Electric Bus Analysis for New York City Transit

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Background

New York City Transit has requested an analysis comparing the current fleet of buses to Electric buses. The current fleet of buses consists primarily of diesel and hybrid diesel buses, plus some CNG buses. The analysis will center on the economics (financials) of the electric bus alternative as well as on the environmental considerations (greenhouse gas emissions and air pollution). In addition, there will be consideration of potential implementation requirements, issues and recommendations.

ABSTRACT

NYC Transit and MTA bus have a combined fleet of about 5,700 buses for public transportation in New York City. The fleet currently consists of a mix of diesel, hybrid diesel and CNG (compressed natural gas) buses. Electric buses have vastly lower greenhouse gas (GHG) emissions than the current fleet. Changing the entire fleet of buses to electric buses would result in a reduction of emissions within the city of approximately 575,000 metric tons of CO2e per year. The net savings, including the incremental power generation required for the electric buses is nearly 500,000 metric tons of CO2e assuming the current mix of power generation in New York City and Westchester (EPA). From a financial perspective, the savings associated with fuel (cost of diesel vs. cost of electricity) and with bus maintenance more than offsets the higher cost of electric buses including the cost of the recharging infrastructure over the lifetime of a bus. Typically, electric buses cost about $300k more than diesel buses, and annual savings are estimated at $39k per year over the 12-year lifetime of the bus, excluding health care cost benefits. Switching to electric buses eliminates the air pollution caused by diesel bus fuel combustion. The resulting health benefit to the populous of the city from the reduction of respiratory and other diseases is estimated at $150k per bus based on EPA data. When applied to the financial case, the $150k improvement makes the case more compelling, and the health benefits should be a key consideration in the decision to switch to the new technology. The MTA will have challenges associated with a changeover to electric buses, but effective planning can make the change nearly invisible to customers. The recommendation of this analysis is that New York City should begin taking steps to convert the bus fleet to all electric.

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EXECUTIVE SUMMARY

New York City Transit has requested an analysis considering changing from the current fleet of buses to Electric buses. NYC Transit and MTA bus have a combined fleet of about 5,700 buses for public transportation in New York City. The fleet includes diesel, hybrid diesel, and CNG (compressed natural gas) buses.

Greenhouse gases emissions from transportation contribute to global climate change, and electric buses have much lower greenhouse gas emissions than diesel, hybrid diesel, or CNG buses. Changing the entire fleet to all electric buses would result in a reduction of emissions within the city limits of approximately 575,000 metric tons of CO2e per year. The <u>net</u> savings, including the incremental power generation required for the electric buses is a reduction of nearly 500,000 metric tons of CO2e assuming the current mix of power generation in New York City and Westchester County (EPA). Consideration was also given to the possibility of a change in the power generation sources. Assuming a power mix that has the highest level of greenhouse gases in the country, the EPA region designated as The Rockies, the "worst case" savings would still be about 300,000 metric tons of CO2e per year. There are some variations possible based on bus manufacturer, bus routes, number of passengers and seasonal impacts to battery life. However, the overall and net results will not change appreciably on an average annual basis.

The financial analysis of electric buses vs. the existing fleet of buses looks at the difference in the cost of a new electric bus vs. a diesel bus, and the cost of overall operations including fuel and maintenance costs. The cost of a diesel bus can range from roughly $450K to $750K depending on the characteristics of the bus. Smaller buses, 35 and 40 foot, typically sit at the lower end of the cost spectrum while 60 foot articulated buses have prices at the high end of the range. Electric buses cost about $300K more including the cost of the infrastructure. From a net financial perspective, the $39K annual savings associated with fuel (cost of diesel or CNG vs. cost of electricity) and bus maintenance more than offsets the higher cost of electric buses over the 12-year lifetime of the bus, excluding health care cost benefits. A sensitivity analysis was performed showing alternative differences in bus cost and in operating costs.

Health benefits and associated reductions in health care costs are important byproducts of a switch from diesel buses to all electric buses. The EPA created a Diesel Emissions Quantifier tool that includes a health benefit analysis component. The health benefits include respiratory, bronchial, heart and other diseases related to particulate matter and other diesel combustion pollutants. The cost reductions from those health benefits are associated with hospitalization, emergency room cost and the cost of missing work. The projected annual cost benefit in New York City associated with health benefits of switching from diesel buses to electric buses is approximately $150k per bus. This translates to roughly $100 per New York City resident of health care savings per year if the entire fleet is converted to all electric. From the perspective of New York City residents including elected officials, this should be significant and compelling.

A number of cities around the world are currently considering or are in the process of changing over to electric buses. These cities, including Chicago, London, Vienna and Los Angeles are gaining valuable experience in the implementation and use of electric buses, and should be consulted to gain a strong understanding of their experiences. The Antelope Valley Transit Authority in Greater Los Angeles wrote a press release earlier this year that they will be the first all-electric fleet in the country. They are working with BYD (Chinese manufacturer) to convert their fleet of 85 buses. London has 22 electric buses including several double decker electric buses and they continue to purchase more electric buses.

The recommendation of this report is that New York City take the first steps towards purchasing electric buses. The financial case closes sufficiently, and the health benefits and greenhouse gas reductions are both compelling. As a first step, the city should consider purchasing about 10 buses from each of two different vendors to pilot for a minimum of 1 year to gain understanding of electric bus operations as well as the impacts of seasonality specifically on battery operation. The pilot tests should be run on at least two routes that could have significantly different battery requirements based on battery size and recharging time alternatives. Investigation of different bus manufacturers should include the experience of other cities. The bus manufacturers most often cited in the United States are BYD (a Chinese company with a bus manufacturing plant in California) and Proterra, (a U.S. electric bus manufacturer headquartered in California).

Approach / Methodology

NYC Transit requested that this analysis be performed based on publicly available information only. Research has primarily included secondary data sources, found by searching through the internet and through journals and publications available through the Columbia University library to find generally available data and information from various journal articles and web sites.

Information on greenhouse gas emissions has come from various protocols and EPA web sites based on knowledge and understanding gleaned in GHG Emissions Carbon Footprint class, as well as from discussions with the professor. The spreadsheet analysis on greenhouse gases (GHG) for the existing NYC Transit fleet of buses has been compared with and validated by the results available in the "Inventory of New York City Greenhouse Gas Emissions," November, 2014. The analysis and validation was required to confirm the basic NYC Transit data needed to calculate GHG emissions for electric buses.

Some information specific to operation of electric buses was obtained through direct discussion and communication with Proterra, the leading U.S. electric bus manufacturer. Information regarding experience with electric buses in Northern Los Angeles was obtained through discussion with the Antelope Transit Authority.

The financial analysis and perspectives were performed based on experience, and were validated to some extent by comparing the results to other publicly available diesel to electric bus analyses.

DATA COLLECTION & ASSUMPTIONS

General

Many sources were consulted to get a general understanding of NYC Transit and the bus fleet. These sources are listed in the footnotes and the Bibliography. There were gaps in the data that was found, and assumptions were needed to fill in the gaps in order to calculate GHG emissions for the electric buses. The assumptions are delineated below.

Quantity of Buses

One of the keys to the analysis is knowledge of the number of buses in use by NYC Transit by fuel type. The primary source for the information used is the "MTA Capital Program Oversight Committee Meeting, January, 2016."[1] The data overview is in Figure 1 below.

Bus Type	YE 2015	Length
Diesel	1503	40 feet
CNG	747	40 feet
Hybrid	1672	40 feet
Total	3922	
Articulated Bus	801	60 feet
Express Bus	1038	45 feet
Total	**5761**	

Figure 1: Quantity of Buses by Fuel Type and Length of Bus

There are several important factors to note.

a. The GHG emissions are calculated for this mix of buses for a period of one year. In reality, the composition of buses changes throughout the course of a year. This mix of buses is assumed to approximate the quantity of buses at year end 2015 (YE15).

b. In looking through various sources, the number of buses used for comparative purposes in NY City is typically given as the combined buses that are managed by both NYC Transit and MTA Bus. This includes the "Inventory of New York City Greenhouse Gas Emissions" which was used to validate the GHG data. As a result, this analysis will use the combined quantity of buses from both NYC Transit and MTA Bus without distinction.

c. The mix of buses between Diesel use, Hybrid Diesel and CNG (compressed natural gas) is available for the 40 foot buses. The composition is not provided for the Articulated buses (60 feet) nor for the Express buses (45 feet). The total quantity of Articulated and Express buses (1,839 buses) is likely to be composed primarily of Diesel buses and of Hybrid buses. The Articulated and Express buses were estimated at 801 Diesel and 1,038 Hybrid buses.

