LET'S MOVE NASHVILLE

Metro's Transportation Solution

Air Quality and Emissions Memorandum

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Metro Nashville PUBLIC WORKS

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Executive Summary

Air pollutants and greenhouse gases (GHGs) harm the environment, the economy, and human health. The *Let's Move Nashville Transit Improvement Program* (TIP) is expected to lessen the detrimental effects of emissions.

The TIP would reduce pollution-based damage to human health and the environment in Metro Nashville and Davidson County (Metro) by an estimated $7.2 million annually, in undiscounted 2017 dollars. While this analysis provides a snapshot of air quality benefits in the year 2033, benefits would continue to accrue annually beyond this single year. The estimated annual benefits are conservative since this study does not account for riders that would switch from their personal vehicles to other modes of transportation, only accounting for new ridership along Light Rail Transit corridors. The full scale of the program's impact cannot be counted in dollars and cents and is likely far higher than figures can represent because of additional qualitative benefits.

Transportation is the main contributor of carbon monoxide and nitrous oxides and second largest source of volatile organic compounds in the local atmosphere.[1] In the year 2015, the U.S. transportation sector contributed 27% of all GHG emissions, second only to electricity's 29%.[2] Put simply, the emissions from burning fuel for transportation significantly contribute to air pollution.[3] Improving Metro's transit fleet efficiency and incentivizing the use of higher-capacity travel options would reduce emissions from burning fuel[4] contributing to a more vibrant and livable city for residents, businesses, and visitors alike.

This analysis evaluates the TIP's potential to reduce air pollutant and GHG emissions on an annual basis for the representative year 2033. It also estimates the environmental and social impacts on the local economy. "Reductive emissions" associated with the TIP include drivers shifting from personal vehicles to transit and the Metropolitan Transit Authority (MTA) bus fleet shifting from a mix of diesel, hybrid diesel-electric, and electric buses to an all-electric fleet. Conversely, "additive emissions" represent adding LRT, Rapid Bus, increased service of the Music City Star (MCS) commuter rail, more local bus trips and new bus routes.

[1] U.S. EPA (2014). National Emissions Inventory Data.
[2] U.S. EPA (2015) Fast Facts on Transportation Greenhouse Gas Emissions.
[3] U.S. EPA (2017) The Clean Air Act and the Economy.
[4] U.S. DOT (2017) Benefit-Cost Analysis Guidance for TIGER and INFRA Applications.

Background

Metro and the MTA are currently in the planning and development stages for several proposed multimodal transit and transportation infrastructure improvements. First proposed in the 25-year "nMotion Strategic Transit Plan" (September 2016) and the "nMotion High Capacity Transit Briefing Book" (August 2017), these improvements have now been more fully articulated in the TIP.

For the purpose of this analysis, the No-Build Scenario is considered to be a baseline scenario identical to today's transit network, comprised of local bus routes and the MCS commuter rail. The Build Scenario includes a combination of LRT and Rapid Bus infrastructure, increased service on the MCS commuter rail, improvements to current bus routes, and four new crosstown bus routes. This analysis calculates potential avoided emissions damages by evaluating the net change in air pollutant and GHG emissions from the No-Build Scenario and the Build Scenario.

Criteria Pollutants

Motor vehicles are a leading source of air pollutants in the United States.[5] Under the Clean Air Act, the EPA regulates the following six criteria air pollutants (CAP) due to their detrimental effects on public health and the environment, and their potential to cause property damage:

- Nitrogen oxides (NOx)
- Sulfur oxides (SOx)
- Carbon monoxide (CO)
- Volatile organic compounds (VOCs)
- Ground level ozone (O_3)
- Particulate matter (PM)[6]

Each of these pollutants harms society from human health to crop production, resulting in a number of social and environmental costs. Detailed information on each pollutant and its impacts can be found in **Appendix A**.

[5] U.S. DOT (2015) Cleaner Air.
[6] U.S. EPA (2017) Criteria Air Pollutants.

Greenhouse Gases

GHGs are compounds that cause heat to be trapped in Earth's atmosphere, contributing to weather patterns including a rise in average global temperature, extreme temperature events, and increased precipitation with heavy snow, rain, flooding, and droughts.[7] The National Oceanic and Atmospheric Administration (NOAA) has reported that the past three years (2015, 2016, and 2017) have been the warmest on record.[8] Extreme weather due to a rise in global temperatures affects human health and safety, while also increasing taxpayer costs for natural disaster damages and assistance. In fact, 2017 was the costliest year of weather and climate disasters to date, exceeding $300 billion in response to 16 separate billion-dollar disaster events.[9]

This study considers the following GHGs as they relate to transportation emissions:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous Oxide (N_2O)

Each of these GHGs contribute to warming the earth's atmosphere, which can lead to potentially dangerous changes in weather and climate as the average temperature of the planet increases.[11] Detailed information on each GHG and its impacts can be found in **Appendix B**.

