615.87	$1,200,000	$3,762,959.67	$86,621.28	$279,825.60	$65,949.67	2,600,000	$2,986,198.98	$776,760.69

For UMass, the present value of the cost of the diesel system was $27,626,427.34 in total or $789,326.50 per bus. This is compared to UMass's present value of the cost of an electric bus system with the same number of buses, which was $20,976,377.25 in total or $599,325.06 per bus. This means that by switching to an electric bus system, UMass would see cost savings over 12 years with the present value of $6,650,050.08 in total or $190,001.43 per bus.

As seen in Figure 1, electric bus systems are initially more expensive than diesel bus systems at UMass. However, after the first year when the initial investment in electric buses is made, the present value of the costs of an electric bus system does not increase very much each year, while the present value of the costs of a diesel system increases steadily. During year six, UMass will see the present value of the diesel bus system become more expensive than the present value of the electric system, and by year 12, the present values show that the electric bus system is significantly cheaper overall.

Figure 1.

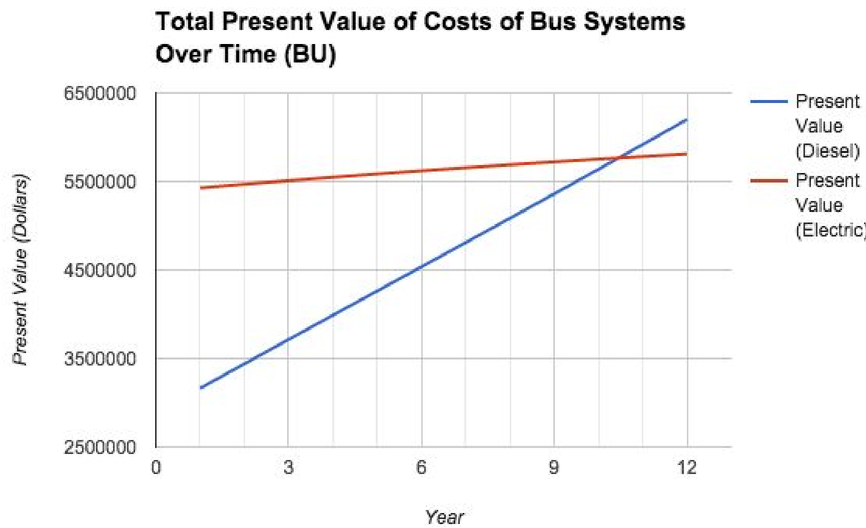


Some schools may not want to consider the external costs that were included in this model, especially because it is difficult to directly observe the positive benefit that is derived by reducing negative externalities. Even with a model that does not include externalities, electric bus systems are more cost-effective overall than diesel bus systems. The present value of the cost of the diesel system over 12 years at UMass is $26,132,323.60, and the present value of the cost of the electric bus system over 12 years is $20,497,663.41.

For BU, the present value of the cost of the diesel system was $6,199,289.58 in total or $619,928.96 per bus. This is compared to BU's present value of the cost of an electric bus system with the same number of buses, which was $5,811,921.84 in total or $581,192.18 per bus. This means that by switching to an electric bus system, BU would see cost savings over 12 years with the present value of $387,367.74 in total or $38,736.77 per bus.

Figure 2 shows the present value of the costs of the two types of bus systems over time at Boston University. Like at UMass, electric bus systems are initially more expensive than diesel bus systems. However, after the first year when the initial investment in electric buses is made, the present value of the costs of an electric bus system does not increase very much each year, while the present value of the costs of a diesel system increases steadily. During year ten, BU will see the present value of the diesel bus system become more expensive than the present value of the electric system, and by year 12, the present values show that the electric bus system is cheaper overall.

Figure 2.