[1] Higgins, John. "Bus Procurement Update." *Metropolitan Transportation Authority* (2016): 70. *Capital Program Oversight Committee Meeting*. Web. Jan. 2016.

Age of the Buses and Fuel Economy/Efficiency (mpg)

The fuel efficiency of the buses was taken from a report by the NREL (National Renewable Energy Laboratory, U.S. DOE) entitled “New York City Transit (NYCT) Hybrid (125 Order) and CNG Transit Buses – Final Evaluation Results,” November, 2006.[2] The report provides the mileage, number of gallons consumed and MPG by bus route for Diesel, Hybrid and CNG buses. This data was collected by actual bus tests through a 12-month evaluation period. The level of fuel efficiency was used as the basis for the GHG evaluation. Details are in Figure 2, below.

Bus Type	MPG
Diesel	2.28
Hybrid	3.19
CNG	1.70

Figure 2: Fuel Economy by Bus Type

Please note the following.

a. Compressed natural gas is actually a volume that is generally measured in standard cubic feet (scf). The NREL report provides the data in Gasoline Gallon Equivalent (GGE) which is based on the effective energy content of CNG.[3]

b. Given that the NREL report is from 2006, the mileage is for buses that are from that approximate vintage, 10 years ago. As a result, an assumption was needed regarding the age of the buses in the fleet and the fuel economy for buses of different ages. Given NYC Transit buses have an expected life of 12 years (“MTA Capital Program Oversight Committee Meeting, January, 2016.”),[4] a decision was made to divide the fleet into 3 equal sections of 4 years of age. The 4-year group of oldest buses (>8 years) was assigned the energy efficiency provided in the NREL report. The “middle aged” buses (4 – 8 years old) were assumed to have 5% better fuel efficiency than the oldest buses and the youngest buses (<4 years old) were assumed to have a fuel efficiency that is 7% better than the “middle aged” buses. See Figure 3 below.

Fuel Economy Improvement>>>>>		Improve 7%	Improve 5%	MPG Given
		Assumed Age of the Buses		
Bus Qty	**YE 2015**	**< 4 Years**	**4 - 8 yrs**	**> 8 Years**
Total	**5761**	1920	1920	1921

Figure 3: Assumed Quantity of Buses by Age of Bus Including the Fuel Economy Improvement Assumed by Age Group

[2] Barnitt, R., and K. Chandler. "New York City Transit Hybrid and CNG Transit Buses: Final Evaluation Results." *National Renewable Energy Laboratory - Technical Report* NREL/TP-540-40125 (2006): 23-25. NREL, Nov. 2016.

[3] "BTUs, CFMs, and GGEs Demystified." *CNG Units Explained*. Nat G - CNG Solutions, 2016.

[4] Higgans, *op. cit.*, page 71

Distance Traveled by the Buses

The average monthly mileage per bus as given by the NREL report is 2300 miles per bus.[5] This figure is used along with the mpg of each bus to calculate the total number of gallons of fuel consumed monthly and then annually.

Environmental Analysis

Measuring greenhouse gas / carbon dioxide emissions is largely a matter of using a consistent set of standards. For this evaluation, the source of the factors used to determine CO2 emissions, CH4 emissions and N20 emissions for both diesel buses as well as for the CNG buses was the EPA (U.S. Environmental Protection Agency).[6] To convert CH4 emissions and N20 emissions to CO2 equivalent (CO2e), factors were obtained from the Intergovernmental Panel on Climate Change (IPCC), 100 year Global Warming Potential (GWP).[7] It is important to note that these calculations require careful and effective use of conversion factors because many emissions factor are provided with different units of measure.[8]

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[5] Barnitt, R., and K. Chandler, *op. cit.*, page 20

[6] "Emission Factors for Greenhouse Gas Inventories." *EPA.gov* (2014): 1-5. Environmental Protection Agency, 4 Apr.

[7] "Direct Global Warming Potentials – 2.10.2." *IPCC Fourth Assessment Report: Climate Change 2007*. Intergovernmental Panel on Climate Change - UNEP, 2007.

[8] "Calculator & Unit Converter." *Search Help*. Google, 2016.

GREENHOUSE GAS ANALYSIS

Results of the GHG Analysis of the Existing Fleet of Buses

The results of the analysis performed are as follows. The CO2e emissions have been calculated for both the diesel buses (including hybrid buses) as well as for the CNG buses. Total emissions for diesel buses for a 12-month period of time are about 497k metric tons of CO2e. For CNG buses, total emissions for a 12-month period of time is about 80k metric tons of CO2e. Total emissions are about 577 MT of CO2e for all buses combined. Highlights are in Figure 4 below. Detailed calculations can be found in Table 1 in the Appendix.

Comparing GHG Emissions of the Existing Fleet with Known Actuals

These results were compared with those in the "Inventory of New York City Greenhouse Gas Emissions."[9] The diesel bus emissions calculated are about 3% higher than those provided in the NYC inventory, and the calculated CNG CO2e emissions are within 1% of the emission results from the NYC GHG inventory. Given the close results, the data and assumptions used in the calculation are assumed to have been validated. The methodology is deemed to be sound and the data and assumptions from the calculation may be used for the analysis of the electric bus emissions. See Figure 4 below.

CO2e Fuel Type	NYC Reported	Analysis Calculated	% Delta	Units
Diesel	484,076	496,861	2.64%	**MT CO2e**
CNG	79,750	80,429	0.85%	**MT CO2e**
Total	563,826	577,290	**2.39%**	

Figure 4: Comparison of NYC Reported Fuel Emissions vs. Emissions Calculated Using the Data and Assumptions in this Report

a. As a side note, the results show that on a unit basis the emissions from the CNG buses are 108 metric tons per bus per year and the average diesel bus emissions are 100 metric tons per bus per year. This is a largely unexpected result because CNG is supposed to burn more cleanly than diesel. The reason for this result in part is that the CNG buses are 25% less fuel efficient than the regular diesel buses and 47% less fuel efficient than the hybrid diesel buses. The fuel efficiency of the buses should be roughly equivalent. If that were the case, the CNG buses would be providing the expected improvement in GHG emissions.

b. Also important to note is that the greenhouse gas analysis in this report is associated with fleet operations only. This analysis does not take into account the greenhouse gases associated with upstream or downstream processes such as the manufacturing of diesel buses vs. electric buses etc.

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[9] City of New York, Inventory of New York City Greenhouse Gas Emissions, November 2014, by Cathy Pasion, Mikael Amar and Michael Delaney. Mayor's Office of Long-Term Planning and Sustainability, New York, 2014., page 40

Greenhouse Gas Analysis for Electric Buses

The basic data and assumptions regarding quantity of buses, bus lifetime, distance traveled etc., were then used to calculate the greenhouse gas projection for electric buses. However, to calculate the emissions for electric buses, electric bus fuel economy, which is measured on a kWh/mile basis, is required. This data was obtained from several sources as follows:

a. The Altoona Bus Research and Testing Center is located at Penn State.[10] They perform STURAA tests (Surface Transportation and Uniform Relocation Assistance Act of 1987) on buses, that simulate 500,000 miles of service over 12 years. Part of the standardized test includes testing for fuel economy. The fuel economy test is useful for comparing one electric bus against another. But it is not as in depth or rigorous as an EPA fuel economy test to determine the average fuel economy for a bus in use. Fuel Economy tests were performed on a Proterra BE40 bus at the Center, and the result was 1.7 kWh/mile.[11] The test was also performed on a BYD 40-foot bus with a resulting fuel economy of 1.988 kWh/mile.[12]

b. The NREL (National Renewable Energy Laboratory, funded by the US Department of Energy) ran a rigorous, but not standardized test on Proterra buses and determined that the fuel economy averaged 2.15 kWh/mile.[13]

GHG Comparison Between the Existing Fleet and Electric Buses

Using an average fuel economy of 2.0 kWh/mile fuel economy, the greenhouse gases (GHG) were calculated for electric buses and compared to the greenhouse gases per year calculated for the existing fleet. To calculate the GHGs for the electric buses requires the GHG emissions associated with the power generation source that supplies NY City. This is obtained from the EPA, which generates regional emissions factors.[14] In this case, the region is NYC/Westchester.

The result, as shown in Figure 5 below, is that the greenhouse gas reduction moving from the current fleet of buses to electric buses is dramatic. The city can save nearly 500,000 metric tons of CO2 per year by switching the fleet to all electric. The detailed calculation can be found in Table 2 in the Appendix.