Methodology

Emissions Factors

The EPA describes emissions factors as "a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant." Mode-specific emissions factors were applied to the total annual work-energy for each mode. These emissions factors, detailed in **Table 1**, were used to estimate the total kilograms (kg) of each air pollutant and GHG. To determine the net change in emissions across Davidson County resulting from the TIP, the

[7] U.S. EPA (2017) Emissions & Generation Resource Integrated Database.
[8] NOAA (2018) Assessing the Global Climate in 2017.
[9] NOAA (2018) 2017 U.S. billion-dollar weather and climate disaster: a historic year in context.
[11] U.S. EPA (2017) Climate Change: Basic Information.

assumptions and formula described in the following sections were used to estimate the total annual work-energy[12] for each transportation mode.

Table 1. Emissions Factors for Each Mode of Transportation Studied

Mode	Bus			Vehicle	Light Rail	Commuter Rail
	Diesel	Hybrid	Electric			
Pollutant	**kg/vehicle mile**	**kg/vehicle mile**	**kg/vehicle mile**	**kg/vehicle mile**	**kg/pass. mile**	**kg/pass. mile**
NO(x)	0.038[A]	0.016[H]	4.54E-04[E]	0.001[G]	8.39E-05[E]	0.006[B]
SO_2	0.002[A]	0.001[A]	0.001[E]	9.01E-06[G]	2.35E-04[E]	5.26E-05[B]
CO	0.008[A]	0.001[H]	1.21E-04[E]	0.005[G]	2.23E-04[F]	0.001[B]
PM(10)	0.003[A]	5.63E-05[H]	8.96E-05[F]	4.41E-05[G]	1.66E-05[F]	1.91E-04[B]
VOC	0.003[A]	0.002[A]	1.72E-05[F]	4.07E-04[G]	3.17E-06[F]	4.39E-04[B]
CO_2	1.401[A]	2.348[H]	0.967[E]	0.557[G]	0.179[E]	0.169[D]
CH_4	5.10E-06[C]	2.55E-06[A]	1.50E-05[E]	1.90E-05[G]	2.78E-06[E]	8.50E-06[C]
N_2O	4.80E-06[C]	2.40E-06[A]	1.03E-04[E]	1.00E-05[G]	1.90E-05[E]	3.40E-06[C]

Source: [A]EPA (1997), [B]EPA(2009), [C]EPA(2014), [D]EPA (2015), [E]EPA (2017), [F]EPA (2016), [G] Nashville MPO (2014), [H]EMBARQ Exhaust Emissions of Transit Buses (2012)

Reductive Air Quality and Emissions Impacts

The reductive, or beneficial, impacts to air pollutant and GHG emissions result from lower vehicle miles traveled (VMT) on roadways as personal vehicle users shift to transit. GHG and air pollutant emissions would also decline from converting the MTA's existing bus fleet to an all-electric fleet.[13]

Personal Vehicles

The *Let's Move Nashville Technical Analysis* estimates the reduction in VMT that would result from implementing the TIP. To calculate avoided emissions of GHGs and air pollutants through VMT reduction, region-specific emissions factors provided by the Nashville Area Metropolitan Planning Organization's (MPO) MOVES model, found in **Table 1**, were multiplied by the estimated reduction in VMT as individuals shift from

[12] The work-energy theorem describes the relationship between work and energy. Work is a product of the force and distance over which it is applied. Upon work being done, energy is transferred.
[13] Nashville MTA, Metro Nashville Public Works, RTA (2017) Let's Move Nashville's Transportation Improvement Program.

vehicles to transit. The MOVES Model is the EPA's *Motor Vehicle Emission Simulator*, a state-of-the-science modeling system that estimates emissions for mobile sources at the national, county, and project level for criteria air pollutants, GHGs, and air toxins.[14]

The TIP's implementation would come to completion in 2032, making 2033 the first year that reductive benefits from fewer air pollutant and GHG emissions would begin to be fully realized. For this reason, the net change in air pollutant and GHG emissions throughout this analysis is modeled for the representative year 2033. While this analysis provides a snapshot of air quality benefits in the year 2033, benefits would continue to accrue annually beyond this single year.

To ensure a conservative estimate, the average in the forecasted range of increased transit trips from the program's technical analysis was used to calculate the reductive benefit of the TIP associated with personal vehicles. An annualization factor of 305 was used alongside ridership projections to include weekends in total emissions estimations for vehicles. This annualization factor was provided by the program's technical analysis.

The following equation estimates the emissions reductions that would result from removing existing cars from the road:

$$\textit{Emissions (kg)} = \textit{Annual change in VMT (mi)} * \textit{Emissions Factor (kg/mi)}$$

