Bus Rapid Transit and Light Rail Transit

A Comparison Analysis of the Orange and Gold Lines in Los Angeles

ABSTRACT

This report provides a comprehensive comparison of two emerging modes of public transportation, Bus Rapid Transit (BRT) and Light Rail Transit (LRT), with a specific focus on the Orange (BRT) and the Gold (LRT) Lines in Los Angeles. The study aims to address two critical questions: first, which mode is more environmentally friendly in terms of emissions, and second, which mode is more cost-effective on an annual basis. To evaluate the environmental impact, the study employs a Life Cycle Assessment (LCA), while a Cost-Effectiveness Analysis (CEA) is utilized to analyze the cost aspects of both modes. The findings demonstrate that BRT exhibits lower costs and a reduced environmental footprint compared to LRT.

Aniket Bahadure, Garett Davis, Marcus D'Avignon, Aidan Hasegawa, Lee Keslerwest, Matthew Lin and Eirini Maria Oikonomaki

CE 256 – TRANSPORTATION SUSTAINABILITY

University of California, Berkeley
Spring 2023

Table of Contents

1.0 Executive Summary

To reduce auto dependency due to concerns about sustainability, traffic congestion, and equity, there is a need for reliable public transportation. Public transportation must provide affordable, fast, accessible, and sustainable services while balancing demands and costs. There are two emerging transportation modes to fulfill these needs: bus rapid transit (BRT) and light rail transit (LRT).

This project compares these two modes of transportation in terms of environmental and cost impact by conducting a Life Cycle Assessment (LCA) and a Cost-Effectiveness Analysis (CEA). The LCA allows insight into which mode of transportation is more environmentally friendly and less carbon intensive, while the CEA allows insight into which mode is more cost-effective. This project conducts a case study of the Orange Line, a BRT line, and the Gold Line, an LRT line, in Los Angeles, California.

The LCA examines the environmental impact of the transportation system across its entire lifecycle, including vehicle and infrastructure manufacturing, a one-year operational period, and end-of-life. The light rail and bus transit system were divided into three components: the train and bus vehicle, energy operations, and stations and infrastructure. The study revealed that the LRT systems have a greater environmental impact than the BRT system in terms of carbon dioxide (CO_2) emissions. Specifically, the Orange Line has life-cycle emissions of 143 tn CO_2 eq/mile, while the Gold Line has 752 tn CO_2 eq/mile. These findings provide a starting point for Los Angeles to reconsider its existing transportation infrastructure and prioritize the decarbonization of the grid, as the operational phase contributes significantly to the emissions, and a much lower environmental impact would be produced with a greater renewable energy mix in the grid.

The CEA is organized into two parts: the capital costs and the operating costs. For the capital costs, the analysis includes the original construction costs, extension or new station costs, as well as any other costs to improve the systems. The capital costs for the two lines are compared based on metrics, such as capital costs per mile and capital costs per average weekday boarding. For the operating costs, the measures of service compared include the vehicle revenue miles and hours, the passenger miles, and the number of unlinked passenger trips. These metrics are compared to the operating expenses for each line. Our analysis found that the BRT system was more cost effective than the LRT system from a capital cost and operating cost perspective. For both of these costs, the BRT system was about one-third the cost of the LRT system.

• 2.0 Introduction

In recent years, there has been a significant investment in rapid buses, which offer passengers a high level of comfort and performance similar to that of rail-based systems. However, the comparison between BRT and LRT systems has generated much interest. More specifically, the debate between supporters of these different transit systems is particularly fierce in the United States, with accusations of the Federal Transit Administration (FTA) favoring BRT over LRT (Lambas, 2017).

BRT is a fixed-route bus system that operates on fixed guideways, defined stations, traffic signal priority, and off-board fare collection (FTA, 2022). On the other hand, LRT is an electric railway with singularly operated passenger rail cars, low or high platform loading, and power drawn from an overhead electric line (FTA, 2022). When compared to each other, BRT lines typically have lower costs, greater flexibility, faster construction times, and more direct service, while LRT lines have higher capacity, more frequency service, and reduced travel times.

When designing transportation systems, urban and transit planners need to consider a wide range of factors, such as public preferences, demographics, and the long-term impact of each system on carbon and capital costs, and equity. In the post-pandemic era, these considerations have become even more important as transit demand and ridership preferences have shifted. In this context, this study aims to provide an overview of the environmental and cost impact of two transit systems in Los Angeles: the Orange Line and Gold Line. By analyzing the benefits and drawbacks of each system, this study can help public agencies make informed decisions about which system to implement, considering the unique challenges and opportunities presented by the current transit landscape.

• 3.0 Background

3.1 Literature Review

To fully comprehend the dynamics at play in this case study, it is important to have an understanding of the respective roles and preferences of the public for both BRT and LRT. To achieve this, an analysis of literature pertaining to the characteristics of both systems, associated costs and the involvement of public transit agencies, and the preferences of the public was conducted.

BRT systems are generally considered more cost-effective than traditional rail-based systems, such as LRT or subway systems, because they require less infrastructure and are easier and quicker to implement (Levinson et al., 2003). The cost of implementing a BRT system can vary, depending on factors such as the size of the system, the level of service, and the infrastructure needed. Some of the main costs associated with implementing a BRT system can include infrastructure costs, such as the cost of constructing dedicated bus lanes, bus stops and terminals, vehicle costs, technology costs such as real-time passenger information system and fare collection systems and operations and maintenance costs. However, BRT systems can provide benefits such as reduced travel times, increased reliability, and improved passenger experience, which can help offset some of the costs (Levinson et al., 2003).

On the contrary, LRT is often viewed as a more advanced option than BRT. Rapid transit systems are designed for densely populated urban areas, with the aim of providing greater passenger capacity than standard bus services, as well as faster and more reliable travel times. Achieving increased capacity and reduced travel times is accomplished through a combination of factors, including the use of high-capacity vehicles, more frequent service, and prioritization and segregation from other modes of transportation, particularly general traffic (Steer, 2015). The costs of implementing and operating LRT systems similarly to BRT depend on factors such as system size, route length, technology, and construction costs. More specifically, capital costs are typically higher than those for BRT systems due to the need for dedicated tracks and other specialized infrastructure.

Regarding socioeconomic patterns, several studies have been conducted that examine mostly preferences of populations in developing countries. A 2018 study has found that factors such as frequency, distance, household income and traveler's perceptions of public transportation improvements affect the decision of choosing either BRT or LRT systems in Pakistan. According to the study, in developing countries it seems that higher income people have a preference towards LRT, while commuters and lower income people are more oriented towards the introduction of a BRT system (Kepaptsoglou, 2018). Another recent study has examined the change of transit demand by different socioeconomic groups during the COVID-19 pandemic in

Bogota. It was found that lower strata had the least reduction of transit use compared to middle and higher strata (Caicedo, 2021).

Transit plays a primary role in the development of all sectors of the economy and in the localization of economic activities. Therefore, careful and strategic planning is required when developing or designing transportation systems in cities and forming new legislation. Transit agencies play a vital and determent role. Garrett & Taylor (1999) mention that "planners in government agencies have too often tended to overlook the uneven distribution of public investment and public services in urban regions and their consequences for the lives of affected residents." This, along with the fact that the government often chooses to invest in large capital projects rather than in improving the existing transit infrastructure, leads to biased decisions and inequity in transportation.

3.2 Case Study

The Orange, or G, Line is a BRT line that runs through the southern San Fernando Valley and opened in 2005. Originally, it ran through for 14.5 miles from the Red Line Subway station in North Hollywood, but in 2012 a 3.5-mile extension to Chatsworth was completed, adding a connection to the northwestern terminus of the Orange Line (Moody, 2006). Currently, the Orange Line runs 18 miles long, with 17 stations, connecting San Fernando Valley to Downtown Los Angeles (Metro, 2023). In 2022, the ridership was 4.16 million people (Metro, 2023). Currently, the line operates 24 hours a day with New Flyer Xcelsior XE60 buses, which are battery-electric buses (Sotero, 2021). The Orange Line also shares right-of-way with an active transportation bike path.

The Gold, or L, Line, opened in 2003, is an LRT line that runs 31 miles long, with 26 stations, connecting Azusa to East Los Angeles through the downtown area (Metro, 2023). In

2022, the ridership was 5.91 million people (Metro, 2023). The line operates 18.5 hours a day from 5 AM to 11:30 PM with a rotation of AnsaldoBreda P2550 and Kinkisharyo P3010 trains (Kinkisharyo, 2023; Chester et al., 2012). Figure 1 below displays both the Orange and Gold Lines in the broader LA Metro map, displayed with the same colors as their names imply.

Figure 1: The Los Angeles Regional Rail Map (LA Metro, 2023).

This case study explores the Orange Line due to its planned conversion from a BRT line to an LRT line by 2050 (Grigoryants, 2018). Due to this plan, the Gold Line is studied to provide a frame of reference for the Orange Line when it is converted into a LRT line, as the two lines were constructed around the same timeframe and serve a similar number of passengers.

• 4.0 Methodological Approach

4.1 Life Cycle Assessment

Life cycle assessments of LRT and BRT systems were conducted to determine the environmental impacts of these two modes of transportation. From the literature review, it was found that the Orange Line case in Los Angeles has been a point of interest for comparison studies to the Gold (L-Line) and Expo (E-Line) lines. These studies use data from 2012 and 2017, which can be considered outdated, as the pandemic and global energy crisis has changed passengers' preferences and has affected fuel prices. As such, this study aims to modernize these LCAs and bridge this gap. In addition, the recent transition of Metro from compressed natural gas (CNG) to electric fleets is an important factor that significantly affects the results of the previous studies which incorporated CNG fleets.

However, prior research cannot go unnoticed, so it serves as a foundation to extract data and analyze the life cycle greenhouse gas emissions of the Orange and Gold Line in Los Angeles. An LCA method is used to properly assess the project's environmental impact by considering the impacts of three main stages: 1) vehicle and infrastructure manufacturing and maintenance, 2) operational use and 3) end of life. In addition, the LRT and BRT systems were divided into three main components for analysis: 1) train and bus vehicles, 2) energy operations and 3) stations and infrastructure. All steps and calculations are presented in Appendix B.

In this study, the "process based" LCA method is used, which identifies and quantifies the resource inputs and environmental outputs at each stage of the life cycle based upon unit process modeling and mass balance calculations. This method allows to map each process to its associated energy and material inputs, and environmental outputs and wastes. The implementation of the LCA method includes four main steps:

- Define the objective and scope of the study, as well as its assumptions.
- Analyze the BRT and LRT components.
- Assess the effects of their prospective environmental impact.
- Interpret and compare the results by reflecting the limitations of the calculation.

The LCA presents first and foremost the lifecycle carbon emissions (CO_2-equivalents), or Global Warming Potential, of each mode of transportation. This parameter was chosen because it is usually selected as the most significant environmental parameter that represents the environmental impact of the products. Furthermore, these emissions are calculated on an annual basis, specifically reflecting 2022 data.

Other factors such as product lifespan, ridership capacity, maintenance requirements, and other inputs are considered. LCA emissions are calculated as a gross CO_2-equivalent value as well as a CO_2 eq/passenger-mile. The latter unit is essential for understanding the total impact when distributed across the vehicle's expected lode. By doing this, we can establish valuable breakeven points and ridership quotas to better understand the benefits being reaped from these transit modes.

