Los Angeles County
Metropolitan Transportation Authority

Greenhouse Gas Emissions Cost Effectiveness Study

Metro

Acknowledgement

This document was prepared by ICF International under contract through Metro's Sustainability Program administered by Metro's Environmental Compliance and Services Department. Technical input was provided by staff in the following Metro departments: Systems Engineering, Rail Vehicle Engineering, Metro Support Services Center, Vehicle Technology & Support, Rail Operations-Wayside Systems Engineering, Community Relations, Central Maintenance, Customer Communications, New Business Development, Standards & Employee Programs, Long Range Planning, and the Westside Area Team.

blank
page

Table of Contents

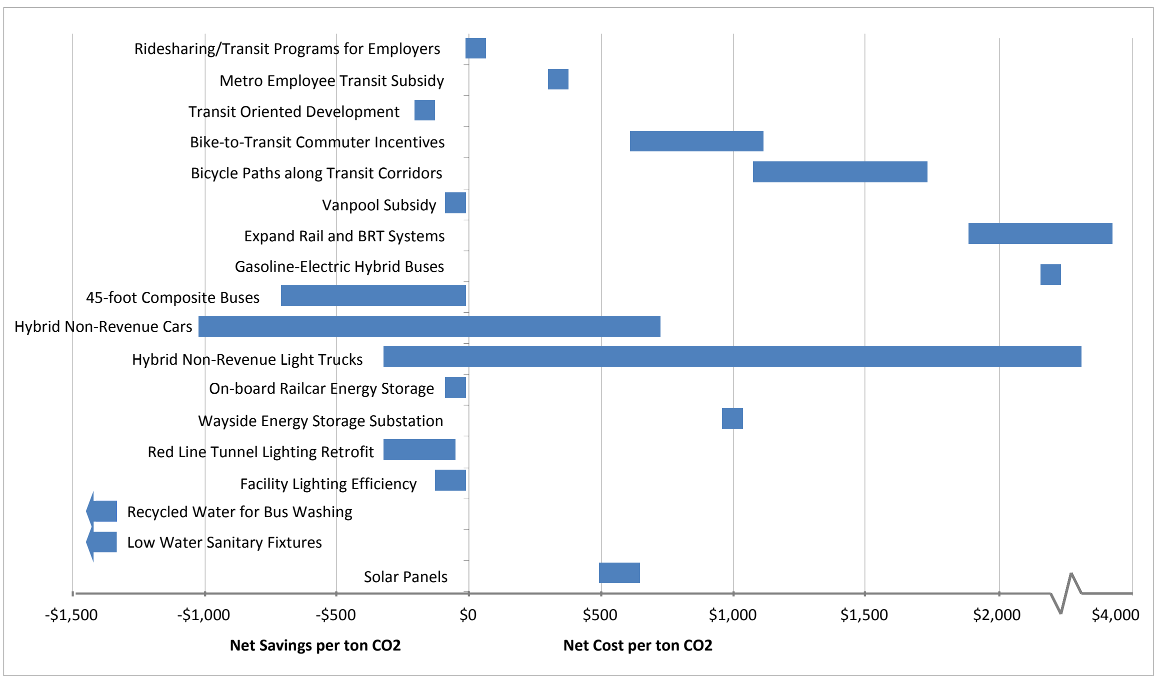
blank page

Executive Summary

As a leader in environmental responsibility, the Los Angeles County Metropolitan Transportation Authority (Metro) is pursuing a variety of sustainability strategies to maximize transportation efficiency, access, safety, and performance while minimizing energy use, consumption, pollution, and the generation of waste. This report evaluates current and potential future Metro sustainability strategies for their costs and impacts on greenhouse gas emissions. Strategies include those focused on Metro's vehicle fleet, buildings, and opportunities to reduce vehicle miles traveled (VMT).

The figure below shows the greenhouse gas reduction cost effectiveness of the strategies that could be quantified. For some strategies, the results are sensitive to a single parameter with a high degree of uncertainty; for these strategies, cost effectiveness is shown as a range (long bar).

Summary of Greenhouse Gas Reduction Cost Effectiveness by Strategy



The figure shows that a variety of strategies can potentially reduce greenhouse gas emissions for Metro at low cost or a net savings. The most cost effective strategies appear to be:

- Ridesharing/transit programs for employers
- Transit oriented development
- Vanpool subsidy
- 45-foot composite buses
- Hybrid non-revenue cars
- On-board railcar energy storage

- Red Line tunnel lighting retrofits
- Facility lighting efficiency
- Recycled water for bus washing
- Low water sanitary fixtures

Note that the cost effectiveness metric provides no information on the magnitude of the greenhouse gas (GHG) reduction. Some cost effective strategies produce emission reductions that are several orders of magnitude larger than others. The table below groups the strategies according to cost effectiveness and maximum emission reduction potential. From a greenhouse gas reduction perspective, the most desirable strategies are those that achieve a net savings and offer large emission reductions.

Summary of Greenhouse Gas Reduction Cost Effectiveness and Maximum Annual Emission Reduction

	Cost Savings/ Cost Neutral	Moderate Cost ($300 - $900 per ton)	High Cost (> $1,000 per ton)
Large GHG Benefit (> 10,000 MtCO2e/year)	• Ridesharing/Transit Programs for Employers • Transit Oriented Development • Vanpool Subsidy • On-board Railcar Energy Storage		• Expand Rail and BRT Systems • Wayside Energy Storage Substation
Moderate GHG Benefit (1,000-10,000 MtCO2e/year)	• 45-foot Composite Buses • Facility Lighting Efficiency	• Metro Employee Transit Subsidy	• Bicycle Paths along Transit Corridors • Gasoline-Electric Hybrid Buses
Small GHG Benefit (< 1,000 MtCO2e/year)	• Red Line Tunnel Lighting Retrofit • Hybrid Non-Revenue Cars • Recycled Water for Bus Washing • Low Water Sanitary Fixtures	• Solar Panels • Bike-to-Transit Commuter Incentives	• Hybrid Non-Revenue Light Trucks

This study considered a number of additional strategies, but did not quantify their emission reduction cost effectiveness due to a lack of data to reliably estimate strategy costs or emissions impacts. These strategies include subway tunnel wind energy capture, battery upgrades in CNG buses, battery electric buses, and buses powered by a hydrogen/CNG blend.

The results presented in this report can help inform Metro’s decisions about future investment in sustainability strategies. As the state of California, and potentially the nation, seeks to achieve greenhouse gas reduction targets, public agencies like Metro will be expected to develop and implement new emission reduction strategies. Moreover, if the U.S. develops a robust market for carbon trading in the future, Metro may be able to generate revenue through its greenhouse gas reduction measures.

It is important to view these results understanding that greenhouse gas reduction cost effectiveness is only one of a number of factors that influences Metro's investment decisions. All of the strategies evaluated in this report have benefits in addition to greenhouse gas reduction, such as reducing transit operating costs, increasing transit ridership, improving mobility, reducing water use, and providing employee benefits. Some strategies involve significant costs. ***Decisions to support any individual strategy should be made based on a composite assessment of all these potential benefits and costs, rather than greenhouse gas impacts alone.***

1. Introduction

As a leader in environmental responsibility, the Los Angeles County Metropolitan Transportation Authority (Metro) is pursuing a variety of sustainability strategies to maximize transportation efficiency, access, safety, and performance while minimizing energy use, consumption, pollution, and the generation of waste. These efforts support environmental stewardship and can result in long-term cost savings for Metro while maintaining its leadership in the transportation industry. Sustainability strategies will also become increasingly important to comply with regulatory processes related to AB 32 greenhouse gas reduction targets and related regulations under the California Environmental Quality Act, the Federal surface transportation re-authorization process, and potential Federal climate change legislation.

This report evaluates a number of current and potential future sustainability strategies for their costs and impacts on greenhouse gas emissions reduction. Reducing greenhouse gas emissions helps to mitigate climate change. Many strategies that reduce greenhouse gas emissions also reduce the consumption of energy, improve air quality, and provide other social and environmental benefits. For these reasons, reducing greenhouse gas emissions is an important component of sustainability efforts at Metro.

This study evaluates promising greenhouse gas emissions reduction strategies, including those focused on Metro's vehicle fleet, buildings, and opportunities to reduce vehicle miles traveled (VMT). Costs and greenhouse gas benefits are quantified for 17 strategies. An additional 4 strategies could not be evaluated quantitatively, due to a lack of data, but are described in terms of what is known about their costs and potential greenhouse gas benefits. Some of these strategies could be evaluated quantitatively if more data becomes available in the future.

The study focused only on strategies under Metro's direct control. Metro can potentially influence greenhouse gas emissions through other regional strategies that it does not directly control, such as those involving Metrolink commuter rail, goods movement, and highway operations. Such strategies should be considered in conjunction with partners such as Caltrans, the Southern California Association of Governments, and other county transportation agencies.

The results of this study can help inform Metro's decisions about future investment in sustainability strategies. However, it is important to view these results understanding that greenhouse gas emissions reduction cost effectiveness is only one of a number of factors that influences Metro's investment decisions. All of the strategies evaluated in this report have benefits in addition to greenhouse gas emissions reduction, such as reducing transit operating costs, increasing transit ridership, improving mobility, reducing water use, and providing employee benefits. Decisions to support any individual strategy should be made based on a composite assessment of all these potential benefits.

2. Methodology

Strategies were selected based on a review of current and proposed programs and projects at Metro and based on conversations with Metro staff. Strategies for which data was readily available from Metro were prioritized. In the case of existing programs, strategies are analyzed based on current performance with a view to maintaining or expanding those programs. In the case of proposed projects or programs, strategies are analyzed to inform these proposals.

