The Yellow School Bus and Kids' Health: A Social Cost-Benefit Analysis

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A Thesis in the Field of Sustainability and Environmental Management

for the Degree of Master of Liberal Arts in Extension Studies

Harvard University

May 2021

Abstract

Improving the air quality for schoolchildren riding aboard public school buses in Montgomery County, Maryland, has been the goal of this project from the outset. As the school district mulled whether to transition its all-diesel school bus fleet to electric, this research strove to provide policymakers with the analysis necessary to make informed decisions for the betterment of public air quality and children's health. Balancing the health needs of an immediate community and the long-lasting consequences of a changing climate is an issue policymakers are expected to face in their efforts to mitigate climate change. This thesis offers a microlevel look at a Maryland school bus fleet in the beginning stages of replacing its all-diesel bus fleet with electric buses.

The Alternative Fuel Life Cycle Environmental and Economic Transportation (AFLEET) tool was used to calculate the emissions of the diesel bus fleet and projected change in emissions as the diesel fleet transitions to an electric school bus fleet. Marginal damages were calculated using the Air Pollution Emission Experiments and Policy (APEEP) analysis tool for NO_x, SO_2, $PM_{2.5}$, and VOC. Additionally, CO_2 marginal damages were calculated using federal and Maryland Social Costs of Carbon.

The analysis showed that the do-nothing option, that is, replacing aging diesel buses with new diesel buses, would continue to contribute upwards of $275,500 in social costs just from a year's worth of schoolyard bus engine idling; another $793,000 in social costs can be attributed to the annual driving of the buses. The proposed 10- and 15-year

plans of replacing diesel buses with electric was projected to reduce marginal damages significantly. The 10-year plan came with a 38.2% reduction in emissions-based social costs from driving the bus and the 15-year plan came with a 46.3% reduction. In the case of 30 minutes per trip of idling, the phasing out of diesel was similar for both the 10- and 15-year plans, about a 38% reduction. The electric buses, however, revealed significant social costs also, although not ones that directly impact Montgomery County schoolchildren. The results varied widely, depending on whether calculating for a minimal renewable energy scenario or the more progressive one touted by policymakers. In the best-case scenario, and following Maryland renewable energy mandates, social costs for the energy needed to power the electric school bus fleet in the 10-year plan would amount to $56.6 million; in the worst case, with the state unable to purchase renewable energy credits to meet its mandate, its social cost under the 15-year plan was projected to be $129.9 million.

Results revealed a potential conundrum for policymakers. Electric school buses do, indeed, remove ground-level pollutants from the community, sparing schoolchildren from exposure. But a fossil fuel heavy electric grid increases the social costs exponentially, forcing greenhouse gases and other pollutants into other communities. The consequences for the world-at-large could be much more dire if the county and state don’t move aggressively to transform the fossil fuel-heavy energy grid into one that is generated primarily by renewable energy sources. Simply put, the move to electrify the transportation sector is not sustainable without a clean energy grid.

Dedication

To my parents, Maj. Gregory Lucht, retired U.S. Army, and Eva Feneberg Lucht, you taught me the value of an education, no matter our stage of life. Thank you, Mom, for lending me Dad for babysitting duties as I launched my thesis research at Harvard, weeks before the pandemic started. And Dad, thank you for dropping everything and flying across the pond to sit with your toddler grandson all day while I attended class.

To my husband, Nathan Baca: Raising a child takes a village, and this past year, with pandemic restrictions, you and I alone made it work. Together we supported each other's professional pursuits and responsibilities, all the while parenting our wee lad. Without your support, enduring encouragement, and toddler-entertainment skills, none of this would have been possible. You have been a fantastic partner through this journey.

And finally, to my beautiful son, Oliver: When I started my thesis journey, you were beginning to walk. Now you are singing the alphabet and learning to ride a bike. I am so incredibly proud of you. I will fight tirelessly for you and your generation, so that the planet you inherit will be one of health, beauty, and peace. Thank you for inspiring me. All of this is for you.

Acknowledgments

I would like to thank my thesis director, Dr. Thomas P. Gloria, for sharing your expertise and enthusiasm. Your guidance assisted me in framing this thesis and your insightful feedback helped me focus my research and elevate my work.

Thank you to Dr. Mark Leighton, who helped me narrow my research as I started out on my thesis journey. Your guidance allowed me to zero in on a single fleet, and by focusing my research and work on this much smaller area, I have developed a deeper understanding of local sustainable transportation issues.

Thank you to Charles Ewald and Joseph Fisher, Sr. of Montgomery County Public Schools' Department of Transportation for the invaluable data you provided, the foundation of my research. This thesis would have paled in comparison without your assistance.

To Dr. Nicholas Muller of APEEP, and Andrew Burnham of AFLEET, thank you for spending your valuable time answering my questions and offering much appreciated guidance. Your tools are invaluable assets in tackling the climate crisis.

To my academic advisor, Lacey Klingensmith, thank you for encouraging me to finish my degree after I became a new mom. Your guidance paved a path to my completing this thesis.

And to Katherine Lucht and Jonathan Whitten, thank you for your hospitality, and for making my family feel at home while we were in Boston. Fred and George are to be commended for putting up with your persistently cat-curious nephew.

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Chapter I

Introduction

These are unusual times. In response to the 2020-2021 pandemic caused by the widespread coronavirus, COVID-19, the yellow school bus, a mainstay fixture throughout America's roadways, sits idle. School buildings have either shut down completely or have shuffled students in-class time to just a couple of days a week to reduce the potential for exposure. In usual times, American schoolchildren are extraordinarily exposed to toxic diesel fumes as they commute to and from school, and during occasional field trips aboard a school bus. Previous research has shown that elemental carbon, in the form of fine particulate matter ($PM_{2.5}$) to be highly biopersistent (Steiner, Bisig, Petri-Fink, & Rothen-Rutishauser, 2016).

One way diesel exhaust harms human health is through the blood stream. Once diesel exhaust is inhaled, it enters the body's vascular system in the form of particles and gases. The circulatory system then transports these toxins through the blood to the heart, liver, kidneys, bone marrow, nervous system, and skin. This could result in long-term system effects such as cardiovascular diseases, stroke, cancer, and premature aging. Because if the inherent nature of elemental carbon, the toxins released by diesel fumes, including metals, can become lodged in human lungs, leading to long-term health effects, including asthma, chronic obstructive pulmonary disease (COPD), and lung cancer (Steiner et al., 2016). Numerous studies have found a link between cancer and diesel exhaust, which contains carcinogens nitrogen dioxide (NO_2) and sulfur dioxide (SO_2).

Research Significance and Objectives

This research provides perspective toward a necessary component of American rural, suburban, and urban infrastructure. Buses are critical to transporting children to school, providing access to education even in the most rural areas. Montgomery County, Md., where this study takes place, is heavily suburban, and in some areas, urban, with tens of thousands of students exposed to bus fumes every day, pandemic home learning aside. This main significance of this research is to provide policymakers and decisionmakers a valuable tool in determining the most sustainable means to transporting schoolchildren, while creating the least amount of harm to children and the environment.

This research analyzes the environmental and potential health exposures of diesel bus fumes when compared to the emerging electric school bus technology being considered by the school district. The primary focus is the social costs involved in the emissions from diesel buses and the electric grid powering the next generation of school buses. The bus fleet analyzed in this research is operated by the Montgomery County School District in Maryland, the 14th largest school district in the United States.

My research objectives were:

- To quantify the level of emissions schoolchildren are exposed to from school bus exhaust fumes or from the environmental impacts from charging an electric bus.
- To analyze the social costs of each bus alternative.
- To inform policymakers on making quantifiable best choices when determining transportation options for American schoolchildren.
- To develop a guidepost that other school districts might follow as diesel fleets age and need to be replaced.

Background

Diesel emissions are present during students' ride to and from school, along with any field trips they might take on a school bus. The inherent function of a standard diesel engine causes toxic fumes to be drawn into the microenvironment of a school bus cabin during operation. The engine can be responsible for a fair share of in-cabin pollutants stemming from the crankcase ventilation system, which is designed to remove gases and evaporated engine oil. Leakage of these fuel and engine gases can end up in the passenger cabin, exposing children to the pollutants.

Children's Health Effects of Exposure to Diesel Fumes

In a study of 275 schoolchildren aged 6 to 12 years in the Seattle-Tacoma, Washington area, lung function improved among children who were riding diesel-powered school buses once ultra-low sulfur diesel was used to fuel their buses. In addition, lower levels of $PM_{2.5}$ were found inside the bus cabin during children's commute after buses were retrofitted with emission-reducing tail pipes (Adar et al., 2015). An earlier study found that a school bus's cabin is susceptible to emission toxin contamination by following another bus or from its own self-pollution (Sabin et al., 2005).

Children's exposure to the particulates present in diesel fumes can negatively impact lung growth and cause asthma or other airway diseases caused by airborne pollution (Pattison & Shea, 2007; Lin, Zhang, & Diaz-Sanchez, 2007). In addition, diesel emissions contain known carcinogens (Steiner, et al. 2016) and have been classified as a group 1 carcinogen. Diesel emissions have been shown to cause lung cancer in humans, and there is limited evidence it might also cause bladder cancer (IARC, 2012). Repeated exposure to CO has been shown to affect not only children's health, but also students' educational outcomes, as pollution-related illnesses cause increased absences from the classroom (Currie, Neidell, & Schmieder, 2009).

Many diesel engines have been retrofitted to reduce children's exposure to diesel fumes, but lower amounts are still being emitted into the environment. Picture, if you will, the end of a school day. The bell rings, students grab their backpacks and pour outside. The children who ride the bus wind their way through the line of buses idling their engines, the exhaust pipes near ground level, spewing fumes into the air. The children, breathing in the toxic air, climb aboard their buses to head home for the day. As the bus caravans off the school lot, closely following other buses, more fumes enter the cab. Unless windows are opened, the children and bus driver inhale the trapped fumes. At the end of their bus ride, the children disembark and wait on the curb to cross the street, breathing in more exhaust as the bus pulls away.

Electric Schoolbuses

For many passengers, electric buses are green, clean machines. Considering electric buses have no emissions coming from a tailpipe, the assumption is understandable. And for urban dwellers concerned with cleaner city air, they might be right, but not without some caveats. For instance, although EV buses have been shown to have a lower GWP than propane buses, they also cannot carry as much weight. This consideration might be important for high passenger count bus routes, though younger children's lighter weight might allow for more flexibility on the issue (Tong, Jaramillo, & Azevedo, 2015). When comparing the life cycles impacts of internal combustion engines to electric vehicles, the electric alternative does contribute least to smog formation, or photochemical oxidation formation potential (POFP), with a reduction of 22% to 33% when compared to the ICEVs during both vehicles' use phase (Hawkins, Singh, Majeau-Bettez, & Stromman, 2013).

LCA of School Buses with Different Power Options

Life cycle assessment (LCA) is a tool that allows the practitioner to assess the impact a product or system has from its inception to when it is discarded or no longer functioning. Commonly referred to as cradle-to-grave, LCA provides an overarching view of a product's environmental impacts. Life cycle impact assessment (LCIA) requires two steps: classification and characterization. The first step, classification, requires the practitioner to assign inventory flows to impact categories (Ryberg, Vieira, Zgola, Bare, & Rosenbaum, 2014). Take a diesel bus, for example, as illustrated in Figure 1. One such inventory flow might be the extraction of raw materials for the production of diesel fuel for the bus's use phase.

A recent comprehensive LCA went beyond tailpipe emissions and considered the fuel sources needed to power electric, natural gas and diesel buses, among others. Unsurprisingly, electric buses were revealed to have no emissions for three out of four pollutants, and the PM emissions stemmed from tires and braking during use. Electric buses did measure significantly higher in SO_2 due to the U.S. energy infrastructure's dependency on coal and natural gas. The study found electric to also use a considerable amount of water because of the energy structures' reliance on nuclear power and coal, which both are dependent upon water. However, when comparing electric buses to the other primary fuels, diesel and compressed natural gas, electric fares better than either in CO, NO_x, and PM_{10} (Ercan & Tatari, 2015) (Figure 2).

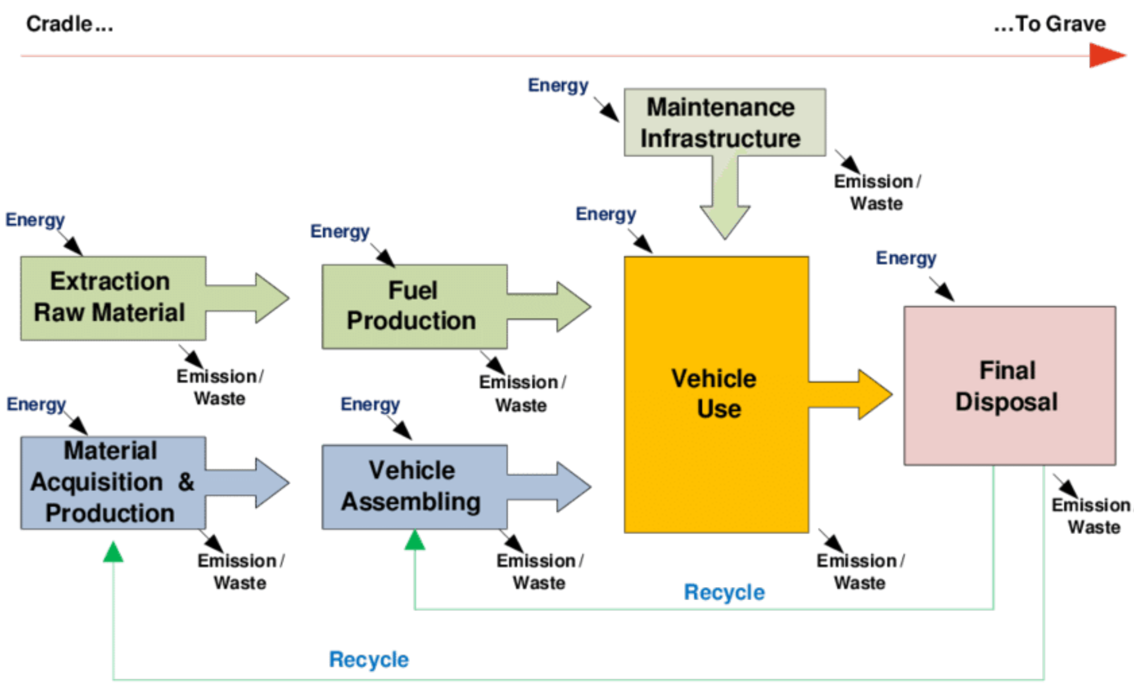

Figure 1. Basic vehicle life cycle model.

Life cycle model begins with the extraction of raw material, includes the production of fuel and use of the vehicle, and ends with the disposal of the vehicle at the end of its life (Vaughan, Faghri, & Li, 2017).

One could argue that should the American energy infrastructure continue to evolve toward renewable energy sources, the environmental impacts of electric buses would be further decreased. Evaluating the overall relative health benefits of electric school buses requires examining the energy mix in the power grid.

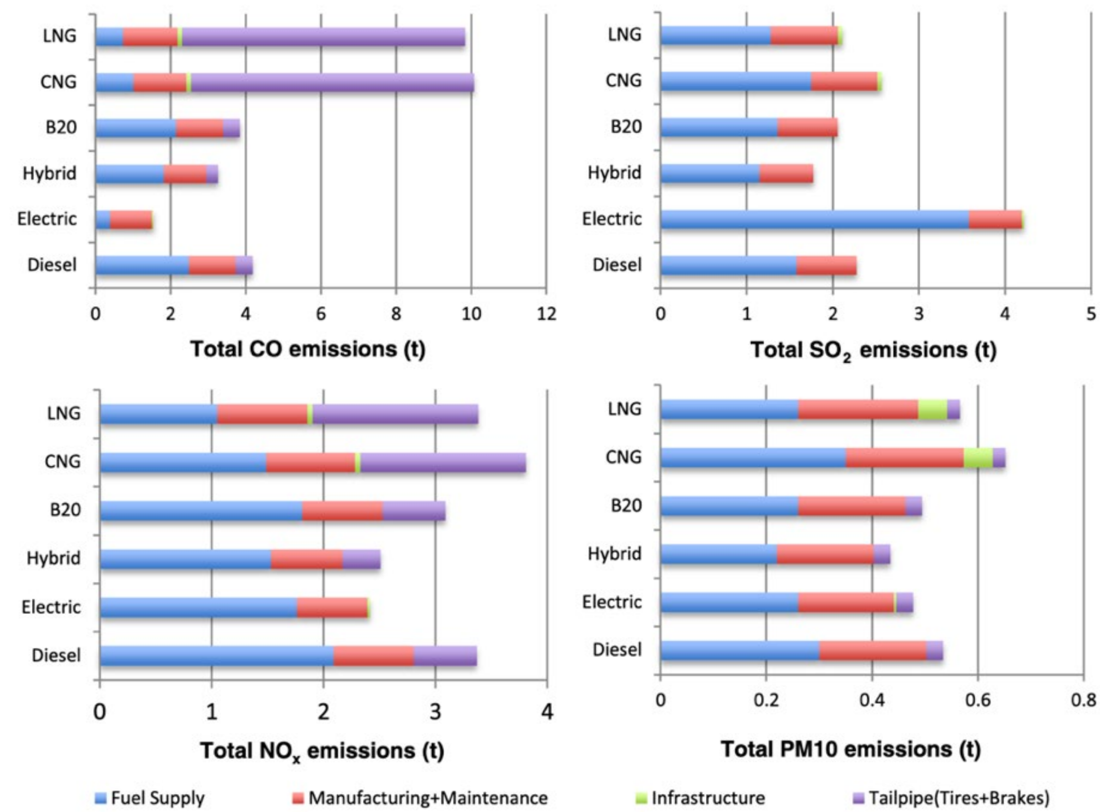

Figure 2. Pollutants over a bus's lifetime.

Diesel and electric lifetime emissions. Focus on this study is on tailpipe and infrastructure, purple and green, respectively (Ercan & Tatari, 2015).

Maryland Renewable Energy Standard

Maryland's electricity grid is currently supported by 11% renewable energy; the primary sources of electricity generation are natural gas-fired (1,777 thousand MWh), nuclear (1,299 thousand MWh), and coal-fired (898 thousand MWh) (U.S. EIA, 2020). In 2019, the state increased its Renewable Energy Portfolio Standard, setting a goal of drawing 25% of electricity for retail purposes (homes, businesses) by 2020. It further established a 2030 goal of 50% renewable energy, including 14.5% from solar and 1,200 MW from offshore wind (Sadzinski, 2019). Maryland's sole nuclear power plant, Calvert

Cliffs, provides 34% of the state's energy needs. The plant's two reactors were commissioned in the mid 1970s; its renewed licenses expire in the mid-2030s (U.S.NRC, 2020).

Maryland's current governor, Larry Hogan, has expressed support for a 100% renewable energy standard by 2040 (Dance, 2019). During the previous Trump Administration, efforts were made to reverse advances toward a renewable power grid, with more emphasis put on fossil fuel-based power, especially oil, natural gas, and coal. The Biden Administration has re-entered the United States into the Paris climate accords, which reestablishes the U.S.'s intent to move away from fossil fuels and focus more on renewable energy. President Joseph Biden also re-established a working group that focuses on the social costs of greenhouse gases (Kavi, 2021).