4.2 Cost-Effectiveness Analysis

A Cost-Effectiveness Analysis (CEA) is developed to weigh the various costs of each alternative to determine which mode is the most cost-effective on an annual basis. The costs of the CEA is divided into two parts: capital costs and operating costs. For the capital costs, the projects included are the original construction of the line, new station constructions, and line extensions, fleet and equipment improvements, and signage. The data for the original constructions, new station constructions, and line extensions are collected from past reports and various news articles. Various other costs are collected from LA Metro's Fiscal Year 2022 (FY 22) Adopted Budget. Furthermore, ridership data is collected from LA Metro's Interactive Estimated Ridership Stats Tool over FY 22 (from July 1, 2021, to June 30, 2022) in order to match the capital costs collected. All capital costs are adjusted for inflation to 2022 dollars using the Consumer Price Index (CPI). The capital costs for the two lines are compared on a per mile and per weekday boarding basis.

For the operating costs, four measures of transit service efficiency and effectiveness were analyzed: vehicle revenue miles, vehicle revenue hours, passenger miles, and unlinked passenger trips. Vehicle revenue miles is the number of miles that vehicles are scheduled to or actually travel while in revenue service. Vehicle revenue hours is the number of hours that vehicles are scheduled to or actually travel while in revenue service. Both of these metrics include layover and recovery time and do not include measures like deadheading and maintenance time. Passenger miles is the sum of the distances traveled by each passenger. Lastly, unlinked passenger trips are the number of passengers who board public transportation vehicles. It is important to note that every transfer means another unlinked passenger trip. Vehicle revenue miles and vehicle revenue hours measure the efficiency of the transit service, while the number of passenger miles and unlinked passenger trips measure transit service effectiveness. The measures above are collected from LA Metro’s FY 19 and FY 22 Adopted Budget and LA Metro’s Interactive Estimated Ridership Stats Tool.

To calculate the operating costs for each line, data for the operating expenses divided by each of the four measures above is collected from LA Metro’s 2019 and 2021 Annual Agency Profiles. This data is divided by mode (BRT and LRT), and not by line (Orange and Gold), but it provides a reasonable estimate for the operating costs for both lines. The numbers of lines in the BRT mode are 2 (Orange and Silver), while the number of lines in the LRT mode is 4 (Blue, Green, Expo, and Gold). The operating costs for the Orange and Gold Lines are compared in both 2019 and 2022 in order to analyze the impact the COVID-19 pandemic had on both ridership, service efficiency, and effectiveness. The various calculations for both the capital and operating costs can be found in Appendix C.

5.0 Results and Analysis

5.1 Life Cycle Assessment

The results showed that for the BRT rolling stock, the emissions per vehicle are approximately 173 tn CO_2 eq, including manufacturing, maintenance, and end of life, for a lifespan of 12 years. The Orange Line has deployed 40 XE Flyer 60' buses, so the emissions for all fleets are a total of 6,920 tn CO_2 eq. For the LRT system, the Metro has deployed 25 AnsaldoBreda P2550 cars and 50 Kinkisharyo P3010 cars, both with lifespans of 30 years. The results showed that 14.3 tn CO_2 eq per year are associated with the AnsaldoBreda cars and 28.7 tn CO_2 eq per year associated with the Kinkisharyo cars, with the maintenance phase contributing significantly to the distribution of carbon emissions. During the operational phase the total emissions for a year are 949.7 tn CO_2 eq for the BRT system which operates at a 24/7 basis while for the LRT system the emissions are 19,786 tn CO_2 eq operating from 5 am to 11:30 pm. The electricity mix was calculated on a "80-20" basis including the electricity mix from the City of Pasadena and LADWP giving more weight to the latter. Finally, the emissions associated with infrastructure include the emissions from the construction, operations, maintenance, and parking, as well as the emissions from charging infrastructure for the Orange Line. The infrastructure emissions for the Gold Line are 3502 tn CO_2 eq/yr while for the Orange Line are 366 tn CO_2 eq/yr and 710.4 tn CO_2 eq/yr for the chargers.

Analyzing results on a per PMT basis, we can see that the Gold Line LRT is more carbon intensive than BRT at current ridership thresholds. It is true that riders average longer trips on

LRT, assumedly due to its faster speed and less frequent stop locations. This makes it imperative to analyze emissions as g CO_2 eq/PMT. The COVID-19 pandemic decimated ridership across both modes, making future predictions challenging. Additionally, both modes were not affected equally. The Orange Line saw PMT decrease by a factor of two while the Gold Line PMT decreased by more than three. Using 2022 ridership data, we determined that the Orange Line emits 76 g CO_2 eq/PMT while the Gold Line emits 545 g CO_2 eq/PMT, or 7.2 times the amount.

Employing a simple breakeven analysis, we determined that ridership would have to increase by at least this much. Given current equipment, each bus has a 61 seat capacity while each dual rail car has 138. We calculated that there are 2,336,256 annual bus miles traveled per year, or 142.5 million seat-miles. When we divide annual PMT we determine that each bus averaged 17% full or at 11 people. Multiplying this by our breakeven factor of 7.2, we can see that this is well within the 138-seat capacity of the rail cars. It is notable however, that this 17% is likely higher, even closer to 100% during peak hours. In order to accommodate a 7.2x increase in ridership, peak-hour LRT service would require increased capacity or frequency, further burdening the operations phase while leaving other sections more or less unaffected. This leads us to conclude that if such a ridership increase can be achieved, per PMT CO_2 eq emissions can be reduced with the introduction of LRT. Detailed calculations of the above results can be found on Appendix B while Figure 2 summarizes the emissions per PMT.

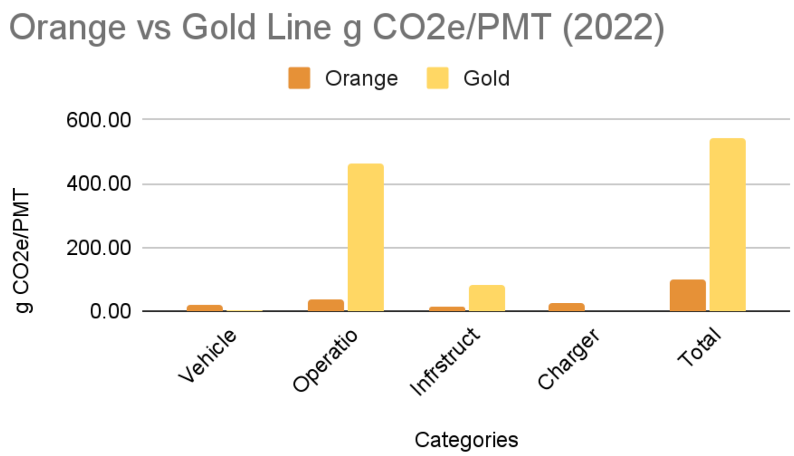


Figure 2: gCO2e/PMT by component, Orange vs Gold Line

5.2 Cost-Effectiveness Analysis

As discussed in Section 4, the capital costs for each line are made up of various projects. In Tables 1 and 2 below, the capital costs for the Orange and Gold Line respectively are displayed. The first column lists the projects with their completion year. If the year is listed as 2022, the project is still under construction. The next two columns list the capital costs in dollars from the year the project was completed, and the capital costs in converted 2022 dollars. The total capital cost for the Orange Line is $940.21 million, while for the Gold Line the capital cost total is $4.28 billion.

Table 1: Capital Costs for the Orange Line BRT

Project (Year)	**Capital Costs (Original $)**	**Capital Costs (2022 $)**
Original Construction (2005)	$323.6 million	$487.87 million
14th Station Construction (2006)	$26 million	$37.70 million
Canoga to Chatsworth 4-Mile Extension (2012)	$215.6 million	$273.47 million

Bus Electrification (2021)	$80 million	$87.93 million
Orange Line Improvements (2021 and 2022)	$36.79 million through 2021 $12.20 million in 2022	$52.64 million
Orange Line Reclaimed Water Project (2022)	$0.18 million through 2021 $0.18 million in 2022	$0.38 million
Orange Line In-Road Warning Lights (2022)	$0.18 million through 2021 $0.03 million in 2022	$0.22 million

Table 2: Capital Costs for the Gold Line LRT

Project (Year)	**Capital Costs (Original $)**	**Capital Costs (2022 $)**
Original Construction (2003)	$859 million	$1,359.2 million
Eastside Extension (2009)	$899.1 million	$1,169.66 million
Gold Foothill Extension 2A to Azusa (2022)	$918.44 million through 2021 $3.5 million in 2022	$1,012.95 million
Gold Foothill Extension 2B (2022)	$490.30 million through 2021 $182.06 million in 2022	$720.95 million
State of Good Repair (2022)	$12.97 million	$12.97 million
TPSS Battery Replacement (2022)	$0.10 million through 2021 $0.52 million in 2022	$0.61 million
Train Control Battery Replacement (2022)	$0.44 million through 2021 $0.31 million in 2022	$0.75 million

A comparison of the capital costs for the Orange and Gold Lines is shown in Table 3 below. The metrics of importance include the length of the line, in miles; the number of stations; the number of average weekday, Saturday, and Sunday boardings in 2022; the total capital costs; the capital costs per mile; and the capital costs per average weekday boarding. When comparing the number of boardings, the Orange Line serves roughly two-thirds of the number of passengers that the Gold Line serves for each category. In addition, the Orange Line's capital costs are approximately one-fifth of the Gold Line's capital costs. Furthermore, when comparing capital costs on a per mile and per weekday boarding basis, the Orange Line's capital costs are around one-third of the Gold Line's capital costs. It is important to note that light rail trains are expected to last twice as long as buses, which is seen in our comparison as the Orange Line accounts for one bus electrification fleet replacement, while the Gold Line does not have a train fleet replacement.

The number of additional passenger trips and passenger miles that would be required for the Gold Line to be approximately as cost-effective as the Orange Line were also calculated (using FY 2022 measures) and shown in Table 3. For the Gold Line to have similarly effective capital costs, passenger miles would need to increase by 149%, or passenger trips would need to increase by 197% (depending on which measure is more significant to the agency) without further investment in capital.

Table 3: Comparison of the Orange and Gold Lines for Performance Items Regarding Capital Costs

Performance Item	Orange Line BRT	Gold Line LRT
Length (miles)	18	31
Number of stations	17	26
Average weekday boardings (FY 22)	11,751	17,523
Average Saturday boardings (FY 22)	8,392	14,015
Average Sunday boardings (FY 22)	6,898	11,680
Capital costs	$940.21 million	$4.28 billion

Capital costs per mile	$52.23 million	$137.97 million
Capital costs per average weekday boarding	$80,011	$244,250
Additional Annual Passenger Miles Required for Similar Cost-effectiveness	0	63,600,852
Additional Annual Passenger Trips Required for Similar Cost-effectiveness	0	11,594,719

To compare the operating costs of the Orange and Gold Lines, data for the operating expenses were divided by each of the four measures of service (vehicle revenue miles, vehicle revenue hours, passenger miles, and unlinked passenger trips) based on the type of mode. These values are shown in Table 4 below, in 2021 dollars. Based on all four of these metrics, BRT is more cost-efficient and cost-effective than LRT for LA Metro. The number of additional trips and passenger miles required for similar cost-effectiveness is also shown in Table 4.