A total of 17 strategies are analyzed quantitatively. Strategies fall into four categories:

1. Promotion of Alternative Travel Modes – strategies that encourage use of existing transit or promote ridesharing, bicycling, walking, and other low-emission travel modes.
2. Transit Service – strategies that expand the transit service provided by Metro
3. Vehicle Technology – cleaner or more fuel efficient buses, trains, or non-revenue vehicles
4. Facility Energy Use – strategies that reduce energy use at Metro's facilities or generate more clean electricity

Emissions for these strategies are estimated in terms of metric tons of carbon dioxide-equivalent (MtCO2e) and include impacts on CO2, methane (CH4), and nitrous oxide (N2O). Both emissions reduced by strategies (e.g., through removing cars from the road) and emissions produced by strategies (e.g., from new vanpools) are captured. Only emissions from vehicle tailpipes and electricity generation are included. Embodied emissions associated with the construction of infrastructure and buildings and the manufacture of vehicles and other equipment are not included. These embodied emissions are generally not a large portion of total emissions for the strategies analyzed, and therefore would not significantly change the results presented in this report.

Cost effectiveness of strategies is reported in terms of dollars of expenditure or savings per ton of greenhouse gases reduced ($/ton). Only Metro's costs and revenues are captured in the $/ton metric, although major costs and revenues that accrue to other parties are also described.

For many strategies, especially those involving capital investments, the costs, revenues, and emissions impacts may occur in different years. Emissions impacts may depend on the specific year of implementation. Some investments may continue to support emission reductions for many years in the future. In this analysis, each strategy's cost and emissions impacts are evaluated based on the lifetime most appropriate for that strategy. To support a side-by-side comparison of strategies, the cost of each strategy is evaluated on a net present value (NPV) basis, with future costs discounted at 5%. A rate of 5% reflects the historic cost of borrowing for local governments, and use of this discount rate is consistent with many other greenhouse gas emissions reduction cost effectiveness analyses.

Nearly all the data used to analyze strategies was provided by Metro. In a few cases, additional data to estimate costs or emission reduction effectiveness was obtained from other agencies or from other research reports. Metro has conducted energy audits for Divisions 10 and 18; these audits were used as the basis to analyze facility energy efficiency strategies.

After a draft of the analysis was completed, a workshop was held with approximately 10 representatives from various Metro departments. The purpose of the workshop was to review the draft analysis and obtain feedback on the data inputs, analysis methods, and results. Following this workshop, the analysis of several strategies was revised to reflect updated information from Metro staff.

3. Greenhouse Gas Impacts of Metro's Current Operations

Metro is already a net reducer of greenhouse gas emissions. By removing private vehicles from the road, reducing congestion, and facilitating compact development, the agency annually prevents more greenhouse gas emissions from entering the atmosphere than it produces from its vehicles and facilities. In addition to the annual impact of its service on greenhouse gas emissions, the agency has enacted policies and made investment choices in recent years that have helped to further reduce greenhouse gas emissions. Some of these current programs and past investments are described as strategies in this report.

In 2009, Metro emitted 483,000 MtCO2e from its buses, trains, non-revenue vehicles, and facilities.[1] The agency's more than 2,500 CNG buses emit greenhouse gases from their tailpipes, as do smaller numbers of gasoline and diesel buses. Light rail and heavy rail trains are responsible for greenhouse gases emitted in the generation of grid electricity. Metro's non-revenue vehicles also emit greenhouse gases from their tailpipes. Facilities use grid electricity and some natural gas, thereby contributing to greenhouse gas emissions.

Metro also keeps greenhouse gases out of the atmosphere by allowing transit riders to leave their cars at home and supporting other forms of low emission travel options. As discussed in guidance from the American Public Transportation Association (APTA), there are three ways that Metro's service reduces greenhouse gas emissions:

1. **Mode shift** – Metro reduces the amount of VMT on Los Angeles County's roads by getting people out of their cars and onto buses and trains.

2. **Congestion reduction** – By reducing the number of vehicles on the road and smoothing the flow of traffic, Metro reduces emissions from cars that operate in congested traffic conditions.

3. **Land use impacts** – Over time, Metro's rail stations and other major transit hubs attract denser, pedestrian-friendly development patterns to their immediate vicinities. (Metro also actively promotes such development patterns through its transit oriented development program; see Strategy: Transit Oriented Development.) These development patterns allow people that live and work in the area to travel shorter distances and to walk and bike more, even if they do not ride Metro.[2]

The first effect is the most easily understood and the most commonly calculated. In 2009, passengers riding Metro buses, trains, and vanpools kept nearly 391,000 MtCO2e out of the atmosphere through mode shift.[3] Considering only this mode shift effect, Metro's net greenhouse gas emissions in 2009 were 92,000 MtCO2e.

When the effects of Metro's service on congestion and land use are considered, Metro prevents more greenhouse gas emissions than it produces. A study from CALPIRG estimated Metro's net emissions, considering emissions from buses, trains, and vanpools, and emissions reduced through mode shift, congestion mitigation, and the land use multiplier: Metro generates a net *reduction* of 862,000 MtCO2 per year.[4]

4. Analysis of Greenhouse Gas Reduction Strategies

4.1. Promotion of Alternative Travel Modes

Strategy: Ridesharing and Transit Pass Programs for Los Angeles Employers

Description

Metro provides a variety of services and product offerings to employers and educational institutions in Los Angeles County to help them promote carpooling and transit as alternatives to driving alone. Products and services offered include:

- Regional ridematching program
- Guaranteed Ride Home program
- Ridesharing incentives
- Special transit passes for employees and students
- Outreach to employers and colleges, including marketing, training, and program support

Many employers use Metro's programs to help them comply with regulations from the South Coast Air Quality Management District (AQMD). Metro provides commute reduction services to 2,500 business locations throughout Los Angeles County; Metro assists more than 500 of these businesses with AQMD regulation compliance. Approximately 260,000 employees work at these 500 regulated employer locations.

Greenhouse Gas Benefits

Evaluating the impact of this strategy on greenhouse gas emissions is complicated by the size and diversity of the program. Individual employers and colleges have a wide variety of arrangements with Metro. Metro does not collect comprehensive data on the impact of services on commuting patterns. To estimate the impact of the entire program on greenhouse gas emissions, we examine two main program areas:

- Employee Commute Reduction Programs (ECRPs) – Worksites in Los Angeles County that have more than 250 employees are subject to the AQMD's Rule 2202 for mitigation of on-road vehicle emissions. More than half of these worksites receive assistance from Metro for commute reduction. Participating employers report their commute mode shares to Metro.
- College Transit Passes – Several colleges and universities in LA County partner with Metro to provide unlimited ride transit passes to their students at discounted prices. Having an unlimited ride transit pass induces some students to ride transit for more of their daily trips.

To evaluate the impact of ECRPs on commute patterns, we compare the commute mode shares reported by employers to the average commute mode share in Los Angeles County. In 2009, 73.2% of employees in Metro's program drove alone to work. In 2005 (the most recent data year available), 74.9% of all employees in Los Angeles County drove alone to work.[5] We therefore estimate that Metro's services reduced vehicle trips by 1.7% at employers reporting to

Metro. VMT impacts are calculated assuming an average one-way commute trip length of 18.4 miles.[6] Under these assumptions, Metro reduced greenhouse gas emissions by 17,100 metric tons through its support to ECRPs in 2009. This is a conservative estimate because it represents commuting at just those companies that report their commuting patterns to Metro.

Greenhouse Gas Benefits of Employee Commute Reduction Programs Supported by Metro - 2009

Participating Employees	260,605
Daily Vehicle Trips Reduced	4,365
Daily VMT Reduced	160,632
Annual VMT Reduced	40,158,097
Annual Greenhouse Gases Reduced (MtCO2e)	17,107

Thirteen colleges comprised the bulk of Metro's college transit pass sales in 2009: Los Angeles Community College District (nine campuses), University of California Los Angeles, Rio Hondo College, and El Camino College Compton. Together students at these colleges purchased about 42,150 passes per semester.

We apply the results of a student survey at Rio Hondo to estimate the impact of these passes on students' travel patterns. In a survey conducted in the fall of 2009, Rio Hondo found that 30% of students using their transit passes had previously driven to campus. Pass holders used transit not just to get to and from the college, but also for other trips—an average total of 5 one-way trips per day, 5 days per week. Assuming that the transit passes impacted students' travel patterns similarly at other colleges, the passes reduced greenhouse gas emissions by about 75,500 metric tons in 2009. (We assume an average vehicle trip length of 10.2 miles in Los Angeles County).[7] This result assumes that each student switching to transit fills an empty seat on an existing bus or train.

Greenhouse Gas Benefits of College Transit Passes - 2009

Number of Passes Sold per Semester	42,150
Daily Vehicle Trips Reduced	64,149
Daily VMT Reduced	654,315
Annual VMT Reduced	177,266,956
Annual Greenhouse Gases Reduced (MtCO2e)	75,516

Including employers who reported their commute mode shares to Metro and students using special transit passes provided through their colleges, Metro reduced nearly 93,000 metric tons of greenhouse gas emissions in 2009.

Cost

Metro Commute Services, which provides most of the services detailed above, incurs costs for staff and administration, marketing and outreach materials, and financial incentives provided to commuters. In fiscal year 2009, the program cost Metro approximately $2.5 million. Metro spent another $240,000 for its Guaranteed Ride Home program and regional ridematching services.

Metro Commute Services also generates some revenue from the sale of special transit passes to employers. If special transit passes were not available, Metro would still receive some of this revenue through sales of normal tickets and transit passes to employees; however, some people would not ride Metro if the special passes were not available. Therefore, Metro Commute Services increases revenue to the agency by some unknown amount. Employer pass sales totaled $3 million in 2009.