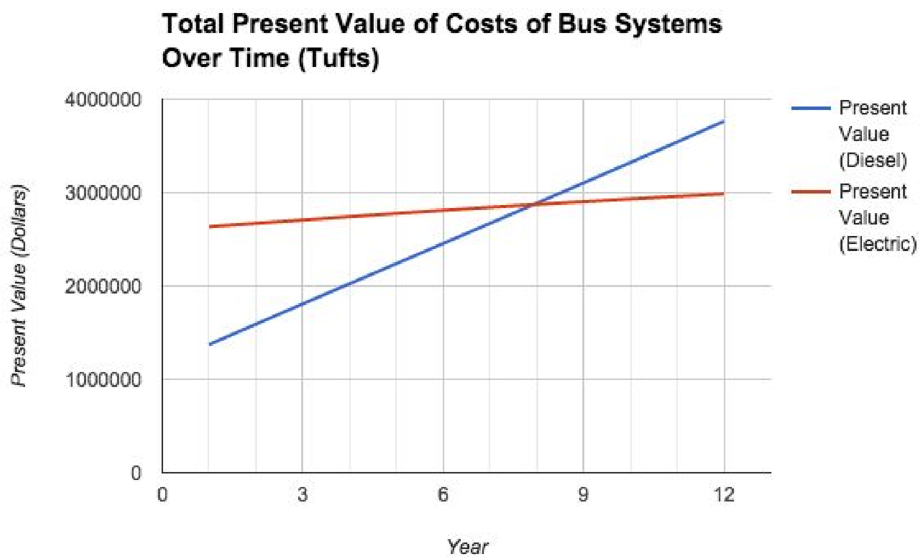


Boston University's model without externalities shows that electric buses are more cost effective than diesel buses as well. Without externalities, the present value of the cost of the diesel system over 12 years at BU is $5,909,465.14, and the present value of the cost of the electric bus system over 12 years is $5,745,924.68.

For Tufts, the present value of the cost of the diesel system was $3,762,959.67 in total or $940,739.92 per bus. This is compared to Tufts' present value of the cost of an electric bus system with the same number of buses, which was $2,986,198.98 in total or $746,549.74 per bus. This means that by switching to an electric bus system, Tufts would see cost savings over 12 years with the present value of $776,760.69 in total or $194,190.17 per bus.

Figure 3 shows the present value of the costs of the two types of bus systems over time at Tufts. Like at UMass and BU, electric bus systems are initially more expensive than diesel bus systems. However, after the first year when the initial investment in electric buses is made, the present value of the costs of an electric bus system does not increase very much each year, while the present value of the costs of a diesel system increases steadily. During year seven, Tufts will see the present value of the diesel bus system become more expensive than the present value of the electric system, and by year 12, the present values show that the electric bus system is cheaper overall.

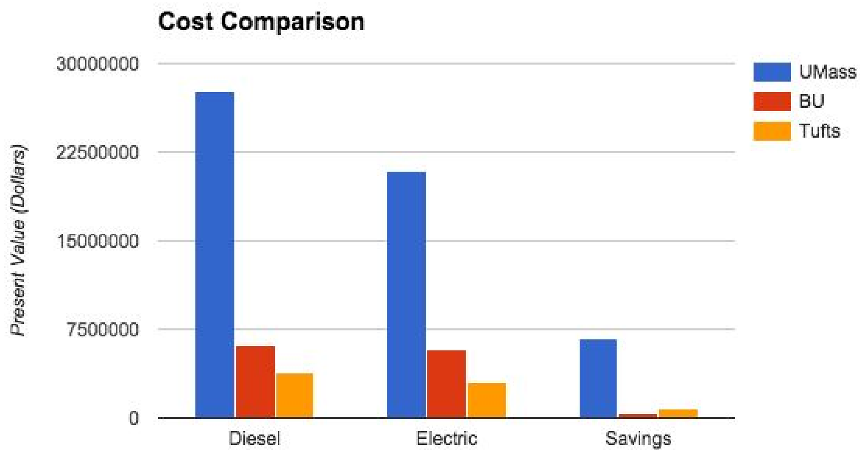
Figure 3.



Tufts' model without externalities shows that electric buses are more cost effective than diesel buses as well. Without externalities, the present value of the cost of the diesel system over 12 years at BU is $3,536,454.14, and the present value of the cost of the electric bus system over 12 years is $2,786,002.03.

Because UMass has a more expansive bus system than BU and Tufts, UMass sees higher overall savings. The savings of the three schools are compared in Figure 4. By converting its entire fleet over to electric buses, UMass would save 24.07% of the present value of its diesel bus costs. This is in contrast to BU, which would save 6.25% of the present value of its diesel bus costs, and Tufts, which would save 20.6%. This suggests that electric bus systems exhibit increasing returns to scale based on miles traveled per bus, as the UMass bus system travels the most miles per bus (28,571.43 miles per bus), followed by Tufts (26,936 miles per bus), and the BU system travels the least amount of miles per bus (13,786.35 miles per bus).

