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# Introduction

In response to the severe negative affects posed by climate change to the Charlottesville and global community, the City of Charlottesville, in 2019, adopted new greenhouse (GHG) emissions reduction goals of 45% of 2011 levels by 2030 and reaching carbon neutrality by 2050. The City of Charlottesville also adopted a community climate action plan in January of 2023 which outlined strategies and key actions to reduce the GHG emissions from core sectors in order to hit their desired emission targets. As indicated in the plan, the transportation sector is responsible for approximately 30% of Charlottesville’s total GHG emissions. Therefore, a key objective of the climate action plan is for Charlottesville Area Transit (CAT), the main transportation agency in the city, to transition their transit fleet to zero-carbon vehicles.

This document seeks to display the climate and health implications of transitioning the current CAT fleet to an alternatively-fueled option. This document is a partner evaluation to a technical and economic feasibility assessment conducted concurrently as this combination of metrics and impacts are needed to make informed decisions that are aligned with the City’s climate goals. Understanding the emissions reductions associated with the alternatives will inform the GHG reduction scenarios and projections work towards achieving the adopted GHG Reduction Goals.

# Background

CAT transit fleet is comprised of 36 vehicles as of Spring 2023. The fleet varies in terms of fuels and bus sizes. The size and composition of CAT’s fleet can be seen in **Table 1**.

Table 1: CAT’s Fleet Inventory

|  |  |  |
| --- | --- | --- |
| **Bus Type** | **Fuel** | **Quantity** |
| 35’ Low Floor Bus | Diesel | 21 |
| 29’ Low Floor Bus | Diesel-Electric Hybrid | 10 |
| 29’ Low Floor Bus | Diesel | 1 |
| 26’ Body-on-Chassis | Gasoline | 3 |
| 26’ Body-on-Chassis | Diesel | 1 |

CAT is planning to expand its fleet size to 58 buses by 2028 to increase the frequency and reliability of its service as part of the CAT Optimization Plan. The expansion began in FY22 (the delivery of the procured vehicles has been delayed to 2023) and will finish in FY28. Along with the expansion of CAT’s transit fleet, CAT is also altering the composition of its fleet:

* No longer purchasing hybrid diesel-electric buses. As of Spring 2023, replace hybrid buses with diesel buses due to the hybrid buses’ costly maintenance issues.
* Procure additional gasoline 26’ body-on-chassis (BOC) buses to expand fleet on a short-term basis, but replace the BOCs with 29’ low floor buses as the BOCs reach their scheduled replacement date.
* Procure two BEB buses in FY2025 as a pilot deployment to familiarize planning and maintenance staff with the technical capacity and restraints of the new bus technology.

**Figure 1** shows the planned quantity and composition of CAT’s fleet year-by-year given the current replacement schedule. Note that this plan indicates that replacements in 2028 and beyond will be with alternative-fueled buses. See the accompanying *CAT Facility Design and Zero Emissions Vehicles Feasibility Study* for more details regarding this transition plan.

Figure 1: CAT’s Fleet Composition by Year

\*Alternative fuel may be battery electric, hydrogen, or gas propulsion system.

As the diesel and gasoline buses in CAT’s fleet reach their useful life balance (ULB)[[1]](#footnote-1), CAT can begin to purchase alternatively fueled buses to replace the diesel and gasoline buses. CAT is considering three different fuel types/technologies as options to transition their fleet to:

* battery electric buses,
* hydrogen fuel cell electric buses (also known as fuel cell, hydrogen, and hydrogen-electric fuel cell), and
* natural gas buses (including buses fueled with renewable natural gas).

The technical capacity and feasibility of the three fuel types and technologies are detailed in the feasibility study memo. This memo will detail the climate and health impacts of a transition to the three potential fuel types with the main focus on the emissions produced through the operation of CAT’s transit fleet and the production of the fuel.

## Targeted Emissions

A byproduct of the operation of motor vehicles is the emission of gasses and particulate matter which affect the environments where released. The following is a list and description of the most common emissions from vehicle operations and their effects on local and global environments and their inhabitants.

**Carbon Monoxide** (CO) is a colorless and odorless gas which is emitted through the incomplete combustion of carbon-contained fuels (California Air Resources Board, n.d.). The most common source of CO is through the combustion of fossil fuels from automobiles and other machinery. CO is harmful to humans and wildlife as inhaling CO emissions will reduce the amount of oxygen one’s blood can carry and thus interferes with the delivery of oxygen to vital organs. The inhalation of CO can cause dizziness, confusion, unconsciousness, and even death at high concentrations likely occurring indoors or in enclosed areas. The severe effects of CO inhalation are unlikely to occur outside, but higher levels of CO emissions in the local environment can cause chest pain and a decrease in exercise tolerance, with the elderly, children, and individuals with heart disease more likely to be affected. CO emissions can also contribute to birth defects when inhaled by expectant mothers.

CO emissions are less impactful to the environment than to human health. The United States Environmental Protection Agency (EPA) did not identify any ecological effects of CO emissions at ambient outdoor levels, but CO can react with other pollutants in the air to produce ozone which is a greenhouse gas and thus CO is classified as a short-lived climate forcing agent (California Air Resources Board, n.d.).

**Greenhouse Gas Emissions** (GHGs) are a waste product of processes, such as the burning of fossil fuels, that trap heat in the atmosphere. The two most abundant greenhouse gases are carbon dioxide (CO2) and methane (CH4), making up 80% and 10%, respectively, of emissions (EPA, 2022).