The School Bus Fleet of Montgomery County

The Montgomery County School District (MCPS), the largest in Maryland, is no exception to relying heavily on diesel buses. As of 2020, the fleet numbered 1,447 diesel-powered buses used to transport 103,000 students to more than 200 schools throughout the county on a daily basis, including special schools in neighboring Virginia and Washington, D.C. In a single day, these buses travel 112,000 miles; in the 2016-2017 school year, nearly 20.3 million miles were traveled (Fisher & Ewald, 2020)(MCPS, 2020). The boundaries of school bus pickups, with the exception of special needs students, are as follows: elementary school – 1 mile; middle school – 1.5 miles; high school – 2 miles (MCPS, 2019).

The student body attending the Montgomery County school system is diverse. As of the 2018-2019 school year, the student body was made up primarily of 32%

Hispanic/Latino, 28% White, 21% Black, and 14% Asian, with 35% of students participating in a free and reduced-price meals program (MCPS, 2018). In regard to children's health, the prevalence of asthma for Black children under the age of 18 is 2.5 times higher than that of Hispanic, Asian, and White children in the same age group, at 14.3% Black, 8% Hispanic, 3.9% Asian, and 5.6% White; moreover, the hospital admissions rate for asthma of Black children ages 2 to 17 was 216.5 per 100,000 for asthma, compared to 41.9 per 100,000 for White children. The death rate from asthma for Black children ages 0-17 was 9.2 per 100,000, compared to 1.3 per 100,000 for White children (HHS, 2021).

Before the pandemic, the Maryland Legislature was considering two bills that would require the state's school districts or their contractors to buy electric school vehicles beginning in 2024 or 2027, respectively. These bills did not restrict the continued use of diesel buses until they age out of the system. One of the bills passed the Maryland House of Delegates, but was adjourned sine die (Maryland State Legislature, 2020), meaning it has been adjourned indefinitely by the Maryland State Senate. It should be noted that the governor stated he would not sign any new legislation that would increase Maryland state expenditures not related to the pandemic response (Wood & Broadwater, 2020) (Maryland State Legislature, 2020).

One of the bills would have required school districts to replace aged-out diesel school buses with electric ones beginning in 2024. A common concern among the state's school districts was not only the increased cost of an electric bus over a diesel one – an estimated $340,000 vs. $90,000 – but infrastructure retrofitting costs, land purchases for charging stations, and more bus drivers and a larger fleet to account for electric buses' shorter mileage range. Montgomery County estimates the proposed bill would cost its school district an additional $4 million per year, assuming 120 buses are replaced annually and are financed over six years. The county has also expressed concern that because electric buses are a newer technology, supply might not be able to meet demand (Fraser-Hidalgo et al., 2020).

For comparison's sake, the Maryland Transit Authority (MTA) owns and operates 775 public transit buses that are either 40-ft long or the extra-long 65-ft long variety. The state's general assembly had considered a bill that would have required the purchase of electric buses beginning in 2023, estimating that it would cost the state about $20.6 million to buy 70 new electric buses annually.

Costs of Replacing Diesel Buses

Replacing diesel school buses is a costly endeavor for school districts, leading to bus fleets around the country averaging 16.2 years for large buses and 14.6 years for small buses (McMahon, 2017). In Montgomery County, the bus fleet averages 15 years (Fisher & Ewald, 2020). A diesel bus costs $50,000 less than a natural gas bus, and a hybrid electric diesel bus costs an additional $25,000 over the former (Clean Energy Fuels, 2020).

In 2019, MCPS was awarded a state grant of $349,000 to purchase a new electric bus and a battery charger. Other counties were also awarded funds to make similar purchases; neighboring Frederick County was also granted funds to purchase 22 propane-powered buses (Apperson, 2019). Under state of Maryland regulations, the first item in a section titled Routing and Operating Procedures, states the "prime consideration is the safety of riders" (Md. Code of Regulations State Board of Ed. §13, 1975). Obviously, at the time of the code's writing, the harmful effects of diesel fumes were not yet understood. It can be assumed the code was alluding to the immediate physical safety of the buses' passengers; however, as ongoing research continues to uncover diesel's harmful effects to those who inhale its fumes, the long-term "safety of riders" should perhaps also be considered by policymakers. However, in April 2020, Maryland Governor Larry Hogan instituted a spending freeze and moratorium on all nonessential programs in response to the ongoing COVID-19 pandemic. It is unclear when or if these transportation funding programs will be reinstated.

Table 1 compares the estimated difference in cost of a diesel bus to an electric bus. In the case of a standard 40-ft bus, a similar length to the average school bus, the state expects to pay nearly $400,000 more for a single bus and the necessary battery charging equipment (Korman et al., 2020). That bill, too, is adjourned sine die (Maryland State Legislature, 2020).

Table 1. Maryland cost estimates of diesel vs. electric buses.

Estimated MTA Purchasing Cost
Diesel Bus vs. Electric Bus

	Cost Per Diesel Bus	Cost Per Electric Bus	Difference
40' Bus	$570,000	$850,000	$280,000
Charging Equipment	0	98,750	98,750
Total	**$570,000**	**$948,750**	**$378,750**
60' Articulated Bus	$840,000	$950,000	$110,000
Charging Equipment	0	98,750	98,750
Total	**$840,000**	**$1,048,750**	**$208,750**

In the meantime, school buses have been parked as classes have been suspended and students have been ordered to stay at home through at least spring 2021, as of this writing (Maryland State Department of Education, 2020). Some students in kindergarten through third grade have returned to school as of March 15, but others remain in virtual classrooms.

Before the pandemic, few initiatives had been undertaken to alleviate the amount of fumes emitted by MCPS school buses as part of daily practice. Maryland initiated a voluntary anti-idling program to encourage buses and other vehicles waiting in school yards to shut down their engines while waiting. Of the 1,300 schools in the MCPS school system, only six schools – one middle school and five elementary schools – have set up a vehicle idling policy (Maryland Department of the Environment, 2020).

At the Montgomery County School District, the average school bus is driven 19,000 miles annually. On a daily basis, the buses are in service an average of seven hours per day, Monday through Friday (Fisher & Ewald, 2020). Determining the best bus alternative for transporting children to and from school is more than a matter of the financial cost of replacement, or the immediate environmental effects.

A broader analysis of major environmental impacts needs to be weighed with the long-term human health impacts as a cost-benefit analysis. In this study, the primary goal is to accentuate schoolchildren's daily exposure to toxic emissions via ground level tailpipes, brakes, and tire wear. Emissions from a tailpipe or a braking bus will affect still-developing children's bodies more acutely than a coal plant miles away that supplies the electricity to run an electric school bus.

Research Questions, Hypotheses and Specific Aims

My research addressed the following questions and hypotheses:

Which bus alternative is the least harmful for long-term children's pollutant exposure during its use phase?

H1: An electric school bus will be the least harmful to children during its use phase.

Which bus alternative is revealed to have the most positive cost-benefit when considering children's mortality and health factors in the use phase and the environmental impacts during the entire life cycles?

H2: Electric buses are a beneficial alternative to replace diesel-powered buses, but until battery technology is updated, propane powered buses are the best option when considering children's health and the environmental impacts.

To test these hypotheses, I quantified the environmental impacts of electric and diesel buses during their use phase (transporting students to and from school) and during idling while awaiting student boarding, along with the impacts on charging electric school buses.

Chapter II

Methods

The primary focus of this study was to quantify the impacts that shifting to an all-electric school bus fleet will have on children's health through the use of marginal damages. A comparative analysis of the use phase found in Life Cycle Impact Assessments (LCIA) on the school bus fleet was conducted using AFLEET (Alternative Fuel Life-Cycle Environmental and Economic Transportation Tool), with a consideration of the current and planned source make-up of the region's electric grid. The environmental impact of an electric school bus was compared to that of a diesel engine school bus. Although not within the scope of this study, a comparison of well-to-wheel impacts by the bus options is recommended due to concerns that electric fuel batteries are more harmful to the environment from the mining and manufacturing of fuel cell batteries, such as lithium-ion batteries, which is an energy-intensive process.

The analysis of potential harm to children's health as it relates to school bus transportation required the creation of a model that analyzed the amount of potential exposure children have while riding a school bus on an annual basis (diesel vs. electric) or being exposed to idling bus exhaust. A cost-benefit analysis considered social costs of the most common pollutants emitted by diesel buses, the marginal damages of which impact children's mortality.

AFLEET

Greenhouse gases, air pollutant emissions, and diesel fuel use were calculated using the AFLEET Tool, available through the U.S. Department of Energy's Clean Cities Program. AFLEET characterizes a school bus as a heavy-duty vehicle that has a capacity of 15 or more people used to transport students to school. Inputs included bus fleet size, fuel makeup of the fleet, miles traveled annually, average miles per gallon, and average cost per bus. Data specific to MCPS were inputted into AFLEET's background data in the Excel spreadsheet. Much of the data provided in AFLEET remained the same; however, school district provided information (i.e., average costs of buying a diesel or EV bus) was changed in the background data section to more accurately reflect the bus fleet.

The school bus emission modelling system information was based on the EPA's Motor Vehicle Emission Simulator (MOVES) (Burnham, 2019). Sources of emissions included in MOVES (and therefore, AFLEET) include tailpipe, brakes, and tire wear (EPA, 2020). By design, AFLEET only accounts for the vehicle operation stage when calculating air pollutants (Burnham, 2019). The MCPS provided data included in the AFLEET model consisted of 1,447 diesel-fueled buses in its current fleet. This study assumed all buses are used during the school year when school is in session. Tire and brake wear is largely reflected in PM10 and PM2.5, although AFLEET does not itemize the sources of individual pollutants.

The pre-pandemic student passenger count was used as the baseline for the 10-year and 15-year scenario Excel tables that forecast the number of diesel busses in the fleet. The assumed decrease in students riding the school buses was determined by dividing the baseline (103,000) by 10 or 15 and substracting from the previous year, until zero students were riding a diesel bus (Table 2). To illustrate, if the baseline is b,

$$b - \left(\frac{b}{12}\right) = b2, then\ b2 - \left(\frac{b}{15}\right) = b3, and\ so\ on.$$

Table 2. Assumed student passenger count aboard diesel buses for the 10- and 15-year scenarios.

Year	Diesel buses in use	Avg. number of students riding diesel bus
1	1447	103,000
2	1303	92,700
3	1159	82,400
4	1015	72,100
5	871	61,800
6	727	51,500
7	583	41,200
8	439	30,900
9	295	20,600
10	151	10,300
Final year	0	0

Year	Diesel buses in use	Avg. number of students riding diesel bus
1	1447	103,000
2	1351	96133
3	1255	89266
4	1159	82399
5	1063	75532
6	967	68665
7	871	61798
8	775	54931
9	679	48064
10	583	41197
11	487	34330
12	391	27463
13	295	20596
14	199	13729
15	103	6862
Final year	0	0

AFLEET Data Inputs

Calculations derived from the On-Road Fleet Footprint Calculator were analyzed to determine the level of air pollutant emissions estimated from MCPS's use of diesel school buses during the course of a traditional school year. In addition, the Electric Vehicle Charging Calculator and the Idle Reduction Calculator were used to determine the GHG and air pollutant benefits of switching to an EV charging system and the reduction of emissions through a reduction in engine idling, respectively.

The number of charging stations at each depot was determined by MCPS's stated preference in DC fast charging infrastructure, the hours a bus is away from its depot (Fisher & Ewald, 2020) and the 3 hours needed to fully charge a bus that can run 120 miles (Thomas manufactured buses). In general, most MCPS buses leave their depot at 6 am, returning at 9:30 am. Those buses then depart again at 1:30 pm and return to the depot by 5 pm. This allows for four (4) charging time slots: One midmorning between 9:30 am and 1:30 pm, and 3 between the hours of 5 pm and 6 am. In AFLEET Inputs, "high" usage was selected. An assumed annual replacement of 144 and 96 diesel buses for electric buses over 10 and 15 years, respectively, was reflected in the charging input, amounting to a total of 1,447 buses (Table 2).

The diesel in-use emissions multiplier was selected in the Input Sheet under Petroleum Use, GHGs and Air Pollutant Calculation Options (Appendix 1). This is to account for higher emissions for actual vehicle operation rather than laboratory certification results. The only change to the footprint output was a doubling of NOx emissions when diesel in-use emissions was selected. This is due to emissions entering the bus cabin through the engine crankcase vent, a common occurrence with diesel vehicles. This is the primary source of NOx, and is a precursor to $PM_{2.5}$ entering the cabin (Clean Air Task Force, 2005).

Financial assumptions, such as loan terms, were not considered, and I assumed that the school district would be purchasing the buses outright. At the time of this writing, MCPS was actively reviewing Requests for Proposals (RFP) to have an outside vendor manage the district's transition as a turnkey operation to convert to an all-electric fleet within 10 years.

Electrical Grid

When determining the makeup of Maryland's electrical grid, several factors had to be considered. The state has a renewable energy requirement of 30.5% by the year 2020; however, when reviewing Maryland's actual energy generation, it only generates a fraction of its electricity from renewable sources. To make up for its lack in electrical generation, and to meet mandated renewable energy goals, renewable energy is purchased from neighboring states.

Maryland's primary sources of electricity generation are natural gas and nuclear power (Figure 3). The state buys renewable energy credits, which includes a solar carve-out, to make up the difference and meet the state's renewable energy portfolio goals. By 2030, the renewable energy requirement increases to 50%.

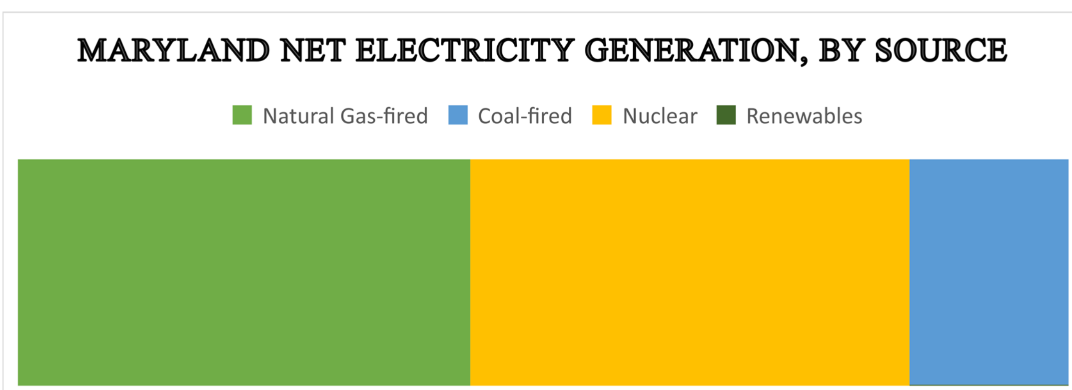

Figure 3. Maryland net electricity generation.

The generation is as follows (in MWh): Natual gas-fired, 1,329; Coal-fired, 465; Nuclear, 1,290; Renewables, 181. Data current as of Aug. 2020. (U.S.EIA, 2020).

In building the AFLEET models, to best reflect the electrical grid that would be powering the school buses, I chose to customize the electric source mix, in addition running the scenarios following the regional electrical generation model set up by AFLEET, which has the Maryland area generating just 5% in renewable energy. By customizing the electricity source, I could input forecasted electricity generation based on state requirements, and adjust the generation of coal, natural gas, and nuclear power. By 2030 – the end of our 10-year model – Maryland has mandated that 50% of its electricity come from renewable sources. The 10- and 15-year models have been built to reflect that future requirement, with a natural progression from 25% to 50% from 2020 to 2030. Taking into account the governor's progressive call for 100% renewable energy by 2040, I have adjusted the 15-year plan accordingly. In order to reach a 30.5% threshold for renewable energy for 2020, I reduced the other primary sources of electricity (natural gas, coal, and nuclear) by 26.5% across the board. In doing so, I assumed the electric grid as of 2021 will be as follows: natural gas, 29%; coal, 10%; and nuclear power, 30%. The following formula computed the reduction, with a, b, and c representing natural gas, coal, and nuclear power, respectively, and the percentage point reduction as x:

$$(a * x) - a$$

I followed this by calculating the corresponding increase in renewable energy by adding the sums of a, b, c to the baseline renewable energy of 181 MWh (from 2020):

$$(a * x) + (b * x) + (c * x) + 181$$

The tables detailing the composition of the assumed electrical grids are in Appendix 2. Considering that Maryland generates only a fraction of its renewable energy, and the growing demand for energy and electric vehicles, a baseline energy model of 5% renewable energy was also built, to reflect the social costs of GHG emissions and other pollutants if Maryland is no longer able to buy renewable energy credits to offset its fossil fuel and nuclear energy generation.

Social Cost of Emissions

The social cost analysis was performed to determine whether the increased costs of an electric bus are offset by the benefits of no-emission travel for school children, or if the benefits are negligible and maintaining the status quo of a diesel-powered fleet is the ideal path forward. All totals have been calculated for net present value, with a social discount rate of 3%.

Marginal Damages

In Holland, Mansur, Muller and Yates (2016), marginal damages are described as the estimated dispersion of pollutants across a county, in this case, Montgomery County. The Air Pollution Emission Experiments and Policy analysis tool, or APEEP, is an integrated assessment model that allows for the calculation of marginal damages of the following exhaust emissions: NOx, PM2.5, SO2, and VOCs. In the study, marginal damages were calculated for electric and gasoline-powered passenger cars, but not vehicles running on diesel fuel (Holland et al., 2016). They found that although electric vehicles have relatively no emissions at the point of operation, its wider, or global impacts, depended on the electric grid mix. Their research revealed that 91% of the emissions caused by powering an electric car – power plants, for instance – were exported to other states, whereas a gasoline powered car exports just 19% of its emissions to other states, through such factors as the wind blowing pollutants away into other counties. Because diesel and gasoline-fueled cars operate in similar manners, I assumed gasoline and diesel point-of-use emission exports are the same.

The calculations do not consider the emissions caused from producing fuel or manufacturing vehicles (Holland et al., 2016). For this research, I assumed that many of the components of an electric school bus are the same as a diesel-powered one; for instance, the body, frame, interior seats, brakes, and wheels, are comparable or identical to each other. An obvious caveat is the manufacturing of batteries large enough to power electric school buses, which do have negative environmental benefits, and deserve to be mentioned. Considering that battery technology continues to evolve, as is renewable energy and fossil fuel production, it was outside the scope of this study.

Ground-level marginal damages were calculated using data specific to Montgomery County. This allowed for the marginal damages of SO2, NOx, VOC, and PM2.5 to be calculated to better understand the effects of local ground-level emissions (Holland et al., 2016). The marginal damages were in year 2000 dollars, converted using the Bureau of Labor Statistics inflation calculator, from January 2000 to November 2020 (BLS, 2020) (Table 3).

In addition, the diesel bus emissions from the two scenarios were converted from lbs. to short tons using the formula, $lb/2000$. In the case of carbon, the short tons were converted to metric tons to comply with the social cost of carbon being used in this study.

Calculating Social Cost of CO_2

Carbon dioxide (CO_2) is the primary pollutant that makes up GHG emissions, comprising of 81% (EPA, 2020). Calculating the Social Cost of Carbon (SC- CO) was a

Table 3. Pollutants' marginal damages per ton.