Table 4: Operating Expenses per Each Measure of Service for 2021.
Source: LA Metro's 2021 Annual Agency Profile

Measure of Service	Bus Rapid Transit (BRT)	Light Rail Transit (LRT)
Operating Expenses per Vehicle Revenue Mile	$26.19	$31.71
Operating Expenses per Vehicle Revenue Hour	$399.60	$663.94
Operating Expenses per Passenger Mile	$1.91	$2.61
Operating Expenses per Unlinked Passenger Trip	$11.16	$17.22
Additional Passenger Miles	0	33,430,341

Required for Similar Cost-effectiveness		
Additional Passenger Trips Required for Similar Cost-effectiveness	0	6,628,645

With the values in Table 4, and the collection of data on the four measures of service, the average operating cost for FY 22 is calculated. To calculate the average operating cost, the values in Table 4 are multiplied by the respective measure of service for FY 22, and these values are averaged and adjusted to 2022 dollars to obtain the average operating cost for each line. In Table 5 below, for the Orange and Gold Lines, the four measures of service are listed: the operating expenses, passenger miles per unlinked passenger trip, unlinked passenger trips per vehicle revenue mile, and unlinked passenger trips per vehicle revenue hour. From the passenger miles per unlinked passenger trip measure, it is evident that compared to Orange Line passengers, Gold Line passengers on average take about 1 mile longer trips. However, this could be attributed to the distance of the Gold Line being twice as long as the Orange Line. Furthermore, the unlinked passenger trips per vehicle revenue mile or hour metrics signify that with an equally weighted amount of service, the Orange Line serves more passenger trips than the Gold Line. The Gold Line would need 79% more passenger trips, or 113% more passenger miles to be as cost-effective as the Orange Line. Lastly, Table 5 depicts that the operating costs for the Orange Line is roughly one-third of the Gold Line's operating expenses.

Table 5: Comparison of the Orange and Gold Lines for Measures of Service Regarding Operating Costs in FY 22

Measure of Service	Orange Line BRT	Gold Line LRT
Vehicle Revenue Miles	1,472,736	5,492,069

Vehicle Revenue Hours	104,921	241,818
Passenger Miles	23,321,189	42,561,270
Unlinked Passenger Trips	3,838,674	5,879,594
Passenger Miles per Unlinked Passenger Trip	6.08	7.24
Unlinked Passenger Trips per Vehicle Revenue Mile	2.61	1.07
Unlinked Passenger Trips per Vehicle Revenue Hour	36.59	24.31
Total Operating Cost	$45.11 million	$146.99 million

One issue with the operating costs for FY 22 is the impact of the COVID-19 pandemic on declining ridership. To explore this concern, a comparison of the operating costs to pre-pandemic 2019 data is performed. The same process is used as before, where data for the operating expenses divided by each of the four measures of service based on the type of mode is needed. These values are shown in Table 6 below, in 2019 dollars. As seen before for the 2021 numbers, BRT is more cost-efficient and cost-effective than LRT for LA Metro. Furthermore, these measures are lower in 2019 compared to 2021, most likely due to more transit service and higher ridership.

Table 6: Operating Expenses per Each Measure of Service for 2019.
Source: LA Metro's 2019 Annual Agency Profile

Measure of Service	**Bus Rapid Transit (BRT)**	**Light Rail Transit (LRT)**
Operating Expenses per Vehicle Revenue Mile	$14.93	$25.14
Operating Expenses per Vehicle Revenue Hour	$231.80	$515.13

Operating Expenses per Passenger Mile	$0.57	$0.96
Operating Expenses per Unlinked Passenger Trip	$3.74	$7.48
Additional Passenger Miles Required for Similar Cost-effectiveness	0	99,340,845
Additional Passenger Trips Required for Similar Cost-effectiveness	0	20,399,787

As done for FY 22, a calculation of the operating expenses is done for FY 19, where the costs are also adjusted to 2022 dollars. In Table 7 below, the four measures of service and operating expenses for the Orange and Gold Lines are listed. Regarding passenger miles per unlinked passenger trip, it is evident that passengers travel further for both the Orange and Gold Lines in FY 19 compared to FY 22. In addition, the unlinked passenger trips per vehicle revenue mile or hour metrics in FY 19 are higher for both the Orange and Gold Lines compared to FY 22. With more service provided and ridership, the Orange and Gold Lines become more cost-efficient and cost-effective. On the other hand, while the Orange Line's operating costs decreased from FY 22 to FY 19, the Gold Line's operating costs actually increased from FY 22 to FY 19. This discrepancy could be attributed to an increase in service and ridership for the Gold Line, but the Orange Line also saw an increase.

Table 7: Comparison of the Orange and Gold Lines for
Measures of Service Regarding Operating Costs in FY 19

Measure of Service	Orange Line BRT	Gold Line LRT
Vehicle Revenue Miles	1,699,964	6,392,123
Vehicle Revenue Hours	121,426	275,108

Passenger Miles	45,206,002	140,755,311
Unlinked Passenger Trips	6,860,145	16,035,517
Passenger Miles per Unlinked Passenger Trip	6.59	8.78
Unlinked Passenger Trips per Vehicle Revenue Mile	4.04	2.51
Unlinked Passenger Trips per Vehicle Revenue Hour	56.50	58.29
Total Operating Cost	$29.31 million	$155.67 million

To compare relative user benefits, travel times for each line were calculated based on the published schedule as of May 2023 (shown in Table 8). For the Gold Line, the northern section from Union Station to Azusa was used for calculation.

Table 8: Comparison of Travel Time and Speed for the Orange and Gold Lines

Measure of Service	Orange Line BRT	Gold Line LRT
Distance (mi)	18	25
Scheduled Time (min)	53	50
Commercial Speed (mph)	20	30

For this measure, the Gold Line is significantly faster than the Orange Line, saving 1 minute per mile. Using the 2016 Value of Time Guidance published by the US Department of Transportation, and adjusting to 2023 dollars using the CPI, the value of time for all trips in 2023 is $17.63. The 1 minute per mile saved by the Gold Line therefore represents $0.29 per passenger mile. For the Gold Line, this is a benefit over BRT of approximately $12.3 million in FY 2022. For the Orange Line, this is a cost over LRT of approximately $6.8 million. While this is a benefit of LRT over BRT, it is not nearly sufficient to offset the much higher operating costs.

• 6.0 Study Limitations

6.1 Life Cycle Assessment - Uncertainty Assessment

Life cycle assessments are inherently limited due to their dependence on temporality, location, and sequences. For example, an LCA on a LRT in Manhattan could not be directly copied over to a LRT in Chicago - it would have to be translated to fit the new situation. This translation is up to the discretion of the author, so it cannot be perfect.

Because of this inherent limitation, life cycle assessments normally include a table called an Uncertainty Assessment that explains the quality of the data and approximations. Each aspect of the LCA is ranked on a scale of 1 to 5, with 1 being the maximum quality data and 5 being the minimum quality data. Table 9 provides the Uncertainty Assessment for this report's LCA.

Table 9: LCA Uncertainty Assessment

	Acquisition Method	Independence of Data Supplier	Representativeness	Data Age	Geographical Correlation	Technological Correlation
BRT Vehicle Manufacturing, Maintenance, and End of Life	2	1	2	2	1	1
LRT Vehicle Manufacturing, Maintenance, and End of Life	3	2	2	3	1	1
Operations	1	1	1	1	1	1
Infrastructure	2	1	2	3	1	1

As seen in Table 9, the average data quality rating was 1.54, meaning the data varied in quality but was overall fairly representative of the system under study. First, the BRT vehicle data was very high quality, but had to be translated from a comparable bus model since the actual bus model's supplier did not provide data. Second, the LRT vehicle data had to be sourced from multiple papers since the two train car models lacked data, but the source quality was overall high. However, the End of Life of the LRT was poor quality, so that decreased its rating. Third, the operations data was straight from LADWP and the City of Pasadena and was very representative of our system, so for this reason, it was given the highest rating. Finally, the infrastructure data was taken from quality sources, but had to be translated to match our system and was not a direct reflection.

To improve this LCA, it would be preferable for the vehicle suppliers to directly provide data on their vehicle models in Environmental Product Declarations. Since there is no current requirement to do so, the suppliers will probably not oblige.

6.2 Cost Effectiveness Analysis

There were several limitations with the cost effectiveness analysis. With the limited time and resources available, certain figures had to be estimated. Costs per station and several extensions, for example, were not available from LA Metro on the Orange Line, but were available on the Gold Line. Thus, only estimates can be used. Another limitation is the lack of vehicle revenue miles and revenue hours. Estimates could be made based on figures in the budget, but unexpected circumstances such as service disruptions could change these figures. Additional estimates had to be made to the operating expenses since they were not broken down by line, but rather by mode. These limitations could skew the data and results significantly if outliers exist in LA Metro's data but are not reflected in their reports and budgets.

User cost calculations in this study were limited to the travel time savings of the Gold Line over the Orange Line. The published schedule was used, which assumes the same travel time throughout the entire day, and which may not accurately reflect the actual travel time or commercial speed. Comparisons to other modes were not performed, nor was the difference in walking time because of stop spacing considered.

The environmental costs of each mode was also omitted from this study. Local greenhouse emissions, particulates from tires, and noise pollution. These metrics also would most likely favor LRT since they do not emit local pollutants and likely are less noisy. These costs are harder to quantify and thus the analysis was deemed too out of scope for this project.

• 7.0 Policy Recommendations

In terms of urban design we recommend to policy makers and urban planners to encourage the development of mixed-use neighborhoods that prioritize transit use. Both BRT and LRT stations should be within walking distance of major trip generators, making it more convenient for riders to access transit and connect downtown hubs and core areas with activity centers such as universities, airports, civic employment centers and high density residential areas. In addition, policies should be developed that serve as catalysts for Transit Oriented Development which will offer incentives that encourage the development of projects around transit centers by providing funding or streamlining the permitting process. This to be successful should be in conjunction with community engagement. However, to be successful, this approach must be undertaken in conjunction with community engagement. Policy makers should put effort to solicit feedback from residents and businesses, offer free trials and passes to encourage ridership and collect and analyze data to identify transportation patterns.

The success of the systems heavily depends on the integration into the existing comprehensive network. Both BRT and LRT systems have the potential of reducing greenhouse gas emissions and improving the air quality which is a major problem in Los Angeles. policies should be developed around promoting the use of alternative modes of transportations such as biking and walking by installing bike racks and bike share systems at transit stations . Additionally, the use of public transport can be encouraged through fare discounts and promotions.

Finally, given the inherent cost hurdles found with building light rail rather than BRT, a broad policy around mitigating those costs should be enacted. While this study only looked at cost, it is evident that cost is not all that needs to be considered. Cost, however, is often weighed most heavily by policy makers. Therefore, we recommend policies that prioritize the non-capital/operational cost of a transit project or lower the higher capital/operation burden of these projects. This could offset the burdens and make LRT more initially appealing if desired. This could include reducing service hours and frequency, introducing skip-stop service of BRT systems, or temporarily closing unproductive segments or stations. In addition, private sector participation should be encouraged which will reduce the burden on public funding sources.