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[10] "Altoona Bus Research and Testing Center - Vehicle Systems & Safety Program." - *Vehicle Systems & Safety Program*. Penn State - The Thomas D. Larson Pennsylvania Transportation Institute, 2015.

[11] "Manufacturer: Proterra Inc., Model: BE40 - Submitted for Testing in Service-Life Category 12 Year /500,000 Miles." *FEDERAL TRANSIT BUS TEST*. Penn State - The Thomas D. Larson Pennsylvania Transportation Institute - Bus Testing and Research Center, May 2015.

[12] "Manufacturer: BYD Motors Inc., Model: BYD Electric Bus - Submitted for Testing in Service-Life Category 12 Year /500,000 Miles." *FEDERAL TRANSIT BUS TEST*. Penn State - The Thomas D. Larson Pennsylvania Transportation Institute - Bus Testing and Research Center, June 2014.

[13] Barnitt, R., and K. Chandler, *op. cit.*, page 19

[14] "Emission Factors for Greenhouse Gas Inventories.", *op. cit.*, page 3, Table 6

GHG Emissions	Current Fleet Annual	Electric Annual	Delta
Total	577,290	91,222	486,068

note: Data is in metric tons of CO2e

Figure 5: Comparison of Greenhous Gas Emissions for Electric Buses vs. the Current Fleet of Buses Used by New York City

There are several important points to note as follows:

a. Even if the assumptions change significantly, the result will be the same. There is an enormous difference between the GHG emissions associated with diesel fuel from a bus, and the emissions associated with power generation supplied to NYC/Westchester. These results are consistent with those published by the Electric Power Research Institute in conjunction with the NRDC.[15]

b. The actual reduction of GHGs in NYC will be higher than the calculation. Some of the power generation sits outside of NY City, and therefore the emissions will not impact the city, but elsewhere. If 100% of the electricity supplying NY City for the buses sits outside of NY City, then the city will benefit from a 100% reduction of the GHGs associated with the buses.

c. In support of the Paris COP21, the United States submitted an INDC (intended nationally determined contribution) that would reduce GHG by about 1,000 million metric tons per year by 2025, from 2015 actuals.[16] If New York City converted the entire bus fleet to electric by 2025, the greenhouse gas savings of the conversion would contribute about .5% to the U.S. objective.

The actual fuel economy of electric buses can vary significantly from these averages during the course of the year because electric bus mileage (the battery) can be sensitive to temperature extremes from the weather. In addition, bus performance will be unique to each city, route and trip based on roads, hills, speeds, the number of people on the bus etc. For a more accurate calculation of the electric bus fuel economy (used to calculate GHG and for the financial analysis below), the city should run tests on a variety of actual bus routes in different weather conditions to get a sense of the implications to the battery operation and to fuel economy. In fact, pilot tests should ideally be run through the course of a calendar year to clearly understand weather impacts on performance.

[15] "Executive Summary." *Electric Power Research Institute* (n.d.): n. pag. *Electrifying Transportation Reduces Greenhouse Gases and Improves Air Quality*. Electric Power Research Institute, NRDC, Sept. 2015.
[16] "Intended Nationally Determined Contribution." *United States of America*. UNFCC, 2015.

FINANCIAL ANALYSIS

A detailed financial analysis has been performed, comparing the purchase of electric buses to the purchase of diesel buses from several perspectives, including a sensitivity analysis. Health care costs and benefits will be addressed in the next section, as will the cost of carbon associated with greenhouse gas emissions.

The primary categories of cost are the initial purchase price of the bus and the operational costs of the bus. The initial purchase price of the electric bus is all inclusive, including recharging infrastructure, manuals and any training that is required. The operational costs include the cost of fuel (electricity vs. diesel gasoline) and bus maintenance.

The cost of a diesel bus in New York City can range from approximately $450K to $750K.[17] This range of costs has a variety of dependencies including time sensitivity (costs change over time), manufacturer, contract negotiations and the characteristics of the bus. The characteristics of the bus at the macro level include the length of the bus, number of passengers that can be accommodated etc. 40 foot buses are at the lower end of the price range, and are less expensive than 60 foot articulated buses that are at the high end of the price spectrum. Other features such as wifi and gps can impact the cost of a bus, as can comfort characteristics such as cushioned seats.

This analysis assumes that buses are purchased at a fixed point in time, and that the features and characteristics of the buses are comparable except for the different technologies, electric vs. diesel. This simplifies the analysis, but the sensitivity analysis provides the ability to use the comparison more broadly. The written part of this report assumes that the average price differential between an electric bus and a diesel bus is about $300,000.[18] [19] However, Tables 3, 4 and 5 in the Appendix shows differences in price ranging from $150K to $400K for each of Alternatives 1, 2 and 3. Alternative 1 represents the average projected cost differences between electric and diesel buses for operational costs, health benefits and the cost of greenhouse gases. Alternative 2 represents a low operational cost differential scenario, and Alternative 3 represents a high operational cost differential scenario. Purchase price differentials are covered by the sensitivity analysis. Bus prices and relative bus prices have been found sprinkled throughout the literature in the Bibliography.[20]

Fuel Cost

The fuel cost of the existing fleet of buses is based on a projection of the cost of diesel fuel ($/gallon). Looking at historical prices for diesel No. 2 ultra-low sulfur, over the past 5 years, diesel fuel prices have held steady at around $4.00. Looking at the past 10 years, prices have fluctuated primarily in the $3.50 to $4.00 range, touching $2.00 several times including the recent price drop to approximately $2.00 per gallon. The average price over the timeframe is about $3.50 per gallon (see Figure 6 below). Projecting out for the next 12 years, it would be unrealistic to

[17] "MTA to Purchase 120 New Buses." *MTA Press Releases*. Metro, n.d.

[18] Koch, Wendy. “Tesla for the Masses: Electric, Fuel Cell Buses Take Off.” National Geographic, March 12, 2015.

[19] Atkins, B., McAlarney, V., Queen, A. “An Impact Analysis of Electrifying Florida’s Public Buses”, AER Group, July, 2013.

[20] Bibliography Sources: 5, 6, 18, 29, 36, 38

expect prices to remain at the $2.00 level. It would also be aggressive to assume that the average for the period would go higher than the $3.50 average of the past 10 years. The assumption used for this analysis for Alternative 1 is that a conservative average fuel price would be about $3.00 per gallon.

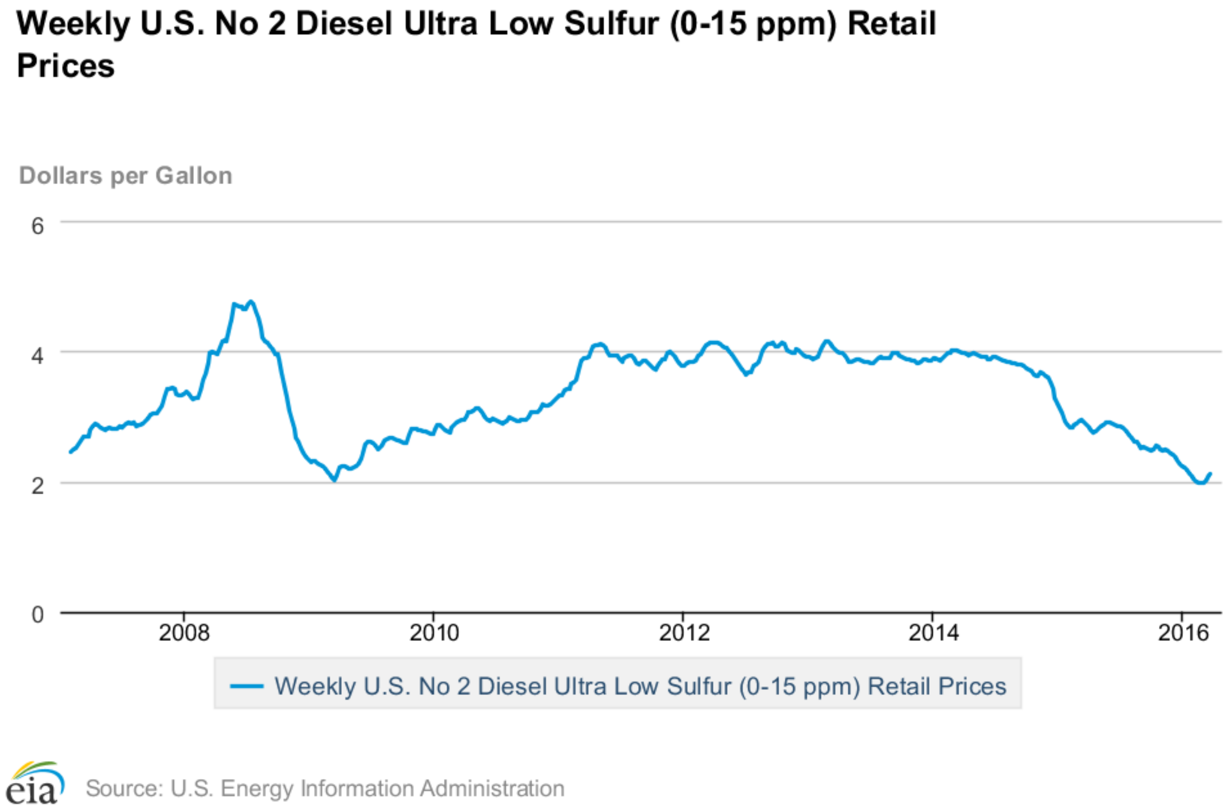

Figure 6: Price of Diesel Fuel by Year, in $/gallon (source: EIA)