Ground-level marginal damages for Montgomery County, Md. per ton (in 2000$)					
fips	NH3_2011	NOX_2011	SO2_2011	VOC_2011	PM25_2011
24031	450250	2569.4	100460	24321	245056
Nov 2020 dollars	694,123.86	3,961.09	154,873.25	37,494.25	377,788.38
Sources: (Holland, Mansur, Muller, & Yates, 2016) (BLS, 2020)					

FIPS is the county-specific code for Montgomery County, Md. The BLS calculator was used to determine the current dollar worth of the pollutants' marginal damages at the ground level. Marginal damage data sourced from Holland et al., 2016. Bureau of Labor Statistics Inflation Calculator used to determine 2020 dollars.

tricky venture, since the calculation is mired in political influences pulling to either increase or lessen the debated cost-of-damage caused by this formidable greenhouse gas. The value can vary significantly depending on the model used.

Initially, this study undertook an updated version of the Dynamic Integrated Climate-Economy (DICE) model by Haensel et al., 2020 to account for the SC-CO since CO_2 is not factored into the APEEP model. The Haensel version of the DICE model used the higher pathway of 2ºC climate mitigation to calculate SC-CO and placed a higher emphasis on future generations (such as the schoolchildren of this study, and beyond) by using a lower social discount rate, which it established through a survey of 173 experts on discounting parameters. The median expert view set the SC-CO at $101 in 2020. In addition, this model meets the UN Climate Paris Agreement temperature targets of 2º Celsius by 2100 (Haensel et al., 2020). This is more than a dozen times higher than the SC-CO established under the previous Trump Administration, which set the SC-CO at

$7, a reduction from a previous estimate and considered politically controversial (Nuccitelli, 2020; Templeton, 2020).

One of the first actions of the Biden Administration was to form an Interagency Working Group on the Social Cost of Greenhouse Gases. The SC-CO, and other pollutants would take into account global damages, including human health (Biden, 2021). The administration also rejoined the Paris climate accord. An interim SC-CO was released by the working group in late February 2021, following the values established in 2016 by a previous interagency working group, adjusted for inflation (Table 4) (Interagency Working Group on Social Cost of Greenhouse Gases, 2021).

The State of Maryland follows a more progressive SC-CO, valuing a ton of carbon at $110, following standards previously established by the U.S. EPA (Maryland Dept. of Natural Resources, 2021). Considering the buses operate in Maryland, the $110 per ton of carbon value was also included in this study as the primary value used.

Table 4. Social Cost of CO_2

	Discount Rate		
Emissions Year	5% Avg.	3% Avg.	2.5% Avg.
2020	14	51	76
2025	17	56	83
2030	19	62	89
2035	22	67	96
2040	25	73	103
2045	28	79	110
2050	32	85	116

The values are in 2020 U.S. dollars per metric ton and allow for three scenarios via the discount rate. It is unclear, and therefore assumed, that these values also follow the higher climate mitigation standard of 2ºC. The expanded table for all years in this study's research can be reviewed in Appendix 5. Source: (Interagency Working Group on Social Cost of Greenhouse Gases, 2021).

Greater emphasis is now being placed on the 1.5ºC warming mitigation threshold to contain the worst effects of climate change on the planet; as such, an additional second SC-CO was sought to better understand the impacts a conversion to an all-electric bus fleet would have; however, such a value is not readily available.

To calculate the amount of CO_2 stemming from school bus emissions for the two scenarios, I first compiled the GHG data from the AFLEET model. Because CO_2 comprises 81% of GHG emissions, I then calculated $x * 81$, x being GHG. As demonstrated in Table 5, this allowed me to later calculate the Social Cost of CO_2 (SC-CO_2) using the aforementioned values.

Table 5. Results of GHG to CO_2 calculation for 10- and 15-year plans.

Potential annual schoolchildren CO2 exposure to riding diesel buses (in short tons) (Ten year plan)		
Year	**GHG**	**CO2=GHG *.81**
1	99.90	80.919
2	90.2	73.062
3	80.4	65.124
4	70.7	57.267
5	61	49.41
6	51.2	41.472
7	41.5	33.615
8	31.7	25.677
9	22	17.82
10	12.3	9.963
Final year	0	0

Potential annual schoolchildren pollutant exposure to riding diesel buses (in short tons) (15 Year Plan)		
Year	**GHG**	**CO2 = GHG*.81**
1	99.9	80.919
2	93.3	75.573
3	86.6	70.146
4	80.1	64.881
5	73.5	59.535
6	66.9	54.189
7	60.4	48.924
8	53.8	43.578
9	47.2	38.232
10	40.7	32.967
11	34.1	27.621
12	27.5	22.275
13	21	17.01
14	14.4	11.664
15	7.8	6.318
16	0	0

Ten- (l) and 15-year scenarios. Year 1 is the baseline for both scenarios.

Social Cost of a Diesel School Bus

Estimating the social cost of a diesel-powered school bus followed a multistep process of compiling emission data, converting it from pounds to short tons, calculating the marginal damages per each pollutant, and calculating NPV (Appendices 3-5). The same process was performed to calculate the annual DC charging output for energy use and emissions benefits scenarios (Table 6). The corresponding tables are in Appendix 3.

Table 6. Annual charging output of GHG for 10- and 15-year plans.

Annual DC charging calculator output - 10 year plan		
Energy use and emissions benefits		
Year	GHG	CO2 = GHG*.81
1	0.00E+00	0.00E+00
2	1.38E+04	1.12E+04
3	2.78E+04	2.25E+04
4	4.24E+04	3.43E+04
5	5.65E+04	4.58E+04
6	7.10E+04	5.75E+04
7	8.66E+04	7.02E+04
8	1.02E+05	8.23E+04
9	1.17E+05	9.45E+04
10	1.32E+05	1.07E+05
Final	1.46E+05	1.18E+05

Annual DC charging calculator output - 15 year plan		
Energy use and emissions benefits		
Year	GHG	CO2 = GHG*.81
1	0.00E+00	0.00E+00
2	9.02E+03	7.31E+03
3	1.82E+04	1.48E+04
4	2.78E+04	2.25E+04
5	3.71E+04	3.01E+04
6	4.67E+04	3.78E+04
7	5.69E+04	4.61E+04
8	6.68E+04	5.41E+04
9	7.67E+04	6.21E+04
10	8.67E+04	7.03E+04
11	9.74E+04	7.89E+04
12	1.08E+05	8.73E+04
13	1.18E+05	9.57E+04
14	1.30E+05	1.05E+05
15	1.41E+05	1.14E+05
Final	1.51E+05	1.22E+05

Final column in each table shows the amount of CO_2 in short tons.

Social Costs of Bus Emissions

The pollutants assessed for their marginal damages were NO_x, $PM_{2.5}$, VOC, and SO_2, using APEEP data. Although APEEP also allows for a physical accounting of ammonia (NH_3), it is not regulated and did not factor into the AFLEET results, and therefore was not considered in this study.

The two primary categories of social costs from bus emissions considered were the bus in motion as it transports children to and from school, and the bus idling in the school parking lot with its engines running. As a reminder, APEEP does not provide a social cost of carbon, and as such, CO_2 is calculated using another methodology.

Social Cost of Riding a Diesel Bus

Children represent a sizeable portion of Montgomery County's population at 23.1% of the estimated 1.05 million people residing in the county (U.S. Census Bureau, 2019). Of those, 103,000 children ride the bus to school when distance learning in not in effect (Fisher & Ewald, 2020). To calculate the potential social cost from riding a school bus (SCd), it was first necessary to calculate the percentage of children riding the school bus against the general population:

$$\frac{Kids\ riding\ bus}{general\ population}$$

This allows for the establishment of the baseline of 10% (0.098) of the county's population riding the school bus under normal circumstances. Bus drivers were not considered in this study. For simplicity's sake, the baseline was used to reduce the number of children exposed to diesel bus emissions as the buses are replaced with electric ones (Table 7).

The social cost of a diesel bus (SCd) was calculated by multiplying pollutants (P) and the individual marginal damages (MDp), then dividing by the percentage of students exposed (KidsBaseline):

$$SCd = (P * MDp) * KidsBaseline$$

The individual calculations for each pollutant, per year, were then summed together to result in an annual social cost of emissions per child. The calculations were performed for both scenarios, with the first year being the baseline (Table 7).

Table 7. Potential share of emission exposure to children.

Year	Kid exposure 10 year	Kid exposure 15 year
1	$79,339	$77,752
2	$63,380	$67,595
3	$50,000	$57,464
4	$38,539	$47,739
5	$28,629	$39,444
6	$20,341	$31,578
7	$14,027	$25,268
8	$8,911	$19,355
9	$5,100	$14,645
10	$2,028	$10,684
11		$7,577
12		$4,817
13		$2,820
14		$1,258
15		$368
Final	$310,294	$408,365
NPV	$290,827.71	$372,360.89

Social Cost of Bus Idling

When children walk through the school bus loading zone to board their buses home, they are exposed to, on average, 30 minutes of emissions from waiting buses idling with their engines' running. Reasons to idle might be attributed to heating and cooling desires, keeping the engine warm, and operator habit.

In the Idle Reduction Inputs section of AFLEET, the proposed electric bus fleet was compared to the currently operating bus fleet. Annual conventional idling hours were estimated at one hour per school day in the afternoon, reflecting common assumptions of school bus drivers practice and state and federal efforts to reduce idling (Anderson & Glencross, 2009). Maryland requires a minimum of 180 school days, so the per vehicle annual idling hours was set at 180 hours. Alternative scenarios were also calculated for 10 and 20 minutes per trip, or 20 and 40 minutes per day, equaling 60 and 120 hours per bus annually of idling emissions, respectively.

The AFLEET model assumed the bus is idling for 30 minutes. In this study, I assumed a child boarding the bus is exposed to those emissions by walking to the bus, boarding, and any safety procedures, so a third of the calculated emissions.

The social cost for an idling bus (SCi) was calculated by multiplying the pollutant (P) by the ground-level marginal damage per pollutant (MDp). This assumes that bus-riding children are exposed the full 30 minutes of a bus idling:

$$SCi = P * MDp$$

Baseline Social Costs

To determine the baseline social cost of NO_x, $PM_{2.5}$, VOC, SO_2, and CO_2 for both models, the total social costs (as calculated above) were multiplied by 10- and 15-

scenario years (SY), respectively, to determine the ground-level marginal damages in Montgomery County, should the status quo of a diesel bus fleet hold (Table 8):

$$Baseline = (\$NOx + \$PM25 + \$VOC + \$SO2 + \$CO2) * SY$$

Table 8. Social cost baseline for all diesel school bus fleet, both scenarios.

SC-NO_x	SC-$PM_{2.5}$	SC-VOC	SC-SO_2	SC-CO_2	SC-Total
\$372,086	\$299,152	\$133,167	\$85	\$8,074	\$792,663

The annual marginal damages of ground-level emissions for the all-diesel fleet. The social cost of CO2 was calculated using Maryland's established SC-CO2 value of \$110 per ton. All other pollutants calculated using APEEP. In 2020\$.

To compare the baseline scenarios against the 10- and 15-year scenarios, the percentage difference between the scenarios' total social costs and the baseline was calculated:

$$(Scenario - Baseline)/Baseline$$

Social Cost of Electric Generation

It would be disingenuous to perform a comparative study between diesel and electric school buses without the consideration of the electricity needed to power a potential future fleet of electric school buses. Although the emissions from power plants would not be at ground-level, directly where children walk and play, they would contribute to the burden of greenhouse gas emissions on the Earth's climate and disproportionately affect populations in rural areas (Holland et al., 2016). The pollutant data is based on the inputs I provided to the AFLEET model. AFLEET does not break down pollutants for electricity generation, only the benefits (Burnham, 2019); therefore, it was necessary to calculate the total marginal damages for local pollutants within the ReliabilityFirst (RFC) electricity region, of which Maryland is a part. APEEP provided marginal damages per kWh for 24 hours in nine electricity regions (Table 9) (Holland et al., 2016).

Table 9. Average marginal damages for kWh in a 24-hour period.

	MD RFC 24hr kWh	
CO2	0.09372	conv $110
SO2	0.044551388	
NOx	0.001636	
PM25	0.003915	
Total	0.050102388	

The marginal damages for SO_2, NO_x, and $PM_{2.5}$ are from the AP2 model for 2011 and are specific to the electricity region of which Maryland belongs. The CO_2 marginal damages follow the AP2 model but adjusted to reflect the SC-CO_2 values establisted by the state of Maryland (Holland et al., 2016).

To calculate the pollution created by electricity generation, the annual electricity (e) generation was subtracted from the portion of renewable energy (r) applicable to that year and multiplied by the total marginal damages (md), adjusted for inflation (2020$).

$$\textit{Social cost of Electricity} = (e-(e*r))*md$$

The results were then converted from 2000 dollars to 2020 dollars using the BLS Inflation Calculator. The total social costs were calculated for net present value using a social discount rate of 3%.

Net Present Value

In determining the discount rate for calculating the scenarios' net present values (NPV), I first had to choose which categorization of NPV would most succinctly capture the goal of this thesis. A strictly financial analysis of NPV would not be appropriate; instead, evaluating the scenarios by way of a social-welfare-equivalent consumption discount rate takes into account the damages caused by the bus fleet's emissions. I selected the discount rate of 3% for the scenarios.

Multiple Linear Regression

Multiple linear regression was performed to determine the statistical significance of the on-the-road models (Appendix 6). The dependent variable was the $PM_{2.5}$ emissions for the scenarios' time span, and the independent variables were the number of electric vehicles in the fleet, petroleum use, and electricity dispensed. The 10- and 15-year models had R Square values of 0.997 and 0.998, respectively. It should be noted that in the 10-year model, an error while running the regression in Excel required removing the number of diesel buses as an independent variable, although this was not an issue in the 15-year model. For consistency's sake, that variable was removed from both models and re-run, removing the error. Both models were found to be statistically significant with most variables having a p-value of <0.05. In the 10-year model, however, the dependent variable and one independent variable, "petroleum use," were found to have p-values of 0.160 and 0.166, respectively, making those variables insignificant. This was not the case in the 15-year scenario, with petroleum use having a p-value of 0.005.

Chapter III

Results

The variations between the 10- and 15-year simulations varied in the time and amount of pollutants schoolchildren would be exposed to throughout the time it took to replace the diesel buses with electric ones. Analysis of the diesel bus fleet revealed several ongoing GHG and emission concerns through the fleet's remaining lifetime. Based on the inputs discussed before, the forecasted air pollutants to be released over the next 15 years amounts are not insignificant.

Driving Emissions

After having computed the emissions data in AFLEET for the two scenarios, the social costs were calculated to determine the amount of potential emissions the county's school bus fleet was emitting on an annual basis. Figures 4 & 5 illustrate the declining rate of potential emissions as the 10- and 15-year scenarios progress. The decrease in pollutant exposure follows an expected downward slope, with the final years having no pollutant exposure from riding a school bus. NO_x is the predominant pollutant found in the bus emissions and has the potential to convert into $PM_{2.5}$, which is also a primary component of the bus emission pollutant profile. Calculating the amount of NO_x that could potentially convert into $PM_{2.5}$ is difficult, due to the limited research on roadside emissions (Hogan & Barnard, UNK).

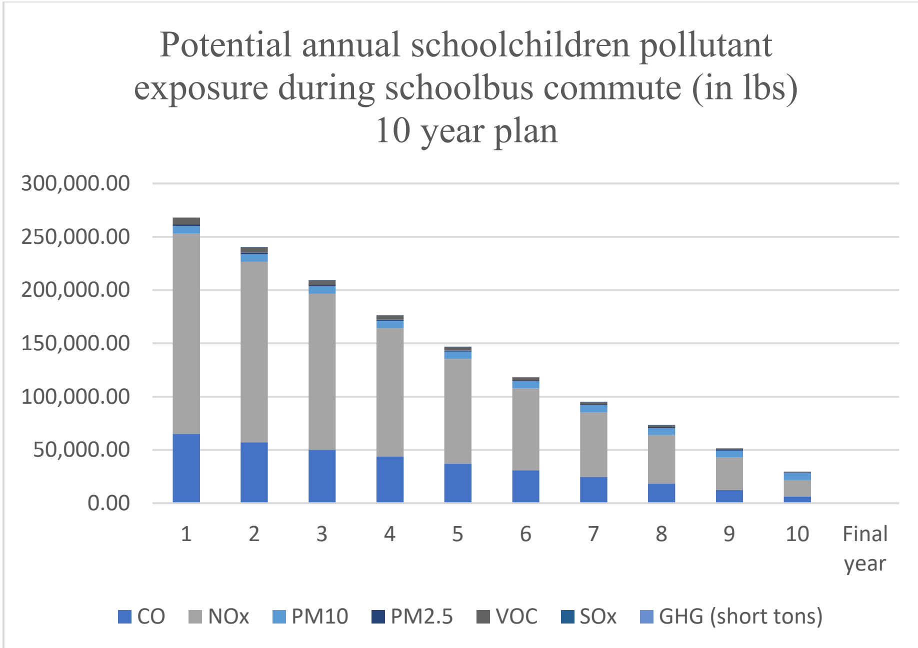

Figure 4. Decrease in potential pollutants from bus emissions. 10-year plan.

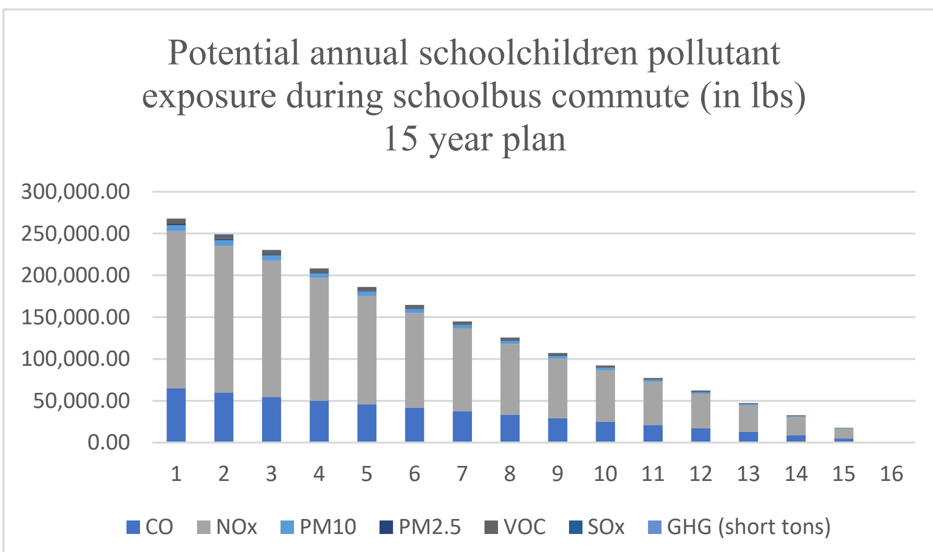

Figure 5. Decrease in potential pollutants from bus emissions. 15-year plan.

In Figures 4 and 5, a decrease in on-road emission pollutants from this study's assumed 10- and 15-year scenarios of converting MCPS' bus fleet from diesel to electric. Emission results from MCPS fleet data, author assumptions, and the AFLEET tool. The tables for the above charts can be found in Appendix 3.