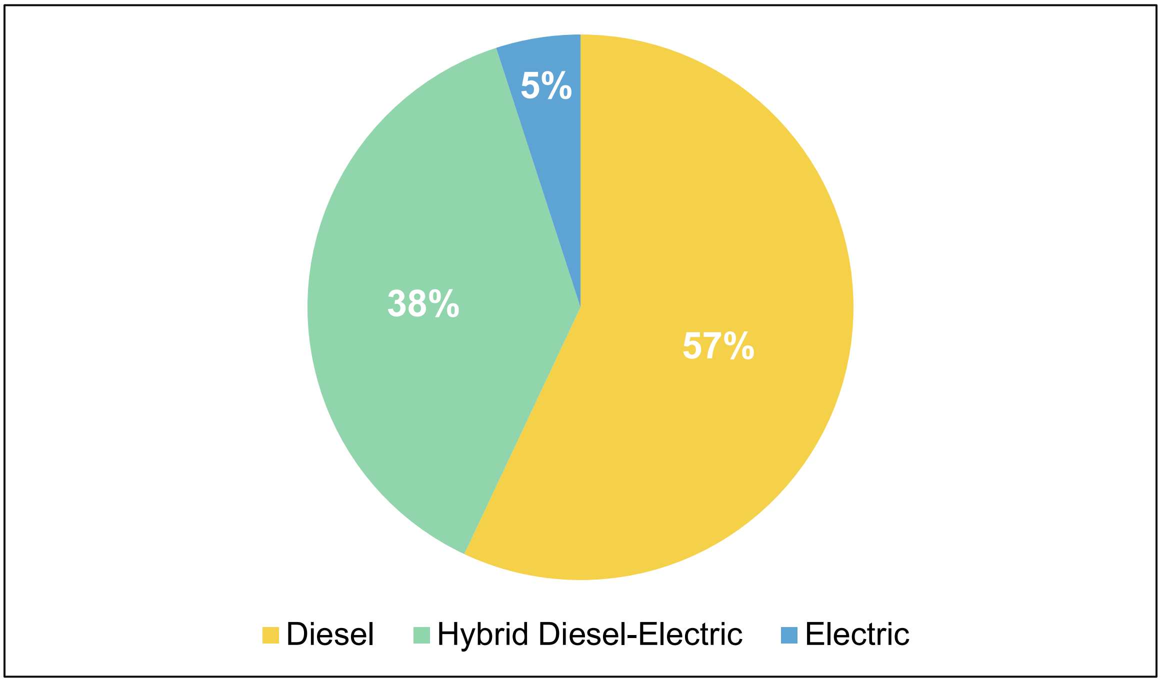
No-Build Bus Fleet

The TIP includes a number of updates to the local bus network that consist of four additional crosstown bus routes, increased frequency on 22 existing bus routes, and the implementation of an all-electric bus fleet. The MTA's current bus fleet, assumed to be consistent with the No-Build Scenario, is comprised primarily of diesel and hybrid diesel-electric buses. A breakdown of the MTA's current bus fleet is described in **Figure 1**. In order to calculate the emissions of buses that would be removed in the Build Scenario, annual emissions for the MTA's current bus fleet were estimated. For the No-Build Scenario, emissions factors for each type of bus in the MTA's current fleet were used along with revenue miles for existing bus service provided by the client. The number of revenue miles for each of the existing routes with no planned improvements is assumed

[14] U.S. EPA (2017) MOVES and other Mobile Source Emissions Models.

to be consistent with current 2017 MTA route mileage, while the number of revenue miles for each of the routes with planned improvements was calculated in accordance with data on frequency improvements[15] provided by the MTA.

Figure 1. 2017 MTA Bus Fleet



Source: Nashville MTA (2017)

Using MTA data, a summary of which is provided in **Appendix C**, it is assumed that the No-Build Scenario includes approximately 7.4 million annual bus VMT for the 48 existing bus routes. Additional assumptions for the emissions calculation and the source for each are included in **Table 2**. The average diesel bus fuel efficiency (MPG) was used to estimate the fuel consumption rate for diesel buses. A conversion factor using British thermal units (BTU) per gallon of diesel fuel was used to calculate an emissions factor in terms of kg. The average increased fuel efficiency of hybrid buses versus diesel buses was also used to estimate emissions for the hybrid share of the existing bus fleet. Finally, a conversion factor describing the number of kilowatt hours (kWh) per one mile was used to calculate the emissions from the electric share of buses in the MTA's current fleet.

[15] Frequency of service refers to the number of daily runs on a given transit route and the associated wait times for individuals.

For hybrid buses in the MTA's current fleet, emissions factors for CO, CO_2, NO_x, and PM were obtained from EMBARQ's SUTFV meta-analysis of transit bus emissions.[16] For the remaining pollutants and GHGs considered for which no emission factor information could be sourced for hybrid buses, including SO_x, VOC, CH_4, and N_2O, the emission factors of hybrid diesel-electric buses were assumed to equal 50% of emissions factors for diesel buses, presented in **Table 1**. This assumption was determined by considering the emissions factors of hybrid buses for which information could be sourced with respect to emissions factors of diesel buses and calculating an overall average. Through this, it was found that on average hybrid bus emissions factors were about 50% of diesel bus emissions factors.

Table 2. Assumptions for Calculations of 2017 MTA Bus Fleet Emissions

Metric	Value	Source
No-Build Annual Revenue Miles	7,374,024	Nashville MTA (2017)
Diesel bus MPG	7.3	USDOT Bureau of Transportation Statistics (2015)
BTU/gallon diesel fuel	137,452	U.S. EIA (2017)
Increased fuel efficiency for hybrid buses	21.6%	National Center for Transit Research (2014)
kWh/mile	2	Aber (2016)

The following equation estimates the reductions in air pollutant and GHG emissions that would result from removing existing buses from the road:

*Emissions (kg) = No-Build Annual Revenue Miles (mi) * Fuel Consumption Rate (gal/mi) * Conversion Factor (MMBTU/gal) * Emissions Factor (kg/MMBTU)*

[16] EMBARQ (2012) Exhaust Emissions of Transit Buses: Sustainable Urban Transportation Fuels and Vehicles. Working Paper.