The increased solar radiation trapped in the Earth’s atmosphere by GHGs causes a rise in average global temperatures. The long-term rise in global temperatures results in the disruption of the usual balance of local and global climate and weather patterns. Increased severe weather events such as drought or flash floods, a rise in sea level, loss of biodiversity, and other critical impacts will result due to rising global temperatures. Local effects of climate change on Charlottesville will be the significant increase in the frequency, duration, and intensity of extreme heat, changing seasonal patterns, and the increase in intensity of storms and flooding in   
Charlottesville (City of Charlottesville, 2021).

**Nitrogen Oxides** (NOx) are a family of poisonous, highly reactive gases. These gases form when fuel is burned at high temperatures. NOx pollution is emitted by automobiles, trucks, and various non-road vehicles (e.g., construction equipment, boats, etc.) as well as industrial sources such as power plants, industrial boilers, cement kilns, and turbines. NOx often appears as a brownish gas.

Breathing air with a high concentration of NO2 can irritate airways in the human respiratory system. Such exposures over short periods can aggravate respiratory diseases, particularly asthma, leading to respiratory symptoms (such as coughing, wheezing or difficulty breathing), hospital admissions and visits to emergency rooms. Longer exposures to elevated concentrations of NO2 may contribute to the development of asthma and potentially increase susceptibility to respiratory infections. People with asthma, as well as children and the elderly are generally at greater risk for the health effects of NO2 (EPA, n.d.). NO2 along with other NOx reacts with other chemicals in the air to form both particulate matter and ozone. Both are also harmful when inhaled due to effects on the respiratory system.

**Sulfur Oxides** (SOx) is a group of gases primarily consisting of SO2 and SO3. SOx are commonly emitted through the burning of fossil fuels from power plants and industrial facilities as well as motor vehicles which burn fuels with a high sulfur content (EPA, n.d.). Short-term exposures to SO2 can harm the human respiratory system and make breathing difficult. People with asthma, particularly children, are sensitive to these effects of SO2. SOx can also react to other gases in the atmosphere to from particulate matter pollution, the effects of which is detailed further on in the memo. Higher concentrations of SOx can also harm local flora by damaging foliage and reducing growth.

**Volatile Organic Compounds** (VOC) are a form of chemical that exist in a gaseous state, emitted during various manufacturing processes and can be harmful to health in both the short and long-term (EPA, n.d.). While VOCs can take many forms both harmful and benign, for the purposes of this report VOCs will refer to pollutant gasses emitted through electrical generation and combustion processes. VOCs can affect the respiratory and central nervous systems at high concentrations, and some VOCs are carcinogenic. VOCs can also react with NOx emissions to produce ozone pollution, a common component in smog (American Lung Association, n.d.).

**Particulate Matter** (PM) is an air pollutant consisting of solid particles and liquid droplets. **PM2.5** (diameter <2.5 micrometers) and **PM10** (diameter <10 micrometers) are the sizes of particulate matter that are commonly measured in the environment, are inhalable, and are harmful to human health (United States Environmental Protection Agency, n.d.). PM can be created through the weathering of brake pads and rubber tires, but most PM in the atmosphere is from chemical reactions of NOx and SOx gases produced from fossil fuel power plants and internal combustion engines.

The microscopic size of PM emissions exacerbates its negative impact on human health as the PM can become deeply embedded into the lungs and even enter the bloodstream; PM2.5 is more harmful to human health compared to PM10 due to its smaller size. PM emissions are also one of the largest components, along with ozone, comprising smog.

# Methodology

This section describes the methodology used in this analysis. Sections consist of analysis tools, data sources, scenario development, electric grid assumptions, and renewable natural gas assumptions.

## Analysis Tools

Emissions for CAT’s fleet were calculated using Argonne National Laboratory’s Alternative Fleet Life-Cycle Environmental and Economic Transportation (AFLEET) Tool 2020. The vehicle types in AFLEET Tool are based on EPA’s Motor Vehicle Emission Simulator (MOVES) as this allows the tool to estimate vehicle operation (e.g., tailpipe, brake and tire wear) emissions for various vehicle vocations (EPA 2020). The AFLEET tool provided estimates for CAT’s emissions for carbon, carbon monoxide, and other air pollutants (NOx, SOx, VOC, PM2.5, and PM10). Note that carbon-based emissions are cumulatively referred to “Greenhouse Gases”, as they can take several molecular formats such as carbon dioxide or methane.

Note that the results presented in this analysis are based on vehicle fueling, fuel feedstock, and vehicle operations. Emissions presented in this analysis are independent of vehicle manufacture, component mining and sourcing, and end-of-life disposal of the vehicle. As such, the emissions described in this analysis pertain to **Scope 1** and **Scope 2** emissions based on the EPA GHG Protocol. While Scope 3 emissions (those indirectly associated with value chain) are important in determining environmental impact, the difficultly in accurately evaluating the value chain of the various vehicle components makes the evaluation infeasible and this analysis focuses on parameters directly controllable by CAT and the City of Charlottesville.

## Data Sources

Emissions were calculated for every calendar year starting in 2022 until 2050 with each yearly calculation accounting for a) Virginia’s changing electric grid composition and b) the changing vehicle propulsion type composition of CAT’s fleet. The electricity generation mix in 2022 is set based in information from the United States Energy Information Administration (EIA) North American Electric Reliability Corporation (NERC) estimates. Future-year estimates are described in the section below. A year-by-year composition of Virginia’s electric grid used for the model can be seen in **Appendix A**.