Social Cost of Diesel Bus Emissions

In Tables 10 & 11, the pollutants' social costs are calculated on an annual basis for the general population. As mentioned before, school bus riding children represent about 10% of the county's population. If the school district decides to maintain the status quo, it can expect its diesel bus fleet to contribute about $793,000 per year in marginal damages while on the road. Should the county follow the 10-year plan, the total marginal damages would amount to about $4.3 million, calculated with an NPV social discount rate of 3%; the 15-year plan would amount to $5.2 million total.

Table 10. Pollutant social costs calculated on an annual basis with a yearly decrease in diesel buses over a 10-year time span.

Potential annual pollutant exposure from diesel buses - Ten year plan (2020$)						
Annual marginal damages of ground-level emissions						
Year	**SC-NOx**	**SC-PM25**	**SC-VOC**	**SC-SO2**	**SC-CO2**	**SC-Total**
1	$372,085.78	$299,151.73	$113,167.02	$85.18	$8,901.09	$793,390.80
2	$335,553.84	$278,656.71	$97,901.24	$77.44	$8,036.82	$720,226.04
3	$289,871.38	$258,879.49	$85,044.46	$69.69	$7,163.64	$641,028.66
4	$239,171.21	$239,498.94	$73,511.23	$61.95	$6,299.37	$558,542.70
5	$194,621.23	$222,706.25	$62,416.68	$54.21	$5,435.10	$485,233.46
6	$152,187.85	$206,763.58	$51,562.09	$46.46	$4,561.92	$415,121.91
7	$120,147.78	$194,598.79	$41,185.56	$38.72	$3,697.65	$359,668.50
8	$90,213.43	$183,208.47	$31,009.62	$23.23	$2,824.47	$307,279.22
9	$60,370.58	$171,818.16	$20,831.81	$15.49	$1,960.20	$254,996.22
10	$30,630.32	$160,427.84	$10,622.12	$7.74	$1,095.93	$202,783.95
Total	$1,884,853.38	$2,215,709.96	$587,251.82	$480.11	$49,976.19	$4,738,271.46
NPV	**$1,739,276.66**	**$1,979,642.23**	**$539,878.54**	**$440.46**	**$45,765.85**	**$4,305,003.73**

Table 11. Pollutant social costs calculated on an annual basis with a yearly decrease in diesel buses over a 15-year time span.

Potential annual pollutant exposure from diesel buses - 15 year plan (2020$)						
Annual marginal damages of ground-level emissions						
Year	**SC-NOx**	**SC-PM25**	**SC-VOC**	**SC-SO2**	**SC-CO2**	**SC-Total**
1	$372,085.78	$299,151.73	$113,167.02	$85.18	$8,901.09	$793,390.80
2	$347,731.02	$275,615.51	$102,989.21	$77.44	$8,313.03	$734,726.20
3	$323,376.46	$252,060.41	$92,811.39	$77.44	$7,716.06	$676,041.75
4	$290,223.52	$229,487.55	$85,125.07	$69.69	$7,136.91	$612,042.74
5	$256,775.48	$206,933.59	$77,515.61	$61.95	$6,548.85	$547,835.48
6	$224,789.68	$185,002.97	$69,998.02	$61.95	$5,960.79	$485,813.40
7	$195,800.05	$164,319.06	$62,718.51	$54.21	$5,381.64	$428,273.45
8	$167,805.64	$144,012.93	$55,557.10	$46.46	$4,793.58	$372,215.71
9	$141,370.31	$124,292.38	$48,465.07	$38.72	$4,205.52	$318,371.99
10	$121,604.27	$107,008.56	$41,680.48	$38.72	$3,626.37	$273,958.40
11	$101,838.04	$89,724.74	$34,967.14	$30.97	$3,038.31	$229,599.20
12	$82,124.88	$72,422.03	$28,251.92	$23.23	$2,450.25	$185,272.31
13	$62,441.24	$55,138.21	$21,538.57	$15.49	$1,871.10	$141,004.61
14	$42,799.18	$37,854.40	$14,812.10	$15.49	$1,283.04	$96,764.21
15	$23,213.57	$20,570.58	$8,063.14	$7.74	$694.98	$52,550.01
Total	$2,753,979.12	$2,263,594.64	$857,660.35	$704.67	$71,921.52	$5,947,860.29
NPV	**$2,430,756.21**	**$1,989,760.60**	**$752,648.71**	**$615.38**	**$62,917.05**	**$5,236,697.95**

Baseline Social Cost

The social cost for the two scenarios can be better understood with a comparison to the baseline scenarios (Table 12). The baselines were calculated by multiplying the year 1 baseline with either 10 or 15, giving the two scenarios their respective baselines for social cost through their length of time (Figure 6). The baseline scenarios were calculated with the net present value social discount rate of 3%.

Table 12. Baseline social cost of pollutants for 1-, 10- and 15-year scenarios.

Baseline of one year	10 years	15 years
$792,663	$6,964,419	$9,746,636

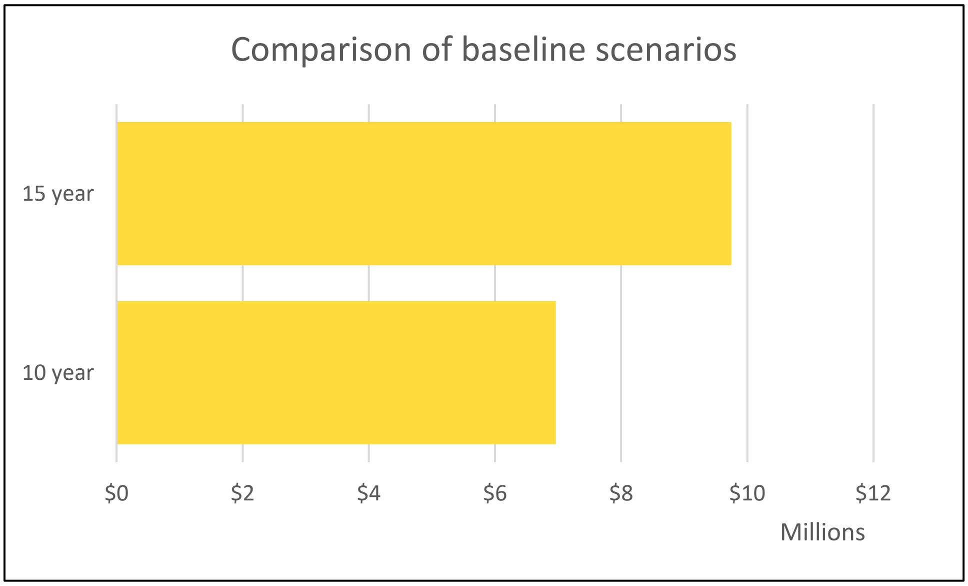

Figure 6. Baseline scenario comparison.

Comparison of the social cost over 10 and 15 years, should the diesel bus fleet remain unchanged. In 2020$ and NPV social discount rate of 3%.

When comparing the two scenarios to their respective baselines, it is clear that the 10-year scenario has the greatest effect on lowering the social cost (Figure 7). The 15-year scenario increases the social costs by 39.95% and prolongs exposure by five years. However, the 15-year scenario has a greater percentage decrease from its baseline while the scenario plays out, as opposed to the 10-year scenario (Table 15).

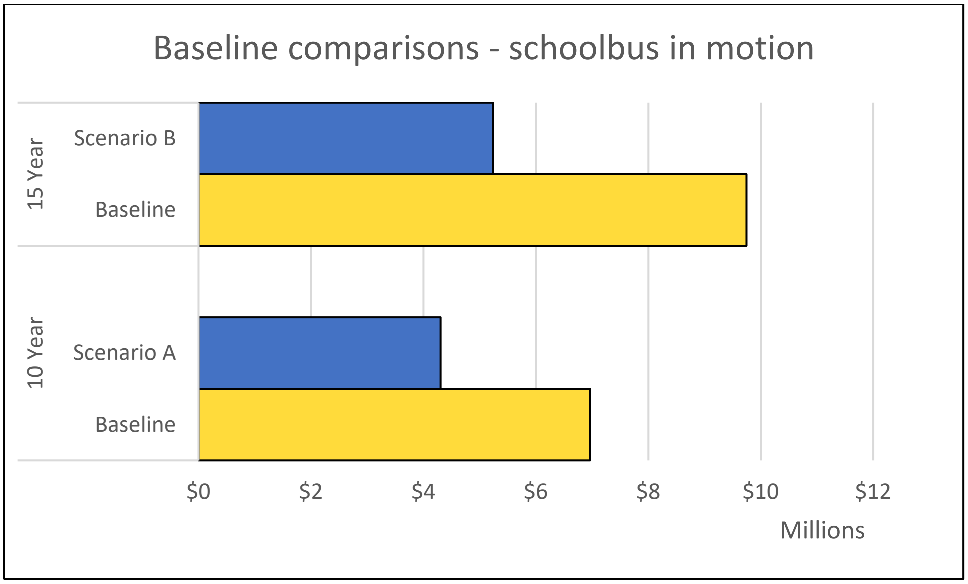

Figure 7. On-the-road baseline.

Visual representation of the differences between the two scenarios of diesel buses being phased out (blue) and the 10- and 15-year baselines (yellow).

Table 13. On-the-road baseline and diesel phase-out comparisons.

		TOTAL SC	***% DIFFERENCE***
10 YEAR	***Baseline***	$6,964,419.33	***-38.19%***
	Scenario A	***$4,305,033.73***	
15 YEAR	***Baseline***	$9,746,636.44	***-46.27%***
	Scenario B	$5,236,697.95	

Comparison of emission pollutant social costs between maintaining a diesel-only fleet and the 10-year and 15-year diesel phase-out scenarios.

Electric Bus Charging Output

Supporting a fleet of electric school buses becomes less beneficial on a global scale when running a non-progressive electrical grid model. In this case, renewable energy generation and use was projected to remain at 5%. This nearly doubled the social costs from electricity generation in both the 10- and 15-year scenarios, from $56.6M to $99.4M in the 10-year scenario, and from $65.6M to $129.9M in the 15-year scenario, as seen in Tables 14-17. There is, however, a significant disparity between the social costs from electrical generation and those from diesel bus emissions that needs to be addressed and will be discussed in the following chapter.

Table 14. Social cost from electricity generation in 10-year scenario.

Year	Annual Electricity dispensed (kWh)	Renewable energy reduction	Adjusted Annual kWh	Multiply by 0.05010239 MD	Converted from 2000$ to 2020$ (BLS)	CO2 MD	Total	Number of electric buses	Number of diesel buses
1	0	0.33	0	$0	$0	$0	$0	0	1447
2	13687500	0.35	8896875	$445,755	$687,180	$833,815	$1,520,995	144	1303
3	27375000	0.36	17520000	$877,794	$1,352,243	$1,641,974	$2,994,217	288	1159
4	41062500	0.39	25048125	$1,254,971	$1,934,715	$2,347,510	$4,282,225	432	1015
5	54750000	0.40	32850000	$1,645,863	$2,537,331	$3,078,702	$5,616,033	576	871
6	68437500	0.42	39693750	$1,988,752	$3,065,941	$3,720,098	$6,786,039	720	727
7	82125000	0.45	45168750	$2,263,062	$3,488,830	$4,233,215	$7,722,045	864	583
8	95812500	0.47	50780625	$2,544,231	$3,922,290	$4,759,160	$8,681,450	1008	439
9	109500000	0.48	56940000	$2,852,830	$4,398,040	$5,336,417	$9,734,456	1152	295
10	123187500	0.50	61593750	$3,085,994	$4,757,495	$5,772,566	$10,530,061	1296	151
Final	134919643	0.52	64761429	$3,244,702	$5,002,166	$6,069,441	$11,071,607	1447	0
NPV					$25,562,593	$31,017,854	$56,580,448		

Assuming Maryland follows its mandated path to 50% renewable energy by 2030, the estimated marginal damages related to electricity generation to power the electric school buses, under the 10-year scenario. The marginal damages for regional electricity generation consider the social costs of CO_2 (Maryland SC-CO), and SO_2, NO_x, and $PM_{2.5}$ (Holland et al., 2016). The total marginal damages, calculated for NPV, is highlighted in yellow.

Table 15. Social cost from electricity generation with minimal renewable energy. 10-year scenario.

Year	Annual Electricity dispensed (kWh)	Renewable energy reduction	Adjusted Annual kWh	Multiply by 0.05010239 MD	Converted from 2000$ to 2020$ (BLS)	CO2 MD	Total	Number of electric buses	Number of diesel buses
1	0	0.05	0	$0	$0	$0	$0	0	1447
2	13687500	0.05	13003125	$651,488	$1,004,360	$1,218,653	$2,223,013	144	1303
3	27375000	0.05	26006250	$1,302,975	$2,008,720	$2,437,306	$4,446,026	288	1159
4	41062500	0.05	39009375	$1,954,463	$3,013,080	$3,655,959	$6,669,039	432	1015
5	54750000	0.05	52012500	$2,605,950	$4,017,440	$4,874,612	$8,892,052	576	871
6	68437500	0.05	65015625	$3,257,438	$5,021,800	$6,093,264	$11,115,064	720	727
7	82125000	0.05	78018750	$3,908,926	$6,026,160	$7,311,917	$13,338,077	864	583
8	95812500	0.05	91021875	$4,560,413	$7,030,520	$8,530,570	$15,561,090	1008	439
9	109500000	0.05	104025000	$5,211,901	$8,034,880	$9,749,223	$17,784,103	1152	295
10	123187500	0.05	117028125	$5,863,389	$9,039,240	$10,967,876	$20,007,116	1296	151
Final	134919643	0.05	128173661	$6,421,806	$9,900,120	$12,012,435	$21,912,556	1447	0
NPV					$44,927,728.48	$54,513,625.31	$99,441,354		

The above adjusted annual kWh needed for an electric bus fleet, assuming Maryland does not increase renewable energy generation within the state, under the 10-year scenario. The marginal damages for regional electricity generation consider the social costs of CO_2 (Maryland SC-CO), and SO_2, NO_x, and $PM_{2.5}$ (Holland et al., 2016). The total marginal damages, calculated for NPV, is highlighted in yellow.

Table 16. Social cost from electricity generation in 15-year scenario.

Year	Annual Electricity dispensed (kWh)	Renewable energy reduction	Adjusted Annual kWh	Multiply by 0.05010239 MD	Converted from 2000$ to 2020$ (BLS)	CO2 MD	Total	Number of electric buses	Number of diesel buses
1	0	0.33	0	$0	$0	$0	$0	0	1447
2	8994643	0.35	5846518	$292,925	$451,584	$547,936	$999,520	96	1351
3	17989286	0.36	11513143	$576,836	$889,274	$1,079,012	$1,968,286	192	1255
4	26983929	0.39	16460197	$824,695	$1,271,384	$1,542,650	$2,814,034	288	1159
5	35978571	0.40	21587143	$1,081,567	$1,667,389	$2,023,147	$3,690,536	384	1063
6	44973214	0.42	26084464	$1,306,894	$2,014,761	$2,444,636	$4,459,397	480	967
7	53967857	0.45	29682321	$1,487,155	$2,292,659	$2,781,827	$5,074,487	576	871
8	62962500	0.47	33370125	$1,671,923	$2,577,505	$3,127,448	$5,704,953	672	775
9	71957143	0.48	37417714	$1,874,717	$2,890,140	$3,506,788	$6,396,929	768	679
10	80951786	0.50	40475893	$2,027,939	$3,126,354	$3,793,401	$6,919,754	864	583
11	89946429	0.52	43174286	$2,163,135	$3,334,777	$4,046,294	$7,381,071	960	487
12	98941071	0.54	45512893	$2,280,305	$3,515,411	$4,265,468	$7,780,879	1056	391
13	107935714	0.56	47491714	$2,379,448	$3,668,255	$4,450,923	$8,119,178	1152	295
14	116930357	0.58	49110750	$2,460,566	$3,793,309	$4,602,659	$8,395,969	1248	199
15	125925000	0.60	50370000	$2,523,657	$3,890,574	$4,720,676	$8,611,250	1344	103
Final	134919643	0.62	51269464	$2,568,723	$3,960,048	$4,804,974	$8,765,022	1447	0
NPV					$29,643,791	$35,968,667	$65,612,458		

Assuming Maryland follows its mandated path to 100% renewable energy by 2040, the estimated marginal damages related to electricity generation to power the electric school buses, under the 15-year scenario. The marginal damages for regional electricity generation consider the social costs of CO_2 (Maryland SC-CO), and SO_2, NO_x, and $PM_{2.5}$ (Holland et al., 2016). The total marginal damages, calculated for NPV, is highlighted in yellow.

Table 17. Social cost from electricity generation with minimal renewable energy. 15-year scenario.

Year	Annual Electricity dispensed (kWh)	Renewable energy reduction	Adjusted Annual kWh	Multiply by 0.05010239 MD	Converted from 2000$ to 2020$ (BLS)	CO2 MD	Total	Number of electric buses	Number of diesel buses
1	0	0.05	0	$0	$0	$0	$0	0	1447
2	8994643	0.05	8544911	$428,120	$660,008	$800,829	$1,460,837	96	1351
3	17989286	0.05	17089822	$856,241	$1,320,016	$1,601,658	$2,921,674	192	1255
4	26983929	0.05	25634733	$1,284,361	$1,980,024	$2,402,487	$4,382,511	288	1159
5	35978571	0.05	34179642	$1,712,482	$2,640,032	$3,203,316	$5,843,348	384	1063
6	44973214	0.05	42724553	$2,140,602	$3,300,040	$4,004,145	$7,304,185	480	967
7	53967857	0.05	51269464	$2,568,723	$3,960,048	$4,804,974	$8,765,022	576	871
8	62962500	0.05	59814375	$2,996,843	$4,620,056	$5,605,803	$10,225,859	672	775
9	71957143	0.05	68359286	$3,424,963	$5,280,064	$6,406,632	$11,686,696	768	679
10	80951786	0.05	76904197	$3,853,084	$5,940,072	$7,207,461	$13,147,533	864	583
11	89946429	0.05	85449108	$4,281,204	$6,600,080	$8,008,290	$14,608,370	960	487
12	98941071	0.05	93994017	$4,709,325	$7,260,088	$8,809,119	$16,069,207	1056	391
13	107935714	0.05	102538928	$5,137,445	$7,920,096	$9,609,948	$17,530,044	1152	295
14	116930357	0.05	111083839	$5,565,566	$8,580,104	$10,410,777	$18,990,882	1248	199
15	125925000	0.05	119628750	$5,993,686	$9,240,112	$11,211,606	$20,451,719	1344	103
Final	134919643	0.05	128173661	$6,421,806	$9,900,120	$12,012,435	$21,912,556	1447	0
NPV					$58,699,879	$71,224,237	$129,924,116		

The above adjusted annual kWh needed for an electric bus fleet following the 15-year scenario, assuming Maryland does not increase renewable energy generation within the state. The marginal damages for regional electricity generation consider the social costs of CO_2 (Maryland SC-CO), and SO_2, NO_x, and $PM_{2.5}$ (Holland et al., 2016). The total marginal damages, calculated for NPV, is highlighted in yellow.