Electricity Cost

The cost of electricity varies throughout the United States based on numerous factors including the type of power generation, land cost, and the age and efficiency of the plant. The U.S. Energy Information Administration provides historical electricity costs by region. The average U.S. cost of electricity has been between $.07 and $.10 per kWh over the course of the past 10 years.[21] For purposes of this analysis, $.12 per kWh will be used to represent the cost of electricity for the next 12 years in each of the alternatives.

Maintenance Cost

The maintenance cost for the current fleet of NYC buses is about $35K per bus annually.[22] The costs include maintenance of the internal combustion engine (ICE) and the associated powertrain including oil and filter changes, changing tires and brake pads, and other wear and tear items plus the occasional large break/fix repair. The electric bus does not have the complexities of the ICE

[21] "Weekly U.S. No 2 Diesel Ultra Low Sulfur (0-15 ppm) Retail Prices." Petroleum & Other Liquids, U.S. Energy Information Administration. April 25, 2016.

[22] Barnitt, R., and K. Chandler, *op. cit.*, page 27, Table 11

and does not require changing oil, replacing filters etc. In addition, experience has shown that there are some driving differences with electric buses that reduce some of the wear and tear on tires and brake pads. Bus drivers slow down differently with regenerative brakes. In aggregate, the cost savings has been demonstrated to be as high as 50% per bus. For purposes of this analysis, the Alternative 1 savings for maintenance cost has been set at 40%.

Lifetime Cost

Per Figure 7 below, assuming a $300K price differential and Alternative 1 assumptions for fuel prices, electricity cost and maintenance cost as described above, excluding health benefits and the cost of carbon, the overall lifetime (12 years) cost of an electric bus is about $168,000 (12.5%) less than the cost of a diesel bus (see Table 6 in the Appendix). Given that the cost is lower, the financial issues are associated with the timing of the costs and with budgeting. The up-front cost of the bus typically comes from a capital budget which has a different funding bucket and a different approval process than operational cost budgets. These distinctions will be addressed in the Payback Period and Net Present Value section below, as well as in Further Suggestions and Considerations.

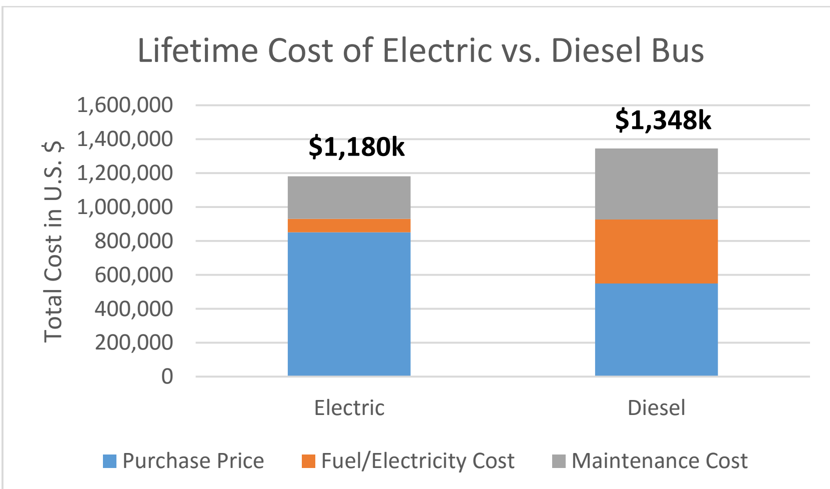

Figure 7: Lifetime Cost of Electric Buses vs. Diesel Buses in U.S. $ Excluding Cost Savings Associated with Health Benefits

Payback Period and Net Present Value (NPV)

From an investor perspective, an up-front investment of cash for one alternative vs. another requires consideration of the payback period and of the net present value of the series of cash flows that takes into account the time value of money. This initial look at payback period and net present value considers Alternative 1 only, and excludes the healthcare cost benefits which will be discussed in the Health Benefits section below.

The payback period for the series of cash flows is 7.69 years (see Table 3), which is generally not considered to be attractive to an investor. Investors typically will want to recover their money in 3 to 5 years. In the case of city government planning, this may be a consideration in the determination of the funding and budgets that may be available. Once the project is funded, however, the payback period is generally not an ongoing concern.

The net present value of the investment is dependent on the discount rate that is used in the calculation. For Alternative 1, the up-front initial cash outlay for an electric bus is $300,000 greater than for a diesel bus. That cash will be recovered over time through the benefits of lower operational costs. Using a 3% interest rate, the NPV of this set of cash flows is a positive $88K (see Table 3), suggesting that the investment is worthwhile. Investors may have different perspectives on the discount rate that should be used. So it is important to note that the breakeven discount rate for this set of cash flows is between 7% and 8%, which is a high discount rate when the rate of inflation has hovered between 1% and 3% for the past decade. Consequently, most investors would consider the NPV of this investment to be attractive.

Sensitivity Analysis

As mentioned previously, the primary analysis discussed is based on Alternative 1 assumptions, using $300K as the difference between the prices of electric and diesel buses. Analysis has been performed considering different alternatives.

From a bus price perspective, Tables 3, 4 and 5 in the Appendix consider differences in bus prices between $150k and $400k. Per the section below on Bus Vendors, Batteries, Range and Efficiency, prices of batteries have been declining in recent years and are expected to continue to decline going forward. In addition, electric bus manufacturers have not yet reached commercial scale in their manufacturing processes[23]. So the price difference between the electric buses and diesel buses is expected to narrow over the course of time.

Alternative 2 is a case that assumes a more conservative difference in the cost savings for fuel vs. electricity as well as for maintenance. The fuel cost is projected to be $2.00 per gallon for diesel. With lower diesel fuel costs, the cost of electricity will provide less savings. Similarly, the savings associated with maintenance cost are estimated to be lower, at $10k per year vs. the $14K per year in Alternative 1. Using these assumptions, the payback is 12.5 years for a $300K difference in bus prices, and the NPV is negative. So the financial case does not close using these conservative assumptions.

Alternative 3 is a case that assumes a more aggressive difference in the cost savings for fuel vs. electricity as well as for maintenance. Diesel fuel cost is projected to be $4.00 per gallon, which results in higher savings when compared to the cost of electricity. Maintenance cost savings are projected to be $17,500 per year per bus in this alternative. For a $300K cost difference in the initial purchase prices of the buses, the payback is now down to 5.71 years using these assumptions, and the NPV is a solid $223k.

As indicated, these alternative comparisons exclude the health care costs savings associated with the reduced particulates and air pollution from the diesel emissions. In addition, they do not consider the carbon cost associated with the greenhouse gas emissions. These will be considered in the next section.

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[23] Eudy, L. Prohaska, R., Kelly, K. & Post, M. "Foothill Transit Battery Electric Bus Demonstration Results." National Renewable Energy Laboratory, January, 2016, page 6.

HEALTH BENEFITS, HEALTHCARE COSTS AND THE COST OF GREENHOUSE GASES

People in any city, generally care about air pollution when it affects them. This includes the diseases that result from the pollution, and the cost of healthcare associated with these illnesses. The degree of concern varies by individual and is dependent on the severity of the air pollution. As an example, the air quality in Beijing is of great concern not only to the city, but to the leadership of the country as well.

New York City air pollution, like the air pollution in many cities, is a problem. According to the nyc.gov web site, air pollution is responsible for about 6% of deaths each year.[24] NY City has committed to have the cleanest air of any large city in the country by 2030.[25] As demonstrated in the discussion below, switching from diesel buses to all electric buses can be a significant step towards achieving this objective.

