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Pioneer Valley Goes Green: Minimizing Franklin Regional Transit Authority’s Carbon Footprint

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Pioneer Valley Goes Green: Minimizing Franklin Regional Transit Authority’s Carbon Footprint

Michelle Mei, Eleanore Colgan Gao Xi Powell, Elizabeth Carper

Written by: Michelle Mei
Professor Barron
ENV 312 Sustainable Solutions
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Executive Summary

Climate change will exacerbate the Pioneer Valley’s existing smog problem and diminish the overall quality of life. Climate change is caused by anthropogenic activities that release carbon dioxide (CO$_2$) into the atmosphere and the transportation sector in the United States being one of the largest contributors of CO$_2$. Franklin Regional Transit Authority (FRTA) has the opportunity to be a leader in climate change mitigation by incorporating more low carbon alternatives into its organization, whether it be in its fleet or buildings.

We conducted a carbon footprint and fuel costs analysis to determine where FRTA would benefit the most from low carbon alternatives. Since FRTA’s fleet was the biggest contributor to CO2 emissions and that the fleet was the most expensive to fuel, FRTA should consider low carbon options in its fleet.

We conducted a spatial analysis in arcGIS to test the feasibility of an electric bus and a cost analysis to evaluate the cost of an electric bus relative to hybrids and diesel buses. A spatial analysis was not necessary for hybrid and diesel buses because FRTA already uses those vehicle types. The main concern with electric buses is the question of their ability to operate in rural areas. Route 21 is the best fit for an electric bus, and the hybrid bus that currently services Route 21 should be rerouted to Route 32. Our cost analysis included the following categories: capital cost of vehicle and infrastructure, maintenance costs, fuel costs, the social cost of carbon, and the social cost of air pollution. Electric buses are the most financially sound option for FRTA.

We recommend that FRTA should adopt electric buses. This study’s finding aligns with the nationwide trend of transit authorities’ incorporation of electric buses. Since FRTA is already in contact with a popular bus manufacturer, we also outlined some talking points for FRTA.

Introduction
As climate change worsens and its effects are more widely felt, people and organizations are looking for mitigation strategies. Climate change refers to the change in earth’s natural systems because of an unprecedented rate at which greenhouse gases (GHG) like carbon dioxide (CO2) are accumulating in the atmosphere (Houghton, 1992). The northeastern United States will experience warming temperatures and more sporadic precipitation patterns due to climate change (Pryor et al, 2014). Because the warming effects and sporadic precipitation patterns will negatively affect Pioneer Valley residents, local organizations are looking for different mitigation strategies to decelerate the rate change in the earth’s climate and natural systems.

In addition to warming temperatures and prolonged periods of drought followed by intense rainfall, the Pioneer Valley will face its own unique problem of worsening air quality. Hampshire County has received a failing smog grade since 2013, in a report released by the American Lung Association (MassLive, 2009). Neighboring Hampden County received a C grade in the same year. There was no available data for Franklin County’s smog levels because there were no air quality monitors to track ozone pollution in that area (Hampshire Gazette, 2014), but there is reason to believe that levels were comparable to those in Hampshire and Hampden counties due to geographical proximity and similarities between the counties. Warmer temperatures will exacerbate poor air quality in the Pioneer Valley because the natural chemical processes that form smog (a fog or haze combined with smoke and other atmospheric pollutants) are amplified. Air quality worsens when heat and sunlight mix with hydrocarbons, like automobile exhaust, leading to increased levels of ozone and particle pollution. Valleys notoriously create inversions of cool and warm air that allows for the development and trapping of smog. Inversion layers are created when the cold air flows from mountain tops to valley bottoms, and the cold air pushes under the warmer air (Edinger, 1973). Common health risks
associated with smog include throat and chest irritation, triggering of asthma, and lung damage (Seaton et al., 1995). Consequently, climate change will pose two threats to the Valley: one being immediate human health threats from smog formation, and the other being a longer term problem of climate change.