Figure 4.



Besides costs savings from switching from diesel to electric bus systems, an overall reduction in emissions is another positive benefit of transitioning bus systems. At UMass, yearly diesel bus emissions were 4,400,000 pounds of carbon per year (2,200 tons), calculated by 22lbs carbon per gallon of diesel X 200,000 gallons diesel per year. In contrast, yearly emissions from a hypothetical electric bus system at UMass were 2,006,000 pounds of carbon per year (1,003 tons), calculated by 1.18lbs carbon per kWh X 1.7kWh per mile X 1,000,000 miles per year. This means that UMass could see emissions reductions of 2,394,000 pounds of carbon per year, which is a 54.4% reduction.

For Boston University, yearly diesel bus emissions were 1,102,908 pounds of carbon per year (551.45 tons), calculated by 22lbs carbon per gallon of diesel X 50,132.18 gallons diesel per year. In contrast, yearly emissions from a hypothetical electric bus system at BU were 276,554.18 pounds of carbon per year (138.28 tons), calculated by 1.18lbs carbon per kWh X 1.7kWh per mile X 137,863.5 miles per year. This means that BU could see emissions reductions of 826,353.82 pounds of carbon per year, which is a massive reduction of 74.93%.

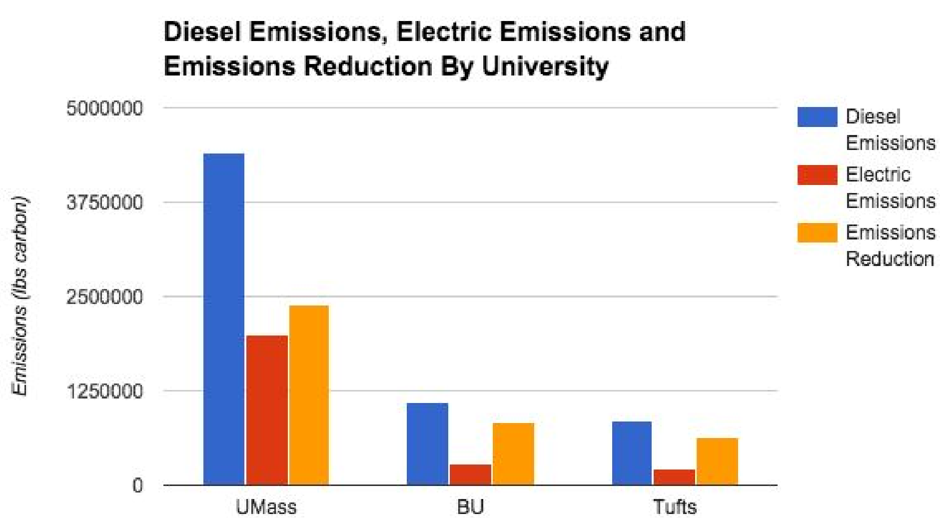
For Tufts University, yearly diesel bus emissions were 861,952 pounds of carbon per year (430.98 tons), calculated by 22lbs carbon per gallon of diesel X 39,179.64 gallons diesel per year. In contrast, yearly emissions from a hypothetical electric bus system at Tufts were 216,134.46 pounds of carbon per year (108.08 tons), calculated by 1.18lbs carbon per kWh X

1.7kWh per mile X 107,744 miles per year. This means that Tufts could see emissions reductions of 645,817.54 pounds of carbon per year, which is a reduction of 74.93%. This is the same percentage as BU because the average fuel economy for a diesel bus was used to calculate yearly diesel consumption for both schools, whereas for UMass, the yearly diesel consumption was provided by Glenn Barrington. The comparison of emissions at each school for both bus systems is shown in Table 2 and Figure 5.

Table 2.

	Diesel Emissions (lbs carbon)	Electric Emissions (lbs carbon)	Emissions Reduction (lbs carbon)	Percent emissions abated
UMass	4,400,000	2,006,000	2,394,000	54.41%
BU	1,102,908	276,554.18	826,353.82	74.93%
Tufts	861,952	216,134.46	645,817.54	74.93%

Figure 5.