Social Cost of Idling

The idling baseline was calculated following the same method as the on-the-road baseline. The total social costs were lower than the on-the-road, but it is important to note that children are directly exposed to idling fumes. CO_2 has the greatest influence on marginal damages, but $PM_{2.5}$ is the second most significant pollutant, which has more potential to cause immediate damage to children's developing lungs (Table 18).

Table 18. Social costs for a bus idling for 30 minutes per trip. Baseline for both scenarios.

Idle time	SC-NOx	SC-PM25	SC-VOC	SC-SO2	SC-CO2	**Total-SC**
10	$1,844	$6,507	$2,135	$788	$72,836	**$84,100**
20	$3,689	$13,017	$4,270	$1,574	$146,165	**$168,715**
30	$5,533	$19,524	$6,405	$2,362	$241,675	**$275,499**

The individual pollutant marginal damages for the first year, or status quo, diesel bus fleet. The full Excel spreadsheet tables are available in Appendix 5.

Tables 19-21 demonstrate the baseline social costs of all pollutants for one year and the total annual "baseline" social cost of pollutants for the two scenarios, if electric buses were not adopted, idle reduction policies were not adopted, and the diesel bus fleet remained in service.

Table 19. Idling scenario baselines.

Baseline Idling (1 year)	10 years	15 years
$255,725.28	$2,246,830.16	$3,144,416.75

Baseline idling demonstrates the social costs should idlying remain at 30 minutes per trip (1 hour per day) during the school year with an all-diesel school bus fleet. Totals are calculated using the net present value and a social discount rate of 3%.

Table 20. Total social cost of an idling diesel school bus. 10-year scenario (2020$).

Idle time	SC-NOx	SC-PM25	SC-VOC	SC-SO2	SC-CO2	Totals
10	$9,340	$32,959	$10,813	$3,987	$369,876	$426,974
20	$18,680	$65,919	$21,625	$7,972	$740,237	$854,434
30	$20,020	$98,878	$32,438	$11,960	$1,223,949	$1,395,245

Total marginal damages of the 10-year scenario if the remaining diesel buses were permitted to continue idling until they were replaced with electric buses. All totasl have been calculated for net present value with a social discount rate of 3%.

Table 21. Total social cost of an idling diesel school bus. 15-year scenario (2020$)

Idle time	SC-NOx	SC-PM25	SC-VOC	SC-SO2	SC-CO2	**Totals**
10	$12,973	$45,779	$15,019	$5,537	$1,028,169	**$1,107,477**
20	$25,946	$91,558	$30,037	$11,074	$1,028,169	**$1,186,784**
30	$38,919	$137,337	$45,056	$16,612	$1,700,034	**$1,937,957**

Total marginal damages of the 15-year scenario if the remaining diesel buses were permitted to continue idling until they were replaced with electric buses. All totals have been calculated for net present value with a social discount rate of 3%.

The above tables illustrate not only the amount of damage a school bus idling for just 10 to 30 minutes in a parking lot over the course of a 180-day school yard could level, but how quickly the damages increase the longer the idle time.

In Figure 8, the yellow denotes the status quo, if the school district does not phase out diesel buses. The blue represents the social costs if electric buses are phased into the fleet following the 10- or 15-year scenarios. In Table 22, the percentage differences of the social cost of pollutants between the two scenarios and the 10- and 15-year baselines.

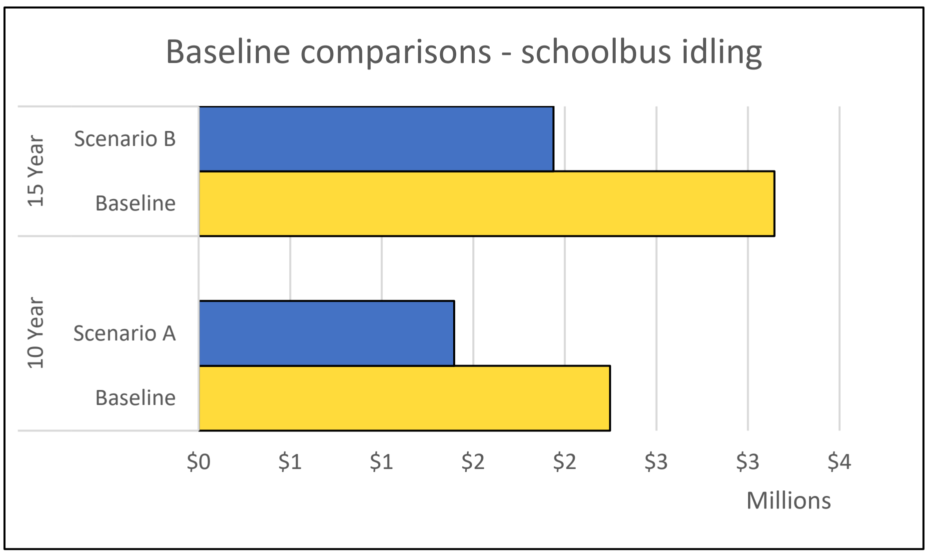

Figure 8. Baseline comparisons comparing 30 minutes of idling per trip.

Table 22. Baseline idling comparisons

		Total Social Cost	% difference
10 Year	Baseline	$2,246,830	-37.90%
	Scenario A	$1,395,245	
15 year	Baseline	$3,144,417	-38.37%
	Scenario B	$1,937,957	

This table represents the 30 minute per trip idling reduction scenarios. All totals have been calculated for net present value with a social discount rate of 3%.

The percentage difference between the two scenarios and their respective baselines are similar, though the 15-year plan does take longer to mitigate pollutant exposure. The 15-year scenario has the potential to expose some children to idling emissions from the time they start pre-K or Kindergarten through graduation from high school, if they ride the bus throughout their time as Montgomery County Schools students.

Uncertainty on just how long a school bus driver might idle led to the creation of separate scenarios that calculated the amount of pollutants are emitted during that timeframe. The Poisson distribution was selected to determine the likelihood of a bus idling during the predetermined timeframe range of 60 to 180 hours per year (10 to 30 minutes per trip, twice daily) (Table 23). The Poisson distribution formula I used in Excel is as follows:

$$= Poisson.Dist(x, mean, cumulative)$$

Table 23. Poisson distribution for idle reduction scenarios.

	Probability	Formulas
	0.51980954	=poisson.dist(180,180,true)-poisson.dist(60,180,true)
	0.999999869	=poisson.dist(180,120,true)-poisson.dist(60,120,true)
	0.465737528	=poisson.dist(180,60,true)-poisson.dist(60,60,true)
Total	1.985546932	

The probability that buses will idle for 20 minutes per trip (40 minutes per day, or 120 hours per year) is the most likely scenario, given the cumulative probability is 99.99999%. The other two scenarios are less likely: the 30 minute per trip idling is slightly more probable (52%) versus idling for 10 minutes per trip (46.6%).

Chapter IV

Discussion

The ongoing COVID-19 pandemic has left school buses parked as children attended class virtually since March 2020. MCPS was expected to start a phased reopening plan in February 2021 (Peetz, 2020), and the youngest elementary students returned March 15. Access to school buses, the ability to observe idling behavior, and visiting the five bus depots was restricted during this time.

This study was a hybrid of factual data provided by MCPS, such as fleet age and size, number of students, along with assumptions made by the author based on either conversation with MCPS or public documents, such as battery usage preference as listed in MCPS's RFP. Because some EV technologies are not yet in use, or haven't been invented, it was impossible to predetermine with absolute certainty the costs and benefits of transitioning the fleet to all electric. Future research specific to child morbidity as it relates to pollution exposure is needed to fully understand the harm caused by diesel emissions. The marginal damages calculated were general in terms of human adult life, not specific to children.

Electricity Generation

Despite Maryland's self-imposed renewable energy mandate of 100% by 2040, the state actually generates only a fraction of renewable energy. As more entities pursue electric vehicles for federal or commercial use (along with growing consumer demand), the demand on the electrical grid will continue to grow. Aggressive projects will be required for Maryland and Montgomery County to keep up with demand and meet renewable energy goals. At some point, buying renewable energy credits from neighboring states will no longer be a viable option as those states begin investing in their own electric vehicle programs.

Montgomery County only generates 7.6 MW of solar power (OES, 2021), for instance, and the Montgomery County Council recently pared down allowing solar farms to be built on 1,800 acres within the county's 93,000-acre agriculture preserve due to objections from farmers and preservationists. Instead of allowing solar projects to be built in a fraction (2%) of agricultural land, solar projects are now further stymied by additional requirements, including the quality of soil (Tan, 2021). In a letter to the council, the Coalition for Community Solar Access decried the council's decision, expressing concern that the requirements will not only prevent proper project siting for solar energy generation, but push solar developers away from pursuing solar projects in the county (Elder & Murray, 2021).

The county's actions were shortsighted and the solar already being generated is a far cry from what is needed, not only for the electric school bus transition, but other electric vehicles currently on the county's wishlist, including electrifying its public buses. In order to meet the county's goal of reducing greenhouse gas emissions by 80% by 2027, more compromise will be needed between groups to move the county and its green initiatives forward for the betterment of society.

Disparities in Marginal Damages

The spread between the calculated social costs of diesel and electric buses is wide, and it is the electric buses that carry the brunt of marginal damages. In both the 10- and 15-year scenarios (Table 24), and when comparing to the bus fleet remaining all-diesel, the social costs from charging the batteries of electric buses are several times that of the current bus fleet. To understand social costs, it is important to realize that social costs don't represent any actual exchange of money; rather it is the cost the government is willing to take on from harm caused by these pollutants.

Table 24. Social costs scenario comparisons.

Scenario	Baseline diesel	Diesel bus emissions	Electric bus mid-level RE	Electric bus low-level RE
10 Year	$7,554,235	$4,304,276	$56,580,447	$99,441,354
15 Year	$10,264,841	$5,236,697	$65,612,458	$129,924,116

The social costs for an all-diesel fleet (baseline), a diesel fleet in transition to electric, and the social costs of a fleet transitioning to electric over the two time periods. It is important to note that the diesel fleet's social costs affect the community in which it operates, and at ground-level; the electric fleet affects communities outside of where it operates with GHG and other pollutants emitted from smokestacks.

One thing is clear: To tackle climate change, a sustainable, clean energy grid is necessary. In the case of the electric school bus fleet, although the children would no longer be exposed to toxic tailpipe emissions, and even with an energy grid comprised of 50% renewable energy, the global social costs from an electric fleet far exceed that of a diesel fleet. Coal and natural gas emissions are the obvious villains in the pursuit of a predominantly electric transportation sector, until energy infrastructure components such as vehicle-to-grid battery storage and on-site renewable energy production solutions become more dominant in the energy landscape.

An ethical argument could be made that the ground-level emissions the school district aims to mitigate, and its associated marginal damages, cannot be compared to the greenhouse gases created by coal and natural gas power plants used to fuel the electric buses. One community is spared the negative health effects of its own transportation needs, and other communities are forced to take up the burden. For this, we must ask, is our children's health more important than that of the children living in rural communities near power plant smokestacks? And this is why, as policymakers develop plans to electrify buses, a policy of sustainability parity needs to be invoked. For every electric bus that is added to the fleet, its energy demands should be met with 100% renewables.

Policy

As this thesis research came to its conclusion, the Montgomery County School District announced its first order of 326 electric school buses through a public-private partnership. The first electric buses are expected to be delivered over the next four years (MCPS, 2021). This is welcome news to proponents of electric vehicles and clean air advocates. In a news article highlighting the electric bus initiative the school district is pursuing, an additional carrot to the emerging electric fleet was announced: The buses would be used to store electricity, offsetting energy demands during peak hours and hot summer months when school is not in session and buses are parked (Mufson & Kaplan, 2021). Adding to the push for electric vehicles are the National Ambient Air Quality Standards that encourage lowering in-state emissions, in effect encouraging policymakers to export emissions to other states. This is important to note, because although Maryland has set ambitious renewable energy standards, it is not producing the majority of its renewable energy in the state, but rather importing it from elsewhere. Maryland consumes five times more energy than it produces (U.S. EIA, 2020), and adding a large fleet of EV school buses will only add to that burden. This necessitates a proactive approach by the school district in seeking solutions to power its fleet using renewable energy sources, such as installing solar panels and incorporating vehicle-to-grid (V2G) technology into the buses and the depots' infrastructure.

Transitioning a large school bus fleet such as Montgomery County's is expected to take several years due to a number of factors: school district and state funding capabilities, political will, electric bus availability, and the burden on the electrical grid, among others. The initial order of 326 Thomas-built buses falls between the 10- and 15-year replacement scenarios I created, which lends credibility to the school district's push to replace its entire diesel fleet within the span of a decade, give or take a couple years. The school district entered into a four-year contract with Massachusetts-based company, Highland Electric Transportation, to assist in the transition. According to a school district press release, the initial 25 electric buses will be based at the Bethesda bus depot (MCPS, 2021), which services five low-poverty high schools and their feeder schools. Students at these schools are predominately White and Asian whose families are higher income (Bonner-Tompkins, 2014).

The reasoning behind the decision to launch the electric bus fleet from a wealthy section of Montgomery County is unknown, but at the beginning of my research, a MCPS transportation employee informed me that the electric buses would be spread among all five of the bus depots, and not just one, from the outset. A special effort should be made by administrators to target schools for electric bus adoption during the early stages where the student body has a high proportion of Black children. Statistics show us that Black children already have a higher incidence of asthma and the disease's related hospital visits and death than their Asian, Hispanic, and White peers.

Idle Reduction

Perhaps the policy change with the quickest and most widespread results would be a ban on idling in all school parking lots. This would have the greatest positive impact on all children from the start of the school district's electric fleet changeover, who no longer would be exposed to unnecessary emissions while on school grounds. The state has a voluntary idle reduction program, however only a handful of schools have signed on. By requiring buses be shut off while waiting in school parking lots or pickup areas, and empowering school administrators to enforce the idle reduction mandate, children's exposure to lung-damaging $PM_{2.5}$ would significantly decline.

Recommendations

Further study is needed on the health impacts of busing children to school, particularly aboard a diesel bus. Proponents of diesel buses will argue that most of the problematic emissions have been mitigated through new technology, but zero emission diesel buses do not exist. A full Health Impact Assessment (HIA) that weighs socio-economic and environmental factors, along with risk mitigation, should be considered. The HIA should be completed to further our understanding of this popular mode of transportation for children. This would be of particular use for other underfunded school districts that would struggle financially with transitioning away from the diesel standard bearers of yesterday to better promote their need for clean student transport, either through grants or convincing the public for a need to support an electric bus and infrastructure through increased taxes. In addition, performing a rapid Social Impact Assessment (rSIA) would provide perspective to policymakers on where to initially deploy electric buses, with a focus on marginalized communities that are already exposed to a disproportionate amount of emissions due to a number of factors, such as urban neighborhoods with heavy traffic. An rSIA would allow policymakers to analyze the intersectional disparities many marginalized students already encounter in their daily lives and assist the school district in alleviating their portion of it.

Conclusions

As this thesis comes to its conclusion, hope abounds that not only is the pandemic of 2020-2021 coming to an end, but that significant efforts will be made to transform and rebuild the United States' transportation and energy infrastructure for a fossil fuel-free future, one that promises generations-to-come a zero-carbon future. One plan, not yet written into legislation, would provide $45 billion in funding to states and municipalities for electric vehicle charging infrastructure. Another $17 billion would provide grants for redesigning factories that once built internal combustion engine cars to instead build electric vehicles (Grandoni, 2019). And a reimagined Cash-for-Clunkers program to entice drivers of poor gas mileage vehicles to trade them in for an electric car (Edelstein, 2020). Legislation harkening back to former U.S. President Franklin D. Roosevelt's New Deal, such as the proposed Green New Deal, or Biden's proposed green infrastructure plans, offer a roadmap, and perhaps incentivize states, counties, and municipalities to create their own clean infrastructure plan.

Discovering the potential benefits and obstacles of an electric fleet, as it pertains to schoolchildren's health is an ongoing issue, and more research needs to be done to fully understand the problem. And although Montgomery County is in the beginning stages of replacing its diesel fleet with electric buses, there are many more school districts that are not. Knowing the impact of continued exposure to diesel fumes is important for children's caregivers and policymakers, alike. It is also important to take early proactive measures, such as idle reduction, that are relatively easy to put into place, and focus early phases of electric fleet deployment in marginalized communities. Finally, when it comes to the energy grid, promoting renewable energy hand-in-hand with electric transportation projects is important to make an electric fleet not only green, but sustainable.

Appendix 1

AFLEET Baseline Inputs

The following are inputs to the AFLEET model, as described in an earlier section.

Table 25. Location input.

Key Vehicle and Fuel Inputs	
Primary Vehicle Location	
State	MARYLAND
County	MONTGOMERY

Table 26. Fleet, mileage, and purchase data per MCPS.

Heavy-Duty Vehicle Information				
Vehicle Type	School Bus			
Vocation Type	School Bus			
Heavy-Duty Fuel Type	**Number of Heavy-Duty Vehicles**	**Annual Vehicle Mileage**	**Fuel Economy (MPDGE)**	**Purchase Price ($/Vehicle)**
Gasoline	0	0	6.4	$0
Diesel	1447	19,000	7.7	$148,000
All-Electric Vehicle (EV)	0	19,000	22.6	$380,000
Gaseous Hydrogen (G.H2) Fuel Cell Vehicle (FCV)	0	0	10.6	$0
Diesel Hybrid Electric Vehicle (HEV)	0	19,000	10.4	$208,000
Diesel Hydraulic Hybrid (HHV)	0	0	9.9	$0
Biodiesel (B20)	0	19,000	7.7	$148,000
Biodiesel (B100)	0	19,000	7.7	$148,000
Renewable Diesel (RD20)	0	19,000	7.7	$148,000
Renewable Diesel (RD100)	0	19,000	7.7	$148,000
Ethanol (E85)	0	0	6.4	$0
Propane (LPG)	0	19,000	6.4	$156,000
Compressed Natural Gas (CNG)	0	19,000	6.5	$178,000
Liquefied Natural Gas (LNG)	0	19,000	6.5	$168,000
LNG / Diesel Pilot Ignition	0	0	7.3	$0

This is the baseline data from which the 10- and 15-year scenarios diverge.

Table 27. Electricity mix.

Source of Electricity for PHEVs, EVs, and FCVs (Electrolysis)	12
	1 - Average U.S. Mix
	2 to 11 - EIA Region Mix (see map)
	12 - User Defined (go to 'Background Data' sheet)

Custom "user mix" as described in an earlier section.

Nicole---most of these are tables, not figures—reformat as I have done the first page, with titles above, and renumbered in sequence. Change "before" to 6pt on the titles so can be cut and pasted above the tables and single spaced.

Table 28. User mix.

5. Electric Generation Mix for On-Road Simulation	
	Mix for Transportation Use
Residual oil	0.0%
Natural gas	29.0%
Coal	10.0%
Nuclear power	28.0%
Biomass	0.0%
Others (Wind, Solar, Hydro, etc)	33.0%

This is the baseline electricity mix from which the 10- and 15-year scenarios diverge. Altered in the Background Data section of AFLEET.

Table 29. Selections for bus operation.