Organizations can adopt mitigation strategies to reduce climate change. Adaptation strategies seek to make lifestyle adjustments to combat the ill effects of climate change (IPCC, 2014). Since climate change is caused by anthropogenic activities that emit GHGs like CO2 into the atmosphere, one possible mitigation strategy includes reducing an organization’s carbon footprint, defined as “the total set of GHG emissions caused by an organization expressed as CO2 equivalent” (Wiedmann, 2008). The transportation sector is one of the largest emitters of CO2 in the United States (EPA, 2017), so mitigation efforts should start within transportation authorities. The largest sources of transportation-related GHG emissions come from the combustion of petroleum-based products, like diesel, in internal combustion engines. Passenger vehicles account for over half of the emissions in the transportation sector (EPA, 2017). Transit authorities can integrate low carbon vehicles into their fleet as a mitigation strategy.

The dual problem of smog formation and climate change presents the opportunity for the public transit authorities in western Massachusetts to be local and national leaders by adopting low carbon vehicles. The Pioneer Valley Transit Authority (PVTA) is taking on a leadership role in the Valley. PVTA introduced three battery electric buses to their Holyoke-Springfield line (MassLive, 2016), and plans to introduce two more electric buses that will operate out of the University of Massachusetts at Amherst. The Franklin Regional Transit Authority (FRTA) can look to do the same by adding electric or more hybrid vehicles to their fleet.

This project will determine if electric buses are an appropriate alternative to hybrid and
diesel buses for FRTA. First, we will conduct a carbon footprint analysis to determine whether or not FRTA’s fleet is the biggest contributor of CO₂ emissions and would benefit the most from low carbon alternatives. Next, we will conduct a spatial analysis to determine which routes are the most compatible with existing electric bus technology. Finally, we will look at financial and environmental costs for each of the vehicles to assess the validity of electric buses relative to hybrid and diesel buses.

Methods

Background research

We conducted a phone interview on March 23, 2017 with FRTA Administrator Tina Cote to discuss the transit authority’s funding structure and interest in future low carbon initiatives. Vehicle purchases are exclusively funded by state and capital grants, and FRTA is currently in the queue for a grant to build a new bus facility. This grant would enable FRTA to build infrastructure to support electric vehicles. FRTA’s current low carbon initiatives include their intermodal center facility, which is the country’s first net zero energy facility; last year’s introduction of a hybrid bus; and fleet-wide use of a 5% biodiesel-diesel blend. A biodiesel blend is burned in a combustion engine like conventional petroleum diesel, but is renewable and biodegradable as it is manufactured from vegetable oils, animal fats, or recycled restaurant grease. Diesel blends with smaller percentages of biodiesel fare better in cold weather (Bhale et al, 2009); FRTA likely opted for 5% to adjust for chilly New England winters. The Massachusetts Department of Transportation (MassDOT) also announced its plans to see electric vehicles integrated into statewide public transportation systems by 2025. Although MassDOT has not formally committed any grants or expressed a timeline to achieve its goal, FRTA is
optimistic about MassDOT’s vision and what it means for FRTA’s low carbon plans according to Cote.

We then contacted Northeast Region Sales Director Steve O’Neil at Proterra, the largest electric bus manufacturer in the US. O’Neil personally helped PVTA acquire electric buses from Proterra, and offered insight into Proterra’s business model and electric bus technology. Proterra not only manufactures electric buses, but also offers a wide range of services. Proterra’s involvement with interested local transit authorities includes: an employee site visit to ride and determine the best route for an electric bus and most appropriate battery size; assistance with grant proposal writing to secure funds for the purchase of vehicles; and on-site assistance with the transition for as long as the transit authority deems necessary. O’Neil also outlined limitations of current electric buses. Depending on the battery, some buses have trouble climbing hills. While technology is constantly improving, most affordable bus options do not have the power to navigate variable grade terrain. Therefore, electric buses run best on flat terrain, usually in commercial and city centers, and for shorter distances. Our conversation with O’Neil informed us of electric buses’ shortcomings, which we later used in our analysis.

**Carbon footprint and fuel costs analysis**

We analyzed FRTA’s carbon footprint and energy costs to determine if the project should focus on electric buses. General Manager Michael Perrault provided us with FRTA’s energy use for the fleet and transit center and maintenance facility, the mileage for two diesel buses and one hybrid bus, as well as fuel and energy costs for fiscal year 2016 (Appendix Tables 1-3). We calculated the carbon footprint using “GHG Emissions from Transport or Mobile Sources” and “GHG Emissions from Stationary Combustion” worksheets from Greenhouse Gas Protocol. Although FRTA uses wood pellets as an energy source (Appendix Table 2), the carbon footprint
did not include emissions from wood pellets because forest-based biomass is carbon neutral per
the EPA so long as the forest is sustainably farmed (American Forest & Paper Association, 2014)
or if the land that produced the biomass would not have an alternative use. Since FRTA’s wood
pellets are wood shavings from a nearby wood processing plant, it is considered carbon neutral
because the trees were not cut down for the sole purpose of fuel; the wood pellets would have
been produced by the wood processing plant regardless of FRTA. We also assumed that FRTA
does not own the solar credit to the solar energy they produce, so their electricity has associated
carbon emissions. We took the operating budget at face value.