VII. Analysis/Recommendation

We recognize that there are several factors that contribute to the feasibility of implementing a zero-emission bus system on certain university campuses. There are limits to available funds, and there are different levels of active climate action and implementation of sustainable initiatives. One major factor that can affect how much funding a university has and where it is allowed to use those funds is its status as either a public or private university. The two universities with existing zero-emission bus systems that are highlighted in this study, University of Montana and Stanford University, are representative of the possibility of the successful shift from conventionally fueled buses to zero-emission buses despite differences in setting and status of private or publicly owned.

To compare possible sources of funding, in 2015, while Stanford University boasted an endowment of $22.2 billion (Stanford University "Admission and Finances", 2015), the University of Montana reported an endowment of just over $170 million (US News and World Report, 2016). While a large percentage of a university's endowment is donated with direction to a certain program or service, there is funding that is put aside for operational costs or to be spent by the university in a way that it deems fit. Because Stanford has proved to be committed to climate action and the continued development of sustainable initiatives, it would seem that the university commits a significant portion of its endowment fund to the institution's reduction of its carbon footprint and even has donors that request their funds to be directed to the development of sustainable programs and services. In addition, based on the length and number of available routes and frequency at which buses travel such routes throughout the suburban setting in which the university resides, Stanford University would experience the long term benefit of reduced fuel and maintenance costs.

Although the University of Montana has less funding as part of its endowment, the institution has the ability to receive state and federal grants due to its status as a public university. Because of this, the university received a grant from the U.S. Environmental Protection Agency to use towards sustainable transportation methods (UM News, 2016). The state of Montana has a particular interest in improving air quality by initiatives that reduce emissions, and implementing sustainable transportation at a state university would not only aid the university in reducing fuel and maintenance costs, but it would also improve the living conditions of all regional and state residents who would experience better air quality.

While the grant did not cover all upfront costs for the purchase of zero-emission buses and forced some of the financial burden on university students through increased tuition fees, it influenced the shift from conventionally fueled buses to zero-emission buses that will allow the institution to experience a plethora of long term benefits. Thus, although public universities may not receive as much funding through donations as private institutions do, it is possible to witness the increase of zero-emission bus systems at public universities as the result of more state and federal grants that are directed towards sustainable initiatives and climate action.

Based on this information and the data we collected from the our cost benefit analyses for UMass Amherst, Boston University, and Tufts University, we have a come up with a number of recommendations for each of the schools. First, we recommend that each of these schools begin the transition away from diesel buses as soon as possible. As our cost benefit analyses have shown, transitioning to electric bus systems would incur immense economic and environmental benefits for each school over a relatively short period of time. Over a twelve year period, UMass Amherst is projected to save $6,650,050.08. Similarly, Boston University is projected to save $387,367.74, and Tufts University is projected to save $776,760.69 over the same time period. In addition to these financial gains, UMass Amherst is projected to reduce transportation related carbon emissions by 54.41% , with Boston University and Tufts University seeing a decrease in transportation related carbon emissions by 74.93% each. Based on these numbers it seems evident that each of these schools should begin implementing electric bus systems immediately. However, as noted above, there are a number of perceived financial barriers to transitioning away from conventional diesel buses. But there are also a number of initiatives, both private and governmental, which help lessen the initial burdens of installing more sustainable technology. The US Department of Transportation has recently put aside $55 million towards grants specifically aimed at putting zero emission buses into service across America (U.S. Department of Transportation, 2015). The Department of Transportation has also recently given $ 4,139,188.00 to the MBTA in order to fund the transition towards electric buses on the system's silver line (U.S. Department of Transportation, 2015). These grants are awarded through the department's Low or No (LoNo) initiative which seeks to encourage the use of buses with low or no carbon emissions. The Pioneer Valley Transit Authority, the transit authority in charge of

UMass Amherst's bus system, was the recipient of $6.2 million to be put towards state-of-the art hybrid and electric buses (Ring, 2010). It is our second recommendation that these universities, especially UMass Amherst, continue to apply for federal support. The UMass Amherst bus system, being utilized by the most students, could see the greatest benefits by transitioning to an electric bus system.