Petroleum Use, GHGs & Air Pollutant Options		
Petroleum Use, GHGs & Air Pollutant Calculation Type		1
1 - Well-to-Wheels Petroleum Use and GHGs & Vehicle Operation Air Pollutants		
2 - Well-to-Wheels Petroleum Use, GHGs, and Air Pollutants		
3 - Well-to-Wheels & Vehicle Production* Petroleum Use, GHGs, Air Pollutants (*LDVs only)		
Diesel In-Use Emissions Multiplier	yes/no	Yes
Low NOx Engines - CNG, LNG, LPG HDVs	yes/no	No

Selection of (1) well-to-wheels petroleum use, GHGs, and bus operation air pollutants. The diesel in-use emissions multiplier was selection. Low NO_x does not apply to school buses, so selected "No."

Table 30. Idle reduction inputs.

Heavy-Duty Vehicle Information					
IR Vehicle Type	School Bus				
IR Vocation Type	School Bus				
Baseline Vehicle Model Year	2020				
		Services Required (% of hours):			
Annual Conventional Idling Hours (per Vehicle)	180	Vehicle Heating	Engine Heating	Cooling	Electri
% of Idle Hours by Service		33%	0%	33%	34%
*Annual Hotelling Hours (per Vehicle)**	0	Vehicle Heating	Engine Heating	Cooling	Electr
% of Hotelling Hours by Service		33%	0%	33%	34%
Heavy-Duty Baseline & Idling Reduction Equipment	Number of Heavy-Duty Vehicles	Services Provided By IR Equipment			
Diesel	1447				

Idle reduction inputs for diesel bus fleet. Baseline for the model before the 10- and 15-year models diverge.

Table 31. Electric bus charging inputs.

DC Fast Charging Infrastructure				
Predicted Weekly Utilization	High			
Venue	Number of Chargers	Weekly Utilization (sessions/week/ station)	Average Session Power (kW)	Charge Time (minutes/ session)
Parking Lot	0	20.0	125	180
Retail & Leisure	0	26.0	24	22
Education	0	26.0	24	22
Healthcare	0	26.0	24	22
Workplace	0	26.0	24	22
Multi-Unit Dwelling	0	26.0	24	22
Single-Unit Dwelling	0	26.0	24	22

Baseline data for all diesel fleet. Note no electric vehicles for baseline.

Table 32. First 10 inputs of fleet's 1,447 school buses.

On-Road Fleet Footprint Calculator

State: MARYLAND | Year: 2020

			Fuel Use																				Remaining Lifetime (years)			
Vehicle Type	Model Year	Annual Vehicle Mileage	Gasoline (gal)	Diesel (gal)	Gasoline HEV (gal)	Gasoline PHEV (gal)	Gasoline PHEV (kWh)	Gasoline EREV (gal)	Gasoline EREV (kWh)	Electricity (kWh)	G.H2 (kg)	Diesel HEV (gal)	Diesel HHV (gal)	B20 (gal)	B100 (gal)	RD20 (gal)	RD100 (gal)	E85 (gal)	LPG (gal)	CNG (GGE)	LNG (gal)	LNG / Diesel (LNG gal)	LNG / Diesel (diesel gal)	Default Lifetime	Calculated Lifetime	Age	Remaining Lifetime
School Bus	2007	19,000		5																				15	15	13	2
School Bus	2007	19,000		5																				15	15	13	2
School Bus	2007	19,000		5																				15	15	13	2
School Bus	2007	19,000		5																				15	15	13	2
School Bus	2007	19,000		5																				15	15	13	2
School Bus	2007	19,000		5																				15	15	13	2
School Bus	2007	19,000		5																				15	15	13	2
School Bus	2007	19,000		5																				15	15	13	2
School Bus	2007	19,000		5																				15	15	13	2
School Bus	2007	19,000		5																				15	15	13	2

This is the baseline from which the 10- and 15-year models diverge and all buses inputted were categorized as diesel. Footprint-onroad section of AFLEET.

Table 33. Well-to-wheels petroleum use and GHGs per bus.

Well-to-Wheels Petroleum Use (barrels)	Vehicle Production Petroleum Use (barrels)	Well-to-Wheels GHGs (short tons)	Vehicle Production GHGs (short tons)
0.125	0.000	0.069	0.000
0.125	0.000	0.069	0.000
0.125	0.000	0.069	0.000
0.125	0.000	0.069	0.000
0.125	0.000	0.069	0.000
0.125	0.000	0.069	0.000
0.125	0.000	0.069	0.000
0.125	0.000	0.069	0.000
0.125	0.000	0.069	0.000
0.125	0.000	0.069	0.000

Baseline data results. The production phase was not considered for this study. Footprint-onroad section of AFLEET.

Table 34. Bus operation air pollutants results per bus.

Vehicle Operation Air Pollutants (lb)								
CO	NOx	PM10	PM10 (TBW)	PM2.5	PM2.5 (TBW)	VOC	VOC (Evap)	SOx
55.166	128.093	0.796	4.356	0.754	0.545	4.314	1.340	0.001
55.166	128.093	0.796	4.356	0.754	0.545	4.314	1.340	0.001
55.166	128.093	0.796	4.356	0.754	0.545	4.314	1.340	0.001
55.166	128.093	0.796	4.356	0.754	0.545	4.314	1.340	0.001
55.166	128.093	0.796	4.356	0.754	0.545	4.314	1.340	0.001
55.166	128.093	0.796	4.356	0.754	0.545	4.314	1.340	0.001
55.166	128.093	0.796	4.356	0.754	0.545	4.314	1.340	0.001
55.166	128.093	0.796	4.356	0.754	0.545	4.314	1.340	0.001
55.166	128.093	0.796	4.356	0.754	0.545	4.314	1.340	0.001
55.166	128.093	0.796	4.356	0.754	0.545	4.314	1.340	0.001

Baseline model for diesel bus fleet. Footprint-onroad section of AFLEET.

Table 35. Electric bus charging inputs.

DC Fast Charger Inputs		
Default Weekly DC Fast Utilization	High	
Number of DC Fast Chargers	0	
Weekly Utilization (sessions/week)	20.0	2
Daily Utilization (sessions/day)	2.9	
Average Session Power (kW)	125.0	2
Average Charge Time (hours/session)	3.0	
Electricity Dispensed (kWh/session)	375.0	
Electricity Dispensed (kWh/day)	0.0	
Electricity Dispensed (kWh/year)	0	
Annual EV Miles from DC Fast Charging	0	

Appendix 2

Electricity Mix

The following tables and charts show the assumed electricity grid mix from 2020 to 2036. The mix remains the same for both scenarios (10-year vs 15-year plans).

Table 36. Baseline for assumed electricity mix.

Maryland Net Electricity Generation by Source Aug. 2020				
https://www.eia.gov/state/?sid=MD#tabs-4				
20:20:21 GMT-0500 (Eastern Standard Time)				
Source: Ener	Electric Power Monthly			
	Maryland Net Electricity Generation thousand MWh			
Category	MWh			
Petroleum-Fi	8			
Natural Gas-	1329			
Coal-Fired	465			
Nuclear	1290			
Hydroelectric	51			
Nonhydroele	130			

Note: Petroleum was not considered due to its low output, and in corresponding tables, hydrolectric and nonhydroelectric were combined under "renewable" for simplicity (EIA, 2020).

Table 37. Fossil fuel and nuclear power generation reduction.

2021	0.286
2022	0.307
2023	0.328
2024	0.349
2025	0.37
2026	0.391
2027	0.412
2028	0.433
2029	0.454
2030	0.475
2031	0.496
2032	0.517
2033	0.538
2034	0.559
2035	0.58
2036	0.601

For the scenarios designed to show fossil fuel demands on a progressive renewable energy electrical grid portfolio, fossil fuels were reduced by the above percentages to correspond with state-mandated renewable energy requirements for 2030 and 2040.

Table 38. Results of calculations of assumed electricity mix.

Maryland Net Electricity Generation thousand MWh

Source	Current	2020	2021	2022	2023	2024
Natural Gas-Fired	1329	977	949	921	893	865
Coal-Fired	465	342	332	322	312	303
Nuclear	1290	948	921	894	867	840
Renewable	181	998	1063	1128	1193	1257

Source	2031	2032	2033	2034	2035	2036
Natural Gas-Fired	670	642	614	586	558	530
Coal-Fired	234	225	215	205	195	186
Nuclear	650	623	596	569	542	515
Renewable	1711	1775	1840	1905	1970	2034

Source	2025	2026	2027	2028	2029	2030
Natural Gas-Fired	837	809	781	754	726	698
Coal-Fired	293	283	273	264	254	244
Nuclear	813	786	759	731	704	677
Renewable	1322	1387	1452	1516	1581	1646

The results of calculating for fossil fuel reductions to meet renewable energy goals for Maryland's electrical grid portfolio. Only renewable energy increases in MWh to meet state electricity demands; all other fuel sources decrease.

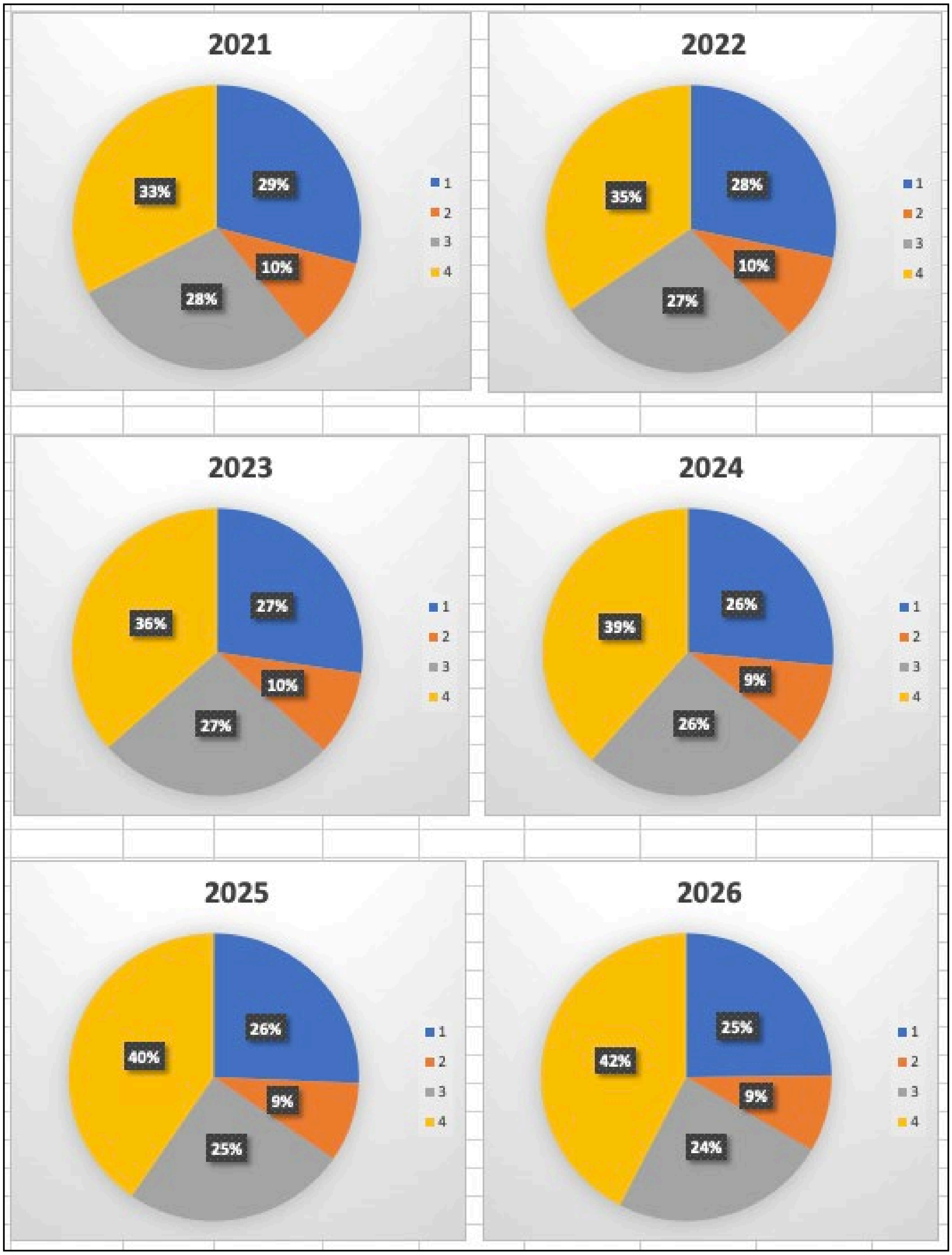

Figure 9. Illustrations of the changing energy portfolio following the assumed progressive fossil fuel and nuclear energy reductions, 2023-2026.

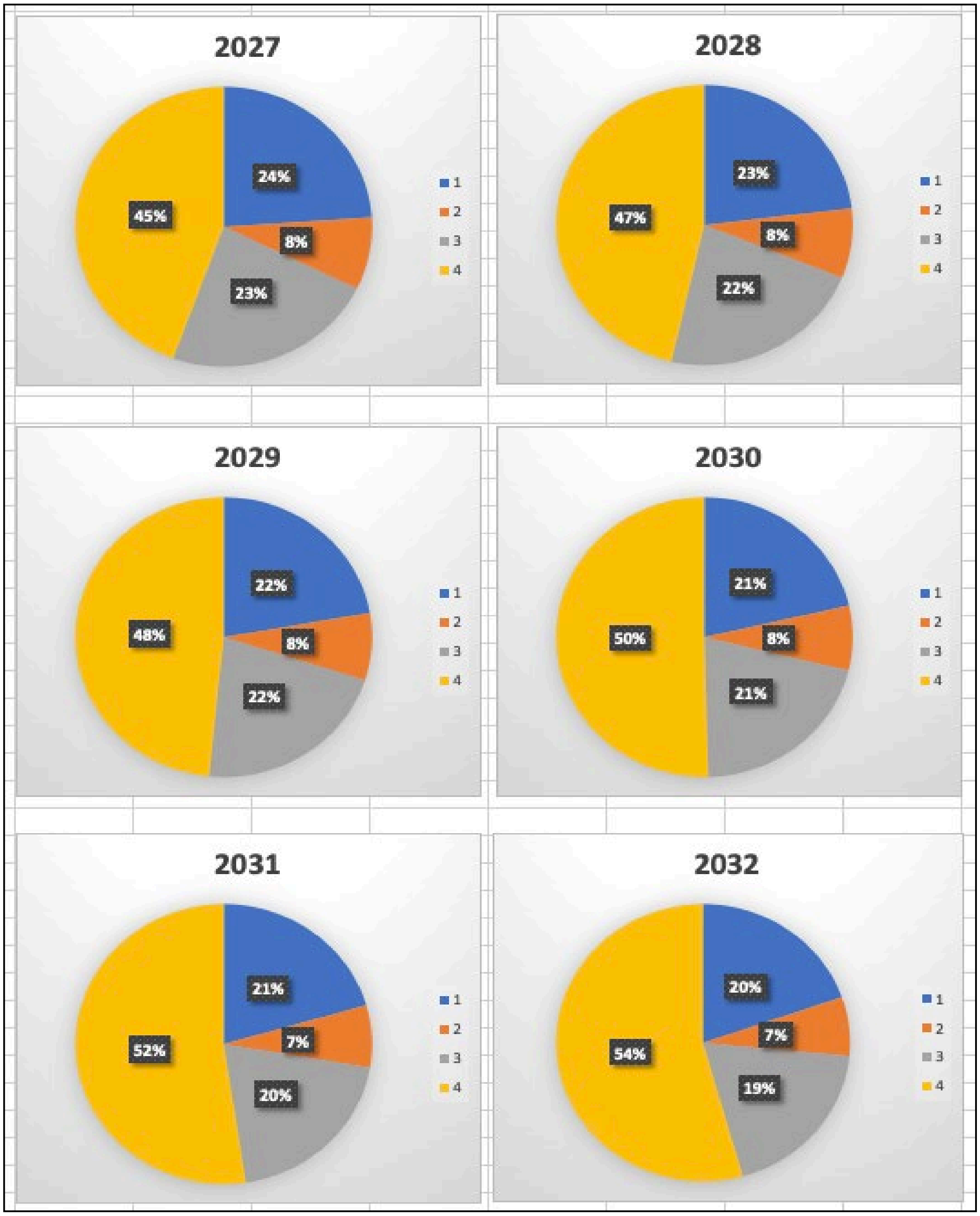

Figure 10. Illustrations of the changing energy portfolio following the assumed progressive fossil fuel and nuclear energy reductions, 2027-2032.

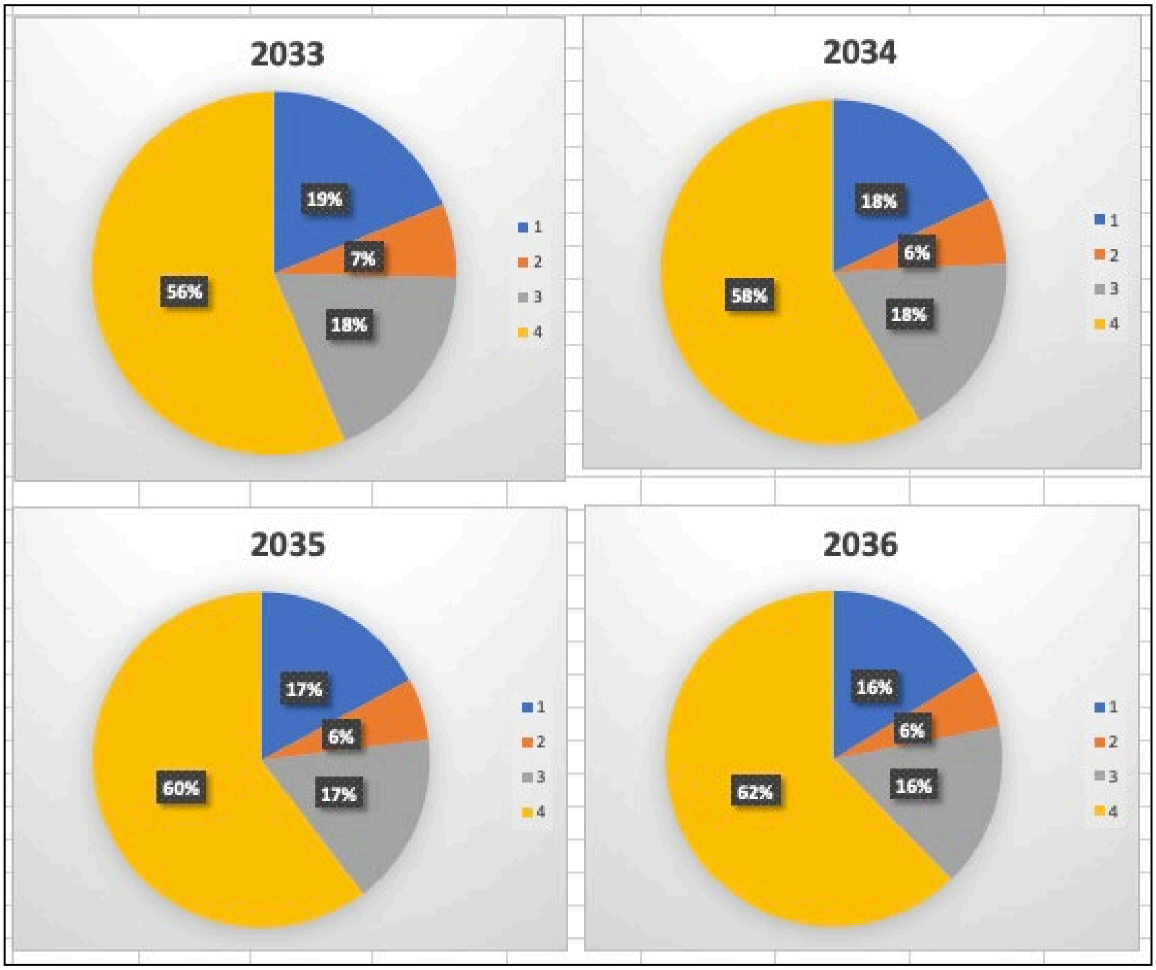

Figure 11. Illustrations of the changing energy portfolio following the assumed progressive fossil fuel and nuclear energy reductions, 2033-2036.