As of the publication of this study, the CAT Transit Strategic Plan (TSP) is planned for completion at the end of 2023; however, the CAT Optimization Plan provides the basis for the future composition of the CAT fleet. As such, the vehicle miles traveled (VMT) for the model was kept consistent across the different transition scenarios for every yearly calculation, and the VMT would increase evenly as CAT’s fleet expanded. CAT’s 2021 vehicle miles traveled (VMT) was input as the systems VMT and was divided evenly across every fleet vehicle for the base 36 bus fleet (approximately 20,300 miles per bus). As CAT’s fleet expanded, each new expansion bus increased the system’s VMT by approximately 20,300 miles, the VMT of one bus in the base 36 bus fleet, resulting in the maximum VMT of approximately 1,180,000 miles. See **Table 2** for a tabulation of VMT by vehicle per scenario.

The BEB transition scenario used the same final VMT and had the same year-by-year VMT as the other transition scenarios but had a different VMT per bus. The range limitations of BEBs will be explained in greater detail later in the document, but the BEB transition scenario had a vehicle replacement ratio of 1:1.62 instead of a 1:1 replacement ratio used by the other transition scenarios; this resulted in the BEB transition scenario having a final fleet size of 94 instead of 58. The full 94 BEB fleet had a VMT per bus of approximately 12,500 miles instead of 20,300. This method provides a comparison of emissions between technologies and by year but is not necessarily indicative of actual mass of forecasted emissions without more detailed modeling and route planning.

Table 2: Estimation of Future VMT by Scenario

|  |  |  |  |
| --- | --- | --- | --- |
| **Year (scenario)** | **Annual VMT** | **Fleet Size** | **VMT per Vehicle** |
| 2021 (base) | 730,629 | 36 | 20,295 |
| 2050 (1:1 replacement) | 1,177,125 | 58 | 20,295 |
| 2050 (1:1.62 replacement) | 1,177,125 | 94 | 12,523 |

## Scenario Development

CAT’s fleet transition and expansion was based on current fleet information and the CAT Optimization Plan. Unless specified by the transit agency, all full-sized transit buses (29’ or 35’) were modeled to have a 12-year service life and the BOC were modeled to have a five-year service life regardless of fuel type; the 12 year and five-year numbers were based off the guidelines for a full-sized transit bus in the FTA’s Useful Life Benchmark. Milestones in the CAT fleet’s transition and expansion are shown in **Table 3**.

Table 3: Planned CAT Fleet Expansion FY22-FY28

|  |  |  |  |
| --- | --- | --- | --- |
| **Fiscal Year** | **Bus Type** | **Number of Buses** | **Replacement or Expansion** |
| FY22 (Awaiting Delivery) | 26’ BOC | 1 | Replacement |
| 35’ Diesel | 3 | Replacement |
| 29’ Diesel | 1 | Replacement |
| 35’ Diesel | 2 | Expansion |
| 26’ BOC | 4 | Expansion |
| FY23 (Awaiting Appropriation) | 26’ BOC | 1 | Replacement |
| 35’ Diesel | 4 | Replacement |
| 29’ Diesel | 2 | Replacement |
| 29’ Diesel | 4 | Expansion |
| FY24 | 26’ BOC | 1 | Replacement |
| 35’ Diesel | 4 | Replacement |
| 29’ Diesel | 7 | Replacement |
| 35’ Diesel | 4 | Expansion |
| FY25 | 35’ Diesel | 3 | Expansion |
| 35’/29’ BEB | 2 | Expansion |
| 29’ Diesel | 1 | Replacement (BOCs to 29’) |
| FY26 | 35’ Diesel | 2 | Replacement |
| 29’ Diesel | 5 | Replacement (BOCs to 29’) |
| FY27 | 35’ Diesel | 5 | Replacement |
| 29’ Diesel | 2 | Replacement (BOCs to 29’) |
| FY28 | 35’ Diesel | 3 | Replacement |
| 35’ Alt Bus | 3 | Expansion |

As described in the Feasibility Study, six fleet transition scenarios were developed for this study consistent with the previously described fleet transition plans:

* Diesel: A 58 diesel bus fleet. This transition scenario used a baseline / ”business-as-usual” scenario for comparison.
* CNG: A 58 CNG bus fleet powered by fossilized natural gas.
* RNG: A 58 CNG bus fleet powered by renewable natural gas from anerobic digestion of wastewater sludge.
* BEB: A 94 BEB bus fleet powered from the projected model of Charlottesville’s electric grid.
* Green FCEB: A 58 FCEB bus fleet fueled through hydrogen produced from an on-site refueling electrolysis station powered from the projected model of Charlottesville’s electric grid.
* Gray FCEB: A 58 FCEB bus fleet fueled through hydrogen produced from an off-site central Steam-Methane Reformation (SMR) plant.

A 58-bus fleet was used as the baseline for CAT’s fleet size. The replacement ratio – the number of alternative fueled buses needed to replace one diesel bus – was based on CAT’s planned operational blocks for their service improvements under the CAT Service Optimization Plan. The total daily mileage for each block was calculated and then compared to the ranges of the alternative fueled buses (diesel buses were used as a baseline comparison and thus were not used in the analysis).