When examining the potential returns for each of the schools we have chosen (UMass Amherst, Boston University, and Tufts University) it has become apparent that UMass Amherst would gain the most from transitioning away from their conventional diesel bus system. UMass is projected to save 24.07% of the present value of the costs of their current bus system by transitioning to an entirely electric bus fleet. In comparison, Boston University would save 6.25% and Tufts University would save 20.6% of the present value of their diesel bus fleet. We believe that the disparity in saving comes about as a result of the differences in each of the school's bus routes and the number of miles traveled by each bus. The UMass bus system is far more extensive than either Boston University's or Tuft University's. We expect to see similar results amongst other schools. Therefore it is our final recommendation that while determining schools which would benefit the most from transitioning to electric buses, it is best to look at schools with more extensive bus systems and schools that use bus systems where each bus in the fleet travels a large number of miles.

It is important to note that while we recommend targeting schools with extensive bus systems for the transition to electric buses, there are a number of concerns in regards to the security and reliability of electric buses. When speaking with transportation directors about transitioning to electric buses, one of the most common hesitations we encountered existed in the form of doubts about the capabilities of electric buses to perform for required distances. This is a valid concern. Studies have shown, however, that this should not be a major factor when considering the implementation of electric bus systems (Ribau et al., 2015) (Tzeng et al., 2005). Furthermore, there are a number of other alternatives to conventional diesel buses that may act as a bridge between diesel and fully electric buses. Transit authorities may consider investing in these alternatives while waiting for electric bus technology to further develop. It is also not necessary for the bus systems to transition away from diesel buses rapidly. Instead we recommend universities replace their outdated bus systems gradually so as to lessen the initial financial burdens of transitioning to electric buses. The savings per bus calculated for each school exhibit the potential to transition gradually. UMass sees cost savings of $190,001.43 per bus that is transitioned, BU sees cost savings of $38,736.77 per bus, and Tufts sees cost savings of $38,736.77 per bus. By these schools transitioning their buses from diesel to electric gradually, they have the ability to realize incremental savings and eventually achieve the cumulative overall savings after diesel is finally phased out.

VIII. Conclusion

Upon considering the overall costs, benefits, and challenges of implementing a zero-emission bus system, it is clear that the University of Massachusetts at Amherst, Tufts University, and Boston University are the best candidates for the introduction of such an initiative to Massachusetts college campuses. Each university has displayed a history of climate action and sustainability that is indicative of a commitment to environmental and climate protection. Such a commitment will lead to the adoption of initiatives that include the reduction of greenhouse gas emissions through a shift from the use of conventional fuels to electricity for modes of transportation.

Proterra remains confident that its continually developing model of electric bus will have an immense impact on the reduction of emissions caused by the transportation sector, and the company's influence is spreading across the nation. The examples of Stanford University and University of Montana provide evidence that a gradual implementation of zero-emission buses into current transportation fleets is possible if institutions are willing to face large upfront costs to build and replace infrastructure with the promise of long term benefits. These long term benefits include a reduction in fuel and maintenance costs and a reduction in greenhouse gas emissions. Not only does the implementation of a zero-emission bus system benefit the institution that will have increasingly available funds to use for other programs and services, but it also benefits the community as a whole, who will enjoy cleaner, less polluted air.

As the University of Massachusetts, Tufts University, and Boston University adopt the initiative to shift from their current bus fleets that are fueled by conventional methods to a zero-emission bus system, they will begin to see a rapid decrease of costs and emissions. Because the University of Massachusetts possesses a more extensive system of routes and buses, it will be the most likely to experience a more immediate difference in costs than the other two universities. However, each university will certainly note a reduction in costs and emissions in the long term. As a result, other surrounding universities will note the benefits these universities have experienced despite the initial costs they incurred, and ultimately, many universities will follow the lead of these three universities.