Appendix 3

AFLEET 10-year Plan Outputs

The following are outputs for the 10-year scenario from calculations using AFLEET emission outputs based on the inputs described in Appendix 1.

Table 39. Results from Footprint-Onroad in AFLEET.

	Potential annual schoolchildren pollutant exposure to riding diesel buses (in lbs) (Ten year plan)							
Year	**CO**	**NOx**	**PM10**	**PM2.5**	**VOC**	**SOx**	**GHG (short tons)**	**Petroleum Use (barrels)**
1	65,114.80	187,870.40	7,119.90	1,583.70	6,036.50	1.1	99.90	180.20
2	57,170.90	169,425.00	7,001.60	1,475.20	5,222.20	1	90.2	162.3
3	50,150.20	146,359.40	6,887.30	1,370.50	4,536.40	0.9	80.4	144.3
4	43,635.80	120,760.30	6,775.10	1,267.90	3,921.20	0.8	70.7	126.4
5	37,238.10	98,266.50	6,676.50	1,179.00	3,329.40	0.7	61	108.4
6	30,880.60	76,841.40	6,582.40	1,094.60	2,750.40	0.6	51.2	90.5
7	24,724.10	60,664.00	6,513.50	1030.2	2,196.90	0.5	41.5	72.5
8	18,607.80	45,549.80	6,449.50	969.9	1,654.10	0.3	31.7	54.6
9	12,491.50	30,481.80	6,385.60	909.6	1,111.20	0.2	22	36.6
10	6,363.20	15,465.60	6,322.50	849.3	566.6	0.1	12.3	18.6
Final year	0	0	0	0	0	0	0	0

Table 40. Results from Charging Output in AFLEET.

	Annual charging calculator output - energy use and emissions benefits (Ten year plan)								
Year	**CO (lb)**	**NOx (lb)**	**PM10 (lb)**	**PM2.5 (lb)**	**VOC (lb)**	**SOx (lb)**	**GHG (short tons)**	**Petroleum use (barrels)**	**Electricity dispensed (kWh)**
1	0	0	0	0	0	0	0	0	0
2	127,377.30	7,039.80	383.3	336.5	14.191.0	167.4	9,351.50	30,613.70	13,687,500
3	254,754.50	14,079.60	766.5	673.1	28,382.10	334.7	18,703.00	61,227.40	27,375,000
4	382,131.80	21,119.40	1,149.80	1,009.60	42,573.10	502.1	28,054.50	91,841.10	41,062,500
5	509,509.00	28,159.20	1,533.10	1,346.20	56,764.10	669.5	37,406.00	122,454.80	54,750,000
6	636,886.30	35,198.90	1,916.40	1,682.70	70,955.10	836.9	46,757.50	153,068.50	68,437,500
7	764,263.50	42,238.70	2,299.60	2,019.30	85,146.20	1,004.20	56,109.00	183,682.20	82,125,000
8	891,640.80	49,278.50	2,682.90	2,355.80	99,337.20	1,171.60	65,460.50	214,295.90	95,812,500
9	1,019,018.10	56,318.30	3,066.20	2,692.40	113,528.20	1,339.00	74,812.00	244,909.60	109,500,000
10	1,146,395.30	63,358.10	3,449.40	3,028.90	127,719.30	1,506.30	84,163.50	275,523.30	123,187,500
Final Year	1,255,575.80	69,392.20	3,778.00	3,317.40	139,883	1,649.80	92,179.00	301,763.60	134,919,643

Table 41. Results from Charging Output in AFLEET.

Annual DC charging calculator output									
Energy use and emissions benefits									
Year	CO (lb)	NOx (lb)	PM10 (lb)	PM2.5 (lb)	VOC (lb)	SOx (lb)	Electricity dispensed (kWh)	Petroleum use (barrels)	GHGs (short tons)
1	0	0	0	0	0	0	0	0	0
2	127,377.30	7,039.80	383.3	336.5	14,191.00	167.40	13,687,500	30,767.30	13,808.60
3	254,754.50	14,079.60	766.5	673.1	28,382.10	334.70	27,375,000	61,536.10	27,769.40
4	382,131.80	21,119.40	1,149.80	1,009.60	42,573.10	502.10	41,062,500	92,318.60	42,364.40
5	509,509.00	28,159.20	1,533.10	1,346.20	56,764.10	669.50	54,750,000	123,092.60	56,489.30
6	636,886.30	35,198.90	1,916.40	1,682.70	70,955.10	836.90	68,437,500	153,870.70	70,996.30
7	764,263.50	42,238.70	2,299.60	2,019.30	85,146.20	1,004.20	82,125,000	184,673.90	86,616.10
8	891,640.80	49,278.50	2,682.90	2,355.80	99,337.20	1,176.60	95,812,500	215,459.80	101,590.70
9	1,019,018.10	56,318.30	3,066.20	2,692.40	113,528.20	1,339.00	109,500,000	246,245.60	116,712.40
10	1,146,395.30	63,358.10	3,449.40	3,028.90	127,719.30	1,506.30	123,187,500	277,035.20	131,993.90
Final	1,255,575.80	69,392.20	3,778.00	3,317.40	139,883.00	1,649.80	134,919,643	303,460.20	146,148.40

Table 42. Results from Idle Reduction in AFLEET.

Annual bus operation idling air pollutants (in lb)						
Year	CO	NOx	PM10	PM2.5	VOC	SOx
1	2,004.59	2,793.56	111.97	103.36	341.66	30.5
2	1,805.10	2,515.56	100.83	93.07	307.66	27.46
3	1,605.61	2,237.55	89.69	82.79	273.66	24.43
4	1,406.12	1,959.55	78.54	72.5	239.66	21.39
5	1,206.63	1,681.54	67.4	62.22	205.66	18.36
6	1,007.14	1,403.54	56.26	51.93	171.66	15.32
7	807.65	1,125.53	45.11	41.64	137.66	12.29
8	608.16	847.53	33.97	31.36	103.65	9.25
9	408.68	569.52	22.83	21.07	69.65	6.22
10	209.19	291.52	11.68	10.79	35.65	3.18
Final	0.00	0.00	0	0	0	0

Table 43. Results from Idle Reduction in AFLEET.

Annual well-to-wheels bus idling petroleum use and GHGs		
Year	**Petroleum use (barrels)**	**Idling GHGs (short tons)**
1	4,893.0	2,712.4
2	4,406.0	2,442.5
3	3,919.1	2,172.6
4	3,432.2	1,902.6
5	2,945.2	1,632.7
6	2,458.3	1,362.8
7	1,971.4	1,092.8
8	1,484.5	822.9
9	997.5	553.0
10	510.6	283.1
Final	0.0	0.0

Appendix 4

AFLEET 15-year Plan Outputs

The following are outputs for the 15-year scenario from calculations using AFLEET emisson outputs based on the inputs described in Appendix 1.

Table 44. Results from Footprint-Onroad in AFLEET.

Potential annual schoolchildren pollutant exposure to riding diesel buses (in lbs) (15 Year Plan)								
Year	**CO**	**NOx**	**PM10**	**PM2.5**	**VOC**	**SOx**	**GHG (short tons)**	**Petroleum Use (barrels)**
1	65,114.80	187,870.40	7,119.90	1,583.70	6,036.50	1.10	99.9	180.2
2	59,818.90	175,573.40	6,625.30	1,459.10	5,493.60	1	93.3	168.3
3	54,522.90	163,276.50	6,130.60	1,334.40	4,950.70	1	86.6	156.3
4	50,195.40	146,537.20	5,645.00	1,214.90	4,540.70	0.9	80.1	144.4
5	45,897.70	129,648.90	5,159.60	1,095.50	4,134.80	0.8	73.5	132.6
6	41,627.80	113,498.90	4,677.30	979.4	3,733.80	0.8	66.9	120.7
7	37,414.70	98,861.70	4,201.70	869.9	3,345.50	0.7	60.4	108.9
8	33,220.50	84,727.00	3,728.20	762.4	2,963.50	0.6	53.8	97
9	29,056.50	71,379.50	3,258.40	658	2585.2	0.5	47.2	85.2
10	25,021.40	61,399.40	2,804.80	566.5	2,223.30	0.5	40.7	73.3
11	20,986.30	51,419.20	2,351.10	475	1,865.20	0.4	34.1	61.5
12	16,951.30	41,465.80	1,897.50	383.4	1,507.00	0.3	27.5	49.6
13	12,916	31,527.30	1,443.80	291.9	1,148.90	0.2	21	37.8
14	8,876.60	21,609.80	990.5	200.4	790.1	0.2	14.4	25.9
15	4,828.20	11,720.80	537.7	108.9	430.1	0.1	7.8	14.1
16	0	0	0	0	0	0	0	0

Table 45. Results from Charging Output in AFLEET.

Annual DC charging calculator output - 15 year plan									
Energy use and emissions benefits									
Year	CO (lb)	NOx (lb)	PM10 (lb)	PM2.5 (lb)	VOC (lb)	SOx (lb)	Electricity dispensed (kWh)	Petroleum use (barrels)	GHGs (short tons)
1	0	0	0	0	0	0	0	0	0
2	83,705.10	4,626.10	251.9	221.2	9,325.50	110.00	8,994,643	20,217.90	9,023.70
3	167,410.10	9,252.30	503.7	442.3	18,651.10	220.00	17,989,286	40,438.00	18,248.50
4	251,115.20	13,878.40	755.6	663.5	27,976.60	330.00	26,983,929	60,666.50	27,839.50
5	334,820.20	18,504.60	1007.5	884.6	37,302.10	439.90	35,978,571	80,889.40	37,121.50
6	418,525.30	23,130.70	1,259.30	1,105.80	46,627.70	549.90	44,973,214	101,115.00	46,654.70
7	502,230.30	27,756.90	1,511.20	1,327.00	55,953.20	659.90	53,967,857	121,357.20	56,919.20
8	585,935.40	32,383.00	1,763.00	1,548.10	65,278.70	769.90	62,962,500	141,587.90	66,759.60
9	669,640.40	37,009.20	2,014.90	1,769.30	74,604.30	879.90	71,957,143	161,818.50	76,696.70
10	753,345.50	41,635.30	2,266.80	1,990.40	83,929.80	989.90	80,951,786	182,051.70	86,738.80
11	837,050.60	46,261.50	2,518.60	2,211.60	93,255.30	1,099.90	89,946,429	202,306.80	97,432.30
12	920,755.60	50,887.60	2,770.50	2,432.70	102,580.90	1,209.90	98,941,071	222,544.60	107,731.70
13	1,004,460.70	55,513.80	3,022.40	2,653.90	111,906.40	1,319.80	107,935,714	242,783.70	118,132.20
14	1,088,165.70	60,139.90	3,274.20	2,875.10	121,231.90	1,429.80	116,930,357	263,054.80	129,991.80
15	1,171,870.80	64,766.10	3,526.10	3,096.20	130,557.50	1,539.80	125,925,000	283,298.90	140,699.00
Final	1,255,575.80	69,392.20	3,778.00	3,317.40	139,883.00	1,649.80	134,919,643	303,534.50	150,748.90

Table 46. Results from Idle Reduction in AFLEET.

Annual bus operation idling air pollutants (in lb)						
Year	CO	NOx	PM10	PM2.5	VOC	SOx
1	2,004.59	2,793.56	111.97	103.36	341.66	30.5
2	1,871.60	2,608.22	104.54	96.5	318.99	28.47
3	1,738.60	2,422.89	97.11	89.64	296.32	26.45
4	1,605.61	2,237.55	89.69	82.79	273.66	24.43
5	1,472.62	2,052.22	82.26	75.93	250.99	22.4
6	1,339.62	1,866.88	74.83	69.07	228.32	20.38
7	1,206.63	1,681.54	67.4	62.22	205.66	18.36
8	1,073.64	1,496.21	59.97	55.36	182.99	16.33
9	940.65	1,310.87	52.54	48.5	160.32	14.31
10	807.65	1,125.53	45.11	41.64	137.66	12.29
11	674.66	940.20	37.69	34.79	114.99	10.26
12	541.67	754.86	30.26	27.93	92.32	8.24
13	408.68	569.52	22.83	21.07	69.65	6.22
14	275.68	384.19	15.4	14.21	46.99	4.19
15	142.69	198.85	7.97	7.36	24.32	2.17
Final	0	0	0	0	0	0

Table 47. Results from fewer buses idling during diesel phase-out.

Annual well-to-wheels bus idling petroleum use and GHGs		
Year	Petroleum use (barrels)	Idling GHGs (short tons)
1	4,893.0	2,712.4
2	4,568.3	2,532.5
3	4,243.7	2,352.5
4	3,919.1	2,172.6
5	3,594.5	1,992.6
6	3,269.9	1,812.7
7	2,945.2	1,632.7
8	2,620.6	1,452.8
9	2,296.0	1,272.8
10	1,971.4	1,092.8
11	1,646.8	912.9
12	1,322.1	732.9
13	997.5	553.0
14	672.9	373.0
15	348.3	193.1
Final	0	0

Appendix 5

Social Cost of Emissions Data

Table 48. Expanded SC-CO values in 2020$.

Social Cost of CO2, per ton*				
	Discount rate			
Emissions Year	5% avg	3% avg	2.5% avg	Maryland SC-CO
2020	14	51	76	110
2021	14.6	52	77.4	110
2022	15.2	53	78.8	110
2023	15.8	54	80.2	110
2024	16.4	55	81.6	110
2025	17	56	83	110
2026	17.4	57.2	84.2	110
2027	17.8	58.4	85.4	110
2028	18.2	59.6	86.6	110
2029	18.6	60.8	87.8	110
2030	19	62	89	110
2031	19.6	63	90.4	110
2032	20.2	64	91.8	110
2033	20.8	65	93.2	110
2034	21.4	66	94.6	110
2035	22	67	96	110
2036	22.6	68.2	97.4	110
2037	23.2	69.4	98.8	110
2038	23.8	70.6	100.2	110
2039	24.4	71.8	101.6	110
2040	25	73	103	110
2041	25.6	74.2	104.4	110
2042	26.2	75.4	105.8	110
2043	26.8	76.6	107.2	110
2044	27.4	77.8	108.6	110
2045	28	79	110	110
2046	28.8	80.2	111.2	110
2047	29.6	81.4	112.4	110
2048	30.4	82.6	113.6	110
2049	31.2	83.8	114.8	110
2050	32	85	116	110
*not calculated for NPV				

Federal and Maryland social cost of CO2, per metric ton. Federal figures are interim values and final social costs are expected in February 2022. Sources: (Interagency Working Group on Social Cost of Greenhouse Gases, 2021; Maryland Dept. of Natural Resources, 2021)

Table 49. Comparison of social cost of pollutants based on use phase.

	On the road scenario			
Year	**Baseline Diesel**	**10 Year Diesel SC**	**10 Year EV mid-RE**	**10 Year EV low-RE**
1	$792,663	$792,663	$0	$0
2	$792,663	$720,226	$1,520,995	$2,223,013
3	$792,663	$641,029	$2,994,217	$4,446,026
4	$792,663	$558,543	$4,282,225	$6,669,039
5	$792,663	$485,233	$5,616,033	$8,892,052
6	$792,663	$415,122	$6,786,039	$11,115,064
7	$792,663	$359,669	$7,722,045	$13,338,077
8	$792,663	$307,279	$8,681,450	$15,561,090
9	$792,663	$254,996	$9,734,456	$17,784,103
10	$792,663	$202,784	$10,530,061	$20,007,116
Final	$792,663	$0	$11,071,607	$21,912,556
NPV	**$7,554,235**	**$4,304,276**	**$56,580,447**	**$99,441,354**

The above categories are based on the social costs calculated previously for the 10-year scenario.

Table 50. Comparison of social cost of pollutants based on use phase.

	On the road scenario			
Year	**Baseline Diesel**	**15 Year Diesel SC**	**15 Year EV mid-RE**	**15 Year EV low-RE**
1	$793,391	$793,391	$0	$0
2	$793,391	$734,726	$999,520	$1,460,837
3	$793,391	$676,042	$1,968,286	$2,921,674
4	$793,391	$612,043	$2,814,034	$4,382,511
5	$793,391	$547,835	$3,690,536	$5,843,348
6	$793,391	$485,813	$4,459,397	$7,304,185
7	$793,391	$428,273	$5,074,487	$8,765,022
8	$793,391	$372,216	$5,704,953	$10,225,859
9	$793,391	$318,372	$6,396,929	$11,686,696
10	$793,391	$273,958	$6,919,754	$13,147,533
11	$793,391	$229,599	$7,381,071	$14,608,370
12	$793,391	$185,272	$7,780,879	$16,969,207
13	$793,391	$141,005	$8,119,178	$17,530,044
14	$793,391	$96,764	$8,395,969	$18,990,882
15	$793,391	$52,550	$8,611,250	$20,451,719
16	$793,391	$0	$8,765,022	$21,912,556
NPV	**$10,264,841**	**$5,236,697**	**$65,612,458**	**$130,574,294**

The above categories are based on the social costs calculated previously for the 15-year scenario.

Table 51. Social costs of a diesel school bus idling for 10 and 20 minutes, respectively. 10-year scenario.