Special passes for college students are less likely to generate new revenue for Metro. For most colleges, Metro sets a revenue-neutral price for student transit passes. In other words, Metro aims to price student passes to cover the undiscounted fares of the current student ridership on Metro trains and buses. However, new riders are gained by the program, and it is hoped that these students will continue to use transit when they transition into the working world. Total college pass sales totaled $3 million in 2009.

Cost Effectiveness

The cost effectiveness of this strategy is calculated in two ways. Assuming that none of the revenue from sales of employers passes is surplus revenue for Metro, the strategy costs about $30 per ton of greenhouse gas emissions reduced. Assuming that all of the revenue from sales of employer passes is surplus revenue for Metro, the strategy generates about $3 per ton of greenhouse gas emissions reduced. The actual cost effectiveness of the strategy lies somewhere between these two values.

Cost Basis	Annual Net Cost	$/ton
Program Cost only	$2,740,000	30
Program Cost and Revenue from Employer Pass Sales	-$260,000	-3

Metro can continue to reduce a large volume of greenhouse gas emissions at low cost or even cost savings just by maintaining its current ridesharing and special transit pass programs. (The reduction of 93,000 metric tons offsets nearly a fifth of Metro's 483,000 MtCO2e emitted in 2009).[8] This strategy is particularly beneficial to the extent that it increases ridership on Metro's existing transit vehicles, thus helping to remove personal vehicles from the road at little additional cost. Metro may be able to increase the impact of this strategy by providing its services to a larger number of employers and colleges.

Strategy: Metro Employee Transit Subsidy Program

Description

This strategy reduces greenhouse gas emissions by encouraging Metro employees to use public transit for their commute trips. This is accomplished by subsidizing transit fares for employees who use transit service other than Metro. (All Metro employees have unlimited free access to Metro's transit service.) Currently, approximately 1,500 employees are enrolled in the transit subsidy program. These employees commute to work via public bus (non-Metro), commuter rail, or vanpool – modes of transportation that require less fuel per commuter than a single-occupancy passenger vehicle. We evaluate the cost effectiveness of continuing annual support for this program. A related strategy, discussed below but not quantified, would increase Metro ridership by Metro employees.

2009 Transit Subsidy Participation

Service Provider	# of Employees
Antelope Valley Transit	10
LADOT	12
EZ Pass	48
Metrocard	136
Foothill	115
Long Beach Transit	3
Santa Monica	4
Metrolink	743
City Subsidy	45
Vanpool	401
Exceptions	16
Total	1,533

Greenhouse Gas Benefits

Reducing the number of passenger vehicle trips taken by Metro employees reduces the amount of fuel consumed for transporting employees between their homes and their worksites. Fuel savings depend on 1) the number of additional employees enrolled in the program, 2) the average roundtrip commute distance for employees, and 3) the average fuel efficiency of passenger vehicles.

Data from Metro shows that the average roundtrip commute distance for employees is approximately 34 miles. Commute surveys suggest that 90% of employees enrolled in the subsidy program use alternative (non-drive alone) modes of transportation on a typical workday. We assume that all subsidy participants using alternative commute modes would drive to work if not for the subsidy. Thus, we assume that the average workday VMT reduction of the program is equal to the number of participants (1,533) times 90% times the average roundtrip commute length (34 miles).

The greenhouse gas benefits of VMT reduction are determined by combining the VMT reduction with appropriate fuel efficiency and carbon intensity factors. The result is a reduction of 4,955 metric tons of CO2-equivalent emissions in 2010.

For the greenhouse gas emissions from transit vehicles, we assume that greenhouse gas emissions per mile for each Metro employee using bus and rail service is zero, since the number of riders is very small compared to total ridership on these systems, and most have excess capacity. Data from Metro shows that 13% of employees using subsidized modes of transportation use vanpools on a typical day. Assuming the average vanpool ridership is 10 employees per vehicle (vanpools can carry 5-15 employees), every 77 automobile trips eliminated will produce one vanpool trip. The average fuel efficiency of gasoline vans in Los Angeles County for 2010 is approximately 15.4 mpg. Thus, the subsidy program increases vanpool emissions by 83 metric tons in 2010.

Cost

Metro subsidizes up to $120 per employee per month for public transit. The actual cost of the subsidy to Metro varies month to month. The subsidy program cost $1,639,114 in 2009, or approximately $1,069 per employee, and we assume this average subsidy rate remains constant for future years. The program is administered by one full-time Metro employee with assistance from a part-time intern. The full cost of this staff labor is assumed to be $210,000 annually.

Cost of Transit Subsidies

Component	Cost
Annual subsidy (per employee)	$1,069
Total annual subsidy	$1,639,114
Metro administration costs	$210,000
Total annual cost	$1,849,114
Lifetime	1 year

Cost Effectiveness

The greenhouse gas emissions reduction cost effectiveness of the current program is $380 per ton. Note that this reflects only cost to Metro. Participating employees will save money on fuel expenditures – an average savings of $1,087 per program participant for commute travel.

Cost Effectiveness Summary

Annual greenhouse gas Reduction (MT)	4,872
Annual Cost	$1,849,114
Cost-effectiveness ($/ton)	$380

Program Expansion Potential

Metro could expand this strategy in several ways and further reduce emissions from employee commute travel.

- One option is to expand the number of employees receiving the transit subsidy and using the subsidy to commute by (non-Metro) transit or vanpool. The program is currently available to all employees, so increasing participation would require more intensive program marketing activities and (potentially) more Metro staff time devoted to program administration. We are not able to estimate the cost of expanding participation in the subsidy program. To achieve a large increase, the marginal cost effectiveness would likely be significantly higher than current average cost effectiveness of $371 per ton.
- A second option is to increase Metro ridership by Metro employees. Currently, Metro estimates that only 2% of employees commute using Metro service, a much smaller fraction than commute using other transit providers (primarily Metrolink).[9] Given Metro's extensive service coverage in proximity to Metro worksites, this fraction is surprisingly low. It may be possible to increase Metro transit use through more intensive outreach and marketing activities. We are not able to estimate the costs and benefits of these activities.

There are important limitations on use of transit and ridesharing by Metro employees. Working hours for many Metro employees preclude transit use. For example, most Metro transit operators and mechanics sign on between 4:00 and 6:00 am, requiring a morning commute that is earlier than the start of public transit service, particularly in outlying areas.

On the whole, Metro currently exceeds the Average Vehicle Ridership (AVR) targets set by SCAQMD's Employee Commute Reduction rule – 1.75 for Zone 1 (the downtown Los Angeles core) and 1.5 for Zone 2 (the rest of Los Angeles County south of the San Gabriel Mountains). For a multi-site employer like Metro, compliance with AQMD's AVR rule is based on the aggregate of all employees in a zone, not individual facilities. The table below shows Metro's AVR is particularly high at the Gateway and Location 30 facilities during the morning commute period. AVR is lower at Division facilities and during off-peak periods.

Metro Average Vehicle Ridership (AVR) by Worksite, 2009

Worksite Name	Peak (6 - 10 AM)			Off-Peak (all other times)		
	Trips	Vehicles	AVR	Trips	Vehicles	AVR
Division 1	429	331	1.3	1,800	1,548	1.2
Division 2	408	313	1.3	1,524	1,295	1.2
Division 3	408	325	1.3	1,456	1,356	1.1
Division 5	328	318	1.0	1,586	1,502	1.1
Division 7	501	463	1.1	1,767	1,612	1.1
Division 8	420	334	1.3	1,310	1,177	1.1
Division 9	588	403	1.5	1,836	1,585	1.2
Division 10	678	467	1.5	2,133	1,912	1.1
Division 15	611	501	1.2	2,171	1,947	1.1
Division 18	582	537	1.1	2,015	1,930	1.0
Division 20	842	592	1.4	1,834	1,566	1.2
Gateway + Location 30	6,610	2,624	2.5	2,615	1,789	1.5
Total	12,405	7,207	1.7	22,047	19,220	1.1
AQMD Target (Zone 2)			1.5			

Strategy: Transit Oriented Development

Description

Metro owns approximately 30 sites adjacent to current and future rail and BRT stations. Many of these sites are prime candidates for mixed use transit oriented development (TOD). A handful of the properties have already been developed as TOD. Generally, properties are developed as primarily residential, with a small retail component.

Metro leases the properties to developers. The developers construct the TODs and then sublease the properties to tenants. Metro thus collects rent directly from the developers.

TODs reduce greenhouse gas emissions by locating homes and businesses near high quality transit, such that residents and employees on site can take the train or bus and leave their cars at home more often. Mixing of land uses within a TOD also allows residents to walk for some trips to retail and service destinations.

Greenhouse Gas Benefits

We analyzed a total of 8 sites that are currently under lease to developers for their likely impacts on greenhouse gas emissions when fully occupied. As planned the sites accommodate the following developed space:[10]

- 1895 residential units
- 300 hotel rooms
- 700,000 square feet of retail space

- 35,000 square feet of office space
- 4,000 square feet of other space.

For U.S. EPA, ICF developed and piloted a methodology to estimate the greenhouse gas emissions impacts of TOD.[11] We apply this methodology to the 8 Metro sites. The methodology calculates VMT generated by TOD relative to an equivalent amount of space in a reference case development. The reference case development is posited to be a conventional suburban style development with little to no transit or mixing of land uses. For the reference case, trip generation rates for each type of development are drawn from the ITE Trip Generation Manual. Trip generation rates for the TOD are drawn from a traffic impact analysis conducted by a traffic consultant prior to construction of the site.

The table below shows the greenhouse gas (GHG) emissions calculated for the 8 sites and their reference cases according to the EPA methodology. Trip generation rates for the reference cases are drawn from the ITE Trip Generation Manual 7th edition. For the TOD projects, the ITE trip generation rates were reduced by 20% from the reference cases. This reduction is consistent with the approach and assumptions made in the traffic impact analyses reviewed for the above mentioned study. VMT associated with the TOD projects and reference cases were calculated assuming an average vehicle trip length of 10.2 miles.[12] When fully occupied, the sites examined will reduce greenhouse gas emissions by 14,600 tons per year.