• 8.0 Conclusions

There are several interesting takeaways comparing the two modes. We found that LRT emits more carbon than BRT mostly because of the larger amounts of energy required to operate and move the vehicles forward. However, LRT does provide greater benefits that are not quantified in the LCA. If the grid were decarbonized, and LRT then became more comparable to BRT in terms of environmental impact, then there would be less qualms about supporting and investing in LRT over BRT.

This study can also be used as a gauge on the value of the Gold and Orange Lines in LA Metro. When looking at how many passengers needed for the Gold Line in order, they are significant. As mentioned in the policy recommendations, additional land use developments could be needed to more adequately justify the use of LRT along corridors.

• 9.0 Recommendations for Future Research

Integrating LCA emission costs into CEA: A more holistic approach should be taken into account to compare BRT vs LRT for future research or studies by adding the cost from the Life-Cycle Assessment to the cost-effectiveness analysis. This will provide a precise understanding of the true costs affiliated with each transportation mode which incorporate both financial and environmental aspects.

Further user-side analysis of cost-effectiveness: Further studies should focus on a user-side cost-effectiveness analysis, which includes factors such as travel time (walking distance from a particular stop, waiting time at stop and in-vehicle travel time), fares, and safety. By examining the perspective of passengers on both systems, policy makers and urban planners can identify the problems associated with both systems and have a better understanding of how these parameters affect passenger preferences .

Quantifying and incorporating benefits into CEA: To have a more comprehensive approach to the CEA of both systems, future research could look into quantifying and inculcating the benefits on health, congestion and economy. Specifically, both systems contribute to the improvement of air quality and noise pollution as well as to the increase in physical activity due to active transportation (walking and cycling to transit stops). In addition, new vacancies are created and the value of properties near to transit corridors increase, developing the economic scenery.

Finally, traffic congestion which has a huge impact on transportation in Los Angeles can be relieved and the associated costs and benefits should be explored.

Social and equity impact: The social and equity impact of BRT vs. LRT and the aspects of accessibility and affordability and inclusivity for people from different demographic groups are important factors that should be examined in future research purposes. Focus should be given on how well both systems serve people from various population groups such as elderly people, people with disabilities, and people from underprivileged or marginalized communities and if their design and distribution of transit stops facilitates choosing them. In addition, another perspective to look at is how the fare structure and discounts affects people from different socio-economic backgrounds in choosing modes of transportation.

- **References**

Boarnet, M. G., Wang, X., & Houston, D. R. (2017). Can New Light Rail Reduce Personal Vehicle Carbon Emissions? A Before-After, Experimental-Control Evaluation In Los Angeles. *Journal of Regional Science*, 57(3), 523–539. https://doi.org/10.1111/jors.12275

Caicedo, J. M., Walker, J. L., & González, M. C. (2021). Influence of Socioeconomic Factors on Transit Demand During the COVID-19 Pandemic: A Case Study of Bogotá's BRT System. *Frontiers in Built Environment*, 7. https://doi.org/10.3389/fbuil.2021.642344.

Chester, M., Eisenstein, W., Pincetl, S.Elizabeth, Z. Matute, J. & Bunje, P. (2012). Environmental Life-cycle Assessment of Los Angeles Metro's Orange Bus Rapid Transit and Gold Light Rail Transit Lines. *Center for Earth Systems Engineering and Management*. http://seeds4green.net/sites/default/files/chester-ASU-SSEBE-CESEM-2012-WPS-003.pdf

Cobalt Institute. (2023). Batteries & Electric Vehicles. *Cobalt Institute.* https://www.cobaltinstitute.org/essential-cobalt-2/powering-the-green-economy/batteries-electric-vehicles/

Covarrubias A., & Liu C. (2005, November 3). Crashes Heighten Busway Concerns. *Los Angeles Times*. https://www.latimes.com/archives/la-xpm-2005-nov-03-me-orange3-story.html

Del Pero, F., Delogu, M., Pierini, M., & Bonaffini, D. (2015). Life Cycle Assessment of a heavy metro train. *Journal of Cleaner Production*, 87, 787–799. https://doi.org/10.1016/j.jclepro.2014.10.023

Doyle, S. (2009, June 23). Canoga Park-Chatsworth Busway Construction Kickoff Wednesday. *Daily News Los Angeles*. https://web.archive.org/web/20110628193224/http://www.dailynews.com/news/ci_12675188

Federal Transit Administration. (n.d.). Metro Gold Line Extension Project Before-and-After Study (2013). *U.S. Department of Transportation*. https://www.transit.dot.gov/sites/fta.dot.gov/files/2013-California-Los-Angeles-Metro-Gold-Line-Extension.pdf

Grigoryants, Olga. (2018). LA's Metro Says Improvements are in the Works for the Orange Line, With Light Rail in Mind. *Los Angeles Daily News.* https://www.dailynews.com/2018/07/16/las-metro-says-improvements-are-in-the-works-for-the-orange-line-with-light-rail-in-mind/

Grimaldi, R., Beria, P., & Laurino A. (2014). A Stylised Cost-Benefit Model for the Choice Between Bus and Light Rail. *Journal of Transport Economics and Policy*, 48(2), 219-239. https://mpra.ub.uni-muenchen.de/24872/

Gqlshare. (2019). Metro gets first electric bus for Orange Line, 39 more on the way. *Daily News*. https://www.dailynews.com/2019/07/25/metro-gets-first-electric-bus-for-orange-line-39-more-on-the-way/

Henry, L. (2010). Energy Efficiency of Light Rail Versus Motor Vehicles. https://trid.trb.org/view/935564

Henry, L., & Litman, T. A. (2022, May 30). Evaluating New Start Transit Program Performance: Comparing Rail and Bus. *Victoria Transport Policy Institute*. https://www.vtpi.org/bus_rail.pdf.

Hoehne, C. G., & Chester, M. (2017). Greenhouse gas and air quality effects of auto first-last mile use with transit. *Transportation Research Part D-transport and Environment*, 53, 306–320. https://doi.org/10.1016/j.trd.2017.04.030

Hymon, S. (2021, August 9). Bus shuttles to replace L Line (Gold) service between Union Station and Pico/Aliso Station during 22-month closure to complete Regional Connector. *The Source*. https://thesource.metro.net/2020/09/15/bus-shuttles-to-replace-l-gold-line-service-between-union-station-and-pico-aliso-stations-during-22-month-closure-to-complete-regional-connector/

Hymon, S. (2017, May 12). New Kinkisharyo rail cars roll on to the Blue Line. *The Source*. https://thesource.metro.net/2017/04/30/new-kinkisharyo-rail-cars-slated-to-roll-on-blue-line-on-monday/

Kinkisharyo. (2023). Los Angeles Technical Data. http://www.kinkisharyo.com/main/wp-content/uploads/2015/08/LACMTA.pdf

Levinson, H. S., Zimmerman, S., Clinger, J., Gast, J., Rutherford, S., & Bruhn, E. (2003). Bus Rapid Transit, Volume 2: Implementation Guidelines. *Transportation Research Board EBooks*. https://doi.org/10.17226/21947.

Lambas, M. E. L., Giuffrida, N., Ignaccolo, M., & Inturri, G. (2017). Comparison Between Bus Rapid Transit And Light-Rail Transit Systems: A Multi-Criteria Decision Analysis Approach. *WIT Press*. https://doi.org/10.2495/ut170131

Los Angeles County Metropolitan Transportation Authority. (2019). FY22 Adopted Budget: July 1, 2018 – June 30, 2019. *LA Metro*.

Los Angeles County Metropolitan Transportation Authority. (2019). 2019 Annual Agency Profile. *LA Metro*. https://www.transit.dot.gov/sites/fta.dot.gov/files/transit_agency_profile_doc/2019/90154.pdf

Los Angeles County Metropolitan Transportation Authority. (2021). 2021 Annual Agency Profile. *LA Metro*. https://www.transit.dot.gov/sites/fta.dot.gov/files/transit_agency_profile_doc/2021/90154.pdf

Los Angeles County Metropolitan Transportation Authority. (2022). FY22 Adopted Budget: July 1, 2021 – June 30, 2022. LA Metro.

Los Angeles County Metropolitan Transportation Authority. (2023, February 23). Metro Facts at a Glance - LA Metro. *LA Metro*. https://www.metro.net/about/facts-glance/

Los Angeles County Metropolitan Transportation Authority. (2023). *Maps and Schedules - LA Metro.* LA Metro. https://www.metro.net/riding/schedules/; Accessed on 05/07/23 at 3:00 pm.

Los Angeles County Metropolitan Transportation Authority. (2023). *Metro System Maps - LA Metro.* LA Metro. https://www.metro.net/riding/guide/system-maps/ ; Accessed on 03/04/23 at 3:38 pm.

LADWP (2021). *2021 Power Content Label.* Los Angeles Department of Water and Power. https://www.ladwp.com/powercontent

Metro. (2023). Interactive Estimated Ridership Stats. *Metro*. http://opa.metro.net/MetroRidership/

Metropolitan Transportation Authority. (2004). 2550 Rail Vehicle Program Memo https://web.archive.org/web/20190610200415/http:/media.metro.net/board/Items/2004/01_January/20040115Item26%20OP.pdf

Moody, M. (2006, September). Orange Line's Second Leg. *Los Angeles Times*. https://web.archive.org/web/20071025194254/http://www.latimes.com/media/graphic/2006-09/25638217.gif

Steer Group. (2015). LRT versus BRT: which is the better option? | *Steer*. https://www.steergroup.com/insights/news/lrt-versus-brt-which-better-option.

National Transit Database Glossary. (2022). *Federal Transit Administration*. https://www.transit.dot.gov/ntd/national-transit-database-ntd-glossary#L.

Nordelöf, A.; Romare, M.; Tivander, J. (2019) Life cycle assessment of city buses powered by electricity, hydrogenated vegetable oil or diesel. *Transp. Res. Part D Transp. Environ*. 2019, 75, 211–222.

Pasadena, C. O. (April 13, 2023). *Commitment to Clean Energy*. Pasadena Water and Power. https://pwp.cityofpasadena.net/pcl/

Puchalsky, C. M. (2005, January 1). Comparison of Emissions from Light Rail Transit and Bus Rapid Transit. *Transportation Research Record*; *SAGE Publishing*. https://doi.org/10.1177/0361198105192700104.

Railway Gazette International. (2023). Hitachi agrees to buy Ansaldo STS and AnsaldoBreda. *Railway Gazette International*. https://www.railwaygazette.com/business/hitachi-agrees-to-buy-ansaldo-sts-and-ansaldobreda/40564.article

Sidek, M. F. J., Bakri, F. A., Hamsa, A. a. K., Othman, N. a. N., Noor, N. H. M., & Ibrahim, M. (2020). Socio-economic and Travel Characteristics of transit users at Transit-oriented Development (TOD) Stations. *Transportation Research Procedia*, 48, 1931–1955. https://doi.org/10.1016/j.trpro.2020.08.225.

Sotero, D. (2021, October 13). Metro Announces Fully Electric Bus Fleet on the G Line (Orange). *The Source*. https://thesource.metro.net/2021/10/13/metro-announces-fully-electric-bus-fleet-on-the-g-line-orange/

Stutsman, J. (2002). Bus Rapid Transit or Light Rail Transit—How to Decide?: Los Angeles Case Study. *Transportation Research Record*. https://doi.org/10.3141/1793-08.