The U.S. Environmental Protection Agency (EPA) has created a tool to help understand the impact of various technologies that improve diesel bus emissions, called the Diesel Emissions Quantifier tool.[26] The tool provides perspectives not only on emissions, but there is a health benefit analysis component that provides perspective on the improvement in health care costs county by county across the United States.

The Diesel Emissions Quantifier calculates emissions improvements for PM 2.5 (particulates), CO2 (greenhouse gases), and for NOx (nitrous oxides). The health benefit analysis is based on improvements in particulate matter only. Particulate matter is responsible for a variety of respiratory/bronchial as well as heart and other diseases. The tool considers the benefits associated with many of those. From a cost reduction perspective, the tool considers the cost of hospitalization, the cost of emergency room visits and the cost of absence from work. Switching from diesel buses to electric buses reduces the amount of particulate matter in the air, which decreases the frequency of incidence of heart and lung diseases, which in turn reduces hospital costs and costs associated with work absence.[27]

The tool was run assuming that buses travel 27,600 miles per year (2,300 per month) and use approximately 10,000 gallons of fuel per year per bus. The particulate matter reduction associated with the elimination of diesel fuel was calculated at 97.5% of that which was produced previously by the diesel buses. For the base case, it was assumed that 30% of bus miles are driven in Manhattan, 20% in each of Brooklyn, Queens and the Bronx, and 10% of the miles are driven in Staten Island. Using that mix of bus miles, the health care cost savings is calculated to be about $150,000 per bus per year. For purposes of this analysis, $100,000 will be used for Alternative 1 to be conservative.

[24] Kheirbek, I., Wheeler, K., Walters, S., Pezeshki, G., Kass, D., "Air Pollution and the Health of New Yorkers: The Impact of Find Particles and Ozone." New York City Department of Health. May 9, 2011. Page 4.

[25] "Air Pollution." NYC Environmental Protection. The City of New York, 2016.

[26] "Diesel Emissions Quantifier (DEQ)," Clean Diesel. U.S. Environmental Protection Agency, October 13, 2015.

[27] ibid

For perspective, the city of Chicago performed a similar analysis to support their purchase of electric buses and calculated a savings of $55,000 per bus per year.[28] For another perspective, when the tool is run assuming a different mix of counties for NY City the result is different. The most conservative alternative that can be assumed for NYC is that 100% of the bus miles are driven in Staten Island (Richmond County). The result for this scenario was a savings of $87,000 per bus per year. Assuming the original mix with healthcare cost savings of $150,000 per bus per year, if the entire fleet of New York City buses is converted to electric, the total health care savings is roughly $100 per NYC resident per year.

A more detailed analysis of the cost savings associated with health care benefits, using the raw data from the EPA would be useful, and would provide a more accurate result. This in-depth analysis is outside of the scope of this report.

Greenhouse gas savings are generally monetized using the cost of carbon. The cost of carbon can vary significantly based on the assumptions used in the calculation. The EPA estimates, using a 3% discount rate, that the social cost of carbon was about $36 in 2015.[29] There is a significant amount of subjectivity around these numbers, but the EPA has used inputs from the Intergovernmental Panel on Climate Change (IPCC) as the basis for these projections. Given that each bus emits about 84 M Tons of greenhouse gases per year, the savings associated with the cost of carbon is about $3,000 per bus per year. This works out to a little over $36,000 for the lifetime of a bus.

[28] "Electric Bus," Chicago Transit Authority, 2016.

[29] "The Social Cost of Carbon," Climate Change. U.S. Environmental Protection Agency, February 23, 2016.

FINANCIAL ANALYSIS SUMMARY

The aggregate financial summary results can be seen in Figure 8 below. The table shows the NPV and payback associated with investing an additional $300k up front to purchase an electric bus in lieu of a diesel bus. As described above, the financial case is modestly acceptable in Alternative 1 (the average case), with an NPV of $88K. The payback period is longer than what an investor would typically look for. However, with the addition of the healthcare benefits and cost savings, as well as the addition of the cost of carbon, the financial results are compelling, and investment in the electric buses becomes very attractive from any perspective.

Assuming Bus Cost	Without Healthcare		With Healthcare Savings	
Difference of $300k	NPV	Payback	NPV	Payback
Alternative 1	**$88,206**	7.69	$1,113,469	2.11
Alternative 2	**($61,104)**	12.50	$466,458	3.90
Alternative 3	**$222,585**	5.71	$2,113,846	1.24

Figure 8: Summary Results of Financial Analysis Using 3 Alternative Scenarios, NPV and Payback Period are Shown with and without Health Benefit Savings

Using the additional cost of healthcare and carbon cost in the diesel bus case, the overall lifetime cost is higher by about $1,400k (see Figure 9 below, and Table 7 in the Appendix). This compares to the case without the additional healthcare and carbon cost (see Figure 7 above) in which the overall lifetime cost of purchasing the diesel bus is higher than the cost of the electric bus by about $168K.

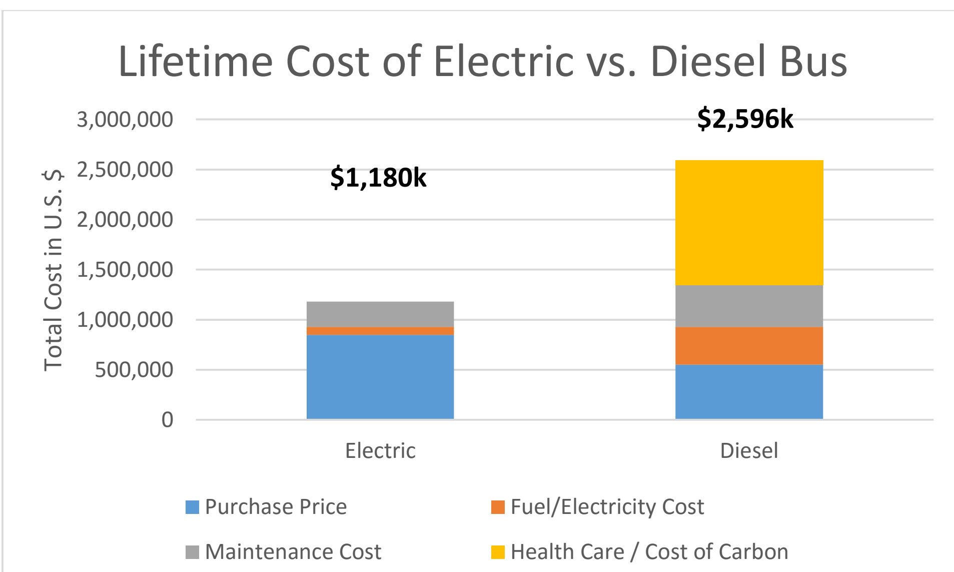

Figure 9: Lifetime Cost of Electric Buses vs. Diesel Buses in U.S. $ Including Cost Savings Associated with Health Benefits

IMPLEMENTATION REQUIREMENTS

The infrastructure required to support a new electric bus implementation has a number of challenges. Each bus route is unique, and implementations will be least costly if they are tailored to the specific needs of the route. The parameters that need to be decided include the size of the battery that is required for the implementation, as well as whether fast charging, slow charging or some combination is most effective for that particular route.

As an example, assume that a route is 10 miles long, takes 45 minutes, has a 15-minute stop at the end of each loop, and the route is run 8 times in a day. The city might consider purchasing a small battery for the bus and using fast charging after each bus loop. Alternatively, the city might prefer to purchase a larger battery and just charge it up once slowly overnight.

The equipment for recharging slowly vs. quickly has some differences that could impact cost and battery performance. A quick charge may not fully recharge the battery. But if the battery is large enough, it will not matter. Alternatively, batteries can be purchased that are sufficiently large to manage the full route for the day without recharging.[30]

In the case of Vienna, Austria, a unique set of requirements were established. Vienna decided to switch to all electric buses for their routes in the old district, which was covered by 12 buses. The requirement was that the buses use fast recharging during stops at the end of each loop. However, rather than setting up new recharging equipment, the city required that the recharging equipment make use of the infrastructure that already exists for trams. The vendor created unique equipment to comply with the city's request.[31] So New York City should plan carefully and consider alternatives before deciding on an approach.

Another possible consideration could be the frequency with which buses are switched between routes. If buses are switched frequently, then the bus configuration would need to be flexible enough to handle the different routes. If buses are not switched frequently, then it may be worthwhile to understand the time, effort and cost that would be required to change configurations when moving a bus from one route to another, rather than over-engineering every bus.