Natural gas buses and FCEBs have ranges of 300 miles with little to no range reduction due to external factors and could complete all of CAT’s planned operational blocks. The four transition scenarios using either natural gas buses or FCEBs were given a 1:1 replacement ratio. As of Spring 2023, the smaller BEBs on the market (29’ to 35’) had a higher end stated range of 225 miles; this was used as the planning estimate for the replacement ratio to account for potential improvements to BEB range capabilities. Industry standard planning estimates calculate the operational range of BEBs as 30%-40% of their stated range due to BEBs’ susceptibility of range reduction due to external factors such as cold weather. As a conservative estimate, the 225-mile range was reduced by 40% to 135-miles which resulted in BEBs failing to complete 61.5% of the blocks. The BEB transition scenario was given a replacement ratio of 1:1.615 which when applied to a 58-bus fleet, resulted in the BEB transition scenario having a 94-bus fleet. Mixed-fueled fleets and charging/fueling techniques such as on-route fast charging have the ability of reducing the number of additional BEBs needed, but mono-fueled bus transition scenarios fueled only through the depot was used for planning and comparison purposes.

Results for the full six scenarios were only displayed for GHG emissions. The Green FCEB and Gray FCEB transition scenarios and the CNG and RNG transition scenarios had the same emissions for non-GHG measured pollutants and thus were displayed as FCEB and CNG/RNG, respectively, to improve the legibility of the results.

## Electric Grid Assumptions

AFLEET allows for users to define the electric grid based on six power sources:

* residual oil
* natural gas
* coal
* nuclear power
* biomass
* renewable energy (wind, solar, hydroelectric, etc.)

Based on data collected from the Energy Information Administration for the Commonwealth of Virginia’s 2022 utility scale facility net generation estimates, the electrical gird composition for the base year was:

* 8.6% renewables
* 29.9% nuclear
* 0.2% residual oil

Figure 2: Charlottesville Electric Grid Energy Sources, US EIA 2022

* 2.2% coal
* 0.4% biomass
* 58.7% natural gas

The changing composition of Virginia’s electric grid composition was based on two state-wide energy production objectives: 30% of Virginia’s electrical power will be from renewable sources by 2030 and 100% of Virginia’s electricity will be produced from carbon-free sources by 2050. The first goal was set by Dominion Energy, while the latter goal was set in law through the 2020 Virginia Clean Economy Act. Nuclear power was specified as a carbon free source by the Virginia Department of Environmental Quality, so the percentage of the grid from nuclear power was counted towards the 2050 carbon-neutral goal but not towards the 2030 30% renewable source’s goal.

As Virginia’s grid composition was 8.6% renewable energy in the base year, this study assumes the percentage of renewable energy increases linearly by 2.68% each year until the grid’s composition of renewable energy hit 30% in 2030. The composition of renewable energy is then assumed to increase linearly by 2.01% each year until the composition of renewable energy hit 70.1% in 2050. For projection purposes, the composition of nuclear energy was kept constant at 29.9% for each year. As the composition of renewable energy increased, the composition of non-renewable/carbon emitting sources were decreased by one source at a time. The carbon emitting sources were decreased in the following order based on how prevalent the respective sources were in Virginia at the base year with the less prevalent sources being decreased first:

* residual oil
* biomass
* coal
* natural gas

## Renewable Natural Gas Assumptions

Note that results in the following section(s) indicate CAT’s fleet producing *negative* greenhouse gas emissions between the years of 2037 and 2050 for the RNG scenario. This period of time indicates when CAT’s fleet is projected to be mainly or entirely comprised of CNG vehicles fueled with RNG (or the use of municipal natural gas and the purchase of equivalent carbon offset credits, or some other decarbonization strategy).

The AFLEET tool follows national emission standards and current industry practice which considers RNG fuel to have negative emissions. RNG fuel is comprised of natural gases produced through means other than fossilized mining (i.e., animal manure, wastewater sludge, landfill emissions, etc.). Instead of releasing these gases directly into the atmosphere, they are considered to be captured and then combusted as fuel. The negative value comes from the fact that methane (the principal element of natural gas) is nearly 25 times more potent than carbon dioxide as a greenhouse gas; as such, combusting RNG lowers the potential of that methane to impact global climate. While this reduces the impact of greenhouse gas on the global climate, the combustion and use of RNG fuel produces nearly identical tailpipe emissions to the combustion and use of non-renewable natural gas fuel. As such, an RNG fleet will still produce tailpipe emissions including particulates, volatile organic compounds, sulfur oxides, nitrous oxides, and carbon dioxide.

# Analysis

The AFLEET model was populated with the aforementioned CAT fleet data and modified to accommodate the change in electric grid feedstock. Then, emissions were projected from the base year through 2050. The results of the GHG analysis are shown in **Figure 3** with a tabulation indicating the percent reduction from the base year shown in **Table 4**. Carbon monoxide emissions are shown in **Figure 4**. Resulting emissions of all other pollutants are shown in **Figure 5**.

Figure 3: GHG Emissions of Transition Scenarios (Base – 2050)

Table 4: GHG Emissions and Reductions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **2030** | | **2050** | |
| **GHG Emissions (Short Tones)** | **% Reduction** | **GHG Emissions (Short Tons)** | **% Reduction** |
| Diesel | 3,670 | N/a | 3,670 | N/a |
| CNG | 3,556 | 3.1% | 3,401 | 7.3% |
| RNG | 3,282 | 10.6% | -1,887 | 151.4% |
| BEB | 3,419 | 6.8% | 15 | 99.4% |
| Gray FCEB | 3,496 | 4.7% | 2,243 | 38.9% |
| Green FCEB | 3,482 | 5.1% | 38 | 99.0% |

From 2022 to 2027, the GHG emissions are consistent between transition scenarios as the fleet composition is the same in all scenarios. This same period also sees a rise in GHG emissions as CAT’s fleet expands, the VMT increases, and as the hybrid diesel-electric buses are replaced by diesel buses. Starting in 2028, the alternatively-fueled scenarios diverge and GHG reductions separate as CAT’s fleet and the composition of the electric grid becomes more powered by renewable energy. The CNG, RNG, and Gray FCEB hit their lowest GHG emissions in 2040 when CAT’s fleet has totally transitioned to the respective alternatively fueled vehicle type. The BEB and Green FCEB transition scenarios also completely transition from diesel buses in 2040 but continue to reduce their GHG emissions as the electric grid becomes less composed of carbon-emitting energy sources.