US Department of Transportation. (2016). Revised Departmental Guidance on Valuation of Travel Time in Economic Analysis. *US Department of Transportation*. https://www.transportation.gov/sites/dot.gov/files/docs/2016%20Revised%20Value%20of%20Travel%20Time%20Guidance.pdf

US Department of Transportation. (2023). Electric Vehicle Types. *US Department of Transportation*. https://www.transportation.gov/rural/ev/toolkit/ev-basics/vehicle-types

Zhao, E., May, E., Walker, P., & Surawski, N. C. (2021). Emissions life cycle assessment of charging infrastructures for electric buses. *Sustainable Energy Technologies and Assessments*, *48*, 101605. https://doi.org/10.1016/j.seta.2021.101605

- **Appendix A - Abbreviations**

Abbreviation	**Definition**
BRT	Bus Rapid Transit
BEV	Battery electric Vehicles
CEA	Cost-Effectiveness Analysis
CNG	Compressed Natural Gas

CPI	Consumer Price Index
HEV	Hybrid Electric Vehicles
FCEV	Fuel Cell Electric Vehicles
FY	Fiscal Year
LADWP	Los Angeles Department of Water and Power
LCA	Life-Cycle Assessment
LRT	Light Rail Transit
PM	Passenger Miles
UPT	Unlinked Passenger Trips
VRH	Vehicle Revenue Hours
VRM	Vehicle Revenue Miles

- **Appendix B - Life Cycle Assessment Calculations**

B.1 Vehicle Manufacturing and Maintenance

B.1.1 BRT

In 2021, the LA Metro announced its transition to fully electric bus fleets by New Flyer (XE 60’ model) to achieve zero emission rides. According to the US Department of Transportation (2023), there are four types of electric vehicles: 1) Battery Electric Vehicles (BEVs) which have an electric engine 2) Plug-In Hybrid Electric Vehicles (PHEVs) and 3) Hybrid Electric Vehicles (HEVs) which have both an electric motor and a gasoline engine and 4) Fuel Cell Electric Vehicles (FCEVs) which use hydrogen gas to power an electric motor, which produces electricity to drive the vehicle. A bus consists of various materials. In regard to the battery, bus manufacturers broadly use lithium-ion batteries (LiB) due to their efficiency, longer life spans and thermal stability (Cobalt Institute, 2023).

Due to the limited LCA studies on electric buses, this study is based on data from an LCA by Nordelöf et al., which studied the Volvo 12-meter 7900 series BEV with a lithium-ion battery and a life span of 12 years. An analogy in terms of curb weight is drawn in order to calculate the emissions from manufacturing to end of life of the New Flyer XE60’. According to Nordelöf et al. (2019), the life cycle emissions of an electric bus fleet is approximately 140 tn CO_2 eq/vehicle for a 12-meter-long Volvo (Figure B1) with a curb weight of 19,500 kg, therefore the CO_2 manufacturing emissions for the NewFlyer fleet are 173 tn CO_2 eq/vehicle. The Orange Line has employed a total of 40 buses; therefore, the total emissions from manufacturing are 6,920 tn CO_2 eq.

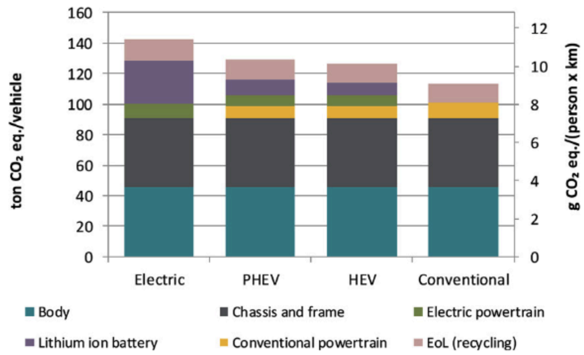


Figure B1: Vehicle life cycle results and contribution to climate change impacts from different parts of the bus (equipment only, i.e. bus operation and WTW life cycle of fuels and electricity for charging are excluded) (Nordelöf et al., 2019)

Table B1: Comparison table of specifications for a New Flyer XE60 and a Volvo 7900

Specifications	New Flyer XE	Volvo 7900
Length	60 feet (18.7 m)	40 feet (12 m)
Capacity	118 passengers (50 seats and 68 standees)	95 passengers
Curb weight	Approx. 53,112 lbs	19,500 kg (42,990 lbs)
Battery Pack	320 kW/hr	320 kW/hr
Range of miles	152 miles	124 miles

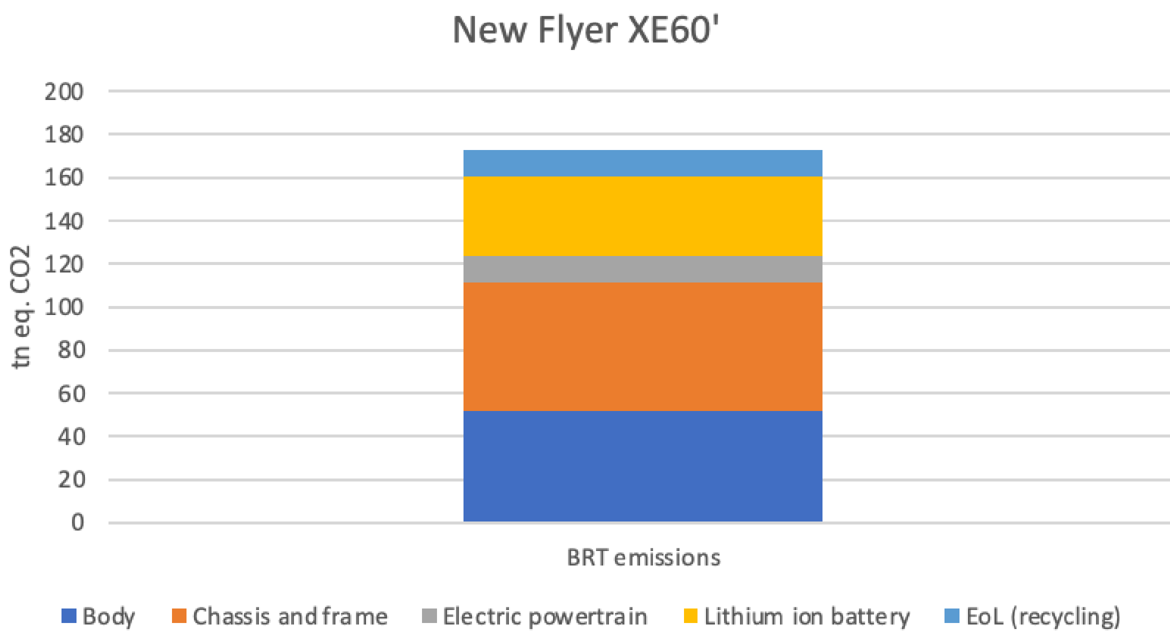


Figure B2: New Flyer Bus Annual Carbon Emissions

B.1.2 LRT

The LRT system of this analysis, the LA Metro L Line, was opened in 2003 and was formerly known as the Gold Line. It is about 31 miles long and contains 26 stations. (Los Angeles County Metropolitan Transportation Authority, 2023).

The Gold Line is currently undergoing a major renovation for the anticipated opening of the Regional Connector tunnel. One of the middle stations, the Little Tokyo/Arts District station is closed, which severs the Gold Line into two lines. In fact, the Gold Line will cease to exist following the opening of the Regional Connector tunnel (Hymon, 2021). However, for the purposes of this analysis, we will assume the Gold Line as being fully functional and connected - the Gold Line is simply a placeholder for a LRT system that can adequately compare to the Orange Line BRT system, similar to how the Orange Line is a placeholder for a BRT system that can adequately compare to the Gold Line LRT system.

The Gold Line employs two rail car models: the AnsaldoBreda P2550 and the Kinkisharyo P3010 (Metropolitan Transportation Authority, 2004 and Hymon, 2017). The exact number of rail cars for each model is hard to pinpoint due to the Gold Line sharing rail cars with other LRT lines. The original AnsaldoBreda contract was for 50 cars between two lines, so this is divided to obtain about 25 cars for the Gold Line (Metropolitan Transportation Authority, 2004). Additionally, the original Kinkisharyo contract was for 235 rail cars for five lines, so this is divided and rounded to obtain about 50 cars for the Gold Line (Hoehne et al., 2017). Overall, there should be about 75 cars in operation on the Gold Line. Each car has around a 30 year lifespan according to previous studies on this topic (Del Pero et al., 2015).

The P2550 train car models of the Italian branch of Hitachi Rail, formerly AnsaldoBreda, are 54-tonne six-axle vehicles with steel structures (Railway Gazette International, 2023 and Chester et al., 2012). Typically, the Manufacturing & Maintenance phase encompasses the raw material extraction and production, manufacturing and assembly, and transportation from the manufacturer to the use site (Del Pero et al., 2015). Since they are manufactured in Italy, this transportation aspect factors in greenhouse gas emissions that result from an ocean shipment of 10,000 miles, according to Google Maps.

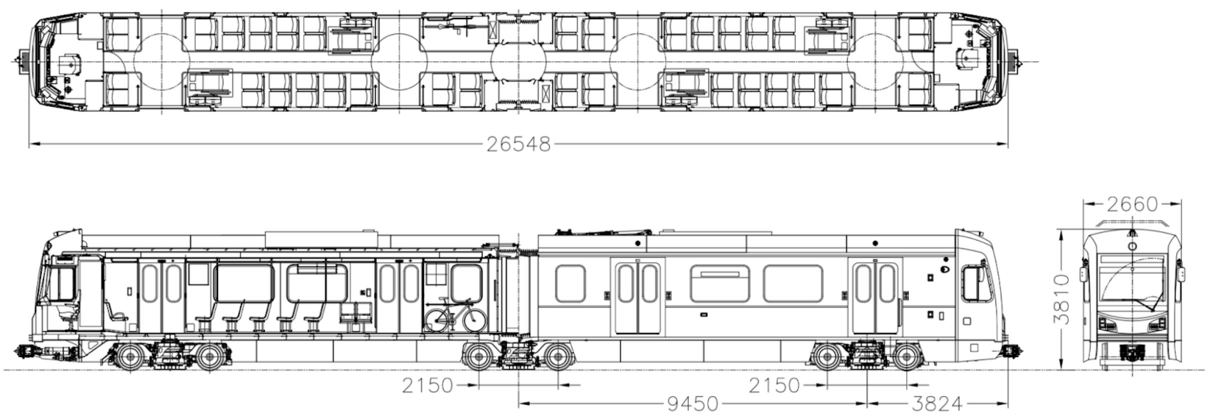


Figure B3: Schematic of the Kinkisharyo P3010 Train Car (Kinkisharyo, 2023)

Similarly, the P3010 train car models of Kinkisharyo International are 45-tonne six-axle vehicles with steel structures (Kinkisharyo, 2023). Much of the Manufacturing & Maintenance phase should be comparable to the P2550, except that they are manufactured in Japan and should be shipped about 5,500 miles, according to Google Maps.