Batteries have unique performance characteristics that will be discussed in the next section. In addition, infrastructure requirements and battery type will vary by vendor. These differences need to be understood.

[30] "Charging Technologies." Proterra Bus Company. April 8, 2016.
[31] "A Cleaner City: Electric Buses in Vienna (Austria)." Eltis. April 8, 2015.

BUS VENDORS, BATTERIES, RANGE AND EFFICIENCY

BYD

The world's number one seller of electric buses is BYD, a Chinese company.[32] BYD (Build Your Dreams) recently opened a new manufacturing facility in California.[33] According to BYD's web site, their buses us an "Fe" (iron) battery that is developed internally, to power their electric buses.[34] The buses have an advertised range of 250km (155 mile) on a full charge, and can fast charge in about an hour. In a stress test by the Antelope Valley Transit Authority (Greater Los Angeles), the actual range of the buses was closer to 250 miles.[35] The BYD web site indicates that the batteries have a life span of greater than 4000 recharging cycles.[36] The BYD bus was tested at the Altoona Bus Research and Testing Center, and was found to have an efficiency of about 19 MPGe (miles per gallon equivalent). MPGe can be used to compare to diesel bus efficiencies.

Proterra

Proterra, the number one U.S. manufacturer of electric buses, is headquartered in California and has manufacturing facilities in both California and in Texas.[37] They have recently changed to an SCiB (lithium-titanate) battery that is manufactured by Toshiba. This battery is a quick charge battery that can be recharged 10,000 times[38] and has an advertised range of 180miles.[39] Similar to Proterra, the buses have been through testing that demonstrated a bus range of over 250 miles.[40] Proterra will tailor the battery configuration and infrastructure to the city and route, potentially lowering the cost of the bus.[41] At the Altoona Bus Research and Testing Center, the 40 foot Proterra bus efficiency was measured at 22 MPGe.

Other Electric Bus Manufacturers

There are numerous other electric bus manufacturers in the United States and around the world. Some of them make electric buses exclusively, while others are bus manufacturers that have introduced a line of electric buses. As an example, Siemens manufactured a unique bus for the

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[32] Koch, Wendy, *op. cit.*

[33] Field, Kyle. "A Look Under the Hood at the BYD Electric Bus Factory." CleanTechnica. October 21, 2015. Web. <http://cleantechnica.com/2015/10/21/look-hood-byd-electric-bus-factory/>

[34] "Long driving range, Easy charging, 0 emissions." BYD. April 25, 2016.

[35] Field, Kyle, *op. cit.*

[36] "Long driving range…" *op. cit.*

[37] Field, Kyle, *op. cit.*

[38] DeMorro, Christopher. "Toshiba to Provide Fast-Charging Batteries for Proterra." CleanTechnica. September 16, 2014.

[39] "Proterra Introduces Extended-Range Electric Bus, Flexible Battery System." Proterra Bus Company. February 24, 2015.

[40] Navarro, Alyssa. "Proterra Catalyst XR Electric Bus with 258-Mile Range is the Bus of the Future." Tech Times. October 5, 2015.

[41] "Proterra Catalyst Platform – The Future of Transportation." Proterra Bus Company. 2015.

city of Vienna (see below).[42] Chicago purchased and tested several buses that were made by New Flyer Industries,[43] which has its headquarters in Canada, and has manufacturing facilities in the United States.[44] In addition to purchasing BYD double-decker electric buses, the city of London has purchased buses from Spanish manufacturer, Irizar and UK manufacturer Optare.[45] [46]

Batteries

There are many different types of batteries with various characteristics. For an electric vehicle, the key battery characteristics are the range (distance) that can be traveled on a full charge and the time required to recharge the battery. However, it is important to understand that these characteristics act differently in the electric vehicle world than they do with gasoline or diesel powered vehicles. For example, most cars have a range of about 400 miles. That range can vary depending on whether the car is being driven primarily on the highway or in the city. Stop and go traffic impacts the fuel economy and therefore the range of the car. In the case of electric vehicles, ambient temperature can influence battery efficiency and therefore fuel economy more than in a gasoline/diesel powered vehicle. The impact will vary by battery type and by the actual ambient temperature in addition to bus load, speed, incline of the bus route etc. Consequently, vehicle testing and piloting is important in order to gain an understanding of electric vehicle performance characteristics and how those will manifest in a local region. Similarly, a transit authority needs to learn proper operations and maintenance for the electric vehicle.

Battery capacity can deteriorate over time, with constant charging and discharging, during normal lifetime and operations.[47] Obviously charging and discharging is a requirement for vehicle operations. So it’s important again to understand the vehicle characteristics, and to test and pilot generously. Lithium-ion batteries, for example, are used successfully in cell phones and in personal computers and laptops every day without appreciable deterioration under situations with a great deal of charging and discharging. So battery operations can be fairly successful.

Also important to note is that battery technology is evolving and improving over time. As a result, battery operations are getting better with each generation of buses. At the same time as technology is evolving, manufacturing is improving and approaching scale. As a result of improved manufacturing, battery costs have dropped considerably over the past decade.

[42] http://www.siemens.com/innovation/en/home/pictures-of-the-future/mobility-and-motors/electric-mobility-electric-buses.html
[43] “Electric Bus.” *op. cit.*
[44] “Introducing the New Flyer Xcelsior Electric.” New Flyer. April 25, 2016.
[45] Liu, Cecily, “Chinese-built Zero-emissions Electric Bus Prepares for Service in London.” The Guardian. July 18, 2015.
[46] “More Than 50 All-Electric Buses to Enter Service in London.” Transport for London. July 15, 2015.
[47] “Is Lithium-ion the Ideal Battery?” Battery University. 2016.

EXPERIENCE IN OTHER CITIES

Foothill Transit, Greater Los Angeles, California

After testing three buses in its service area, Foothill Transit decided to purchase 12 battery electric buses (BEBs) from Proterra. The buses purchased were 35 foot buses with fast charge capability, and a charging station was installed along the bus route. The cost of the buses including infrastructure was $10.2 million, funded by a Federal Transit Authority (FTA) *Transit Investments for Greenhouse Gas and Energy Reduction* (Tigger) grant. The average cost per bus including infrastructure was roughly $850,000.[48]

Antelope Valley Transit Authority, Northern Los Angeles, California

The Antelope Valley Transit Authority is planning to convert its entire fleet of 85 buses to all electric, the first transit authority in the country to convert completely. Currently, they are running 2 electric buses, both purchased from BYD. They are seeing a savings of $46,000 per bus per year from fuel savings plus significant savings in maintenance cost based in part on less wear and tear on brakes and tires associated with driving differences with the regenerative brakes.[49] Burbank, California has ordered 5 buses from BYD and Long Beach Transit has ordered 10 electric buses from BYD.[50]

Vienna, Austria

Vienna, Austria wants to be a leader in the green movement and has decided to eliminate greenhouse gases in its historic central district as a first step. As part of the transition, they have replaced all 12 buses on the inner city route to electric buses, not only reducing greenhouse gases, but reducing bus noise as well.

The requirements for the city were very specific because there is an existing electrical infrastructure associated with the extensive trolley system used in the city, and Vienna wanted to make use of that infrastructure rather than creating a duplicate electrical charging infrastructure. Siemens designed and built buses specifically for the Vienna requirement by putting a pantograph on the roof that allows the charger and inverter installed in the roof of the bus to connect to the existing infrastructure.[51]

Another unique requirement by Vienna was that they wanted to limit the amount of recharging time required along the route. The buses that were designed for them recharge at the end of the route in less than 15 minutes while passengers board the bus. This allows the bus to recharge sufficiently to get through the daily routes, and the buses charge fully overnight.[52]

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[48] Eudy, L. Prohaska, R., Kelly, K. & Post, M., *op. cit.*

[49] Williams, Wendy. "Antelope Valley Transit Authority to Become Nation's First 100 ercent Electric Public Transit Fleet." Antelope Valley Transit Authority. February, 11, 2016.

[50] Campbell, Jerome. Five Electric Buses Join Metro's Fleet; More May be Coming." Los Angeles Times. April 30, 2015.

[51] Falzeder, Florian. "Electric Buses: Rapid Charging in Vienna." Electric Mobility. Siemens. April 22, 2016.