Figure 4: Carbon Monoxide Emissions at Full Transition

50,758

50000

40000

30000

20000

10000

4,414

0

0

0

CNG/RNG

Diesel

Gray/Green FCEB

BEB

The level of carbon monoxide emissions was directly related to the fleet composition and not based on the composition of the electric grid. A total transition to FCEBs or BEBs will eliminate localized carbon monoxide emissions, while transitioning to CNG/RNG buses will result in a 1,050% increase in carbon monoxide emissions as compared to a diesel fleet.

Figure 5: Nitrogen Oxide (NOx) Emissions at Full Transition

7,000

6,445

6,000

5,000

4,000

3,000

2,000

1,000

322

0

0

0

Diesel

CNG/RNG

Gray/Green FCEB

BEB

The level of NOx emissions was also directly related to the fleet composition and not based on the composition of the electric grid. A total transition to FCEBs or BEBs will eliminate localized nitrogen oxide emissions, while transitioning to CNG/RNG buses will result in a 95.0% decrease in nitrogen oxide emissions as compared to a diesel fleet.

Figure 6: Other Pollutant Emissions (PM10, PM2.5, VOC, and SOx) at Full Transition

The emissions of the remaining measured pollutants are also based around CAT’s fleet composition. The BEB and FCEB transition scenarios produce zero VOC, and SOx emissions and have slightly lower PM emissions than a diesel fleet. A CNG/RNG fleet transition has slightly lower VOC and SOx emissions. A CNG/RNG fleet has the same Particulate Matter emissions as a diesel fleet.

# Discussion

## Global Environmental Impact

There are significant differences between the transition scenarios when it comes to impacts on the global environment. As previously stated, the City of Charlottesville and Albemarle County set a shared goal in their respective climate action plans to become carbon neutral by 2050 to mitigate the effects of climate change. Part of the effort to achieve carbon neutrality for the jurisdiction is for CAT to also achieve carbon neutrality (though no interim milestone date is set for a department-specific reduction).

Assuming Virginia’s electric grid achieves its carbon neutral goal by 2050, the BEB and the Green FCEB scenarios come close to achieving carbon neutrality by reducing 99.4% and 99.0% of GHG emissions, respectively, compared to the baseline diesel fleet. Only one of the six transition scenarios – the RNG fleet transition scenario - achieves more than 100% reduction by 2050. However, the GHG emissions of RNG fueled buses produce “negative” emissions as a result of mitigated methane emissions, not a true reduction of tailpipe emissions as compared to the base scenario. The Gray FCEB and CNG transition scenarios reduce GHG emissions compared to baseline but cannot achieve carbon neutrality, even with a 100% carbon neutral electric grid. As such, a transition to Gray FCEB or CNG would be a temporary transition before completing a second transition to a fuel source with greater GHG reduction potential to hit the 2050 neutrality goal.

Regardless of the chosen transition scenario, the reductions in GHG emissions from CAT’s fleet are limited by the rate of transition from the diesel buses to the chosen alternatively fueled buses. With the exception of the two BEBs to be procured in FY25 as a pilot, CAT’s fleet begins to transition to alternatively fueled buses starting in 2028. The initial transition begins at a slow pace and then accelerates in 2034 due to previous purchase quantities and minimum replacement age requirements. As such, meaningful GHG emission reductions begin in 2034.

CAT could accelerate GHG emissions through an expedited fleet replacement, but the FTA’s ULB standards limit the pace at which CAT transitions its fleet with federal funding. Additionally, the GHG emission reductions for the Gray FCEB, CNG, and RNG transition scenarios cease once CAT’s fleet is 100% transitioned (planned for 2040), while the GHG emission reductions from the BEB and Green FCEB transition scenarios are dependent on Virginia’s electric grid.

An alternative option to achieve carbon neutrality goals may be the capital purchase of credits: either carbon offset credits, renewable natural gas credits, or virtual power purchase agreement arrangements. However, these credits are based on either the electricity or natural gas consumed, and are still limited by fleet size; however, this may be an option to deploy BEBs or FCEBs and achieve a carbon-neutral transit system by 2040. Carbon offsets also differ in quality and effect. If CAT were to use carbon credits as part of their carbon-neutrality strategy, considerable attention should be paid towards the type of credit/the effect (i.e., removal or avoidance), the issuer of the carbon credit, and how the credit is verified. Use of carbon credits to reduce CAT’s emissions would also not have any of the local beneficial health impacts that transitioning to low- or no- carbon fuels would have.