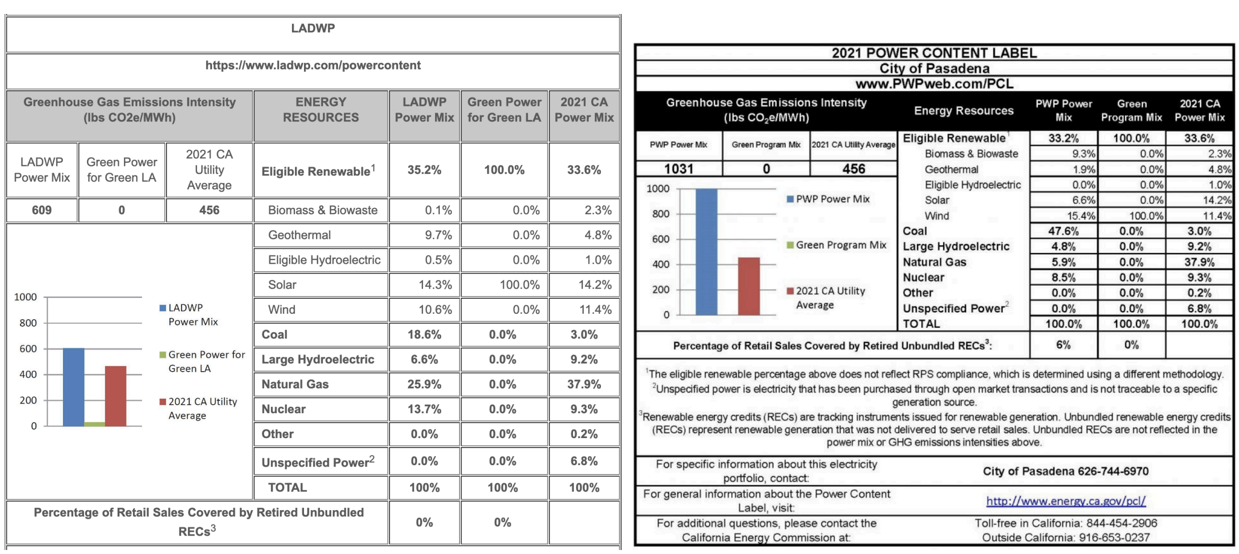
Manufacturing will overall produce about 1.3 g CO_2 eq per PMT (Boarnet et al., 2016). Since the Gold Line traveled 43 million PMT in 2022, manufacturing produces 55.9 tn CO_2 eq per year. With a 1:2 numerical split between the AnsaldoBreda train cars and the Kinkisharyo train cars, that means there are 18.6 tn CO_2 eq per year associated with the AnsaldoBreda cars and 37.3 tn CO_2 eq per year associated with the Kinkisharyo cars.

Vehicle maintenance involves the repairing, refurbishing, and replacing of these LRT train cars. Considering the context of the system in question, maintenance is critically important and will be continuously monitored; for example, the train cars will be cleaned every day. The greenhouse gas emissions associated with the vehicle maintenance phase result in about 1 g CO_2 eq per PMT (Chester et al., 2012). With 43 million PMT in 2022, that means this phase contributes to 43 tn CO_2 eq per year. With a 1:2 numerical split between the AnsaldoBreda train cars and the Kinkisharyo train cars, that means there are 14.3 tn CO_2 eq per year associated with the AnsaldoBreda cars and 28.7 tn CO_2 eq per year associated with the Kinkisharyo cars.

B.2 Operations

B.2.1 Electricity Mix

First, the greenhouse gas emissions associated with the electricity mix in California had to be determined. This information is provided by the main gas & electricity company. In Los Angeles, the main provider is Los Angeles Department of Water and Power (LADWP) for the operation of the rail system and electric buses. However, the City of Pasadena supplies a small amount to the Gold LRT system and has its own electricity mix. To take into account the different electric supplies and calculate the electricity mix used for the BRT and LRT, we assume an "80-20" allocation giving more weight to the LADWP mix. The respective mixes and results are presented in Table B2.



LADWP

https://www.ladwp.com/powercontent

Greenhouse Gas Emissions Intensity (lbs CO2e/MWh)			ENERGY RESOURCES	LADWP Power Mix	Green Power for Green LA	2021 CA Power Mix
LADWP Power Mix	Green Power for Green LA	2021 CA Utility Average	Eligible Renewable[1]	35.2%	100.0%	33.6%
609	0	456	Biomass & Biowaste	0.1%	0.0%	2.3%
			Geothermal	9.7%	0.0%	4.8%
			Eligible Hydroelectric	0.5%	0.0%	1.0%
			Solar	14.3%	100.0%	14.2%
			Wind	10.6%	0.0%	11.4%
			Coal	18.6%	0.0%	3.0%
			Large Hydroelectric	6.6%	0.0%	9.2%
			Natural Gas	25.9%	0.0%	37.9%
			Nuclear	13.7%	0.0%	9.3%
			Other	0.0%	0.0%	0.2%
			Unspecified Power[2]	0.0%	0.0%	6.8%
			TOTAL	100%	100%	100%
Percentage of Retail Sales Covered by Retired Unbundled RECs[3]				0%	0%	

2021 POWER CONTENT LABEL
City of Pasadena
www.PWPweb.com/PCL

Greenhouse Gas Emissions Intensity (lbs CO_2e/MWh)			Energy Resources	PWP Power Mix	Green Program Mix	2021 CA Power Mix
PWP Power Mix	Green Program Mix	2021 CA Utility Average	Eligible Renewable[1]	33.2%	100.0%	33.6%
1031	0	456	Biomass & Biowaste	9.3%	0.0%	2.3%
			Geothermal	1.9%	0.0%	4.8%
			Eligible Hydroelectric	0.0%	0.0%	1.0%
			Solar	6.6%	0.0%	14.2%
			Wind	15.4%	100.0%	11.4%
			Coal	47.6%	0.0%	3.0%
			Large Hydroelectric	4.8%	0.0%	9.2%
			Natural Gas	5.9%	0.0%	37.9%
			Nuclear	8.5%	0.0%	9.3%
			Other	0.0%	0.0%	0.2%
			Unspecified Power[2]	0.0%	0.0%	6.8%
			TOTAL	100.0%	100.0%	100.0%
Percentage of Retail Sales Covered by Retired Unbundled RECs[3]:				6%	0%	

[1]The eligible renewable percentage above does not reflect RPS compliance, which is determined using a different methodology.
[2]Unspecified power is electricity that has been purchased through open market transactions and is not traceable to a specific generation source.
[3]Renewable energy credits (RECs) are tracking instruments issued for renewable generation. Unbundled renewable energy credits (RECs) represent renewable generation that was not delivered to serve retail sales. Unbundled RECs are not reflected in the power mix or GHG emissions intensities above.

For specific information about this electricity portfolio, contact:	City of Pasadena 626-744-6970
For general information about the Power Content Label, visit:	http://www.energy.ca.gov/pcl/
For additional questions, please contact the California Energy Commission at:	Toll-free in California: 844-454-2906 Outside California: 916-653-0237

Figure B4: (a) Los Angeles Electricity Mix (LADWP, 2021) and (b) City of Pasadena Electricity Mix (Pasadena, 2023)

Table B2: Regional Electricity Mix and Total Emissions (g CO_2 eq /kWh) Attributed to Electricity Production

Energy Source	**LCA Emission Factors for Electricity Generation** (g CO_2 eq /kWh)	**LADWP Electricity Mix** (2021)	**City of Pasadena Electricity Mix** (2021)	**"80-20" Mix**	**"80-20" Mix Emissions** (g CO_2 eq/kWh)
Coal	1029	18.6%	47.6%	24.40%	251.1
Natural Gas	696	25.90%	5.9%	21.90%	152.42
Oil	957	0.00%	0.00%	0.00%	0.00
Nuclear	17	13.70%	8.5%	12.66%	2.15
Hydro	55	7.1%	4.8%	6.64%	3.65
Biomass	56	0.1%	9.3%	1.94%	1.10
Solar PV	64	14.30%	6.6%	12.76%	8.16
Wind	31	10.60%	15.4%	11.56%	3.58
Geothermal	28	9.70%	1.9%	8.14%	2.28
Total Emissions from electricity (g CO_2 eq /kWh)		**424.44**			

B.2.2 BRT

The total greenhouse gas emissions in terms of CO_2, produced by driving an electric bus fleet, are the product of the electricity emissions (g CO_2 eq /kWh) and the total kWh required for driving the 18-mile line at a 24/7 basis. According to the bus schedule, 490 routes depart for the North Hollywood Station from Monday to Friday and 158 routes on weekends, therefore a total of 1,296 routes of 18 miles every week considering these routes are round-trips. It is assumed that each bus travels the same distance each weekday. A total of 23,328 miles are driven per week, or 3,332 miles per day, or 1,216,180 miles on a year-basis. A New Flyer XE60 consumes 1.84 kWh/mile and requires a total of 2,237,770 kWh for one year of driving. By multiplying the total emissions factor with the total kWh required, it is calculated that the total emissions from operations are 949.7 tn CO_2 eq.

B.2.3 LRT

The Operations of the LRT system will produce greenhouse gas emissions from the electrical propulsion that allows the train cars to move forward (Chester M. et al., 2012).

Based on the electricity mix as determined in Section B.2.1, the electricity production of the area is about 424.44 g CO_2 eq/kWh. Light rail cars use about 3,700 BTU/passenger-mile (Henry, 2010). With an amount of 43 million PMT in 2022 and a conversion factor of 0.000293 kWh/BTU, that means the Gold Line consumed 46,616,300 kWh across the year, or 19,786 tn CO_2 eq for its Operations stage.

B.3 Infrastructure

B.3.1 Stations and Rails

Station and rail/roadway data was taken from ASU's 2017 analysis (Chester 2017). Due to the complexities of accounting for each individual station, total emissions values were averaged over the number of stations to create a station-by-station comparison. Two changes were made to the existing data. To achieve the desired per-PMT unit, 2010 values were multiplied by 2010 PMT and then re-calculated using 2022 PMT. One item to note is the addition of 4 stations in 2012 which are not included in the 2010 values bringing the total from 14 to 18 or an increase of 29%. Thus all 2010 values are scaled up by 29%. The following categories were considered for infrastructure components:

- *Construction* – Material installation including extraction, transport and fabrication.
- *Operation* – Daily functionalities including lighting, signage, and mobility devices.
- *Maintenance* – General upkeep activities including inspections, cleanings, and minor fixes.
- *Parking* – Associated parking facilities for riders.

To create the most accurate present-day comparison possible, variable quantities such as operation and maintenance were evaluated on a MJ/PMT basis. We assumed energy usage would remain relatively constant from year to year so we recalculated g CO_2 eq using the present-day electricity mix. Fixed values such as construction and parking were kept as their original g CO_2 eq values.

For the Orange Line, most stations consist of concrete platforms beside existing roadway. For these, the volumes and quantities of concrete and steel were considered. The length of the line includes a 24-foot by 12-inch sub base. The roadways are excluded due to their prior existence for automobile use.