Spatial analysis

We conducted a spatial analysis to determine the best possible route for electric buses
given the topography of Franklin County. We created two maps in arcGIS. The first map shows
FRTA’s current bus routes (provided by FRTA Manager Michael Perreault) overlaid onto satellite
imagery of Franklin County. This map provides an idea of the extent of Franklin County and its
surrounding terrain. The second map overlays the bus routes onto the Massachusetts digital
elevation model (DEM). This map shows the bus routes in the context of the topography and
enabled us to determine which route is flattest and shortest, i.e. the most suitable for electric
buses.

Cost analysis

Since FRTA is a small transit authority and operates on a tight budget, it is important to
evaluate the costs of electric buses against the vehicles FRTA owns, i.e. hybrids and diesel
buses, to determine if electric buses are a better alternative to what FRTA already uses. We
decided that relevant costs include both market costs and environmental costs. Market costs refer
to capital costs of the vehicle itself and any associated infrastructure; maintenance costs; fuel
costs. Environmental costs refer to environmental damages, such as the social cost of carbon (SCC) and the cost of air pollution. The SCC is defined as an “estimate of the economic damages associated with an increase in CO₂” (EPA, 2016), and the specific air pollutants were particulate matter 2.5 (PM 2.5), sulfur dioxide (SO₂), and nitrogen oxides (NOx). We focused on PM 2.5 because those tiny particles can travel deeply into the respiratory tract to reach the lungs, causing short-term health problems such as eye, nose, throat, and lung irritation as well as potential long-term health problems such as chronic bronchitis and increased mortality from lung cancer and heart disease (Seaton et al., 1995). Exposure to SO₂ can lead to burning of the nose and throat, breathing difficulties, and changes in lung functions (Dab et al., 1996). Long term exposure to NOx will lead to damage to lung tissue, negative effects on the respiratory system, and even premature death (Kampa, 2007). The market and environmental costs were calculated using the best possible estimates from recent studies.

We estimated market costs by referencing current costs from bus manufacturers, studies from other transit systems in the US, and fuel projection costs from the US Energy Information Administration. The cost of an electric bus, charging station, and cost of maintenance were provided by Proterra. There are two electric bus options: one is fast-charging but can only travel a short distance before needing to recharge, and the other can travel longer distances but is slow-charging. We decided to adopt the slow-charging bus that can travel longer distances because it is cheaper, and because FRTA will not have to worry about constantly recharging the bus throughout the day. The bus can be charged overnight when not in service, and is better for FRTA’s carbon footprint because New England’s electric grid provides cleaner energy during non-peak hours (ISO New England, 2015). We estimated the cost of a hybrid bus from online research and the cost of a diesel bus from a study by Columbia University and New York City
Transit. There are no associated costs of infrastructure for hybrid and diesel buses because FRTA already has the infrastructure in place. The maintenance cost of electric buses, hybrids, and diesel buses are from the Environment and Energy Study Institute. We decided that FRTA would only need Proterra-led maintenance during the first year; FRTA’s own staff can maintain electric buses after learning from the Proterra representative the first year to save on maintenance costs. The fuel projection costs are from the US Energy Information Administration. We used two different projections: a reference case and a high oil price case. The reference case is defined as prices of oil reflecting current laws and policies, i.e. business-as-usual prices. The high oil prices case reflects a scenario in which the cost of oil dramatically rises. These two cases were chosen to highlight the difference in fuel costs for electric vehicles versus gas-based vehicles should the price of oil increase, and help underscore the importance of energy independence.