Annual Greenhouse Gas Benefits of 8 TOD Projects

	Weekday Vehicle Trips Generated	Annual VMT	Year 2010 GHG Emissions (MtCO2e)
TOD Projects	36,828	137,109,122	58,408
Reference Cases	46,034	171,386,402	73,010
Reduction	9,207	34,277,280	14,602

Cost

The monetary impact of the strategy is largely determined by the rents received for the sites. Metro purchased most of the sites in question many years ago. The purchase price is therefore considered a sunk cost. Metro does incur some costs for legal and economic advice associated with the TOD projects.

In fiscal year 2011, Metro expects that it will receive $2.9M in rent from leases on the 8 sites in question. This is a conservative estimate of the revenues from the sites. Revenues from some of the sites will increase when construction is completed. No data is currently available on the legal and economic costs of the program, but we assume that the annual sum of these costs is much less than the lease revenues and will therefore not substantively change the net revenues of the program. Three full time equivalent (FTE) staff positions at Metro support the TOD program. We estimate the annual cost of these staff, in terms of salaries and benefits, at $210,000 each.

Annual Cost Impacts of 8 TOD Projects

Revenue Generated (FY11)	2,859,431
Staff Costs	630,000
Net Revenues	2,229,431

Cost Effectiveness

When the 8 sites in question are fully occupied, Metro will generate $153 for every ton of greenhouse gas emissions reduced through its joint development program. This represents an important opportunity to both reduce greenhouse gas emissions and generate revenue.

In considering the development of future TOD sites, we expect that Metro can achieve about the same rate of cost savings per ton of greenhouse gas emissions reduced. Future TODs on Metro property are expected to both reduce greenhouse gas emissions and generate revenue.

Strategy: Bike-to-Transit Commuter Incentives

Description

This strategy reduces greenhouse gas emissions by increasing the number of people who commute by combining bicycles with transit. Bicycles can be stored at many Metro rail stations, and can also be carried on buses and trains. Bicycling is a much quicker way to access transit stops and stations than walking. As a result people are willing to bicycle further to access transit than they would walk.

Metro can encourage bicycling to transit by offering financial incentives, such as assistance purchasing a bicycle. Financial incentives may be especially important for bikes that are designed for commuters – including electric bikes and folding bikes – which tend to be more expensive than standard bicycles. Free transit passes offered to those who bike to transit also encourage more biking, as do amenities such as bike lockers, and marketing initiatives.

Greenhouse Gas Benefits

The greenhouse gas impacts of the strategy depend on how people targeted by the incentives change their travel habits and on the length of their commute trips. Before bicycling to transit, most people either:

- Drive to transit, or
- Drive for the entire trip.

The greenhouse gases eliminated depend on the total amount of driving that is eliminated.

To estimate the potential greenhouse gas impact of an incentive program, we evaluate the MyGo Pasadena program. In 2007, MyGo offered incentives for commuters in Pasadena to purchase electric bikes and use them to connect to Metro's Gold Line stations in Pasadena. The program offered participants $500 towards the purchase of an electric bike and a limited subsidy towards the purchase of transit passes. In turn, participants committed to bike to transit at least two days per week. The program also installed bike lockers at Gold Line stations that participants could use to secure their bikes at the stations, rather than carry them on board.[13]

Of the program's 41 participants, an estimated 17 previously drove to transit. An estimated 24 previously drove for their entire commute.[14] An evaluation of the greenhouse gas emissions reduction potential of the program assumed that each participant biked to transit 3 times per week. A driving trip to the transit station was assumed to be 10 miles roundtrip. A full driving trip was assumed to be 34 miles roundtrip, the distance from Pasadena to downtown Los Angeles. The table below estimates the greenhouse gas benefits of the program—a total of 65 tons of greenhouse gas emissions reduced in 2007.

Impacts of MyGo Pasadena

Previous Mode	No. of Participants	VMT eliminated per year	GHGs eliminated per year (MtCO2e)
Park-N-Ride	17	26,863	11
Drive Alone	24	126,129	54
Total	41	152,992	65

MyGo Pasadena targeted riders at three Gold Line stations in Pasadena. If a similar program were implemented at half of Metro's approximately 60 rail stations, the total greenhouse gas reduction would be 650 tons annually.

Cost

We estimate an upper and lower bound strategy cost. For the upper bound, we use the cost of MyGo Pasadena, which included subsidies for the purchase of bikes ($500 per participant) and transit passes (up to $30 per month per participant). Metro estimates that it could conduct a similar program using less expensive folding bicycles, with a subsidy of $200 per bicycle. We use this as part of the lower bound cost estimate.

The program also incurred administrative costs. Management required about 40 hours of staff time per month after initial program design and startup; we use this as part of the upper bound cost estimate. For the lower bound, we estimate the average of amount of staff time required per program participant could be reduced by half by scaling up the program. MyGo Pasadena also installed 8 bike lockers at Gold Line stations at a cost of $1,500 each. The lockers were not much used by program participants, even though initial surveys found that prospective participants highly valued the bike lockers. As a result, we exclude the cost of the bike lockers from the total cost estimate.

We assume the bicycles purchased have a lifetime of 4 years, in order to account for the continuing benefit of the bicycles after their initial year of purchase. Therefore the bicycle subsidy costs $50 - $125 per year per participant. Administrative costs are estimated assuming an annual staff cost (including salary and benefits) of $210,000. Transit subsidy costs are estimated assuming that all users received the maximum possible subsidy. Thus for 41 participants, the program costs $43,060 to $72,385 per year.

Cost Effectiveness

Using the cost range described above, we estimate that incentives for bicycling to transit can reduce one ton of greenhouse gas emissions for $661 to $1,111. Administrative costs are the largest cost component. Metro may be able to improve the cost effectiveness of this strategy by reducing or removing the subsidies or by increasing the number of participants in the program to achieve greater administrative economies of scale. Currently, Metro is designing a similar subsidy program for folding bicycles.

Strategy: Bicycle Paths along Transit Corridors

Description

This strategy provides dedicated bicycle paths and other amenities for bicyclists along key transit corridors in Los Angeles County. Integrating bicycle and pedestrian facilities with transit facilities provides a higher multimodal level of service than transit or bicycle/pedestrian facilities alone, allowing travelers to switch more easily between modes and use more than one non-auto mode per trip.

This strategy is modeled on the Metro Orange Line bike path and associated bicycle amenities. The Metro Orange Line is a 14-mile Bus Rapid Transit (BRT) busway that extends from the terminus of the Metro Red Line subway in North Hollywood to Warner Center in Woodland Hills. To complement the busway and promote alternative transportation, a bikeway was constructed together with the busway. From east to west, the bikeway is a Class II bike lane (between the North Hollywood Station and just west of Coldwater Canyon Avenue) and then becomes a Class I bike path (between just west of Coldwater Canyon Avenue and Canoga Boulevard). Since its opening, the Metro Orange Line has generated higher than expected ridership, and the parallel bicycle facility is well-utilized by bicyclists as well as pedestrians for both commute and recreational purposes. Of the 14 Metro Orange Line stations, 13 have bicycle accommodations (bike racks and rentable lockers). Only the Warner Center Station is without bicycle accommodations. In addition, Orange Line BRT vehicles each have racks that accommodate 3 bicycles, whereas Metro’s standard buses accommodate 2 bikes.

The bike path, bike racks and lockers at Orange Line stations, and bike racks on Orange Line vehicles all promote mode shift from private auto trips to bicycle and bicycle/transit trips.

Greenhouse Gas Benefits

A study conducted in 2010 counted bicyclists using the bike path and surveyed Orange Line users about the impact of the bicycle facilities on their travel patterns.[15] That study surveyed both people who biked to access the Orange Line BRT and people who exclusively used the bike path.

On an average weekday, 72 people who formerly drove alone for their trip now bike to access the Orange Line BRT. If these bicyclists formerly drove to access the BRT, an average one-way distance of 1.9 miles, the bicycle facilities reduce 274 VMT per weekday. If these bicyclists formerly drove for the entire trip, an average one-way distance of 14.4 miles, the bicycle facilities reduce 2,074 VMT each day.

On an average weekday, 168 people who formerly drove alone for their trip now use the Orange Line bike path (without riding the BRT). These bicyclists travel an average 7.8 miles one-way by bike, reducing 2,621 VMT per day.

Depending on the change in travel patterns for people using both bicycle and transit for their trip, the Orange Line bicycle facilities reduce between 314 and 507 MtCO2e per year. In addition to the Orange Line BRT, Metro operates 71 miles of light- and heavy-rail service. Approximately one third of those miles are below grade, either in an open cut or subway. The remainder are elevated or at grade. If Metro implemented integrated bike paths, lockers, and other facilities along half of its elevated or at-grade rail system, it could reduce an additional 1,051 to 1,697 MtCO2e per year.

Scenario	VMT eliminated per year	GHGs eliminated per year (MtCO2e)
Low Impact	752,700	314
High Impact	1,220,700	507

Cost

The Orange Line bikeway was constructed for a total cost of $10.6 million. In addition to bikeway construction, Metro also incurred costs for installation of bike racks and lockers at Orange Line stations. Metro installed about 112 bike lockers, at a cost of $2,000 each, and 60 bike racks, at a cost of $150 each, at Orange Line stations. The additional cost of the 3-bike racks over standard 2-bike racks for the new Orange Line BRT vehicles was most likely negligible. Sportworks, the manufacturer of a popular brand of bike rack for buses, sells standard 2-bike racks for about $570 each, a very small fraction of the total purchase price of a new bus.[16]

With a 20 year lifetime, the Orange Line bicycle facilities cost $541,650 per year. [17]

Cost Effectiveness

Depending on the change in travel patterns for people using both bicycle and transit for their trip, the Orange Line bicycle facilities cost between $1,068 and $1,727 per ton of greenhouse gas emissions reduced.