Additive Air Quality and Emissions Impacts

As previously discussed, the TIP would divert personal vehicle users to transit and replace the MTA's existing bus fleet. While there would be reductions in air pollutants and GHGs, there would also be increases in emissions due to factors including: operations of LRT, introduction of Rapid Bus, increased service of the MCS commuter rail, more local bus trips and the addition of four crosstown bus routes. For this reason, the additive impacts have also been evaluated to ultimately arrive at the net emissions that would result from implementing the TIP.

Light Rail Transit

The TIP includes the addition of five LRT corridors. Forecasted reductions in VMT are attributed to the addition of LRT operations in the Build Scenario. In estimating LRT emissions, inputs include service statistics for the LRT system, such as annual passenger miles, a metric of energy intensity per passenger mile and an emissions factor for energy generation, each of which are presented alongside their sources in **Table 3**. In addition to the assumptions presented below, emissions factors for LRT were also used in air pollutant and GHG emissions estimations, presented in **Table 1**.

Table 3. Assumptions for Calculation of LRT Emissions

Metric	Value	Source
BTU / passenger mile	1,262	Oak Ridge National Lab (2017)
BTU / kWh	3,412	USDOT Bureau of Transportation Statistics (2015)
Annual passenger miles	77,464,205	Assumption from the client

To estimate the annual GHG and air pollutant emissions that would occur as a result of implementing LRT, the following equation was used:

*Emissions(kg) = Annual Passenger Miles[17] (mi) * Load Factor (BTU/mi) * Conversion Factor (kWh/BTU) * Emissions Factor (kg/kWh)*

[17] Passenger miles traveled (PMT) describe the cumulative sum of distances ridden by each passenger. A passenger mile is then one mile traveled by one passenger in a passenger car.

Commuter Rail

In addition to the introduction of LRT corridors, improvements to the existing transit system are part of the TIP, including increased service on the existing MCS commuter rail line. In the Build Scenario, the MCS commuter rail would offer improvements through increased hours and frequency of service.

Assumptions in estimating MCS commuter rail emissions include conversion factors describing the energy intensity per passenger mile, the British thermal units per gallon of diesel fuel, and the brake horsepower-hour-per-gallon of diesel fuel. The increased number of annual vehicle miles and daily MCS ridership were also used to estimate the total annual passenger miles for estimation of emissions in kg. Each of the assumptions is presented in **Table 4**. Emissions factors for locomotives were also used as a final input to the emissions estimation, found in **Table 1**.

Table 4. Music City Star Assumptions for Calculations

Metric	Value	Source
Increase in annual vehicle revenue miles	257,920	Assumption from the client
bhp-hr/gal	20.8	EPA (1997)
Nashville BTU per passenger mile of commuter rail	7,434	Oak Ridge National Lab (2015)
BTU/gallon diesel fuel	137,452	U.S. EIA (2017)
MCS daily ridership	1,100	Nashville MTA (2016)

The following equation[18] calculates the emissions for commuter rail:

*Emissions (kg) = Emission Factor (kg/bhp-hr) * Conversion Factor (bhp-hr/gal) * Nashville BTU per passenger mile traveled (BTU/passenger mile) * Conversion Factor (gal diesel/BTU) * Annual Change in Vehicle Miles (mi)* Passengers per trip*

[18] Emissions factors are not documented in identical units across all criteria air pollutants and GHG for all modes of transportation. For this reason, this exact equation was not used to calculate all air pollutant and GHG emissions for the MCS commuter rail. Instead, similar equations were used with varying conversion factors dependent on the units of documentation for emissions factors.

Electric Bus

The TIP includes multiple updates to the local bus network, including the addition of four crosstown routes, increased frequency on 22 existing routes, and converting the entire existing bus fleet to electric. For the Build Scenario, emissions factors for an all-electric bus fleet were used to calculate annual emissions, described in **Table 1**. The number of revenue miles for each of the existing routes with no planned improvements is assumed to be constant, while the number of revenue miles for each of the routes with planned improvements was calculated using data regarding frequency improvements.

Using data provided by the MTA, it is assumed that the Build Scenario includes approximately 10.5 million bus VMT for the 48 existing bus routes and four new crosstown routes. The increase in VMT reflects the additional trips resulting from increased hours and frequency of service on certain MTA routes. A conversion factor for kWh per mile was assumed based on an analysis by Columbia University on New York City's electric transit buses to evaluate annual emissions of the all-electric bus fleet in kg, noted previously in **Table 2**.

The following equation was used to calculate the emissions for the MTA's bus fleet in the Build Scenario:

*Emissions (kg) = Build Annual Revenue Miles (mi) * Energy Consumption (kWh/mile) * Emissions Factor (kg/kWh)*

Air Quality and Emissions Damages

Criteria air pollutants and GHGs have numerous detrimental impacts on human health, environmental quality, agriculture, and visibility, as described in **Appendices A** and **B**. Economic research funded by the EPA, the Department of Energy and other government entities has been performed to monetize emissions damages (costs associated with some damages caused by emissions) and estimate the public benefits associated with reducing emissions.