We calculated the environmental costs by estimating the amount of CO$_2$ and air pollutant emissions and then converting those emission estimates to associated dollar values. The SCC is from the EPA’s website, but is no longer available as of April 28, 2017. We used the “GHG Emissions from Transport or Mobile Sources” worksheet from Greenhouse Gas Protocol to calculate CO$_2$ emissions from buses and the MJ Bradley Report from Pennsylvania State University and the Energy Systems Division from Argonne National Labs to calculate SO$_2$ and NOx emissions. We converted these emissions totals to the associated dollar amount in damages by referring to the “extreme case” of a study from the National Environmental Publications Information System. We consciously chose to use the extreme case because the moderate case showed little to no costs of air pollution. Because the emissions rate from diesel is already low, SO$_2$ emissions for hybrids were estimated at 0 so the total cost of hybrid SO$_2$ emissions would be negligible in the grand scheme of hundreds of thousands of dollars. The emissions rate for PM
We projected the total costs over 10 years, from 2020-2030, with a discount rate of 3%. We chose to start at the year 2020 because that is when FRTA is eligible for their grant, and falls within the timeline for MassDOT’s goal to see electric vehicles integrated into transit systems by 2025. We chose a lifetime of 10 years because most transit vehicles are eligible to be replaced by state grants after 10 years. We chose a discount rate of 3% because the EPA offered the SCC at 2%, 3% and 5%, and 3% is the middle-of-the-road option. We also assumed that while FRTA produces renewable solar energy, they do not own the solar credits so FRTA has a positive net carbon emissions footprint from electricity use. All vehicles were estimated to travel 20,000 miles because the current hybrid travels roughly that many miles in a given year (Appendix Table 1). All dollar amounts were converted to 2016 dollars using the Consumer Price Index from the US Bureau of Labor Statistics.

Results

Carbon footprint and fuel cost analysis

The percentage of CO$_2$ emissions from fuel usage (90% total, 51% for unleaded gasoline and 39% for diesel) far outweighed emissions from FRTA’s facilities (10%) (Appendix Figure 1). Similarly, fuel costs (unleaded gas and diesel) comprised the biggest energy expense for FRTA (74%) (Appendix Figure 2).

Spatial analysis

Route 21 looks to be the most feasible option for an electric bus because it is a relatively short distance compared to the other routes (Appendix Figure 3). FRTA confirmed that Route 21
is just 18.5 miles long. Route 21 is also a prime candidate because it is in an urban area (depicted by the white buildings in the satellite imagery in Appendix Figure 3), and most electric buses are used in urban areas. The electric bus traveling along Route 21 would also be close to the battery charging station because the bus facility and battery charging station are located in Greenfield Center.

The map of the bus routes superimposed on the DEM further supports the implementation of electric bus on Route 21. Given that electric buses operate more efficiently on relatively flat terrain and shorter distances, Route 21 is the most feasible option for the future introduction of an electric bus because it is in a consistently low elevation area, depicted by the dark green in the DEM, and because it is a sub-20 mile route, depicted by the relatively short length of the chartreuse green line (Appendix Figure 4).

**Cost analysis**

Under the reference case for oil prices, the total cost of the hybrid bus is the highest, followed by electric and then diesel. The fuel costs and social cost of carbon are much higher for hybrids ($101,000 and $16,000, respectively) and diesel buses ($139,000 and $22,000, respectively), but the capital costs of the electric ($709,000) are much higher than the capital costs of hybrids ($651,000) and diesel buses ($550,000). The maintenance costs are similar for all three vehicle types (electric $73,000; hybrid $77,000; diesel $81,000), and the cost of air quality is so low (electric $0; hybrid $3000\(^1\); diesel $1000) that they are almost negligible (Appendix Table 4). The total cost of hybrids ($848,000) is larger than the cost of electric ($798,000) and diesel buses ($792,000), but the difference between the cost of electric and diesel are minimal. The reference case for oil prices does not make a strong case for FRTA to adopt electric buses over diesel buses.

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\(^1\) Hybrid buses had a higher cost of air quality because they emit more PM 2.5 than diesel buses.
The case for FRTA to adopt an electric bus over hybrids and diesel buses is much stronger under the high oil prices case. The capital cost of vehicles is still the biggest cost, but the disparity between fuel costs of electric buses ($15,000), hybrids ($178,000), and diesel buses ($244,000) is much greater (Appendix Table 5). The cost of electricity increases by $1,000 but the cost of fuel for hybrids increases by $77,000 and the cost of fuel for diesel buses increases by $105,000. Because of the drastic increase in fuel costs, the total cost of electric buses ($799,000) is then a lot cheaper than diesel buses ($897,000) and hybrids ($925,000).