4.2. Transit Service

Strategy: Vanpools

Description

This strategy maintains and possibly expands Metro's existing vanpool program. Metro contracts with two vanpool providers (VPSI and Enterprise Rideshare) to offer shared ride vans to commuters with a destination in Los Angeles County.

The basic premise of a vanpool is that people ride together from home or a common meeting location to an employment center. Generally, a vanpool consists of 5 to 15 people. Commute distances vary significantly, but generally are greater than 30 miles round-trip. In addition to sharing a ride to and from work, participants also share the costs of the service, including gas, tolls, parking and vehicle cleaning and maintenance fees. Vanpool members also fulfill responsibilities of general coordination and driving the van.

Metro assists with the formation of vanpools and offers riders a subsidy of up to $400 per van per month. The number of Metro's vanpools has increased dramatically in recent years, from 327 in 2007 to 892 as of February 2010.

Greenhouse Gas Benefits

Metro's vanpools traveled more than 1.6 million miles in February of 2010. Vanpools carried an average of 6.5 people each. Assuming that each of those riders would have driven alone had the vanpool not been available, vanpools collectively removed 10.7 million VMT from the roads in February 2010 and reduced greenhouse gas emissions by 4,500 MtCO2e.

Vanpools also emit greenhouse gases from the tailpipes of vans. Accounting for these emissions, Metro's vanpools produced a net reduction of nearly 3,600 MtCO2e in February 2010. If the program has similar effects all year, the annual greenhouse gas reduction would be about 46,000 MtCO2e.

February 2010 Vanpool Program

Number of Vanpools	892
Revenue Miles of Service	1,632,667
Average Vanpool Occupancy	6.5
Passenger Miles Traveled	10,664,581
Greenhouse Gases Reduced (MtCO2e)	4,543
Greenhouse Gases Emitted by Vans (MtCO2e)	980
Net greenhouse gas Emissions Reduced (MtCO2e)	3,563

Cost

In February 2010, Metro paid $354,000 in subsidies for the vanpool program, or an average of $397 per van. Metro also incurs costs for the vanpool program in the form of staff salaries and benefits – $37,000 in February 2010. Metro receives federal funds through FTA's Section 5307 for every vanpool on the road. In the 2010 fiscal year, the region received an estimated average of $654,100 in federal funding per month. About 96% of that amount, or an average of $628,000 per month, will be received by Metro. With the federal funding, the vanpool program is a net revenue generator for Metro.

February 2010 Vanpool Program Net Cost

Administrative Costs	$37,000
Vanpool Subsidies	$354,000
FTA 5307 Funds	-$692,000
Total	-$237,000

Cost Effectiveness

As noted above, the vanpool program generates revenue for Metro as a result of the FTA subsidy. Thus, the program *saves* $67 per ton of greenhouse gas emissions reduced.

Given the rapid growth of vanpools in recent years, there may be an opportunity to continue expanding the vanpool program. Vanpools have several advantages over fixed route transit. Vanpools provide a door-to-door convenience that is superior to traditional bus and rail transit. Individual vanpools are also easy to form, requiring little to no service planning.

Strategy: Expand Rail and BRT Systems

Description

This strategy enhances transit access in Los Angeles County by expanding the rail and BRT systems. Fixed guideway systems generally provide a higher quality transit service than buses traveling in general purpose lanes. Expanding fixed guideway systems allows more people to use transit to travel from their homes to places of work, school, and other destinations. Some people using these segments will be new transit riders who previously used a car to make the same trip. If the cars removed from the road generate more greenhouse gas emissions than the bus and rail vehicles that replace them, system expansion will reduce greenhouse gas emissions.

Metro's 2030 Long Range Transportation Plan lists 21 potential new fixed guideway transit projects. (In some cases, multiple project alternatives for a single corridor are included.) Proposed projects include extensions to the Gold, Green, and Red Lines, connections between existing lines, and other new transit lines.

Expanding rail and BRT systems differs from the other strategies presented in this report on several counts:

- First, the expansion of the fixed guideway system is a central part of Metro's Long Range Transportation Plan, with a goal of providing high quality transit service to a greater share of the County's population. Much more than a greenhouse gas emission reduction strategy, system expansion contributes to the core role of Metro as a transit service provider. System expansion is important in the long run to support other greenhouse gas emissions reduction strategies that depend on increasing Metro's ridership.
- Second, system expansion is a long term project with benefits that accrue over many decades. The projects listed in the LRTP will be built over the next 10 to 20 years. It may take several years after completion of a project for ridership to reach maximum levels. In addition, fixed guideway transit has an impact on the long term evolution of land use patterns. Extending high quality rail and BRT transit to more areas of Los Angeles County makes more compact, transit oriented development viable.
- Third, expanding rail and BRT lines is far more capital intensive than any of the other strategies presented here. Individual projects cost hundreds of millions of dollars per mile to build, but the capital investment has a lifetime of several decades. In this way, transit system expansion is more aptly compared to roadway expansion projects than to the other greenhouse gas emission reduction strategies that are based in operational changes and investments in vehicle and energy technologies.

Greenhouse Gas Benefits

Given the impact of system expansion on the transit system as a whole, we evaluate the ability of this strategy to reduce greenhouse gas emissions through all three of the mechanisms discussed in APTA's guidance.[18] Transit systems reduce greenhouse gas emissions through mode shift, reducing congestion, and influencing long term land use patterns. See Section 3 for an explanation of each of these effects. In addition, system expansion also increases emissions when new transit vehicles enter service, using additional electricity and fuel each day. The greenhouse gas impact of the system expansion is the combination of emissions reduced and emissions produced.

The greenhouse gas benefits of new fixed guideway transit are estimated based on the projects in Metro's LRTP. The LRTP forecasts the number of boardings on proposed new segments. The plan estimates an average of 544,000 annual boardings per mile, but there is substantial variation among individual projects. Projects are scored according to boardings per mile and boardings per dollar of expenditure. Among the four highest performing projects in the plan, Metro forecasts an average 2.2 million boardings per mile.

The table below estimates greenhouse gas benefits per mile for both the average proposed project and the four highest performing projects:

- Metro Red Line Extension from North Hollywood Station to Burbank Airport Metrolink Station
- Metro Red Line Westside Extension from Century City to City of Santa Monica

- Metro Red Line Westside Extension from Wilshire/Western Station to Century City
- Regional Connector Light Rail in tunnel from LA Union Station to 7th St/Metro Center

The effect of passenger boardings on regional VMT is estimated assuming that 44% of trips on the new segments remove a private vehicle from the road and that the average displaced vehicle trip is 9.1 miles.[19] The effect of system expansion on congestion is estimated by apportioning the congestion reduction benefit of all fuel savings from transit in the Los Angeles-Long Beach-Santa Ana Metropolitan Statistical Area proportionally to passenger miles traveled.[20] The effect of system expansion on land use is estimated using an average national multiplier, as provided in APTA's guidance document. Note that the land use effect of system expansion is realized in the very long term, in the decades following opening of new projects. Emissions produced per mile are estimated based on Metro's 2009 greenhouse gas emissions from electricity used in propulsion per mile of rail service.

The greenhouse gas benefits of new fixed guideway transit vary substantially depending on the projects included. The average project in the LRTP would reduce greenhouse gas emissions by 2,700 MtCO2e annually per mile, if operational today. The highest performing projects would reduce emissions annually by an average 14,700 MtCO2e per mile.

Annual Greenhouse Gas Impacts per Mile

	All Projects Proposed	Top 4 Performing Projects
Boardings per mile	543,997	2,204,232
VMT Reduced per mile	2,183,034	8,845,469
Emissions Avoided from Mode Shift, per mile (MtCO2e)	930	3,768
Emissions Avoided from Congestion, per mile (MtCO2e)	139	564
Emissions Avoided from Land Use Changes, per mile (MtCO2e)*	2,876	11,653
Emissions Produced, per mile (MtCO2e)	1,240	1,240
Net Emissions, per mile (MtCO2e)	-2,705	-14,746

*Long term effects

The projects proposed in the LRTP will be built over a period of many years. Most of the projects proposed will not be operational until 2020 or later. By that time, the energy efficiency of rail transit will likely have improved substantially. For example, the use of on-board units to store energy recovered in braking may reduce per mile electricity use by 15% (see Strategy: On-board Storage of Regenerative Braking Energy). A study for the Bay Area Rapid Transit District (BART) found that measures to improve the lighting and ventilation of BART cars, change propulsion systems, and store regenerative braking energy could reduce per mile electricity use by 43%.[21] In Los Angeles, Metro is planning to retrofit Red Line cars with interior LED lights, which will save energy compared to the current fluorescent lights. On the Gold Line, Metro has implemented a smarter propulsion technology that reduces the electricity demand of rail cars in response to fluctuations in line voltage. According to Metro staff, this technology may help to reduce per mile electricity consumption as well.

Renewable energy projects can also reduce the amount of grid-derived electricity that rail cars use, and thus reduce the amount of greenhouse gases emitted per mile. For example, the proposed solar panel projects along the Orange Line and along freeway soundwalls could generate enough carbon-free electricity to provide 1% of Metro's current propulsion electricity needs (see Strategy: Solar Panels).[22] Metro is also considering a project to generate clean electricity from windmills installed in subway tunnels (see Strategy: Wind Energy in Subway Tunnel). Even using more power from Southern California Edison, which has an electricity carbon intensity half that of Los Angeles Department of Water and Power, would improve the greenhouse gas performance of new rail transit service.