The impacts factored into the emissions damages value vary depending on the type of emission, detailed in **Table 5**. In the case of criteria air pollutants, the damages cost includes those associated with air pollution and its human health impacts but excludes other environmental impacts such as acid rain and reductions in plant productivity. For GHGs, the damages cost, also referred to as the "social cost," does not account for the increased risk of droughts, loss of biological diversity and other impacts on livelihood.[21] While these impacts are not monetized, they nonetheless affect countless people and economies.[22] Unlike criteria air pollutant impacts, GHG impacts are not localized, and their emissions have an aggregate effect.

Table 5. Impacts Accounted for in Damage Cost Values

Criteria Air Pollutants	Greenhouse Gases
• Human health impacts from air pollution	• Changes in net agricultural productivity • Economic damages caused by adverse effects on human health • Property loss and damages from sea level rise • Changes in energy systems costs from reduced heating and increase air conditioning

Source: U.S. DOT (2012), EPA (2016)

To estimate avoided emissions damages from the implementation of the TIP, values for the emissions damages of criteria pollutants (**Table 6**) and GHGs (**Table 7**) were applied. The following equation was used to estimate the annual damages for each air pollutant and GHG:

Emissions Damage ($) = Emissions (kg) * Damages Cost per Unit of Emissions ($/kg)

Table 6. Emissions Damages Cost of Criteria Pollutants per kg Pollutant (2017 dollars)

Pollutant	Damages Cost per kg
NO()	$8.36[A]
SO_2	$49.39[A]
CO	$0.00[B]
PM(10)	$382.31[A]
VOC	$2.12[A]

Source: [A]U.S. DOT (2017), [B]U.S. DOT

[21] U.S. DOT (2012) Corporate Average Fuel Economy for MY 2017-MY2025 Passenger Cars and Light Trucks.
[22] Intergovernmental Panel on Climate Change (2014) Synthesis Report.

As of 2016, the “U.S. Department of Transportation (DOT) Benefit-Cost Analysis (BCA) Guidelines” provided recommended values for reductions in GHGs. On March 28, 2017, “Executive Order 13783” rescinded the previous approach for valuing reductions in CO_2 and other GHGs. The BCA guidelines now recommend calculating values by estimating domestic damages and discounting them at the same rate as costs and other benefits. To support the assigned value, documentation of sources and details of calculations are requested. Following this guidance, the damages costs were calculated using EPA values for the social cost of carbon (**Table 7**) as published in 2013 and revised in August 2016.

Table 7. Emissions Damages Cost ($/kg) of Carbon, Methane, and Nitrogen Oxide 2015 (2017 dollars)

Greenhouse Gas	Damages Cost
SC – CO_2	$0.04[A,B]
SC - N_2O	$15.47[A]
SC – CH_4	$1.19[A]

Source: [A]EPA (2016), Interagency working Group on the Social Cost of Greenhouse Gases (2016)

Results

Using the formulas and assumptions listed in the sections above, the total annual air pollutant and GHG emissions were calculated to estimate the net change resulting from the TIP. **Table 8** shows the emissions in kg by each mode of transportation and the aggregated net change associated with the TIP.

Table 8. Reductive, Additive and Net Emissions (in kg)

Pollutant	Reductive		Additive			Net Reduction
	No-Build Bus Fleet	Auto Diversion	Commuter Rail	LRT	Build Bus Fleet	
	kg/year	kg/year	kg/year	kg/year	kg/year	kg/year
NO(x)	202,034	84,175	66,492	6,498	4,770	(208,448)
SO_2	14,349	517	622	18,195	13,357	16,064
CO	36,958	288,450	17,022	1,727	1,268	(339,435)
PM(10)	11,319	2,532	2,261	1,283	942	(13,887)
VOC	17,238	23,331	5,186	246	180	(45,328)
CO_2	12,822,606	31,926,841	1,997,805	13,847,464	10,165,292	(22,734,496)
CH_4	34	1,088	100	215	158	(849)
N_2O	65	574	40	1,471	1,080	1,872

The societal damages that air pollutant and GHG emissions cause to Metro Nashville and Davidson County are tangible. The estimated avoided emissions from the TIP include annual GHG emissions of about 22,235 metric tons of CO_2e, shown in **Table 9**.[23]

Table 9. Greenhouse Gases as CO_2e

Greenhouse Gas	Emissions (kg)	Emissions (lbs)	CO_2e (lbs)	CO_2e (metric tons)
CO_2	(22,734,496)	(50,120,925)	(50,120,925)	(22,734)
CH_4	(849)	(1,872)	(59,904	(27.17)
N_2O	1,872	4,127	1,161,878	527.02
Total				**(22,235.65)**

Offsetting annual emissions in a similar manner to the TIP's implementation would require great efforts and resources from the city and its residents. To generate this offset, 1,021,228 trees that would need to be planted and allowed time to mature. The forest area, in square feet, required to plant over 1 million trees is equal is surface area to more than 2,500 football stadiums. This estimate is based on the yearly absorption rate of CO_2 by a mature tree, the number of trees that can be planted per acre in Nashville, and Global Warming Potential factors[25] for methane and nitrous oxide, presented in **Table 10.** To supplement this estimation, the EPA estimates that these

[23] CO_2e is a standard unit for the measurement and comparison of greenhouse gases. It expresses the impact of each GHG in terms of the amount of CO_2 that would create the same amount of warming.
[25] Global Warming Potential factors were developed to allow comparisons of global warming impacts of different gases.