Discussion

Given that the fleet is not only the biggest contributor of CO₂ emissions but also the most costly, there is both an environmental and financial incentive for FRTA to look into low carbon and fuel-efficient vehicles like electric buses.

A spatial analysis of FRTA’s current bus routes relative to the terrain suggests that FRTA should introduce electric buses onto Route 21. The hybrid bus that currently services Route 21 should be rerouted to make room for the electric bus because hybrids are more robust than electric buses. Hybrids are capable of traveling longer distances, and have a comparative advantage over electric buses because of hybrid buses’ combustion engines. The combustion engine allows the hybrids to climb hills, whereas the battery in most electric buses cannot generate enough power to navigate variable terrain. A possible alternative route for the hybrid bus is Route 32, which encompasses slightly more variable terrain but is still not a drastic change from the Greenfield Center as it travels along a ridge. The elevation of Greenfield Center is about 70 meters, and the ridge fluctuates between 100 meters and 300 meters (Appendix Figure 4). With the hybrid’s ability to adapt to rougher terrain, it would make the most sense for the electric to service Route 21 and for the hybrid to be moved to Route 32.
The cost analysis suggests that FRTA should incorporate electric vehicles into its fleet. The capital cost of an electric bus is the biggest barrier for FRTA, as it outweighs the cost of both diesel and hybrid options. The fuel costs of the fleet continue to be the biggest component of FRTA’s energy costs budget. We compared the cost of fuel under a reference case and a high oil prices case, and found that the electric bus was the cheapest option under the high oil prices case, but not that much more expensive than a traditional diesel bus under the reference case. An electric bus is projected to save FRTA $98,000 compared to a diesel bus and $126,000 compared to a hybrid bus under high oil prices, and an electric bus is only $6,000 more than diesel bus over the course of 10 years under a reference case. We believe that a high oil price case is the preferable case given political instability in the Middle East and the volatile nature of the oil market. There is no guarantee that laws and policies will stay the same in the next ten years, making the reference case a little less reliable. FRTA can safeguard against uncertainty and possible increases in the price of oil by adopting the fuel projections under the high price of oil case. The high oil price case makes a strong argument for FRTA to adopt an electric bus: if FRTA were to obtain a grant to cover the capital cost of an electric bus, their annual operating budget (defined by maintenance and fuel costs) will be a significantly lower than if they were to utilize only diesel and hybrid options.

This study assumed that FRTA should bear both the financial and environmental costs of all the vehicles, but that is not the case in reality. FRTA only covers the financial costs and society covers the environmental costs. This is because the financial costs (capital costs, maintenance costs, fuel costs) are goods that can be bought and sold on the market. The value of these market goods will appear on FRTA’s financial statements. On the other hand, the environmental costs are non-market goods (or in this case, non-market “bads”) and will not
appear on FRTA’s financial statements. Because the environmental costs do not appear on FRTA’s financial statements, there is no reason for FRTA to consider the environmental costs when looking to purchase its next vehicle apart².

However, the removal of the environmental costs to FRTA still results in electric buses being the best option for FRTA. If FRTA were to consider the high oil prices case, the total financial costs of an electric bus ($797,000) is still much cheaper than hybrids ($906,000) and diesel buses ($874,000). This argument does not hold true for the reference case if FRTA were to disregard the environmental costs (electric $796,000; hybrid $829,000; diesel $769,000). We still believe that FRTA should defer to the high oil prices case because of the importance of energy independence given the uncertainty of the current political climate.

This study also failed to explore other types of vehicles aside from electric, hybrid, and diesel buses. Other options include propane buses. Propane, also known as liquefied petroleum gas or propane autogas, has been in use for decades to power light-, medium-, and heavy-duty propane vehicles. Propane school buses have been generally well-received (DOE, 2014), and could be a possible option for FRTA. This study did not explore propane buses because we looked to PVTA’s successful implementation of electric buses as an example for FRTA.