Table B3: Metro Infrastructure Energy Conversion Factors

	Orange (2022)	Gold (2022)	Per Station Difference (G - O)
Operation (MJ/PMT)	0.1338	0.4299	0.006
Maintenance (MJ/PMT)	0.0000	0.2758	0.009

Construction (gCO_2e/PMT)	0.1161	0.1525	-0.002
Operation (gCO_2e/PMT)	15.7757	50.6857	0.759
Maintenance (gCO_2e/PMT)	0.0000	32.5154	1.049
Parking (gCO_2e/PMT)	0.0295	0.0487	0.000

B.3.2 Chargers

For the electric-bus fleets, installation of rapid chargers is essential. The Metro has installed rapid en-route chargers at North Hollywood, Canoga, and Chatsworth Stations, which offer a 24/7 operating capability to the buses serving the 18-mile Orange Line.

The chargers in use are the Siemens pantograph chargers (ZEBGO Partners, 2021) with:

- Two (2) chargers at Canoga station (450-600 kW)
- Four (4) chargers at North Hollywood Station (450 kW)
- Two (2) chargers at Chatsworth Station (450-600 kW)

The charging process is initiated when the bus arrives via wi-fi and starts automatically when the driver activates the hand brake allowing the buses to charge in regular stops for four to six minutes.

The emissions for the charging infrastructure are based on a 2021 study conducted by Zhao et al. for the charging infrastructure into existing bus depots in Australia. Studies in the area of emissions produced by chargers manufacturing are limited and for this reason this study serves as a basis for our results.

The charger analyzed is a Tritium BEV charging station with an output power up to 350 kW which weighs 260 kg. According to this study, the total emissions are 690 tn CO_2 eq and include the production phase of transportation of the finished product to the loading site, the power consumption during installation, operations, and end-of-life (recycling and disposal). Because the operations of the charging infrastructure are calculated above, the total emissions are 7.7 tn CO_2 eq per charger, taking into account only the emissions for the production, transportation, installation and end-of-life phases (Figure B5).

A Siemens pantograph charger is composed of two parts: a cabinet and a mast and a 400kW charger weighing 3,000 kgs. The cabinet comes with “an isolation transformer, AC-DC converter, charger controls, communications, as well as incoming and outgoing connection panels” (Siemens, 2023) and the mast is the main part that charges the bus and gets supplied by the high-power cabinet. To simplify the life cycle assessment, it is assumed that the same type of charging station is installed in all bus stations and the Siemens charger can be compared to the Tritium charger. This simplification is attributed to the fact that Siemens does not provide a detailed LCA for their product and the studies in this area are limited. A detailed examination of the emissions attributed to the manufacturing, transportation to the site, and end-of-life of the chargers are out of this scope of this project. For this reason, the calculations are simplified, and for the Siemens pantograph charger, we proportionally allocate the emission from the Tritium BEV charging station, which results in 88.8 tn CO_2 eq per charger and a total of 710.4 tn CO_2 eq for all chargers in the Orange Line.

	$kgCO_2$	$kgCH_4$	kgN_2O	$kgCO_2e$	% of Total Emissions
Production	4,460.6	9.1	0.1	4,737.6	0.69%
Transportation	71.0	0.0	0.0	71.0	0.01%
Installation	86.3	0.0	0.0	86.3	0.01%
Operations	682,344.0	0.0	0.0	682,344.0	98.8%
Recycling & Disposal	3,094.1	7.1	0.1	3,310.7	0.48%
Total Emissions (kg)	690,056.0	16.3	0.1	690,549.6	100%

Figure B5: Life-Cycle GHG Emissions Results for One Charging Station (Zhao et al., 2021)

B.4 End-of-Life

B.4.1 BRT

For the electric vehicle bus fleets, the end-of-life emissions are already calculated and included in the vehicle's total emissions and account for 7% of the total vehicle's emissions (12.35 tn CO_2 eq). The emissions for the end-of-life phase accounts for the total energy required for disassembling and separating all parts of the electric fleet and the preparation of materials for recycling (Nordelöf et. al., 2019).

B.4.2 LRT

End-of-life for train cars normally encompasses the production of energy for disassembly, shredding, material recovery, and incineration (DelPero et. al, 2015). However, it is worth noting that up to 92% of material in the train car models can be recycled, as much of it is steel (DelPero et. al, 2015). Because of this, and because LA Metro would likely want to recycle their train cars, it is assumed that the end-of-life phase of the LRT system is recycling; thus, the greenhouse gas emissions associated with this phase are negligible.

B.5 Sensitivity Analysis

B.5.1 Electricity Mix

The operational phase of each system significantly impacts the amount of emissions produced. To assess this impact, a sensitivity analysis was conducted with an "80-20" allocation method using the electricity mixes of the City of Pasadena and Los Angeles. The analysis considered the scenario where 100% renewable energy was used during the operational phase, resulting in zero carbon emissions associated with this phase. A new electricity mix was calculated by incorporating the weight of renewable resources, such as nuclear, hydro, solar, biomass, wind, and geothermal energy, and re-allocating them in the "new" electricity mix. To ensure consistency with the LADWP mix, an "80-20" allocation method was applied again. The resulting "green" electricity mix is presented in Table B4.

Table B4: "Green" Electricity Mix and Total Emissions (g CO_2 eq /kWh) Attributed to Electricity Production

Energy Source	**LCA Emission Factors for Electricity Generation** (g CO_2 eq /kWh)	**LADWP Electricity Mix**	**City of Pasadena Electricity Mix**	**"80-20" Mix**	**"80-20" Mix Emissions** (g CO_2 eq/kWh)
Coal	1029.00	0%	0%	0%	0.00
Natural Gas	696.00	0%	0%	0%	0.00
Oil	957.00	0%	0%	0%	0.00
Nuclear	17.00	25%	18%	23%	3.98

Hydro	55.00	13%	10%	12%	6.76
Biomass	56.00	0%	20%	4%	2.32
Solar PV	64.00	26%	14%	23%	15.01
Wind	31.00	19%	33%	22%	6.79
Geothermal	28.00	17%	4%	15%	4.14
Total Emissions from electricity (g CO_2 eq/kWh)		**39**			

By multiplying the total emissions factor with the total kWh required, it is calculated that the total emissions from operations are 67.1 tn CO_2 eq/yr for the BRT system while for the LRT system are 1,398 tn CO_2 eq/yr. The emissions results decreased by 92%, suggesting that if operational energy use was “clean”, a significant increase in operational emissions can be achieved. The comparison results are shown in Figure B6.

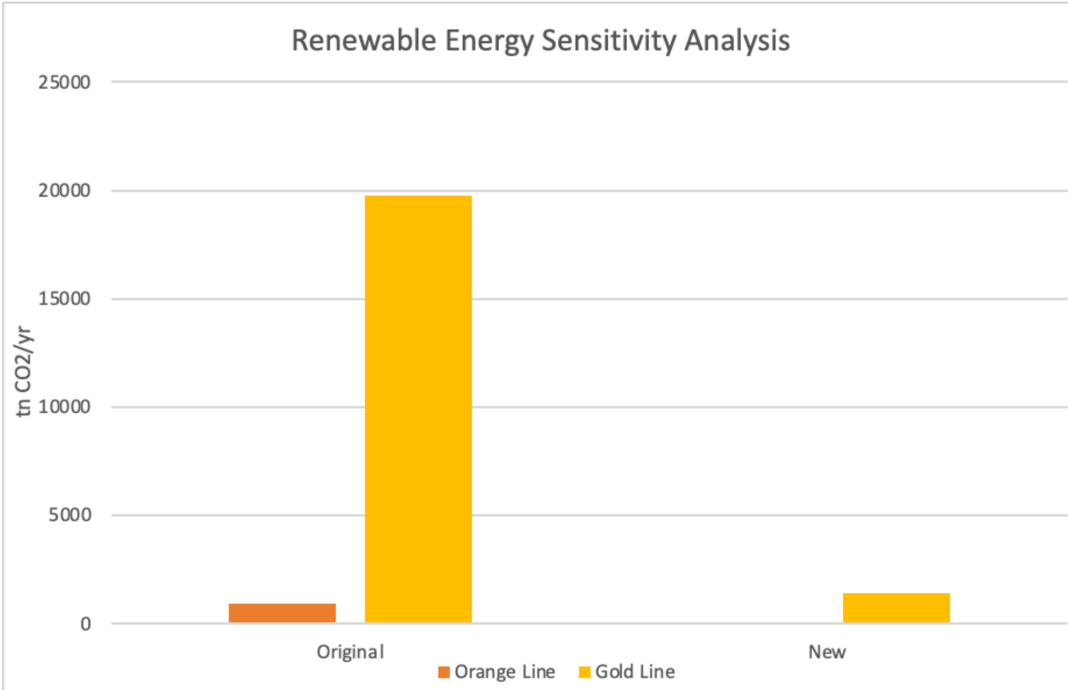


Figure B6: Comparison of the emissions produced by both systems during the operations phase with the "original" and the "new" electricity mix.

B.5.2 Pre- vs. Post-Pandemic Ridership

Another sensitivity analysis was conducted to evaluate the impact of decreased ridership on the Global Warming Potential of the system. First, the ridership difference must be explained through numbers obtained from LA Metro. Table B5 shows the ridership between 2019 (pre-pandemic) and 2022 (post-pandemic).

Table B5: Ridership and PMT of Gold Line and Orange Line, 2019 vs 2022

	Orange	Gold
Ridership (2019)	6,700,000.00	15,100,000.00
Ridership (2022)	4,162,000.00	5,907,000.00
% Change Ridership	**-37.88059701**	**-60.8807947**
PMT (2019)	43,700,000.00	132,456,000.00
PMT (2022)	25,363,000.00	42,800,000.00
% Change PMT	**-41.9610984**	**-67.6873829**

As seen in Table B5, the pandemic has been devastating on ridership, especially for the LRT, with around 40% decrease and 60% decrease in both total ridership and PMT for the Orange and Gold Lines, respectively.

Using the same percent change to calculate overall carbon emissions, Figure B7 was created. These new numbers are the carbon emissions for 2019 ridership in tn CO_2 eq. While an increase in PMT does not affect all aspects of BRT and LRT, it would still increase overall emissions by 31%, as seen in Figure B7. The manufacturing, maintenance, end of life, and infrastructure aspects of the BRT decreased by 42% when transitioning from 2019 to 2022, and the same aspects of the LRT decreased by 68%. These reflect the numbers in Table B5. Therefore, while the decrease in PMT may not be financially beneficial, it was environmentally beneficial.