GHG emissions would equate to 3,333 homes' electricity use for one year or 5.8 wind turbines running for one year.[26]

Table 10. Assumptions for an Alternative Method of Offsetting Emissions

Value	Description	Source
48	Yearly absorption rate of CO_2 for a mature tree (lbs)	American Forests (2018)
300	Trees per acre	Nashville Reforestation Guidelines (2016)
32	CH_4 Global Warming Potential	U.S. EPA (2017)
281	N_2O Global Warming Potential	U.S. EPA (2017)

These representations of avoided GHG emissions due to the TIP's implementation highlight the magnitude of impact that the program would have on the city. The TIP would improve air quality and overall health for Davidson County residents and contribute to the productivity of the local economy in a number of ways.

Air pollutant and GHG emissions damages have an impact on human health costs and result in other societal costs that affect the environment. Implementation of the TIP would result in annual damage cost savings, amounting to an estimated $7.2 million undiscounted dollars in 2033 (**Table 11**).[27]

Table 11. Avoided Emissions Damages from Transit Improvement Program

Pollutant	Emissions	Damages
NO(x)	(208,448)	(1,742,625.67)
SO_2	16,064	793,404.42
CO	(339,435)	$-
PM(10)	(13,887)	(5,308,972.07)
VOC	(45,328)	(96,096.29)
CO_2	(22,734,496)	(909,379.85)
CH_4	(849)	(1,010.46)
N_2O	1,872	28,962.69
Total		**(7,235,717.23)**

[26] EPA (2018) Greenhouse Gas Equivalencies Calculator.
[27] Although $7.2 million is estimated as an annual figure, these estimates of avoided emissions damages would not materialize in full until all proposed components of the TIP have been constructed and implemented in Davidson County.

Conclusion

Metro stands to gain a more livable, breathable Nashville by implementing the TIP. Consider the anticipated annual savings of $7.2 million in avoided damages from emissions upon the TIP's full implementation. This estimation reflects only those factors that can be monetized with industry-accepted methods. The unquantifiable impacts to health, the environment, the economy, and the vitality of the city likely far exceed that figure. Further, the estimation does not account for the reduction in VMT that is likely to take place because of auto-diversion to other modes other than LRT.

Upgrading bus routes to LRT, converting to an all-electric bus fleet and reducing the number of personal vehicles on the road each day would result in reduced health complications related to air quality. For the people of Nashville, that means fewer emergency room visits, less cases of asthma and respiratory distress, and improved organ function.[29] The TIP's positive impacts would include supporting the area's agricultural productivity while cutting flood risk to properties. The TIP's proposed emissions reductions and the associated avoided costs would contribute to a healthier, more livable city better positioned to attract businesses, citizens, and tourists to Nashville.

[29] Sierra-Vargas, M and Teran, M (2012) Air pollution: Impact and Prevention. Respirology. 17(7):1031-2018.

Appendices

Appendix A. Criteria Air Pollutant Glossary

Nitrogen oxides

Nitrogen oxides (NOx) represents seven highly reactive compounds in total. NOx forms when fuel is burned at very high temperatures.[30] The most prevalent nitrogen oxide is nitrogen dioxide. Nitrogen dioxide reacts in the atmosphere to form particulate matter and ozone. Human exposure to particulate matter can result in heart and lung problems.[31] Exposure to ozone can cause difficulty breathing and is often one of many causes associated with the development of asthma.[32] Additionally, nitrogen dioxide contributes to the formation of acid rain. Automobiles are the main emitters of nitrogen oxides along with non-road vehicles and other industrial sources.[33] Nitrogen dioxide, one of the seven nitrogen oxides, can be harmful to human health as well as the environment, particularly to the human respiratory system.[34]

Sulfur oxides

Sulfur oxides (SOx) is a compound of sulfur and oxide molecules. The most common form in the atmosphere, sulfur dioxide (SO_2), is produced through burning fossil fuels that contain sulfur. Coal burning and vehicles emit sulfur dioxide and contribute to high concentrations of the compound in the atmosphere. Exposure to SO_2 has been associated with reduced lung function in humans. Emissions of SO_2 are particularly harmful to vegetation, causing them to become less productive or die prematurely.[35]

Carbon monoxide

Carbon monoxide (CO) is a tasteless, colorless, odorless gas that is found in fumes of various fuels including coal and gasoline. CO is emitted by gasoline-fueled vehicles as well as other mobile sources.[36] In humans and animals, CO exposure results in decreased capacity of the blood to carry oxygen throughout the body, which can have lasting effects on tissues and organs, including the heart. Those most at risk from ambient CO are persons with heart disease, angina, anemia, diabetes, and obstructive pulmonary disease. Research shows that fetal development periods are also a

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[30] U.S. EPA (2017) Nitrogen Oxides Control Regulations.
[31] U.S. EPA (2017) Health and Environmental Effects of Particulate Matter.
[32] U.S. EPA (2017) Health Effect of Ozone Pollution.
[33] U.S. EPA (1999) Technical Bulletin Nitrogen Oxides (NOx), Why and How They Are Controlled.
[34] U.S. EPA (2016) Nitrogen Dioxide (NO2) Pollution.
[35] World Bank Group (1998) Sulfur Oxides. Pollution Prevention and Abatement Handbook.
[36] Harvard University (2013) Carbon Monoxide Poisoning.

vulnerable period for exposure to CO. Additionally, research indicates that exposure from traffic-related sources of CO can be harmful to respiratory systems in children[37].