Based on the available research on options to improve the energy efficiency of rail cars and generate renewable electricity, we estimate that Metro could reduce the per mile grid electricity consumption of its rail systems by 30% during the time horizon of the LRTP. Under this assumption, the average project would reduce greenhouse gas emissions by 3,100 MtCO2e per mile. The top 4 performing projects would reduce emissions by 15,100 MtCO2e per mile.

Annual Greenhouse Gas Impacts per Mile: 30% Reduction in Grid Electricity Use

	All Projects Proposed	Top 4 Performing Projects
Emissions Avoided – All Mechanisms (MtCO2e)	3,945	15,986
Emissions Produced (MtCO2e)	868	868
Net Emissions (MtCO2e)	-3,077	-15,118

Two other factors beyond Metro's control will also determine the net impact of new fixed guideway segments on greenhouse gas emissions: the fuel economy of private vehicles and the carbon intensity of electricity purchased from utilities. Both are expected to improve over time. By 2020, the greenhouse gas emissions per mile of Los Angeles' private vehicles will decrease by about 20% according to federal CAFE standards. Reductions will continue after 2020. Over the same period, the carbon intensity of the electricity that Metro purchases from utilities should decrease by about 24%, according to California's Renewable Portfolio Standard. After 2020, new projects will be less likely to reduce greenhouse gas emissions if vehicle fuel economy continues to improve but the carbon intensity of propulsion electricity does not.

Cost

Costs of new fixed guideway segments include the capital costs of construction and new rolling stock, and operating and maintenance expenses. The LRTP forecasts capital costs for the transit projects listed. Average operating and maintenance costs for Metro's rail transit are estimated from data submitted by Metro to the National Transit Database.

The table below calculates cost per mile for both the average proposed project and the highest performing projects. The capital costs of projects are amortized over a 35 year period at 5% interest.[23] The average LRTP project will cost about $12 million per mile each year to build, operate, and maintain. The four highest performing projects will cost $27 million per mile each year to build, operate, and maintain.

Annual Cost per Mile (million $)

	All Projects Proposed	Top 4 Performing Projects
Amortized Capital Costs	$8	$23
Operating and Maintenance Costs	$4	$4
Total	$12	$27

Cost Effectiveness

Expanding rail and BRT systems is one of the most costly ways that Metro can reduce greenhouse gas emissions. Metro must spend hundreds of dollars for each new trip it attracts to the system. The net impact of the new segments on greenhouse gas emissions depends heavily on the volume of ridership that they attract.

Under the scenario of 30% reduction in grid electricity consumption, the average project in Metro's LRTP would reduce greenhouse gas emissions by one ton for every $3,800 spent. On the other hand, the projects that attract the highest ridership are more than twice as cost effective. These projects cost an average $1,800 for every ton of greenhouse gas emissions reduced.

While system expansion is not cost competitive based on its greenhouse gas reduction potential alone, it is an important long term strategy nonetheless. Expanding transit access provides many co-benefits to regional transportation systems, air quality, disadvantaged communities, and businesses. In addition, a growing transit system provides an important basis for subsequent strategies that can increase ridership beyond the levels initially projected. As discussed above, system expansion should not be considered comparable to other types of greenhouse gas emission reduction strategies.

4.3. Vehicle Technology

Strategy: Gasoline-Electric Hybrid Buses

Description

This strategy aims to reduce greenhouse gas emissions by replacing conventional CNG buses with a more fuel-efficient alternative, gasoline hybrid electric (GHE) buses. GHE buses operate using a gasoline engine in tandem with a battery pack and electric motor. The gasoline engine provides the primary power source for moving the bus and charging the batteries, while the battery / electric motor combination contributes secondary power. Electric hybrids increase efficiency in three ways: 1) by using regenerative braking technology to store electricity, then releasing that electricity to power the bus; 2) by contributing to the motive power during peak power requirements such as acceleration, reducing the amount of time the gasoline engine operates in a less-efficient state, and 3) by enabling the use of a smaller engine than would otherwise be required to operate a bus.

While the GHE buses achieve better fuel economy than the conventional CNG buses, their benefits in terms of carbon intensity are much smaller. Gasoline is more carbon-intensive than natural gas. If “upstream” emissions from fuel production and distribution are factored into the analysis, GHE buses result in higher greenhouse gas emissions than CNG buses.

Greenhouse Gas Benefits

To estimate greenhouse gas benefits, we used Metro’s assumptions of 43,000 annual miles per bus and an average bus lifespan of 13.5 years.

Metro has been operating a small number of GHE buses in revenue service and is analyzing the performance data to determine their benefits. The results are promising: GHE buses achieve nearly 30% higher fuel economy than conventional CNG buses, at 3.6 miles per gallon of gasoline, compared to the equivalent of 2.8 miles per gallon (2.1 miles per therm) for the CNG bus.

However, because gasoline is more carbon-intensive than natural gas, the greenhouse gas benefits of GHE buses are much smaller than the fuel economy benefits. While a CNG bus emits 111 metric tons of CO_2e annually, a GHE bus under identical operation would emit 105 metric tons annually – a reduction of just 5.4%. If 10% of Metro CNG bus fleet were replaced with GHE buses, the total annual greenhouse gas emissions reduction would be about 1,200 $MtCO_2e$.

Greenhouse Gas Impacts of GHE and CNG Buses

	GHE Bus	CNG Bus
Annual VMT	43,000	43,000
Fuel Economy (miles per gal or therm)	3.6	2.1
Annual Fuel Consumption (gal or therm)	11,911	20,476
Carbon Intensity (g CO_2 / gal or therm)	8,800	5,417
Annual Emissions ($MtCO_2e$)	105	111

Cost

Metro’s recent procurement experience suggests hybrid drive systems can add $150,000 to $200,000 to the purchase price of a new bus. Bus manufacturers claim that with larger volume orders, the price differential could be a low as $100,000 in future years. For analyzing this strategy, we assume a new GHE bus would cost $600,000, compared to the $450,000 cost of a comparable 40-foot CNG bus. The costs of this strategy include the up-front price premium of the GHE bus as well as the premium for fuel purchases over the life of the vehicle. Initial Metro tests do not indicate any difference in per-mile maintenance costs.

The primary driver for lifetime costs will be the difference in gasoline vs. fuel prices. In general, prices for the two fuels do not move in tandem, as each is subject to different market forces. As a result, this cost analysis is extremely sensitive to price projections of each fuel over the next 13 years.

We used gasoline and CNG fuel price projections from the Department of Energy Annual Energy Outlook 2010, which forecast more rapid growth in gasoline prices than natural gas prices. GHE buses are calculated to have an annual fuel premium of about 20% currently ($4,400 per bus), increasing to 40% by 2020 ($12,000 per bus). Thus, even with the increased fuel economy, GHE buses still incur greater fuel costs.

When the upfront purchase price of the vehicle is factored in, GHE buses cost about $230,000 more than CNG buses over the 13.5 year vehicle lifespan, or an average annual cost increment of about $17,000.

If a large number of Metro's CNG bus fleet were replaced with GHE buses, Metro would also incur significant fueling infrastructure costs, since most divisions are currently configured to provide CNG. We have not estimated these costs.

Cost Effectiveness

Because the annual greenhouse gas savings are small considering the large annual price differential, the cost effectiveness of this strategy is relatively poor. At a cost of $2,796 per metric ton of CO2e reduced, this strategy is much more expensive than most other greenhouse gas reduction alternatives.

Lifetime Costs, Benefits, and Cost-Effectiveness, per vehicle

	GHE Bus	CNG Bus	Difference
Annualized Cost	$71,305	$54,248	$17,057
Annual greenhouse gas Emissions (MtCO2e)	104.8	110.9	6.1
Cost Effectiveness ($ per MtCO2e)			$2,796

Strategy: 45-foot Composite Buses

Description

This strategy replaces Metro's standard 40-foot NABI buses with 45-foot NABI Metro 45C buses. Both buses are powered by CNG, and both travel about 2.1 miles per therm. The 45-foot bus is a larger vehicle that accommodates approximately an additional 7 passengers. The body of the 45-foot bus is made of composite fiberglass, which is lighter than the traditional steel bodies of the 40-foot buses. Metro has purchased approximately 100 of the 45-foot composite buses to date.

Metro began purchasing 45-foot buses as a way to comply with a 1996 consent decree reached between the agency and the Los Angeles Bus Riders Union. The consent decree limited the ratio of standees to total passengers traveling on Metro buses. The 45-foot buses provide 46 seats, versus the 40-foot buses' 40 seats. The consent decree expired in 2006.

While Metro has not purchased 45-foot buses with the intent of increasing total ridership, the longer buses do increase the agency's capacity to carry passengers. Since the buses achieve the same fuel economy as the 40-foot buses, they can reduce greenhouse gas emissions by accommodating existing riders on buses. The impact of the strategy depends on the number of additional passengers accommodated.

The 45-foot vehicles come at a cost premium; however, they also have a longer lifespan than the traditional 40-foot vehicles.

Vehicle Properties

	40-foot NABI	45-foot NABI Metro 45C
Passenger Capacity (Seated and Standing)	48	55
Fuel Economy	2.1 miles/therm CNG	2.1 miles/therm CNG
Purchase Cost	$450,000	$590,000
Vehicle Lifetime (years)	13.5	18
Annual Maintenance Cost (per bus)	$65,000	$65,000

Greenhouse Gas Benefits

The impact of the strategy on greenhouse gas emissions depends upon the number of additional riders accommodated on each 45-foot bus. In the absence of any data on actual load factors on 40-foot versus 45-foot vehicles, we examine two scenarios for ridership. The low impact scenario assumes that the 45-foot buses attract no additional riders. The high impact scenario assumes that the additional capacity of the 45-foot buses is completely absorbed by new ridership. Because capacity constraints are typically only an issue during peak travel periods, we constrain the analysis to weekday AM and PM peak hours. We analyze the impact of replacing an entire fleet of 40-foot buses with an entire fleet of 45-foot buses.