[52] ibid

The unique bus implementation costs the city nearly twice what it would pay for diesel buses, but they have avoided the initial infrastructure cost, their operating and maintenance costs are 25% to 35% cheaper and bus prices will come down for them over time. [53]

Although greenhouse gases from buses have been eliminated in the historic district, there are greenhouse gases associated with the city's power generation, which sits outside of the city. The electricity used to power the buses comes from a mix of sources with 50% coming from hydropower, 15% coming from wind, 8% from solar, and the remaining 27% coming from fossil fuel generated electricity.[54]

Chicago, Illinois

Chicago has purchased 2 electric buses. Several of the factors used in the Chicago analysis were compared to the factors used in this analysis. Chicago estimates fuel savings at $25 per bus per year. This is the same factor that was used in Alternative 1. Chicago's experience with the buses in winter and summer can be instructive to New York City's understanding of battery performance characteristics. The buses were purchased from New Flyer Industries, funded in part by the FTA's TIGGER and Clean Fuels Grant programs. These buses use slow charge batteries that charge overnight. Charging takes between 3 and 5 hours.[55]

London, England

London has purchased several electric double-decker buses from Chinese manufacturer BYD (Build Your Dreams). These buses use slow charging technology, which has been installed in the bus parking facility where charging takes about 4 hours and occurs overnight. According to Transport for London, the double-decker buses augment an electric fleet of 22 single deck buses purchased from Spanish manufacturer Irizar and UK manufacturer Optare.[56] [57]

University Campus Buses

What do the University of Utah (test), the University of Georgia (demo), Stanford University (purchased and operating), and the University of Montana (ordered) all have in common? All of them are either considering or recently purchased electric buses to shuttle students around campus.[58] [59] [60] [61]

[53] "A Cleaner City…" *op. cit.*

[54] Ibid

[55] "Electric Bus." *op. cit.*

[56] Liu, Cecily, *op. cit.*

[57] "More than 50…" *op. cit.*

[58] Opsahl, Kevin. "USU-developed Wirelessly-charged Electric Bus Debuts in Salt Lake City. HJnews. October 30, 2014.

[59] Harris, Nate. "Campus Transit Experiments with Electric Buses, Hopes to Increase Sustainability." Sustainable UGA. October 27, 2015.

[60] Kwiatkowski, Lisa. "Margeurite Goes Electric." Stanford News. October 28, 2014.

[61] Hanley, Steve. "University of Montana Chooses Electric Buses." GAS2. February 7, 2016.

BUS FINANCING

The Federal Transit Authority (FTA) in the U.S. Department of Transportation (DOT) has two grant programs that are potentially available to defray some of the cost associated with the purchase of electric buses as part of the NYC Transit bus fleet. Those programs are the Clean Fuels Grant Program (5308),[62] and the TIGGER Program (see Foothill Transit above). The DOT recently announce that there is $266 million available for these programs.[63]

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[62] "Clean Fuels Grant Program (5308) – Program Overview." U.S. Department of Transportation, Federal Transit Administration. March 16, 2016.

[63] "U.S. Department of Transportation Announces $266 Million Funding Opportunity to Inprove Buse Service Nationwide." U.S. Department of Transportation, Federal Transit Administration. March 19, 2016.

RESULTS / CONCLUSION / SUGGESTIONS

This analysis has shown that although there would be some potential bumps in the road, conversion of NYC Transit's fleet to an all-electric fleet would provide an improvement in overall lifetime bus cost to the city, while reducing greenhouse gases appreciably, and significantly improving the health of NY City residents, and lowering their cost of healthcare.

The overall cost of an electric bus is appreciably higher than the cost of the diesel bus. However, the operations and maintenance cost savings should more than offset the up-front cost differential, and provides a modestly positive business case (excluding healthcare benefit costs). This is because of the lower cost of electricity for an electric bus compared to the cost of diesel fuel for the current buses, as well as the simpler bus power train and other lower maintenance costs for the electric bus. Using Alternative 1 shows savings of about $160,000 over the 12-year lifetime of the bus, with a NPV of $85K associated with the incremental investment, although with a not- very-attractive payback period of 7.69 years. Adding the lower healthcare costs of $100k per bus per year into the equation makes the financial case compelling. The cost of carbon for greenhouse gases can be added to the financial analysis, but the case is really already made without it.

The greenhouse gas savings of nearly 500,000 metric tons per year is large enough that it can help the United States achieve its INDC. That's a lot of greenhouse gas savings. NYC Transit currently has a mix of buses including diesel, diesel hybrid and compressed natural gas. The savings estimates are for a full year, and assume the specific emissions associated with each bus type. The emissions are also comprehensive CO_2e emissions which include not just CO_2 emissions, but CH_4 emissions and N20 emissions, all converted to CO_2e.

New York City should take the first steps towards purchasing electric buses. The financial case closes and the health benefits and greenhouse gas reduction are all sufficiently compelling.

The first step that the city should take is to speak with other cities across the United States and around to world to learn from their experiences. Very few cities really have much experience in this new technology. So getting multiple perspectives from different cities can improve New York City's implementation plans.

NY City Transit should consider purchasing approximately 10 buses from each of at least two different vendors to pilot for a minimum of 1 year. The city has a large fleet, and education and experience with electric bus operations is important before considering a larger rollout. The reason for using a minimum of 2 different vendors is that the vendors each use different technologies. So unless bus manufacturers converge on battery technology and recharging standards, the city will be "wed" to a single bus manufacturer for the foreseeable future. The city will not be able to purchase buses from different manufacturers to run on an existing route. So given the size of the NYC fleet, starting with two vendors, and consideration for additional vendors later on, will ensure future flexibility for the city. The bus manufacturers most often cited in the United States are BYD and Proterra.

The reason for running tests for a minimum of 1 year is to gain experience and understanding in battery performance, which can vary in either hot or cold weather. The tests should also be run on at least two routes that could have significantly different battery requirements based on battery life and recharging time alternatives. This will provide the city with a broader range of experience, which will help as the city decides how to expand the rollout.

Mass Transportation in N.Y. City is considered to be the best in the country and one of the best in the world. There are many complexities and intricacies associated with the conversion of an entire fleet of buses. Given the size of the current fleet and the quality of service currently provided, a transition of this magnitude must be thoughtful. This analysis has examined the economics (financials) of the electric bus alternative as well as environmental impacts (GHG emissions and air pollution). In addition, there has been consideration of potential implementation requirements, issues and recommendations. These perspectives provide input that is important to the decision making process, but are not all inclusive. The decision to make a significant transition to all electric buses should include input from various constituents, an in depth understanding of political considerations, and an understanding of sources of financing. Adoption of the recommendations in this analysis should also be followed by a detailed operational analysis of the steps required for successful implementation to maintain the high quality level of service currently provided by the city. By taking these steps as part of a transition to electric buses, the city will continue to demonstrate transit leadership both in the United States as well as around the globe.

FURTHER SUGGESTIONS & CONSIDERATIONS

The physical cost of an electric bus should be roughly the same as the cost of a diesel bus once scale is reached, with the possible exception of the cost of the battery.[64] The buses are currently considered to be at technology readiness level 7 out of 9 on the path to achieving scale for commercial deployment. The significant difference between bus types is the internal combustion engine (ICE) vs. the electrical components. The electrical components should be less expensive than the ICE, excluding the battery, because the components are less complex. The battery cost is a significant component of the purchase price of the bus. However, battery costs are dropping appreciably over time. As a result, it might make sense for the purchase contract for an electric bus to be negotiated with the battery as a separate cost. The actual battery cost upon delivery could be a markup on an official lithium-ion battery cost standard, as an example. Since battery costs are going down over time, the cost of the buses should come down over time as well.

If they haven't already, Electric bus manufacturers might consider making buses modular to allow for easy replacement and configuration changes for the batteries by the city. This will have a number of advantages, such as giving cities the ability and opportunity to reconfigure buses for use on different bus routes as needed without having to make significant changes, or perhaps needing to purchase additional buses.

Bus manufacturers might also consider "leasing" the batteries to cities for several related reasons. First, the cost of the battery is part of the "fuel cost" of the bus. By spreading out the cost of the battery, the city will more closely match "fuel cost" from the diesel bus, with the equivalent of electricity cost plus battery cost. The reason that this is important is because that more closely matches the budgeting process of the city. The city currently budgets the cost of the bus in the capital budget, and the cost of fuel in the annual budget. Given that cities already have their budgets constructed that way, and given that the lifetime cost of the electric bus is lower than that of the diesel bus, by providing the financials to the city in that fashion, the bus manufacturer eliminates the issue of higher up-front costs for the electric bus, and financial consideration for the return on investment and the payback period. The electric bus becomes straight out less expensive to the city from a financial perspective.