As air pollution continues to worsen and climate change advances, a shift in the transportation sector is critical. The zero-emission bus is not a solution to the issues currently plaguing the globe, but it does have the potential to make an impact on how humans consider transportation. It has the potential to become a completely clean form of transportation as electricity generation becomes completely renewable through expanded solar, wind, hydroelectric, and geothermal power. Once institutions are able to view the upfront costs as an investment to receive long term benefits, they will be more willing to make that shift, and as more institutions take on this initiative, even more will follow. The goal is to eventually complete the transition from conventionally fueled to electric buses not only on college campuses, but throughout the nation. The zero-emission bus is a clean, cost effective mode of transportation, and its implementation should be considered with the greatest degree of seriousness by institutions throughout the Commonwealth of Massachusetts and even throughout the United States.

Bibliography

Borison, Rebecca. (2014, June 18). How Electric Buses Could Convince More People to Buy Teslas. *Business Insider*. Retrieved from http://www.businessinsider.com/proterra-electric-buses-spur-more-teslas-2014-6.

Boston University. (2016). *About the BUS*. Retrieved from http://www.bu.edu/thebus/about-the-bus/.

Boston University. (2016). *Advertising on the Bus.* Retrieved from http://www.bu.edu/thebus/advertising-on-the-bus/.

Boston University. (2016). *Annual Report 2015*. Retrieved from http://www.bu.edu/sustainability/files/2016/03/Sustainability_FY15AnnualReport_12webspr.pdf.

Boston University. (2016). *What We're Doing.* Retrieved from https://www.bu.edu/sustainability/what-were-doing/.

BU Today Staff. (2016, March 24). A Day in the Life of the BUS. *BU Today*. Retrieved from http://www.bu.edu/today/2016/bu-shuttle/

Casey, Tina. (2015, October 5). Proterra's Diesel-Killing Electric Buses Are Killing It (CleanTechnica Exclusive Interview). *Clean Technica*. Retrieved from http://cleantechnica.com/2015/10/05/proterras-diesel-killing-electric-buses-killing-cleantechnica-exclusive-interview/.

De Filippo, Giovanni, Marano, Vincenzo, & Sioshansi, Ramteen. (2014). Simulation of an Electric Transportation System at The Ohio State University. *Applied Energy*:1686–91. doi:10.1016/j.apenergy.2013.09.011.

EPA Office of Transportation and Air Quality. (2005). *Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel*. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1001YTF.txt.

Interagency Working Group on Social Cost of Carbon. (2013, May). *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*. Retrieved from https://www.whitehouse.gov/sites/default/files/omb/inforeg/social_cost_of_carbon_for_ria_2013_update.pdf

Kontou, A., & Miles, J.. (2015). Electric Buses: Lessons to Be Learnt from the Milton Keynes Demonstration Project. *Procedia Engineering*, 118:1137–44.doi:10.1016/j.proeng.2015.08.455.

MacKechnie, Christopher. (2015, December 31). *How Much Does a Bus Cost to Purchase and Operate*?. Retrieved from http://publictransport.about.com/od/Transit_Vehicles/a/How-Much-Does-A-Bus-Cost-To-Purchase-And-Operate.htm.

Maynard, Micheline. (2009, October 20). As Hybrid Buses Get Cheaper, Cities Fill Their Fleets. *New York Times*. Retrieved from http://www.nytimes.com/2009/10/22/automobiles/autospecial2/22BUS.html?_r=0.

Miles, J., & Potter, S.. (2014). Developing a Viable Electric Bus Service: The Milton Keynes Demonstration Project. *Research in Transportation Economics,* 48: 357–63. doi:10.1016/j.retrec.2014.09.063.

National Research Council. (2010). *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. Washington, D.C.: The National Academies Press. http://www.nap.edu/read/12794/chapter/1.

Noel, Lance & McCormack, Regina. (2014). A Cost Benefit Analysis of a V2G-Capable Electric School Bus Compared to a Traditional Diesel School Bus. *Applied Energy*, 126: 246-265. Retrieved from http://www.udel.edu/V2G/resources/V2G-Cost-Benefit-Analysis-Noel-McCormack-Applied-Energy-As-Accepted.pdf.

Pihlatie, M., Kukkonen, S., Halmeaho, T., Karvonen, V., & Nylund, N.O. (2014). Fully Electric City Buses - The Viable Option. *Electric Vehicle Conference (IEVC), 2014 IEEE International*, 1–8. doi:10.1109/IEVC.2014.7056145.

Proterra. (2016). *About Proterra*. Retrieved from http://www.proterra.com/our-company/overview/.