## Local Environmental Impact

The City of Charlottesville’s local environment, air quality, and the health of its citizens are affected by the potential selection of alternative fuel. Transitioning CAT’s fleet to BEBs or FCEBs (either Gray or green hydrogen) would improve the local air quality, environment, and noise levels for inhabitants of the City. As BEBs and FCEBs are zero emission vehicles, a transition to either would eliminate CO, NOx, VOC, and SOx emissions within the City of Charlottesville. A BEB or FCEB fleet would also reduce the amount of PM emissions by 4.4% and 25.1% for PM10 and PM2.5 compared to a diesel fleet, respectively. However, PM emissions cannot be eliminated with BEBs and FCEBs as the wear-and-tear of the vehicle’s brake pads and tires produces PM regardless of bus technology.

Note that FCEB will likely require the delivery of hydrogen fuel to the CAT depot. This analysis assumed diesel trucks would deliver the fuel until such time as delivery trucks are converted to comparable zero-emissions technologies or a municipal hydrogen gas distribution system is established.

A transition to natural gas-powered buses (CNG or RNG) would result in a variety of impacts to Charlottesville’s local environment. A CNG/RNG transition will improve Charlottesville’s local air quality through the reduction of the level of NOx emissions and relatively smaller reductions of VOC and SOx emissions when compared to a diesel baseline. NOx emissions would be reduced by 95.0%, while VOC and SOx emissions would be reduced by 52.0% and 42.1%, respectively. Conversely, the level of CO emissions would increase dramatically by 1,050% with a transition to CNG/RNG vehicles from a diesel fleet baseline. PM emissions would remain the same between CNG/RNG and diesel vehicles.

## Qualitative Supply Chain Impact

As described in the **Methodology** section, this analysis assumes a Scope 1 and Scope 2 emissions evaluation. However, several considerations impact the alternative fuel technologies described in this study. These are described below separate from a quantitative evaluation of emissions, health, or other social impacts.

### Battery Electric Buses

The manufacturing and supply chain of a BEB differs substantially from a conventional diesel bus due to the materials and processes required to manufacture the eponymous battery. The batteries used for BEBs are lithium ion (Li-ion) batteries. As of the publication of this document, there are three main types of Li-ion battery cell chemistries used for BEBs: lithium titanium oxide, lithium iron phosphate, and lithium nickel magnesium cobalt oxide (Ager-Wick Ellingsen et al., 2022). While these cell chemistries differ on their elemental composition, energy density, lifespan, and charge rates, all Li-ion batteries require a significant amount of lithium. A global increase in battery electric vehicle production will require a significant upscaling in the lithium supply chain and lithium mining. Lithium production has already tripled between 2010 and 2020 and estimates have production increasing between 18 and 40-fold by 2050 (Vera et al. 2023).

There are two main forms of lithium mining: mineral/hard rock mining and brine mining. The method of extraction depends on the natural state in which the lithium is found. Hard rock mining is used when hard rock lithium ore can be found; Australia, the world’s largest lithium exporter, uses the hard rock mining method. Hard rock mining is, in essence, “classic mining” where ore is discovered and then extracted either through surface mining or underground mining. Brine mining is used in areas such as the lithium triangle (a section of salt flats in the Atacama Desert where the political boundaries of Chile, Bolivia, and Argentina converge and is the world’s largest source of lithium), Tibet, and the United States where the lithium is dissolved in an underground brine, an aqueous solution with dissolved solids. The brine is pumped out of the ground and placed in into holding beds/pools where the solution is left for months until evaporation reduces the water content and increases the lithium carbonate concentration. The concentrated brine is then shipped to a refinement facility to become the final product. Throughout the evaporation process, fresh water and chemicals are used to treat and filter the brine (Vera et al., 2023).

The environmental impacts of hard rock mining are the destruction of the environment directly at the site of the mining operation and disturbances in the area adjacent, large emissions of PM containing potentially containing toxic heavy metals, the pollution of surface water and groundwater, as well as GHG emissions from the work vehicles and mining equipment which do not have a zero-emission alternative, currently. Brine mining limits the number of changes to the physical landscape compared to hard rock mining, but brine mining is extremely water intensive. Local areas often experience water shortages due to the necessary water inputs of a brine mining operation, and the extracting of the underground brine causes changes to the soil composition negatively affecting local flora and agriculture (Ahmad, 2020). Additionally, the chemicals used to treat and filter the brine solution often leaches out into the environment which pollutes local water supplies, contaminates the soil, and damages the biodiversity of the corresponding area (Vera et al., 2023).

Another important consideration with BEB production is that the demand for lithium might outstrip the lithium industry’s production capacity. The global demand for lithium has increased recently, so the lithium industry and lithium extraction practices are not as mature as extraction practices for other minerals. Additionally, the USGS estimates that as of 2017, that only one third of the world’s lithium could be extracted/recoverable. Extraction practices are likely to mature as the lithium industry grows (for example, since the 2017 USGS report, the USGS's estimate of the global supply of lithium doubled due to better discoverable practices) but ramping up production will still take time as a lithium mine takes years to begin full production (Bradley et al., 2017). Depending on how fast the EV industry grows, the supply for lithium may become pinched in the short-term and competition from the electronics and personal automobile industries may drive up the price of lithium batteries. It is important to note, that lithium is a non-renewable resource, so while the Earth has enough lithium reserves to supply the global demands for years to come, lithium mining and thus lithium products are not self-sustaining. Depending on the maturation of extraction methods, a lithium shortage is unlikely in the long-term, but it is worth consideration that lithium is ultimately a finite and fleeting resource.