Volatile organic compounds

Volatile organic compounds (VOCs) are a large group of chemicals that release harmful organic compounds into the atmosphere. The chemical reactions associated with VOCs contribute to ozone formation, which can increase health risks for humans and warms Earth's atmosphere.

VOCs exist in both indoor and outdoor environments because they are released during the manufacturing of various types of products and materials.[38] Indoor VOCs are released by everyday products such as cleaning supplies, building materials and furnishings. Typically, VOCs have an odor associated with their exposure. VOCs can be released outdoors as well—vehicle tailpipe emissions of VOCs can be converted into particulate matter and are highly influential on the creation of smog, which is associated with adverse health effects for humans and the environment.[39] VOCs from outdoors can also become trapped inside through windows or vents of houses.[40]

Ground level ozone

Ground level or tropospheric ozone (O_3) is not directly emitted into the air but results from the chemical reaction between NOx and VOCs in the presence of sunlight. Breathing air containing ozone O_3 may trigger a variety of health problems including throat irritation, coughing, chest pain, and airway inflammation. Asthma patients, children, older adults, people who are active outdoors, and individuals with certain genetic characteristics are the most vulnerable to ozone's detrimental health effects. O_3 also imposes negative effects to sensitive vegetation and ecosystems since it reduces plants' photosynthetic activity and makes them more vulnerable to disease, damage from insects, other pollutants and severe weather.[41] Since O_3 is not directly emitted into the atmosphere, this analysis only accounts for the direct social and environmental costs of the pollutants that produce it.

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[37] U.S. EPA (2015) Criteria Air Pollutants. America's Children and the Environment.
[38] Stanford University (2007) Air Quality: Air Pollutants, SLAC Emissions Sources, and Regulatory Reference.
[39] U.S. EPA (1994) Automobile Emissions: An Overview. Fact Sheet OMS-5.
[40] New York State Department of Health (2013) Volatile Organic Compounds (VOCs) in Commonly Used Products.
[41] U.S. EPA (2017) Ozone Pollution.

Particulate matter

Particulate matter (PM) is a term used to describe a mixture of solid particles and liquid droplets found in air.[42] PM is created by both human and natural sources. Emissions of PM can be in the form of direct emission or by atmospheric transformations of gaseous emissions. As combustion engines and appliances produce exhaust gases, particulate matter is released into the air. Scientific evidence links detrimental human health effects with short and long-term exposure to various PM. Children, the elderly, those with preexisting heart and lung conditions, and those of lower socioeconomic status are considered most at risk to experience adverse reactions from exposure to PMs.[43]

Appendix B. Greenhouse Gas Glossary

Carbon dioxide

Carbon dioxide is the primary greenhouse gas emitted by humans. Carbon dioxide exists in the atmosphere naturally as part of the planet's carbon cycle, however, carbon dioxide emissions have increased rapidly since the Industrial Revolution. The global atmosphere average of carbon dioxide has increased more than 40% since the Industrial Revolution with a current global average of 400 parts per million (ppm). If energy demand continues to grow and is met with fossil fuels, this average is expected to grow to 900 ppm by the end of the century.[44] To accompany the additional emissions, human activities are also making it more difficult for carbon dioxide to be removed from the atmosphere through natural sinks such as soils, wetlands, and forests. The primary activity of humans that emits carbon dioxide is the combustion of fossil fuels for energy and transportation uses. Carbon dioxide emissions associated with transportation were second only to electricity as the largest source of emissions of the greenhouse gas emitted in 2015.[45]

Nitrous oxide

Nitrous oxide (N_2O) accounted for about 5 percent of all U.S. GHG from human activities in 2015. N_2O occurs naturally in Earth's atmosphere and is produced as a result of a number of human activities including agriculture, fuel combustion, and industry. According to the U.S. EPA, N_2O emissions have decreased by 7% between 1990 and 2015, likely due to increased efficiency and reduced emissions from on-road vehicles. N_2O has a severe impact on warming the atmosphere—one pound of N_2O warms the atmosphere 300 times as much as one pound of CO_2.[46] Excessive nutrient

[42] U.S. EPA. (2017) Particulate Matter Basics.
[43] U.S. EPA (2015) Criteria Air Pollutants. America's Children and the Environment.
[44] NOAA (2017) Climate Change: Atmosphere Carbon Dioxide.
[45] U.S. EPA (2017) National Emissions Inventory Data.
[46] U.S. EPA (2017) Nitrogen Oxides (NOx) Control Regulations.