Proterra. (2016). *Advantages*. Retrieved from http://www.proterra.com/advantages/overview/.

Proterra. (2016). *Homepage*. Retrieved from http://www.proterra.com/.

Proterra. (2016). *Product Portfolio: Proterra Catalyst*. Retrieved from http://www.proterra.com/product-tech/product-portfolio/.

Proterra. (2016). *The Proterra Catalyst Platform*. Retrieved from http://www.proterra.com/wp-content/uploads/2016/01/Tearsheets_CatalystPlatform.pdf.

Redden, Jim. (2014, August 12). TriMet Plugs Electric Bus Into Local Routes. *Portland Tribune*. Retrieved from http://portlandtribune.com/pt/9-news/229845-92773-trimet-plugs-electric-bus-into-local-routes.

Ribau, J.P., Sousa, J.M.C., and Silva, C.M. (2015). Reducing the Carbon Footprint of Urban Bus Fleets Using Multi-Objective Optimization. *Energy,* 93: 1089–1104. doi:10.1016/j.energy.2015.09.112.

Ring, Dan. (2010, October 04). PVTA to Use $6.2 Million Federal Grant for State-of-the-Art Electric Hybrid Buses. *MassLive*. Retrieved from http://www.masslive.com/news/index.ssf/2010/10/pvta_to_use_62_million_federal.html.

Scheuren, Paul. (2011, September 12). Choosing a Discount Rate. *Impact DataSource*. Retrieved from http://www.impactdatasource.com/choosing-a-discount-rate/.

Sierra Club. (2015). *Zero-Emission Bus Information*. Retrieved from https://www.sierraclub.org/sites/www.sierraclub.org/files/uploads-wysiwig/ZEBmetrics.pdf.

Sierra Club. (2015). Cool Schools 2015 Full Ranking. *Sierra Magazine*. Retrieved from http://www.sierraclub.org/sierra/2015-5-september-october/cool-schools-2015/full-ranking.

Small, Ezra. (2012). Climate Action Plan 2.0. *Sustainable UMass:* Paper 3. Retrieved from http://scholarworks.umass.edu/cgi/viewcontent.cgi?article=1001&context=csi.

Stanford University (2016). *Transportation Initiatives*. Retrieved from https://sustainable.stanford.edu/solutions/transportation-initiatives.

Tufts University. (2016). *About the Office of Sustainability*. Retrieved from http://sustainability.tufts.edu/about-the-office-of-sustainability/.

Tufts University. (2016, April 21). *Second Nature Climate Commitment*. Retrieved from http://sustainability.tufts.edu/greenhouse-gas-emissions/second-nature-climate-commitment/.

Tufts University. (2016). *Shuttle Services*. Retrieved from http://publicsafety.tufts.edu/adminsvc/shuttle-services-2/.

Tzeng, Gwo-Hshiung, Lin, Cheng-Wei, & Opricovic, Serafim. (2005, July). Multi-Criteria Analysis of Alternative-Fuel Buses for Public Transportation. *Energy Policy* 33, no. 11: 1373–83. doi:10.1016/j.enpol.2003.12.014.

University of Massachusetts Amherst (UMass). (2016). *Sustainability Points of Pride*. Retrieved from https://www.umass.edu/sustainability/sustainability-points-pride.

University of Montana (UM). (2016, February 2). *UM Orders Zero-Emission Electric Buses for UDASH Fleet.* Retrieved from http://news.umt.edu/2016/02/020216ebus.php.

United States Department of Energy. (2016). Alternative Fuel Price Report [Data file]. Retrieved from http://www.afdc.energy.gov/fuels/prices.html.

United States Department of Transit. (2015, February 5). *U.S. Department of Transportation Announces $55 Million in Grants To Put More Zero-Emission Buses Into Service Across America*. Retrieved from https://www.transportation.gov/briefing-room/us-department-transportation-announces-55-million-grants-put-more-zero-emission-buses.

U.S. Energy Information Administration. (2016). Monthly Reports [Data file]. Retrieved from http://www.eia.gov/.

US News and World Report. (2016). Colleges in Massachusetts. *US News and World Report.* Retrieved from http://colleges.usnews.rankingsandreviews.com/best-colleges/ma.