FRTA should also look into definitive costs from bus manufacturers and the difference between the Proterra’s buses versus what kind of bus meets FRTA’s operational needs. The costs we used were estimates from studies, with none being exact costs except the electric bus from Proterra. Slightly different costs for hybrids and diesel buses might result in different optimal outcomes. Additionally, the prices for the capital cost of the Proterra are accurate, but the Proterra bus we considered seats at 28 people at the minimum; FRTA buses typically seats just

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² One could argue that FRTA benefits from being positively perceived by the community as “environmentally friendly”, but it is hard to quantify the value of goodwill.
18. FRTA should consult not only with hybrid and diesel bus manufacturers to solidify more accurate quotes, but also make sure that Proterra’s buses are able to meet FRTA’s operational needs. FRTA should by no means take this study as final.

This study can serve as a starting point for FRTA when deciding what to do with the grant money from MassDOT. We recommend that FRTA should strongly consider incorporating electric buses into its fleet. The findings of this study align with a nationwide trend of transit systems adopting electric buses (Proterra, 2017). Proterra is already in contact with FRTA and is planning to visit FRTA in the upcoming weeks. Hopefully the visit and further conversations result in FRTA’s contemplating using the grant money to build a charging station for future electric buses.
Appendix

Table 1. Data collected from FRTA’s 2 diesel buses and 1 hybrid bus for fiscal year 2016 (July 1, 2015 - June 30, 2016). Bus number 1503 has been fitted with the Lightning Hybrid system and buses 1501 and 1502 are the same make/model without the hybrid unit. Provided by FRTA.

<table>
<thead>
<tr>
<th>Bus Number</th>
<th>Model Year</th>
<th>Vehicle Type</th>
<th>Seat Capacity</th>
<th>Bus Length</th>
<th>Date In Service</th>
<th>End Date</th>
<th>Years In Service</th>
<th>Ending Miles (FY16)</th>
<th>Start Miles</th>
<th>Total Miles</th>
<th>Avg Miles/Year</th>
<th>Avg Fuel</th>
<th>Avg MPG</th>
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<tbody>
<tr>
<td>1501</td>
<td>2015</td>
<td>Ford E450</td>
<td>18</td>
<td>25</td>
<td>4/27/2015</td>
<td>6/30/2016</td>
<td>1.18</td>
<td>31985</td>
<td>391</td>
<td>31594</td>
<td>27150.06</td>
<td>4261.9</td>
<td>7.41</td>
</tr>
<tr>
<td>1503</td>
<td>2015</td>
<td>Ford E450</td>
<td>18</td>
<td>25</td>
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<td>6/30/2016</td>
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<td>411</td>
<td>19272</td>
<td>20469.93</td>
<td>2933.3</td>
<td>6.57</td>
</tr>
</tbody>
</table>

Table 2. Energy usage and costs for FRTA’s Intermodal Transit Center (houses administrative offices) and Operations and Maintenance Facility for fiscal year 2016. Provided by FRTA.

<table>
<thead>
<tr>
<th>Building</th>
<th>Energy type</th>
<th>Usage</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit Center</td>
<td>Electricity</td>
<td>47,760 kWh</td>
<td>$13,530.33</td>
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<tr>
<td>Transit Center</td>
<td>Wood Pellet Boiler</td>
<td>46.167 tons</td>
<td>$9,963.28</td>
</tr>
<tr>
<td>Maintenance Facility</td>
<td>Electricity</td>
<td>60,600 kWh</td>
<td>$11,895.97</td>
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<tr>
<td>Maintenance Facility</td>
<td>Propane Furnace</td>
<td>1,012.4 gallons</td>
<td>$932.33</td>
</tr>
<tr>
<td>Maintenance Facility</td>
<td>Oil Furnace</td>
<td>4,404.1 gallons</td>
<td>$5,291.54</td>
</tr>
<tr>
<td>Maintenance Facility</td>
<td>Waste Oil Furnace</td>
<td>566 gallons (approximate)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 3. Fuel usage and costs for FRTA’s entire fleet for fiscal year 2016. Provided by FRTA.