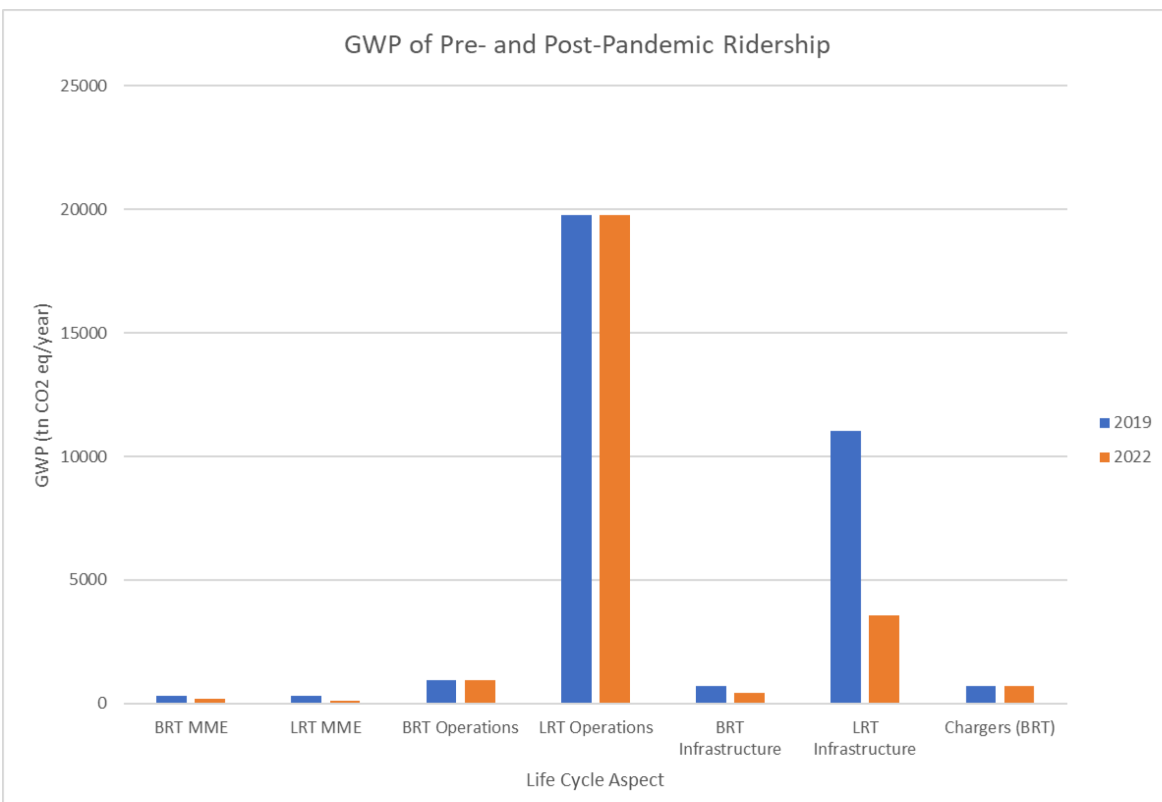


Figure B7: Comparison of the emissions produced by all life cycle stages with 2019 and 2022 Ridership Numbers

B.6 PMT Conversion

The following contain figures and data visualizations related to the ridership and conversion to per PMT units. Table B6 shows the average miles traveled per passenger for 2022, using PMT numbers found in Table B5.

Table B6: Miles traveled per passenger, Orange Line vs Gold Line

	Orange	Gold
Miles traveled per pass (Avg)	6.308166639	8.008780647

To obtain g CO_2 eq/PMT, total tn CO_2 eq for each component was divided by PMT and converted to grams. Table B7 illustrates the breakdown by component with operations accounting for the most emissions on both lines.

Table B7: gCO_2 eq/PMT by sector, Orange Line vs Gold Line

	gCO2e/PMT (2022)	
	Orange	Gold
Vehicle Mfg., Maint., EoL	22.71	2.03
Operations	36.90	462.10
Infrastructure	14.19	81.12
Charger	2.77	--
Total	**76.58**	**545.25**

- **Appendix C - Cost Effectiveness Analysis Calculations**

C.1 Capital Cost Calculations

Orange (G) Line:

- Original Construction (2005): $323.6 million in 2005 dollars
  - 487.87 million in 2022 dollars
- 14th station construction (2006): $26 million in 2006 dollars
  - 37.70 million in 2022 dollars
- Extension from Canoga to Chatsworth (4 mile): $215.6 million in 2012 dollars
  - 273.47 million in 2022 dollars
- Bus Electrification Project: $80 million in 2021 dollars
  - Includes $1.15 million per bus (40 buses)
  - 87.93 million in 2022 dollars
- Orange Line Improvements: 36,791.9 thousand through FY 21, 12196.6 thousand in FY 22
  - 40.44 + 12.20 = 52.64 million in 2022 dollars
- Orange Line Reclaimed Water Project: 183.6 thousand through FY 21, 176.4 thousand in FY 22, 400 thousand over life of project (LOP)
  - 201.79 thousand + 176.4 thousand = 378.19 thousand = 0.38 million
- Orange Line In-Road Warning Lights: 165.8 thousand dollars through FY 21, 33 thousand in FY 22, 198.4 thousand over LOP
  - 182.23 thousand + 33 thousand = 215.23 thousand = 0.22 million

Gold (L) Line:

- Original Construction (2003): $859 million in 2003 dollars

- Eastside Extension (2009): $899.1 million YOE in 2009 dollars
- Azusa Extension (2016):
    - Gold Foothill Extension 2A to Azusa: 918,436 thousand through FY 21, 3503.3 thousand in FY 22, 923,550.2 thousand over LOP
        - 1,009.45 million + 3.50 million = 1,012.95 million
    - Gold Foothill Extension 2B: 490,300.8 thousand through FY 21, 182,055.2 thousand in FY 22, 1,406,870.8 thousand over LOP
        - 538.89 million + 182.06 million = 720.95
- Operating Capital for Gold (State of Good Repair): 12970.9 in thousands of dollars
- Green/Gold Line TPSS Battery Replacement: 87.6 thousand through FY 21, 515 thousand in FY 22, 1871.5 over LOP
    - 96.28 thousand + 515 thousand = 611.28 thousand = 0.61 million
- Blue/Gold Line Train Control Battery Replacement: 402.6 thousand through FY 21, 307.8 thousand in FY 22, 1685.5 thousand over LOP
    - 442.5+307.8 = 750.3 thousand = 0.75 million

Additional Passenger Miles and Trips Calculation

- Passenger Miles:
    - $4,280,000,000 / ($940,210,000 / 23,321,189 pax-mi) - 42,561,270 pax-mi = 63,600,852 pax-mi
- Passenger Trips:
    - $4,280,000,000 / ($940,210,000 / 3,838,674 trips) - 5,879,594 trips = 11,594,719 trips

C.2 Operating Cost Calculations

Average Operating Cost Calculations (FY 22):

Orange Line:

- Vehicle Revenue Miles (VRM):
  - $1,472,736\ VRM \cdot 26.19\ \$/VRM = \$38,570,955.84$
- Vehicle Revenue Hours (VRH):
  - $104,921\ VRH \cdot 399.60\ \$/VRH = \$41,926,431.6$
- Passenger Miles (PM):
  - $23,321,189\ PM \cdot 1.91\ \$/PM = \$44,543,470.99$
- Unlinked Passenger Trips (UPT):
  - $3,838,674\ UPT \cdot 11.16\ \$/UPT = \$42,839,601.84$
- Average Calculation:
  - $(38,570,955.84 + 41,926,431.6 + 44,543,470.99 + 42,839,601.84)/4$
    $= \$41,970,115$
- Adjusting for Inflation:
  - $\$41,970,115 \cdot 1.075 = \$45,110,000\ in\ 2022\ dollars$

Gold Line:

- Vehicle Revenue Miles (VRM):
  - $5,492,069\ VRM \cdot 31.71\ \$/VRM = \$174,153,507.99$
- Vehicle Revenue Hours (VRH):
  - $241,818\ VRH \cdot 663.94\ \$/VRH = \$160,552,642.92$
- Passenger Miles (PM):

  - $42,561,270\ PM\ \cdot 2.61\ \$/PM = \$111,084,914.7$
- Unlinked Passenger Trips (UPT):
  - $5,879,594\ UPT\ \cdot 17.22\ \$/UPT = \$101,246,608.68$
- Average Calculation:
  - $(174,153,507.99 + 160,552,642.92 + 111,084,914.7 + 101,246,608.68)/4 = \$136,759,419$
- Adjusting for Inflation:
  - $\$136,759,419 \cdot 1.075 = \$146,990,000\ in\ 2022\ dollars$

Additional Passenger Miles and Trips Calculation

- Passenger Miles:
  - $146,990,000 / ($45,110,000 / 23,321,189 pax-mi) - 42,561,270 pax-mi = 33,430,341 pax-mi
- Passenger Trips:
  - $146,990,000 / ($45,110,000 / 3,838,674 trips) - 5,879,594 trips = 6,628,645 trips

Average Operating Cost Calculations (FY 19):

Orange Line:

- Vehicle Revenue Miles (VRM):
  - $1,699,964\ VRM\ \cdot 14.93\ \$/VRM = \$25,380,462.52$
- Vehicle Revenue Hours (VRH):
  - $121,426\ VRH\ \cdot 231.80\ \$/VRH = \$28,146,546.8$
- Passenger Miles (PM):
  - $45,206,002\ PM\ \cdot 0.57\ \$/PM = \$25,767,421.14$

- Unlinked Passenger Trips (UPT):
  - $6,860,145\ UPT \cdot 3.74\ \$/UPT = \$25,656,942.3$
- Average Calculation:
  - $(25,380,462.52 + 28,146,546.8 + 25,767,421.14 + 25,656,942.3)/4$

    $= \$26,237,843.19$
- Adjusting for Inflation:
  - $\$26,237,843.19 \cdot 1.117 = \$29,310,000\ in\ 2022\ dollars$

Gold Line:

- Vehicle Revenue Miles (VRM):
  - $6,392,123\ VRM \cdot 25.14\ \$/VRM = \$160,697,972.22$
- Vehicle Revenue Hours (VRH):
  - $275,108\ VRH \cdot 515.13\ \$/VRH = \$141,716,384.04$
- Passenger Miles (PM):
  - $140,755,311\ PM \cdot 0.96\ \$/PM = \$135,125,098.56$
- Unlinked Passenger Trips (UPT):
  - $16,035,517\ UPT \cdot 7.48\ \$/UPT = \$119,945,667.16$
- Average Calculation:
  - $(160,697,972.22 + 141,716,384.04 + 135,125,098.56$

    $+ 119,945,667.16)/4 = \$139,371,280.50$
- Adjusting for Inflation:
  - $\$139,371,280.50 \cdot 1.117 = \$155,670,000\ in\ 2022\ dollars$

Additional Passenger Miles and Trips Calculation

- Passenger Miles:

    - $155,670,000 / ($29,310,000 / 45,206,002 pax-mi) - 140,755,311 pax-mi = 99,340,845 pax-mi
- Passenger Trips:
    - $155,670,000 / ($29,310,000 / 6,860,145 trips) - 16,035,517 trips = 20,399,787 trips

- **Appendix D - A Poem**

Light rail glides like a swan,
Efficient, fast, and sleek,
Swiftly carrying passengers
With hardly a single squeak.

Its steel tracks gleam in the sun,
As it speeds through city streets,
A modern marvel of engineering,
A solution that can't be beat.

Bus transit, though, has its own charm,
A humble and versatile friend,
Navigating through bustling crowds,
With flexibility to bend.

Its rubber wheels may seem less grand,
But they can go just about anywhere,
And with their honking horns and roaring engines,
Buses brave the city's hustle and snare.

Both offer unique benefits,
To help move people from place to place,
And in the end, the choice is ours,
To decide which to embrace.

For some, light rail may be the best,
With its swift and steady ride,
While others may prefer the bus,
For its flexibility and pride.

So let us celebrate these modes of transport,
For the ways they move us to and fro,
And remember that each has its own strengths,
And each has its own flow.

~ ChatGPT, 2023