The table below provides an estimate of the greenhouse gas impact of 45-foot buses under the two scenarios. We assume that 40-foot buses operate at capacity during peak hours. If the 45-foot buses attract no additional riders, they have no impact on greenhouse gas emissions. If all of the additional capacity of the 45-foot buses is absorbed by new riders during peak periods, 44,100 metric tons of CO2e are reduced annually.

Greenhouse Gas Benefits of 45-foot Buses

	40-foot Buses	45-foot Buses	
		Low Impact Scenario	High Impact Scenario
Weekday Peak Passengers per Vehicle	48	48	55
Weekday Peak Vehicle Revenue Miles[24]	126,000	126,000	126,000
Weekday Peak Passenger Miles Traveled	6 million	6 million	6.9 million
Weekday Peak VMT Reduced[25]	2.8 million	2.8 million	3.3 million
Annual Emissions Reduced—Relative to 40-foot Buses (MtCO2e)	n/a	0	44,100

There are no increased greenhouse gas emissions from the use of 45-foot buses. Therefore if the additional capacity attracts just one new transit rider per bus, greenhouse gas emissions will be reduced.

Cost

The cost of the strategy is determined by two factors: the capital cost of buses and additional fare revenue received from new riders. We assume that this strategy would replace all 2,084 buses operating in maximum service with 45-foot composite buses.[26] The capital cost of buses is spread over the lifetime of the bus, to account for the longer lifetime of the composite buses. Even so, the composite bus fleet costs $8 million more per year than the 40-foot bus fleet. Operating and maintenance costs are the same for both fleets. Fare revenues would not increase under the low impact scenario, but would increase by $41 million per year under the high impact scenario.

If no additional passengers ride the 45-foot buses, the strategy will cost Metro $8 million per year. If the buses carry an additional 7 passengers during the entire weekday peak periods, the strategy will save Metro $33 million. Even if each bus carries only 2 additional passengers, the strategy will save Metro money.

Cost Impacts of 45-foot Buses

	40-foot Buses	45-foot Buses	
		Low Impact Scenario	High Impact Scenario
Annual Capital Costs[27]	$97 million	$105 million	$105 million
Annual O&M Costs (Weekday Peak)[28]	$263 million	$263 million	$263 million
Annual Fare Revenue (Weekday Peak)[29]	$284 million	$284 million	$325 million
Annual Net Cost	$87 million	$95 million	$54 million
Difference from 40-foot Buses	n/a	$8 million	-$33 million

Cost Effectiveness

As with the cost and emissions impact, the cost-effectiveness of the strategy is highly dependent upon the number of additional riders on 45-foot buses. In the low impact scenario, the strategy produces no change in greenhouse gas emissions. In the high impact scenario, the strategy saves $757 for every ton of greenhouse gas emissions. If the 45-foot vehicles carry an average of just 1.4 additional riders for every vehicle mile traveled, Metro will break even on the strategy, while still reducing greenhouse gas emissions.

Anecdotal evidence suggests that the 45-foot buses currently in use have not increased total ridership, but have rather allowed customers to ride more comfortably. If that is the case, the low impact scenario is the more likely one for Metro.

Strategy: Hybrid Vehicles for Non-Revenue Fleets

Description

This strategy reduces greenhouse gas emissions by increasing the number of hybrid vehicles in Metro's fleet of non-revenue vehicles. Metro's non-revenue fleet includes all vehicles used for employee transportation, maintenance, or other purposes. It generally comprises: light-duty cars and trucks for passenger transportation; medium-duty pickup trucks for maintenance and construction work; heavy-duty trucks for moving cargo and other maintenance / construction work; and offroad vehicles such as fork lifts and landscaping equipment. Metro has more than 2,100 total vehicles in its non-revenue fleet, including more than 700 light-duty cars and trucks. In total, these non-revenue fleets can consume approximately 800,000 gallons of gasoline and 130,000 gallons of diesel annually, contributing approximately 2% of Metro's greenhouse gas emissions.

This analysis is limited to the passenger car and light-duty fleet, as these vehicle classes contain the greatest number of commercially-available hybrid options. These vehicles achieve greater fuel economy and are sold at a small price premium over comparable conventional vehicles. Metro has been purchasing hybrid non-revenue fleet vehicles for at least six years, and has not made a large purchase of conventional (non-hybrid) vehicles for at least 10 years.

Greenhouse Gas Benefits

This strategy uses the difference in purchase price and fuel costs between conventional and hybrid vehicles in order to calculate cost effectiveness. The fuel costs depend heavily on usage of the vehicle, which vary widely at Metro. Some of Metro's light-duty vehicles are driven as little at 5,000 miles per year, while others are driven as much as 18,000 mile per year. Because the resulting cost effectiveness of this strategy is very sensitive to annual VMT, we calculate cost-effectiveness is calculated under two scenarios: 5,000 annual miles and 18,000 annual miles. Based on recent patterns, we assume Metro purchases 282 automobiles (sedans) and 20 light trucks in a year. Metro indicates that vehicles have a six-year average lifetime.

This analysis examines the benefits of hybrids for both cars and light trucks. In order to capture fuel economy and vehicle costs, specific vehicle models are used. The hybrid models were chosen based on specifications from Metro, and the conventional vehicles were chosen as equivalent counterparts to the hybrid vehicles. Values for vehicle fuel economy were provided by US Department of Energy, and values for vehicle cost were provided by the manufacturer.

Comparison of Vehicle Parameters for Conventional vs. Hybrid Vehicles

Make/Model	Fuel Economy (MPG)	Purchase Price
Toyota Camry 2010	26	$20,645
Toyota Camry Hybrid 2010	34	$26,400
Difference	8	$5,755
Toyota Highlander 2010	22	$25,855
Toyota Highlander Hybrid 2010	26	$34,900
Difference	4	$9,045

By introducing more hybrid vehicles into the non-revenue fleet, Metro will increase the fleet fuel economy and reduce per-vehicle fuel consumption. The fuel savings and greenhouse gas emissions reduction are greater under the High VMT scenario, shown below.

Fuel and Emissions Impacts of Hybrid Vehicles

	Lifetime Fuel Consumption (gal)		Lifetime GHG Emissions (MtCO2e)	
	Low VMT	High VMT	Low VMT	High VMT
Sedan				
• Conventional	1,154	4,154	10.2	36.6
• Hybrid	882	3,176	7.8	28.0
Difference	-271	-977	-2.4	-8.6
Light Truck				
• Conventional	1,364	4,909	12.0	43.3
• Hybrid	1,154	4,154	10.2	36.6
Difference	-210	-755	-1.8	-6.7

Cost

There are two components to the cost of this strategy: the upfront price premium of a new hybrid vehicle and the lifetime fuel savings of the hybrid. The total lifetime premium is calculated here by discounting future year fuel savings and combining with present year price premium.

Future fuel savings depend on estimates of fuel prices over the lifetime of the vehicle, obtained by the DOE Annual Energy Outlook 2010. Since fuel consumption and expense vary depending on distance driven, the lifetime price premium is calculated for the two VMT scenarios. Based on information from Metro, this analysis assumes that there is no difference in maintenance cost between hybrid and conventional vehicles. As such, the price premium only depends on up-front cost and annual fuel savings.

As is shown in the table below, the results vary between VMT scenarios and vehicle classes. For both the sedan (Camry) and SUV, the hybrid saves money over its lifetime under only under the High VMT scenario. The annual VMT at which the strategy breaks even (i.e., lifetime fuel savings equals lifetime cost) is 7,300 annual miles for the sedan (Camry) and 14,850 miles for the light truck (Highlander).

Lifetime Cost, per Vehicle

Vehicle Type and Scenario	Upfront Price Premium	Lifetime Fuel Savings (discounted)	Lifetime Cost
Sedan			
• Low VMT	$5,755	-$3,943	$1,812
• High VMT	$5,755	-$14,384	-$8,629
Light Truck			
• Low VMT	$9,045	-$3,047	$5,998
• High VMT	$9,045	-$11,115	-$2,070

Cost Effectiveness

The cost-effectiveness of this strategy is heavily dependent on annual VMT: greater mileage leads to both a lower cost premium and higher greenhouse gas emissions reduction for hybrids. In addition, hybrid sedans are more cost-effective at reducing emissions than hybrid light trucks. This is due to the greater up-front premium for a hybrid truck as well as the smaller differential in fuel economy between hybrid and conventional models. The table below presents the annual greenhouse gas emissions reduction per vehicle and for the annual fleet purchase (282 sedans and 20 light trucks), assuming no change in maintenance costs. The cost effectiveness ranges from a savings of about $1,000 per ton to a cost of more than $3,000 per ton, depending on the type of vehicle and annual VMT.

Cost Effectiveness Non-Revenue Hybrid Vehicles

Vehicle Type and Scenario	Annual GHG Reduction (MtCO2e)		Cost Effectiveness ($ per MtCO2e)
	Per Vehicle	Annual Fleet Purchase	
Sedan			
• Low VMT	0.40	113	$757
• High VMT	1.44	405	-$1,001
Light Truck			
• Low VMT	0.31	6	$3,242
• High VMT	1.11	22	-$311

Strategy: On-board Storage of Regenerative Braking Energy

Description

This strategy reduces greenhouse gas emissions by using railcar energy storage technology to capture the electricity produced by dynamic braking, store that energy in an on-board device, and release the energy to partially power the train in acceleration or other modes of operation. This technology is already used by some European rail transit agencies, and several agencies in the United States are considering it as well.