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>Usage</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unleaded Gas</td>
<td>45,876.37 gallons</td>
<td>$75,114.82</td>
</tr>
<tr>
<td>Diesel</td>
<td>30,971.8 gallons</td>
<td>$46,581.80</td>
</tr>
</tbody>
</table>
Figure 1. FRTA’s carbon footprint for fiscal year 2016. The shades of red represent the carbon footprint of the fleet; sources of carbon dioxide emissions are unleaded gas and diesel. The shades of blue represent the carbon footprint of FRTA’s buildings; sources of carbon dioxide emissions are electricity, propane, oil, and waste oil. Wood pellets are carbon neutral and were omitted from the carbon footprint. The carbon footprint was calculated using worksheets from Greenhouse Gas Protocol with data provided by FRTA. Graph made on Excel.
Figure 2. FRTA’s energy and fuel costs for fiscal year 2016. The shades of red present the fuel costs for the fleet. Fuel costs include the cost of unleaded gas ($75,114.82) and the cost of diesel ($46,581.80). The shades of blue represent the energy costs for FRTA’s transit center and maintenance facility. Energy costs for the buildings include the cost of electricity ($25,426.30), wood pellets ($9,963.28), propane ($932.33), and oil ($5,291.54). The cost of waste oil (from Table 2) was not included because FRTA is using the waste oil from their vehicles, which they already own. Costs were provided by FRTA and the graph was made on Excel.
Figure 3. A map of FRTA’s current bus routes overlaid onto satellite image of Franklin County. This map provides an idea of the extent of Franklin County and its surrounding terrain. The map inset shows Franklin County in the context of Massachusetts. Map created on arcGIS.
Figure 4. A map of FRTA’s bus routes overlaid onto the Massachusetts digital elevation model (DEM). This map shows the bus routes in the context of the topography. The inset map shows a more condensed overview of FRTA’s bus routes. Map created on arcGIS.
Table 4. The cost of popular types of buses from 2020-2030 using reference case oil prices and a discount rate of 3%. The total cost of a battery electric bus ($798,000) is cheaper than a hybrid bus ($848,000) but more expensive than a conventional diesel bus ($792,000).

<table>
<thead>
<tr>
<th></th>
<th>Battery Electric Bus</th>
<th>Hybrid</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost (vehicle)</td>
<td>669,000</td>
<td>651,000</td>
<td>550,000</td>
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<tr>
<td>Capital cost (infrastructure)</td>
<td>40,000</td>
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<td>0</td>
</tr>
<tr>
<td>Maintenance cost NPV</td>
<td>73,000</td>
<td>77,000</td>
<td>81,000</td>
</tr>
<tr>
<td>Fuel costs NPV</td>
<td>14,000</td>
<td>101,000</td>
<td>139,000</td>
</tr>
<tr>
<td>Cost of carbon emissions NPV</td>
<td>2,000</td>
<td>16,000</td>
<td>22,000</td>
</tr>
<tr>
<td>Cost of air quality NPV</td>
<td>0</td>
<td>3,000</td>
<td>1,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>798,000</strong></td>
<td><strong>848,000</strong></td>
<td><strong>792,000</strong></td>
</tr>
</tbody>
</table>

Table 5. The cost of popular types of buses from 2020-2030 using high oil prices and a discount rate of 3%. The total cost of a battery electric bus ($799,000) is cheaper than a hybrid bus ($925,000) and a conventional diesel bus ($897,000).

<table>
<thead>
<tr>
<th></th>
<th>Battery Electric Bus</th>
<th>Hybrid</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost (vehicle)</td>
<td>669,000</td>
<td>651,000</td>
<td>550,000</td>
</tr>
<tr>
<td>Capital cost (infrastructure)</td>
<td>40,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Maintenance cost NPV</td>
<td>73,000</td>
<td>77,000</td>
<td>81,000</td>
</tr>
<tr>
<td>Fuel costs NPV</td>
<td>15,000</td>
<td>178,000</td>
<td>244,000</td>
</tr>
<tr>
<td>Cost of carbon emissions NPV</td>
<td>2,000</td>
<td>16,000</td>
<td>22,000</td>
</tr>
<tr>
<td>Cost of air quality NPV</td>
<td>0</td>
<td>3,000</td>
<td>1,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>799,000</strong></td>
<td><strong>925,000</strong></td>
<td><strong>897,000</strong></td>
</tr>
</tbody>
</table>
Literature Cited


Crowley, Dan. “What’s the grade of your air? Hampshire County gets ‘F’ smog grade, again.” The Hampshire Gazette [Northampton, MA], 02 May 2014.


Williams, Michelle. “PVTA to introduce electric buses on Holyoke-Springfield line”. MassLive [Springfield, MA], 17 May 2016.