A second consideration related to leasing the battery is that bus battery life is not absolutely clear based on lack of long term experience. By leasing the battery to the city, the bus manufacturer displays partnership with the city by taking on the risk of battery life in the early years of initial rollout and implementation. If the battery lasts the full 12 years of the life of the bus, then the manufacturer is whole. If the battery lasts less than the full 12 years, the manufacturer can replace it (customer is whole and customer is satisfied), and when the bus reaches the end of its natural life, the battery can still be used by the manufacturer in future buses (either in new buses or as a replacement battery), since they would own the battery.

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64 Liu, Cecily, *op. cit.*

APPENDIX

Table 1: Calculation of CO2e Emissions for CO2, CH4, N20, for Existing Buses

CALCULATION OF EMISSIONS						
CO2 Emissions Calculation	Fuel	GHG Emissions	kg CO2 per Unit	Unit	GHG Emissions	MT CO2 Annual
Total K-Gallons of Diesel/year	48,664	Diesel Fuel	10.21	gallon	Diesel	496,861
Total K-GGE of CNG/year	11,650	CNG	6.903515	GGE	CNG	80,429
Total Gallons/GGE	60,315				Total	577,290
CH4 Emissions Calculation	Mileage	Grams Per Mile	CH4		GHG Emissions	MT CH4 Annual
Miles Driven per Month	2,300	Diesel	0.0051		Diesel	0
Miles Driven per Month	2,300	CNG	1.966		CNG	0
					Total	0
N2O Emissions Calculation	Mileage	Grams Per Mile	N2O		GHG Emissions	MT N2O Annual
Miles Driven per Month	2,300	Diesel	0.0048		Diesel	0
Miles Driven per Month	2,300	CNG	0.175		CNG	0
	4,600				Total	0
Conversion to CO2e	-	IPCC	CH4	N2O	GHG Emissions	MT CO2e Annual
		CO2e	25	298	Diesel	496,861
					CNG	80,432
					Total	577,293

Table 2: Calculation of CO2e Emissions for CO2, CH4, N20, for Electric Buses

Annual Electric	Quantity YE 2015	Annual Distance Per Bus (K)	Total Annual (K) Distance	Typical kW-hr per Mile	Electricity Usage MW-hrs	lb. CO2 per MWh	Mtons CO2
Total Buses	5761	27.98	161,212	2.0	322.4	622.42	91.01
for CH4					322.4	0.02381	0.00
for NO2					322.4	0.00280	0.00
CO2e							91.22

Table 3: Alternative 1 – Financial Sensitivity Analysis

Alternative 1 (avg)	Difference in Cost Between Electric Buses and the Current Fleet of Buses Based on Final Prices Negotiated by NYC Transit / MTA					
Category of Cost (annual)	**150,000**	**$200,000**	**$250,000**	**$300,000**	**$350,000**	**$400,000**
Fuel Cost vs. Electricity Cost	25,000	25,000	25,000	25,000	25,000	25,000
Maintenance Savings/bus	14,000	14,000	14,000	14,000	14,000	14,000
Subtotal Savings/year	39,000	39,000	39,000	39,000	39,000	39,000
Payback at Subtotal (yrs)	3.85	5.13	6.41	7.69	8.97	10.26
NPV	$238,206	$188,206	$138,206	$88,206	$38,206	-$11,794
Health Benefits (annual)	100,000	100,000	100,000	100,000	100,000	100,000
Greenhouse Gas Benefits	3,000	3,000	3,000	3,000	3,000	3,000
Total Savings/year	142,000	142,000	142,000	142,000	142,000	142,000
Total Payback (years)	1.06	1.41	1.76	2.11	2.46	2.82
NPV	1,263,469	1,213,469	1,163,469	1,113,469	1,063,469	1,013,469
Notes:	1 - One time implementation cost is included in the bus cost differential					
	2 - $3.00/gallon for diesel, $3.00/GGE for CNG, $.12/kWh for electricity					
	3 - based on Antelope Valley Transit experience					
	4 - EPA Diesel Emissions Quantifier Health Benefits Methodology					
	5 - Cost of Carbon = $36/metric ton, per EPA, 3% discount rate, 2015					
	6 - Assumes no Federal grants					

Table 4: Alternative 2 – Financial Sensitivity Analysis

Alternative 2 (low)	Difference in Cost Between Electric Buses and the Current Fleet of Buses Based on Final Prices Negotiated by NYC Transit / MTA					
Category of Cost (annual)	**150,000**	**$200,000**	**$250,000**	**$300,000**	**$350,000**	**$400,000**
Fuel Cost vs. Electricity Cost	14,000	14,000	14,000	14,000	14,000	14,000
Maintenance Savings/bus	10,000	10,000	10,000	10,000	10,000	10,000
Subtotal Savings/year	24,000	24,000	24,000	24,000	24,000	24,000
Payback at Subtotal (yrs)	6.25	8.33	10.42	12.50	14.58	16.67
NPV	$88,896	$38,896	-$11,104	-$61,104	-$111,104	-$161,104
Health Benefits (annual)	50,000	50,000	50,000	50,000	50,000	50,000
Greenhouse Gas Benefits	3,000	3,000	3,000	3,000	3,000	3,000
Total Savings/year	77,000	77,000	77,000	77,000	77,000	77,000
Total Payback (years)	1.95	2.60	3.25	3.90	4.55	5.19
NPV	616,458	566,458	516,458	466,458	416,458	366,458
Notes:	1 - One time implementation cost is included in the bus cost differential					
	2 - $2.00/gallon for diesel, $2.00/GGE for CNG, $.12/kWh for electricity					
	3 - based on Florida Transit analysis					
	4 - EPA Diesel Emissions Quantifier Health Benefits Methodology					
	5 - Cost of Carbon = $36/metric ton, per EPA, 3% discount rate, 2015					
	6 - Assumes no Federal grants					

Table 5: Alternative 3 – Financial Sensitivity Analysis

Alternative 3 (high)	Difference in Cost Between Electric Buses and the Current Fleet of Buses Based on Final Prices Negotiated by NYC Transit / MTA					
Category of Cost (annual)	150,000	$200,000	$250,000	$300,000	$350,000	$400,000
Fuel Cost vs. Electricity Cost	35,000	35,000	35,000	35,000	35,000	35,000
Maintenance Savings/bus	17,500	17,500	17,500	17,500	17,500	17,500
Subtotal	52,500	52,500	52,500	52,500	52,500	52,500
Payback at Subtotal (yrs)	2.86	3.81	4.76	5.71	6.67	7.62
NPV	$372,585	$322,585	$272,585	$222,585	$172,585	$122,585
Health Benefits	150,000	150,000	150,000	150,000	150,000	150,000
Greenhouse Gas Benefits	40,000	40,000	40,000	40,000	40,000	40,000
Total	242,500	242,500	242,500	242,500	242,500	242,500
Total Payback (years)	0.62	0.82	1.03	1.24	1.44	1.65
NPV	2,263,846	2,213,846	2,163,846	2,113,846	2,063,846	2,013,846
Notes:	1 - One time implementation cost is included in the bus cost differential					
	2 - $4.00/gallon for diesel, $4.00/GGE for CNG, $.12/kWh for electricity					
	3 - based on assumption of 50% improvement					
	4 - EPA Diesel Emissions Quantifier Health Benefits Methodology					
	5 - Cost of Carbon = $36/metric ton, per EPA, 3% discount rate, 2015					
	6 - Assumes no Federal grants					

Table 6: Alternative 1 – Lifetime Cost of Electric Bus vs. Diesel Bus Excluding Healthcare Cost and Cost of Carbon

Lifetime - 12 Year View			
Category of Cost (cost in $)	Electric	Diesel	Delta
Purchase Price	850,000	550,000	300,000
Fuel/Electricity Cost	78,000	378,000	-300,000
Maintenance Cost	252,000	420,000	-168,000
Total Cost	1,180,000	1,348,000	-168,000

Table 7: Alternative 1 – Lifetime Cost of Electric Bus vs. Diesel Bus Including Healthcare Cost and Cost of Carbon

Lifetime - 12 Year View			
Category of Cost (cost in $)	Electric	Diesel	Delta
Purchase Price	850,000	550,000	300,000
Fuel/Electricity Cost	78,000	378,000	-300,000
Maintenance Cost	252,000	420,000	-168,000
Health Care / Cost of Carbon	0	1,248,000	-1,248,000
Total Cost	1,180,000	2,596,000	-1,416,000

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