Social cost of an idling diesel bus (2020$) 10 minutes idlling								
Annual marginal damages of ground-level emissions - Ten year plan								
Year	SC-NOx	SC-PM25	SC-VOC	SC-SO2	SC-CO 5%	SC-CO 3%	SC-CO 2.5%	SC-CO Mary.
1	$ 1,844.26	$ 6,507.40	$ 2,135.11	$ 787.53	$ 9,667.34	$ 34,431.63	$ 51,250.16	$ 72,836.14
2	$ 1,660.73	$ 5,859.50	$ 1,922.52	$ 708.55	$ 9,094.02	$ 31,709.42	$ 47,145.32	$ 65,811.99
3	$ 1,477.19	$ 5,213.48	$ 1,710.11	$ 630.33	$ 8,408.08	$ 28,736.48	$ 42,678.99	$ 58,537.27
4	$ 1,293.65	$ 4,565.57	$ 1,497.71	$ 552.12	$ 7,642.78	$ 25,631.27	$ 38,027.49	$ 51,262.55
5	$ 1,110.12	$ 3,917.67	$ 1,285.12	$ 473.91	$ 6,798.12	$ 22,393.80	$ 33,190.81	$ 43,987.83
6	$ 926.60	$ 3,269.76	$ 1,072.71	$ 395.70	$ 5,808.62	$ 19,095.02	$ 28,108.40	$ 36,721.19
7	$ 743.06	$ 2,621.85	$ 860.31	$ 317.49	$ 4,764.97	$ 15,633.39	$ 22,861.16	$ 29,446.46
8	$ 559.52	$ 1,973.94	$ 647.71	$ 238.50	$ 3,668.42	$ 12,013.05	$ 17,455.21	$ 22,171.74
9	$ 375.99	$ 1,326.04	$ 435.31	$ 160.29	$ 2,518.95	$ 8,233.99	$ 11,890.53	$ 14,897.02
10	$ 192.45	$ 680.02	$ 222.72	$ 82.08	$ 1,317.97	$ 4,300.76	$ 6,173.67	$ 7,630.38
Final	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
NPV	$ 9,340.05	$ 32,958.63	$ 10,812.80	$ 3,986.53	$ 54,438.70	$ 184,785.33	$ 273,244.70	$ 369,875.89

Social cost of an idling diesel bus (2020$) 20 minutes idlling								
Annual marginal damages of ground-level emissions - Ten year plan								
Year	SC-NOx	SC-PM25	SC-VOC	SC-SO2	SC-CO 5%	SC-CO 3%	SC-CO 2.5%	SC-CO Mary.
1	$ 3,688.51	$ 13,016.70	$ 4,270.03	$ 1,574.29	$ 19,400.13	$ 69,096.35	$ 102,847.26	$ 146,165.35
2	$ 3,321.45	$ 11,720.88	$ 3,845.22	$ 1,417.86	$ 18,186.93	$ 63,414.94	$ 94,284.85	$ 131,615.91
3	$ 2,954.38	$ 10,425.07	$ 3,420.23	$ 1,260.67	$ 16,816.16	$ 57,472.96	$ 85,357.99	$ 117,074.54
4	$ 2,587.30	$ 9,129.26	$ 2,995.23	$ 1,104.25	$ 15,285.56	$ 51,262.55	$ 76,054.98	$ 102,525.10
5	$ 2,220.25	$ 7,835.33	$ 2,570.23	$ 947.82	$ 13,597.49	$ 44,791.72	$ 66,387.73	$ 87,983.73
6	$ 1,853.18	$ 6,539.52	$ 2,145.42	$ 790.63	$ 11,615.97	$ 38,185.83	$ 56,210.61	$ 73,434.29
7	$ 1,486.12	$ 5,243.70	$ 1,720.42	$ 634.21	$ 9,529.95	$ 31,266.79	$ 45,722.33	$ 58,892.92
8	$ 1,119.05	$ 3,949.78	$ 1,295.43	$ 477.78	$ 7,336.83	$ 24,026.10	$ 34,910.41	$ 44,343.48
9	$ 751.97	$ 2,653.96	$ 870.62	$ 320.59	$ 5,039.27	$ 16,472.44	$ 23,787.51	$ 29,802.12
10	$ 384.92	$ 1,358.15	$ 445.62	$ 164.17	$ 2,634.55	$ 8,596.96	$ 12,340.80	$ 15,252.67
Final	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
NPV	$ 18,680.10	$ 65,919.04	$ 21,625.41	$ 7,972.34	$ 108,941.77	$ 369,800.03	$ 546,830.87	$ 740,237.40

Table 52. Social costs of a diesel school bus idling. 10-year scenario.

Social cost of an idling diesel bus (2020$) Annual marginal damages of ground-level emissions - Ten year plan						
Year	SC-NOx	SC-PM25	SC-VOC	SC-SO2	SC-CO2	Total-SC
1	$5,532.77	$19,524.10	$6,405.14	$2,361.82	$241,674.84	$275,498.67
2	$4,982.18	$17,580.38	$5,767.74	$2,126.41	$217,626.75	$248,083.46
3	$4,431.57	$15,638.55	$5,130.34	$1,891.78	$193,578.66	$220,670.89
4	$3,880.98	$13,694.83	$4,492.94	$1,656.37	$169,521.66	$193,246.77
5	$3,330.37	$11,753.00	$3,855.53	$1,421.74	$145,473.57	$165,834.20
6	$2,779.77	$9,809.28	$3,218.13	$1,186.33	$121,425.48	$138,418.99
7	$2,229.16	$7,865.55	$2,580.73	$951.70	$97,368.48	$110,995.62
8	$1,678.57	$5,923.72	$1,943.14	$716.29	$73,320.39	$83,582.11
9	$1,127.96	$3,980.00	$1,305.74	$481.66	$49,272.30	$56,167.65
10	$577.37	$2,038.17	$668.34	$246.25	$25,224.21	$28,754.33
NPV totals	$28,020.15	$98,877.67	$32,438.23	$11,960.21	$1,223,948.82	$1,395,245.09

Table 53. Expanded SC-CO2 for idling for 30 minutes. 10-year scenario.

Year	SC-CO 5%	SC-CO 3%	SC-CO 2.5%	SC-CO Mary.
1	$ 29,099.66	$ 103,642.61	$ 154,268.04	$ 219,243.99
2	$ 27,280.95	$ 95,124.35	$ 141,430.17	$ 197,427.90
3	$ 25,224.24	$ 86,209.44	$ 128,036.98	$ 175,611.82
4	$ 22,928.34	$ 76,893.82	$ 114,082.47	$ 153,787.65
5	$ 20,395.60	$ 67,185.52	$ 99,578.54	$ 131,971.56
6	$ 17,424.59	$ 57,280.85	$ 84,319.01	$ 110,155.47
7	$ 14,293.61	$ 46,895.89	$ 68,577.21	$ 88,331.30
8	$ 11,005.25	$ 36,039.15	$ 52,365.62	$ 66,515.22
9	$ 7,558.22	$ 24,706.43	$ 35,678.03	$ 44,699.13
10	$ 3,952.53	$ 12,897.72	$ 18,514.46	$ 22,883.05
NPV	$ 163,411.55	$ 554,696.39	$ 820,240.94	$ 1,110,349.01

Table 54. Social costs of a diesel school bus idling for 10 and 20 minutes, respectively. 15-year scenario.

Social cost of an idling diesel bus (2020$) - 10 minutes idlling								
Annual marginal damages of ground-level emissions - 15 year plan								
Year	SC-NOx	SC-PM25	SC-VOC	SC-SO2	SC-CO 5%	SC-CO 3%	SC-CO 2.5%	SC-CO Mary.
1	$ 1,844.26	$ 6,507.40	$ 2,135.11	$ 787.53	$ 19,400.13	$ 69,096.35	$ 102,847.26	$ 146,165.35
2	$ 1,721.91	$ 6,076.73	$ 1,993.38	$ 734.87	$ 18,857.08	$ 65,751.67	$ 97,759.08	$ 136,465.72
3	$ 1,599.55	$ 5,644.16	$ 1,851.65	$ 682.99	$ 18,209.38	$ 62,234.59	$ 92,429.90	$ 126,774.17
4	$ 1,477.19	$ 5,213.48	$ 1,710.11	$ 630.33	$ 17,454.75	$ 58,537.27	$ 86,848.02	$ 117,074.54
5	$ 1,354.83	$ 4,780.91	$ 1,568.38	$ 578.45	$ 16,594.30	$ 54,663.59	$ 81,019.25	$ 107,374.91
6	$ 1,232.47	$ 4,348.34	$ 1,426.84	$ 525.79	$ 15,450.45	$ 50,791.15	$ 74,765.99	$ 97,675.28
7	$ 1,110.12	$ 3,917.67	$ 1,285.12	$ 473.91	$ 14,237.37	$ 46,711.36	$ 68,307.37	$ 87,983.73
8	$ 987.78	$ 3,485.10	$ 1,143.57	$ 421.26	$ 12,952.46	$ 42,415.75	$ 61,630.94	$ 78,284.10
9	$ 865.42	$ 3,054.42	$ 1,001.85	$ 369.37	$ 11,597.01	$ 37,908.51	$ 54,742.88	$ 68,584.47
10	$ 743.06	$ 2,621.85	$ 860.31	$ 317.49	$ 10,172.41	$ 33,194.19	$ 47,649.73	$ 58,892.92
11	$ 620.70	$ 2,191.17	$ 718.58	$ 264.83	$ 8,765.35	$ 28,174.34	$ 40,427.94	$ 49,193.29
12	$ 498.34	$ 1,758.60	$ 576.85	$ 212.95	$ 7,252.47	$ 22,978.13	$ 32,959.26	$ 39,493.66
13	$ 375.99	$ 1,326.04	$ 435.31	$ 160.29	$ 5,635.31	$ 17,610.34	$ 25,250.52	$ 29,802.12
14	$ 253.63	$ 895.36	$ 293.58	$ 108.41	$ 3,910.85	$ 12,061.49	$ 17,288.14	$ 20,102.48
15	$ 131.27	$ 462.79	$ 152.04	$ 55.75	$ 2,080.57	$ 6,336.28	$ 9,078.85	$ 10,402.85
Final	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
NPV	$ 12,973.07	$ 45,778.98	$ 15,018.56	$ 5,537.47	$ 158,076.03	$ 528,837.61	$ 777,269.09	$ 1,028,169.03

Social cost of an idling diesel bus (2020$) - 20 minutes idlling								
Annual marginal damages of ground-level emissions - 15 year plan								
Year	SC-NOx	SC-PM25	SC-VOC	SC-SO2	SC-CO 5%	SC-CO 3%	SC-CO 2.5%	SC-CO Mary.
1	$ 3,688.51	$ 13,016.70	$ 4,270.03	$ 1,574.29	$ 19,400.13	$ 69,096.35	$ 102,847.26	$ 146,165.35
2	$ 3,443.81	$ 12,151.56	$ 3,986.76	$ 1,469.75	$ 18,857.08	$ 65,751.67	$ 97,759.08	$ 136,465.72
3	$ 3,199.10	$ 11,288.32	$ 3,703.49	$ 1,365.21	$ 18,209.38	$ 62,234.59	$ 92,429.90	$ 126,774.17
4	$ 2,954.38	$ 10,425.07	$ 3,420.23	$ 1,260.67	$ 17,454.75	$ 58,537.27	$ 86,848.02	$ 117,074.54
5	$ 2,709.66	$ 9,561.82	$ 3,136.96	$ 1,156.90	$ 16,594.30	$ 54,663.59	$ 81,019.25	$ 107,374.91
6	$ 2,464.97	$ 8,698.58	$ 2,853.69	$ 1,052.36	$ 15,450.45	$ 50,791.15	$ 74,765.99	$ 97,675.28
7	$ 2,220.25	$ 7,835.33	$ 2,570.23	$ 947.82	$ 14,237.37	$ 46,711.36	$ 68,307.37	$ 87,983.73
8	$ 1,975.53	$ 6,972.08	$ 2,286.96	$ 843.28	$ 12,952.46	$ 42,415.75	$ 61,630.94	$ 78,284.10
9	$ 1,730.82	$ 6,106.95	$ 2,003.69	$ 738.75	$ 11,597.01	$ 37,908.51	$ 54,742.88	$ 68,584.47
10	$ 1,486.12	$ 5,243.70	$ 1,720.42	$ 634.21	$ 10,172.41	$ 33,194.19	$ 47,649.73	$ 58,892.92
11	$ 1,241.41	$ 4,380.46	$ 1,437.15	$ 529.67	$ 8,765.35	$ 28,174.34	$ 40,427.94	$ 49,193.29
12	$ 996.69	$ 3,517.21	$ 1,153.89	$ 425.13	$ 7,252.47	$ 22,978.13	$ 32,959.26	$ 39,493.66
13	$ 751.97	$ 2,653.96	$ 870.62	$ 320.59	$ 5,635.31	$ 17,610.34	$ 25,250.52	$ 29,802.12
14	$ 507.26	$ 1,790.72	$ 587.16	$ 216.82	$ 3,910.85	$ 12,061.49	$ 17,288.14	$ 20,102.48
15	$ 262.56	$ 925.58	$ 303.89	$ 112.28	$ 2,080.57	$ 6,336.28	$ 9,078.85	$ 10,402.85
Final	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
NPV	$ 25,946.14	$ 91,557.87	$ 30,037.00	$ 11,074.09	$ 158,076.03	$ 528,837.61	$ 777,269.09	$ 1,028,169.03

Table 55. Social costs of a diesel school bus idling for 30 minutes. 15-year scenario.

Social cost of an idling diesel bus (2020$)						
Annual marginal damages of ground-level emissions - 15 year plan						
Year	**SC-NOx**	**SC-PM25**	**SC-VOC**	**SC-SO2**	**SC-CO2**	**Total-SC**
1	$5,532.77	$19,524.10	$6,405.14	$2,361.82	$241,674.84	$275,498.67
2	$5,165.70	$18,228.29	$5,980.15	$2,204.62	$225,645.75	$257,224.50
3	$4,798.64	$16,932.48	$5,555.15	$2,048.20	$209,607.75	$238,942.21
4	$4,431.57	$15,638.55	$5,130.34	$1,891.78	$193,578.66	$220,670.89
5	$4,064.51	$14,342.74	$4,705.34	$1,734.58	$177,540.66	$202,387.83
6	$3,697.44	$13,046.92	$4,280.34	$1,578.16	$161,511.57	$184,114.43
7	$3,330.37	$11,753.00	$3,855.53	$1,421.74	$145,473.57	$165,834.20
8	$2,963.31	$10,457.18	$3,430.54	$1,264.54	$129,444.48	$147,560.05
9	$2,596.24	$9,161.37	$3,005.54	$1,108.12	$113,406.48	$129,277.74
10	$2,229.16	$7,865.55	$2,580.73	$951.70	$97,368.48	$110,995.62
11	$1,862.11	$6,571.63	$2,155.73	$794.50	$81,339.39	$92,723.36
12	$1,495.03	$5,275.81	$1,730.73	$638.08	$65,301.39	$74,441.05
13	$1,127.96	$3,980.00	$1,305.74	$481.66	$49,272.30	$56,167.65
14	$760.91	$2,684.19	$880.93	$324.46	$33,234.30	$37,884.78
15	$393.83	$1,390.26	$455.93	$168.04	$17,205.21	$19,613.27
Total	$44,449.55	$156,852.07	$51,457.86	$18,971.97	$1,941,604.83	$2,213,336.28
npv	$38,919.22	$137,336.81	$45,055.55	$16,611.60	$1,700,034.02	$1,937,957.20

Table 56. Expanded social cost of CO2 for 30 minutes in the 15-year scenario.

Year	**SC-CO 5%**	**SC-CO 3%**	**SC-CO 2.5%**	**SC-CO Mary.**
1	$ 29,099.66	$ 103,642.61	$ 154,268.04	$ 219,243.99
2	$ 28,286.18	$ 98,629.45	$ 146,641.52	$ 204,702.62
3	$ 27,312.91	$ 93,347.92	$ 138,638.95	$ 190,153.18
4	$ 26,182.13	$ 87,805.91	$ 130,272.04	$ 175,611.82
5	$ 24,891.46	$ 81,995.39	$ 121,528.88	$ 161,062.37
6	$ 23,176.96	$ 76,190.92	$ 112,155.17	$ 146,521.01
7	$ 21,355.40	$ 70,064.90	$ 102,457.92	$ 131,971.56
8	$ 19,429.36	$ 63,625.82	$ 92,449.59	$ 117,430.20
9	$ 17,396.20	$ 56,865.00	$ 82,117.54	$ 102,880.75
10	$ 15,257.23	$ 49,786.74	$ 71,468.06	$ 88,331.30
11	$ 13,148.03	$ 42,261.51	$ 60,641.92	$ 73,789.94
12	$ 10,878.71	$ 34,467.20	$ 49,438.89	$ 59,240.49
13	$ 8,452.20	$ 26,413.12	$ 37,872.36	$ 44,699.13
14	$ 5,865.48	$ 18,089.81	$ 25,928.73	$ 30,149.69
15	$ 3,121.66	$ 9,506.89	$ 13,621.81	$ 15,608.32
NPV total	$ 237,112.99	$ 793,252.83	$ 1,165,898.44	$ 1,542,246.76

Appendix 6

Multiple Linear Regression

Table 57. Statistical analysis of 10-year plan.

Multiple linear regression 10 year plan

y	x1	x2	x3
1,583.70	0	180.20	0
1,475.20	144	162.3	13,687,500
1,370.50	288	144.3	27,375,000
1,267.90	432	126.4	41,062,500
1,179.00	576	108.4	54,750,000
1,094.60	720	90.5	68,437,500
1030.2	864	72.5	82,125,000
969.9	1008	54.6	95,812,500
909.6	1152	36.6	109,500,000
849.3	1296	18.6	123,187,500
0	1447	0	134,919,643

y = PM2.5 emissions (lbs)
x1 = number of electric school buses
x2 = petroleum use (barrels)
x3 = electricity dispensed(kWh)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99826598
R Square	0.99653497
Adjusted R S	0.99504995
Standard Erro	29.8565579
Observations	11

The model of this data
y = -84.33X1 - 486.86X2 + 0.00024X3 + 89285.37

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	1794580.17	598193.39	671.061207	5.6939E-09
Residual	7	6239.89836	891.414052		
Total	10	1800820.07			

	Coefficients	*tandard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	89285.3719	56817.8149	1.57143269	0.16007666	-45067.411	223638.155	-45067.411	223638.155
X Variable 1	-84.333464	37.2762646	-2.2623904	0.0581261	-172.47782	3.81089489	-172.47782	3.81089489
X Variable 2	-486.85811	315.24692	-1.5443707	0.16641165	-1232.2986	258.582405	-1232.2986	258.582405
X Variable 3	0.0002427	2.5633E-05	9.46835703	3.0633E-05	0.00018209	0.00030331	0.00018209	0.00030331

Table 58. Statistical analysis of 15-year plan.

Multiple linear regression - 15 year plan

y		x2	x3	x4
1,583.70		180.2	0	0
1,459.10		168.3	8994643	96
1,334.40		156.3	17989286	192
1,214.90		144.4	26983929	288
1,095.50		132.6	35978571	384
979.4		120.7	44973214	480
869.9		108.9	53967857	576
762.4		97	62962500	672
658		85.2	71957143	768
566.5		73.3	80951786	864
475		61.5	89946429	960
383.4		49.6	98941071	1056
291.9		37.8	107935714	1152
200.4		25.9	116930357	1248
108.9		14.1	125925000	1344
0		0	134919643	1447

y = PM2.5 (lbs)

x2 = petroleum use (barrels)
x3 = electricity dispensed (kWh)
x4 = Number of electric buses

The model of this data
y = 340.54X1 - 0.0008X2 + 111.53X3 - 59788.9

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99915016
R Square	0.99830104
Adjusted R S	0.9978763
Standard Err	22.8245923
Observations	16

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	3673371.27	1224457.09	2350.37692	7.0476E-17
Residual	12	6251.54414	520.962012		
Total	15	3679622.82			

	Coefficients	*tandard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-59788.903	17820.6434	-3.3550362	0.00572654	-98616.749	-20961.057	-98616.749	-20961.057
X Variable 1	340.540909	98.9659843	3.44098946	0.00488554	124.912553	556.169266	124.912553	556.169266
X Variable 2	-0.000753	0.00020225	-3.7229571	0.00291111	-0.0011936	-0.0003123	-0.0011936	-0.0003123
X Variable 3	111.527183	31.0300713	3.59416457	0.00368517	43.9184655	179.135901	43.9184655	179.135901

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