loads (associated with nitrogen and phosphorus pollution) can cause large and sometimes toxic algal blooms and microbial growth that result in massive dead zones. Dead zones occur when there is little oxygen (hypoxia) or no oxygen (anoxic) remaining in the water.[47] Currently, hypoxia and anoxia are among the most widespread deleterious anthropogenic influences on estuarine and marine environments, and now rank with overfishing, habitat loss, and harmful algal blooms as major global environmental problems.[48]

Methane

Methane (CH_4) is emitted during the burning and transport of fossil fuels. Methane is emitted by the production and distribution of natural gas as well as in the production, transportation, and storage of petroleum.[49] In the U.S., methane is primarily emitted from natural gas and petroleum systems. Like other greenhouse gases, methane has environmental impacts on Earth's atmosphere and can accelerate weather-related impacts after it is released into the atmosphere. Methane is 100 times more potent than carbon dioxide.[50] Toxic chemicals that are detrimental to human health are typically released alongside methane from oil and gas industry production activities, which can be carcinogenic or have other lasting human health impacts.[51]

Appendix C. Build and No-Build Trips and Vehicle Mile Estimates for MTA Routes

Route Name	Route No.	No-Build Trips	Build Trip Increase	No-Build Miles	Build Miles
100 OAKS	1	3,810	0	22,292	22,292
BELMONT	2	5,080	0	37,855	37,855
WEST END	3	24,622	15,320	178,787	270,751
SHELBY	4	28,770	19,645	237,301	375,092
WEST END - BELLEVUE	5	21,876	0	291,552	260,050
LEBANON PIKE	6	13,978	6,940	217,106	325,046
HILLSBORO	7	28,862	20,345	147,808	238,016

[47] Robertson, G P and Vitousek, P M (2009) Nitrogen in Agriculture: Balancing the Cost of an Essential Resource. The Review of Environment and Resources. 34, 97-125.
[48] Diaz, R J and Rosenberg, R (2008), Spreading dead zones and consequences for marine ecosystems, Science. 321(5891), 926-929.
[49] U.S. EPA. (2017) Overview of Greenhouse Gases.
[50] Environmental Defense Fund (2012) The climate impacts of methane emissions.
[51] Environmental Defense Fund. Methane Pollution from the Oil & Gas Industry Harms Public Health.

8TH AVENUE SOUTH	8	13,697	10,760	90,088	151,357
METROCENTER	9	14,224	4,800	61,306	81,994
CHARLOTTE	50	31,840	30,800	258,048	507,735
TRINITY	11	0	25,160	0	161,200
WHITES CREEK	14	13,925	22,770	111,206	280,308
MURFREESBORO PIKE	55	32,348	37,800	426,760	925,620
12TH AVENUE SOUTH	17	21,297	20,170	134,423	251,132
AIRPORT - DOWNTOWN HOTELS	18	13,791	12,904	126,702	226,639
HERMAN	19	22,375	13,930	125,987	193,586
SCOTT	20	11,962	0	93,029	93,088
UNIVERSITY CONNECTOR	21	13,236	0	144,332	125,477
BORDEAUX	22	27,755	18,734	181,391	290,792
DICKERSON ROAD	23	25,532	32,047	231,823	498,610
BELLEVUE EXPRESS	24	4,064	0	50,289	50,289
MIDTOWN	25	13,575	0	131,768	115,879
GALLATIN PIKE	56	33,188	35,600	397,311	813,584
OLD HICKORY	27	2,032	0	54,580	54,580
MERIDIAN	28	18,294	9,200	81,552	112,765
McFERRIN	30	12,802	8,020	66,879	99,037
HICKORY HOLLOW-LENOX EXPRESS	33	2,032	0	38,108	38,108
OPRY MILLS	34	8,270	8,057	111,066	203,247
RIVERGATE EXPRESS	35	2,032	0	35,919	35,919
MADISON EXPRESS	36	4,318	0	57,905	57,905
TUSCULUM - McMURRAY EXPRESS	37	1,019	0	24,680	24,680
ANTIOCH EXPRESS	38	2,205	0	54,056	54,056
BELL	40	0	24,160	0	150,800
GOLDEN VALLEY	41	2,540	0	26,719	26,719
ST. CECILIA - CUMBERLAND	42	14,168	9,002	64,423	98,568
HICKORY HILLS	43	4,826	0	77,487	77,487
MTA SHUTTLE	44	3,497	0	7,743	7,743
AIRPORT - OPRY MILLS	49	0	24,927	0	150,800
NOLENSVILLE PK LOCAL	52	50,842	16,620	513,651	629,086

MUSIC CITY BLUE CIRCUIT	60	33,232	33,260	40,064	74,432
MUSIC CITY GREEN CIRCUIT	61	32,248	0	63,077	54,005
GRASSMERE-EDMONDSON CONNECTOR	72	16,723	0	112,838	99,976
MADISON CONNECTOR	76	10,380	11,070	73,987	145,457
GALLATIN PIKE BRT LITE	150	50,582	0	605,532	567,080
WEST END	250	48,530	0	481,043	430,062
MURFREESBORO PIKE BRT LITE	350	49,910	0	660,985	627,519
CHARLOTTE PIKE BRT LITE	450	49,148	0	424,569	400,071
TOTAL				7,374,024	10,516,495

Source: Nashville MTA (2017)