The supply of lithium and thus utility of BEBs can be extended with recycling or repurposing of old batteries, but the actual effectiveness of recycling and repurposing old bus batteries is ambiguous. Currently, only 5% of Li-ion batteries are recycled in the US, but that number will likely rise as Li-ion battery technology matures and greater research is performed (Seltzer, 2022). The relative size of a Li-ion for a BEB compared to an EV or a personal electronic device increases the likelihood of the battery being repurposed or scrapped for parts. However, assumptions that the batteries of procured BEBs will be recycled/repurposed thus minimizing the effects of manufacturing the batteries is currently unfounded.

### Hydrogen Fuel Cell Buses

The manufacturing of hydrogen fuel cell buses carries similar external environmental and social impacts as a BEB because a FCEB propulsion system also relies on a Li-ion battery. However, the Li-ion battery for a FCEB is much smaller than a Li-ion battery for a BEB, and the greater range of a FCEB results in less vehicles needing to be procured to replace diesel buses than with a BEB. As a result, the production of one FCEB is less responsible for the negative social and environmental impacts associated with the mining of lithium and the production of Li-ion batteries as one BEB, but the negative externalities will still result from FCEB production.

Hydrogen fuel technology is still maturing and not widely used for transportation purposes outside of California, thus few energy companies currently produce hydrogen fuel. Currently, the primary hydrogen production method is gray hydrogen: hydrogen produced through a process known as *Steam Methane Reformation* (SMR), without carbon capture. SMR is a process where a methane source, such as natural gases, is heated to the point where the methane molecules break down into hydrogen, carbon monoxide, and small amount of carbon dioxide (US Department of Energy, n.d.). The carbon monoxide and carbon dioxide are released into the atmosphere negatively affecting the local air quality near the plant and resulting in GHG emissions. A transition to FCEBs would likely require the use of gray hydrogen in the near-term, thus the CAT fleet would have notable upstream GHG emissions as demonstrated in the Gray Hydrogen scenario.

Green hydrogen production (hydrogen produced through electrolysis powered using electricity from renewable sources) is not as established as gray hydrogen production and thus the supply of green hydrogen is scarce. Additionally, electrolysis is an energy-intensive process, and emissions as a result of production vary based on the composition of the electric grid. Green hydrogen has great potential for GHG reductions and efforts are underway to increase its production. However, a near-term transition of CAT to hydrogen fuel may require a proportion of gray hydrogen while technology and supply chains develop. Additionally, a FCEB transition would likely require CAT to received hydrogen fuel deliveries by truck unless a hydrogen production facility is built on site. The shipping of the hydrogen fuel would result in GHG emissions as the closest industrial hydrogen production plants to the City of Charlottesville are over 150 miles away.

### Natural Gas and Renewable Natural Gas Buses

The production of fossilized (non-renewable) natural gas has increased in the United States and throughout the world. In the United States, the most common form of natural gas extraction is through hydraulic fracturing, commonly known as fracking. Natural gas is commonly found trapped within shale and other sedimentary rock, and with fracking, a well is dug into the layer of shale and sedimentary rock (Water Resources Mission Area, 2019). A highly pressurized mixture of water, sand, and chemicals is then pumped through the well to further split and crack the layer of rock to release and capture the stored oil and gas. The liquid mixture is then pumped back up to the surface, the oil and gas is extracted, and the pumping liquid is either disposed of or reused.

Fracking poses multiple negative social and environmental externalities. The pumping liquid-mixture used to crack the layer of rock often contains toxic chemicals, such as benzene, lead, and methanol, which has been known to seep into the surrounding area’s water supply due to cracks in the wells, improper disposal of the used mixture, or traveling through the rock layer into groundwater (United States House of Representatives Committee on Energy and Commerce Minority Staff, 2011). This often leaves the communities in the vicinity of fracking operations without access to clean drinking water and can cause serious health effects if the contaminated water in ingested. The pumping of highly pressurized liquid underground for extraction or storage purposes also causes seismic activity to occur in the area at and around the fracking or storage site; this is commonly referred to as induced earthquakes/seismicity (Schultz, et al., 2020). As fracking often occurs in areas not known for seismic activity, the seismic activity induced from the fracking process has been known to damage public utilities and private property.

While RNG presents the opportunities to repurpose a by-product and decrease carbon emissions in the near-term, a long-term transition to RNG presents challenges. The largest challenge with a potential transition to RNG is RNG’s limited availability. The potential RNG that could be produced from renewable sources (i.e., landfills, wastewater sludge, animal manure, and organic waste) could replace about 5% of the energy sector’s demand for natural gas and 56% of the transportation sector’s consumption of natural gas (NREL, 2013). While improved anaerobic digestion and the repurposing of greater biomass resources for gas production could increase the amount of RNG available, the supply of RNG would likely not be great enough to be used reliably as a fuel for municipal transit fleets; competing interests to use RNG for the energy sector or for heating buildings would also cut into the supply of RNG.

A secondary consideration for RNG is that a transition to RNG buses might not produce the GHG reductions the City of Charlottesville intends to reach. As previously stated in the methodology section, the calculations behind the AFLEET tool produces “negative” GHG emissions that are evaluated as methane that ***would have*** been vented into the atmosphere. The methodology considers the combustion of RNG produces less total GHG emissions than letting the methane vent into the atmosphere directly from its fuel stock source (e.g., an anaerobic digester, farm, or landfill); the difference between the GHG emission from the untreated methane and the combustion of the RNG fuel is then used as the resulting GHG emissions from the fuel (US Environmental Protection Agency, 2021). While RNG fuel has a lower carbon intensity than pure methane and may reduce atmospheric carbon, the combustion of RNG will still produce the same tailpipe GHG emissions as fossilized natural gas fuel. A CAT fleet that transitions to RNG fuel will still produce GHG emissions, and CAT could not reach the City of Charlottesville’s goal of carbon neutrality with a RNG fleet.

# Conclusion

This assessment laid out climate and health impacts of transitioning away from a diesel-based fleet to one fueled through alternative fuels. All alternative fuel transition scenarios will reduce CAT’s GHG emissions, and transitioning to a fleet composed of either BEB, Green FCEB, or RNG buses will bring CAT closer to their carbon emissions reduction goal. A BEB or FCEB transition would also eliminate and/or reduce local emissions of air pollutants which negatively affect human health. A natural gas bus (CNG or RNG) transition from diesel buses would benefit the health of Charlottesville’s local community through the reduction of local air pollutants such as NOx, VOC, and SOx, but this would also result in a ten-fold increase in local CO emissions.

The environmental and health benefits of transitioning to an alternatively fueled fleet are limited by the rate of replacement of diesel buses and the decarbonization of Virginia’s electric grid.While this assessment does not lay out a recommended transition scenario for CAT’s fleet, the environmental and health impacts of a potential transition of CAT’s fleet should be considered with the results of the accompanying Feasibility Study.

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# Appendix A

*Table A-1: Virginia’s Electric Grid Composition Model Used for ALFEET Calculations*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Oil** | **Natural Gas** | **Coal** | **Nuclear** | **Biomass** | **Others (Wind, Solar, Hydro, etc)** |
| Base | 0.2% | 58.7% | 2.2% | 29.9% | 0.4% | 8.6% |
| 2022 | 0.2% | 58.7% | 2.2% | 29.9% | 0.4% | 8.6% |
| 2023 | 0.0% | 57.7% | 1.2% | 29.9% | 0.0% | 11.3% |
| 2024 | 0.0% | 56.2% | 0.0% | 29.9% | 0.0% | 14.0% |
| 2025 | 0.0% | 53.5% | 0.0% | 29.9% | 0.0% | 16.6% |
| 2026 | 0.0% | 50.8% | 0.0% | 29.9% | 0.0% | 19.3% |
| 2027 | 0.0% | 48.1% | 0.0% | 29.9% | 0.0% | 22.0% |
| 2028 | 0.0% | 45.5% | 0.0% | 29.9% | 0.0% | 24.7% |
| 2029 | 0.0% | 42.8% | 0.0% | 29.9% | 0.0% | 27.3% |
| 2030 | 0.0% | 40.1% | 0.0% | 29.9% | 0.0% | 30.0% |
| 2031 | 0.0% | 38.1% | 0.0% | 29.9% | 0.0% | 32.0% |
| 2032 | 0.0% | 36.1% | 0.0% | 29.9% | 0.0% | 34.0% |
| 2033 | 0.0% | 34.1% | 0.0% | 29.9% | 0.0% | 36.0% |
| 2034 | 0.0% | 32.1% | 0.0% | 29.9% | 0.0% | 38.0% |
| 2035 | 0.0% | 30.1% | 0.0% | 29.9% | 0.0% | 40.0% |
| 2036 | 0.0% | 28.1% | 0.0% | 29.9% | 0.0% | 42.0% |
| 2037 | 0.0% | 26.1% | 0.0% | 29.9% | 0.0% | 44.0% |
| 2038 | 0.0% | 24.1% | 0.0% | 29.9% | 0.0% | 46.0% |
| 2039 | 0.0% | 22.1% | 0.0% | 29.9% | 0.0% | 48.0% |
| 2040 | 0.0% | 20.1% | 0.0% | 29.9% | 0.0% | 50.1% |
| 2041 | 0.0% | 18.0% | 0.0% | 29.9% | 0.0% | 52.1% |
| 2042 | 0.0% | 16.0% | 0.0% | 29.9% | 0.0% | 54.1% |
| 2043 | 0.0% | 14.0% | 0.0% | 29.9% | 0.0% | 56.1% |
| 2044 | 0.0% | 12.0% | 0.0% | 29.9% | 0.0% | 58.1% |
| 2045 | 0.0% | 10.0% | 0.0% | 29.9% | 0.0% | 60.1% |
| 2046 | 0.0% | 8.0% | 0.0% | 29.9% | 0.0% | 62.1% |
| 2047 | 0.0% | 6.0% | 0.0% | 29.9% | 0.0% | 64.1% |
| 2048 | 0.0% | 4.0% | 0.0% | 29.9% | 0.0% | 66.1% |
| 2049 | 0.0% | 2.0% | 0.0% | 29.9% | 0.0% | 68.1% |
| 2050 | 0.0% | 0.0% | 0.0% | 29.9% | 0.0% | 70.1% |

**Table A-2: Non-GHG Emissions Reductions by Transition Scenario**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **BEB** | **FCEB** | **CNG/RNG** |
| CO | -100% | -100% | 1050.0% |
| NOx | -100% | -100% | -95.0% |
| PM10 | -4.4% | -4.4% | 0.0% |
| PM2.5 | -25.1% | -25.1% | 0.0% |
| VOC | -100% | -100% | -52.0% |
| SOx | -100% | -100% | -42.1% |

1. Useful Life Balance is dictated by the Federal Transit Administration for vehicle purchased with Federal funds. Vehicles are also subject to either a condition score for the asset and/or a minimum number of service miles to be eligible for replacement funding. [↑](#footnote-ref-1)