Currently, Metro light rail and heavy rail cars rely on dynamic braking to slow the train without using the pneumatic brakes. This reduces wear and tear on the braking system and provides a secondary braking source for an improved safety margin. Under dynamic braking, the electric motor is run in reverse and acts like a generator, slowing the train down while producing electricity. Current trains do not capture the generated electricity, instead burning it off through resistors typically located on the top of the cab (rheostatic braking).

Metro is considering a new regenerative braking technology – a retrofit component for light rail and heavy rail vehicles. The component, manufactured by ABB Technologies, contains a power converter and supercapacitor array in a compact form factor that can be installed on top of a light rail or metro car. The device captures braking energy from that car and returns it to the vehicle when needed.

Greenhouse Gas Benefits

By reducing the total electricity consumed by rail cars, regenerative braking technology will reduce greenhouse gas emissions associated with the generation of the grid electricity. Total electricity savings will depend on 1) the number of rail cars with the system, 2) the electricity consumed by each rail car, and 3) the percentage benefit from the technology. Data from Metro shows that the average rail car consumes about 769,000 kWh of electricity annually. At an average rate of 11.5 cents per kWh, this translates to an expense of $88,420 per car per year.

Electricity Use per Car, 2008 [30]

Annual Propulsion Electricity Consumed (kWh)	175,301,756
Rail Cars	228
Electricity Use per Car (kWh)	768,867

According to information provided by Metro and the manufacturer, ABB Technologies, this technology results in an average 15% reduction in electricity use. According to the manufacturer, the technology effectiveness will vary greatly depending on the drive profile of each rail car – specifically the amount of braking and acceleration used along the route to stop at stations and overcome grades. A more precise method of calculating costs and benefits would use the acceleration profiles of each Metro line. However, for a simplified calculation the average effectiveness is appropriate.

The greenhouse gas benefits are determined by combining the electricity savings with an appropriate carbon intensity factor for the electricity supply. Metro purchases power from three utilities: Southern California Edison, Los Angeles Department of Water and Power, and Pasadena Water and Power. While the latter two have a relatively high carbon intensity factor; SCE power has relatively low carbon intensity due to a high proportion of renewable energy sources. The weighted average carbon intensity for all three utilities is 470 g CO2e per kWh. This translates to greenhouse gas emissions of 362 MtCO2e per rail car per year.

Greenhouse Gas Emission Factors

Utility	Carbon Intensity 2006		% Power 2005-2008
	Lbs CO2e / MWh	g CO2e / KWh	
Southern California Edison	631	286	34%
LA Dept of Water & Power	1,228	556	63%
Pasadena Water & Power	1,664	754	3%
Weighted Average	1,038	470	

Cost

The technology employed in this strategy is an electricity conversion and storage device that is installed on-board each individual railcar. According to information provided by Metro, and a subsequent conversation with the manufacturer, ABB Technologies, the device costs approximately $100,000 installed and has a lifetime of 20 years with no expected increase in operations and maintenance cost.

Electricity costs were assumed to be $0.115 per kWh, the average electricity cost to Metro over the period 2005 – 2008.

For each year over the lifetime of the technology, the total costs for that year were calculated as the sum of capital costs, O&M costs, and electricity savings. These annual costs were converted to a current-year net present value using a discount rate of 5%.

Cost Effectiveness

Notably, this technology provides significant savings in terms of reduced electricity use, and results in a negative cost per ton of CO2 reduced. On a system-wide average basis, the technology would save about $78,000 per rail car, or $70 per MtCO2e reduced.

The technology may be more cost effective on some lines than others, depending on the specific rail car operating profiles of each line. Rail cars that consume more electricity will offer a greater return on investment for the initial capital cost of the regenerative braking component.

Per-Car Costs and Benefits: System-wide Average

Lifetime Strategy Cost	Annual GHG Reduction, MtCO2e	Lifetime GHG Reduction, MtCO2e	Cost per MtCO2e
-$78,178	55.7	1,114	-$70

If all Metro rail cars were upgraded with this technology, the net cost over the 20-year lifetime would be a savings of $17.8 million and an annual greenhouse gas emissions reduction of about 12,700 metric tons. This net cost reflects the purchase cost of the regenerative braking technology and the energy cost savings that will accrue once it is installed.

Total Costs and Benefits - Entire Fleet Upgrade

Total Savings	Annual GHG Reduction, MtCO2e	Lifetime GHG Reduction, MtCO2e
-$17,824,610	12,694	253,882

In addition to the savings available from retrofitting the current rolling stock, Metro can also reap the benefits of regenerative braking by incorporating it in new rail cars purchased. The agency plans to require regenerative braking technology in new rail cars going forward.

There are some constraints inherent in on-board energy storage. On-board units require either retrofitting or redesign of rail cars. Finding space to install the unit is one potential constraint. Energy storage units also add weight to rail cars, which affects vehicle performance. Finally, installing energy storage devices on-board requires rail cars to be taken out of service for any maintenance and repair of energy storage units.

Strategy: Wayside Energy Storage Substation (WESS)

Description

This strategy uses stationary electricity storage devices to capture energy released when a rail car unit decelerates and feed the energy back into the system when required. The result is a “battery” that recycles energy that would have otherwise been wasted, reducing the overall amount of electricity consumed from the grid.

Wayside energy storage is a novel concept in rail efficiency management, currently under pilot testing in selected locations. WESS is generally seen as an alternative to on-board energy storage units. In contrast to on-board storage technology, in which a battery pack or storage device is installed on the railcar itself, wayside storage relies on stationary systems installed within each electrical substation (at each station or mile of track).

Metro conducted a feasibility study of WESS in 2008-09. Metro has also begun a wayside storage pilot project, funded through a $4.5 million TIGGER grant from the Federal Transit Administration. The project, the Red Line Westlake Energy Storage System, will capture and release energy at the Westlake at-grade rail station.

Greenhouse Gas Benefits

The greenhouse gas benefits of wayside energy storage would be comparable to benefits from mobile regenerative braking systems. Both operate in a similar fashion – storing braking energy that would have been wasted, subsequently releasing it for later use – and reduce greenhouse gas emissions through the same mechanism. By reducing the amount of electricity consumed, these systems reduce the associated carbon footprint of the electricity accordingly.

Metro's feasibility study of WESS focused on the Gold Line between the Mission and Highland Park stations. The study found that a single WESS would reduce grid electricity consumption by 366,720 kWh annually. At Metro's average emission rate of 470 grams CO2e per kWh (see Strategy: On-board Storage of Regenerative Braking Energy), the WESS would reduce emissions by 172 MtCO2e per year.[31]

Results at other locations will vary based on the specific operating characteristics of rail line segments. Assuming that WESS could achieve comparable results at all of Metro's approximately 60 rail stations, the maximum potential greenhouse gas reduction would be 10,320 MtCO2e per year.

Cost

Cost components of the wayside energy storage facility include:

- The upfront capital costs of the units;
- Annual maintenance costs;
- Annual savings from reduced electricity consumption.

The WESS feasibility study found that each installation will cost $2.08 million in up-front capital costs. These up-front costs would be offset by annual savings in electricity. Based on the electricity savings demonstrated above, a WESS station would save $42,173 annually, at an average rate of 11.5 cents per kWh. Even though the WESS saves money over its lifetime, any savings are dwarfed by capital costs.

The total lifetime cost for the WESS system is $1.74 million per installation, in 2010 dollars. This assumes an equipment life span of 10 years. The feasibility study did not address the issue of maintenance, so this analysis does not include any consideration of maintenance costs.

While the above values apply for a retrofit installation of WESS at a substation, the feasibility study determined that when installed in the context of new construction, a WESS installation could save up to $1.77 million in capital costs alone. Since WESS reduces the demand on traditional electrical infrastructure, a new line would need fewer electrical substations for operation. The study determined that when installed on a new 10-mile light rail line, WESS technology could save $8.85 million, or 21% of the capital cost of electric infrastructure. Maintenance costs for WESS are also expected to be lower than those of conventional substations. However, this analysis focuses only on the retrofit scenario, as it is the most likely scenario in which LA Metro would implement this technology.

Cost Effectiveness

The WESS costs $1,010 per ton of greenhouse gas emissions reduced. However, because this cost-effectiveness analysis is based on the results of a feasibility study at one location, the results may not be representative of all installation locations. A preliminary analysis of several sites would identify the most promising locations for deploying WESS technology.

WESS has several advantages over on-board energy storage. WESS operates independently of the rail car fleet. Any Metro rail car can operate with a WESS system without the need for retrofitting. Likewise, a WESS system can be maintained without removing rail cars from service. On the other hand, WESS systems require transmission of energy to and from rail cars, which results in some energy losses.

A study for BART concluded that installing a WESS system was preferable to retrofitting existing rail cars with on-board storage units, but that on-board storage would be preferable if applied only to new rolling stock. WESS would cost about 10% more in up front capital costs than on-board storage, but has a lifespan of 30 years versus an on-board system's 23 years.[32]

While it is technically feasible to use both WESS and on-board storage on a single rail alignment, there would likely be little additional energy savings from combining the two technologies. Braking activity generates a finite amount of electrical energy. WESS and on-board units offer two different ways to store that energy. Deploying both systems would probably be far less cost effective than using one system or the other. Still, a detailed feasibility study would be required to evaluate specific configurations of WESS and on-board storage for Metro's system, and to compare the costs and benefits of the two technologies.

4.4. Facility Energy Use

Strategy: Retrofit Lighting in Red Line Tunnel

Description

This strategy reduces labor hours, energy usage, and greenhouse gas emissions by installing an efficient "plug and play" lighting fixture every 40-50 feet on each side of the 22 mile Red-Line subway tunnel. The lighting is mainly used to illuminate the tunnel for train operators, as well as to illuminate the walkway eight feet below in the case of emergencies, evacuations, and repairs.

Currently, an older, less efficient lamp and fixture combination is used in the tunnel. The fixture includes two four-foot 40 watt lamps that operate 24 hours per day. The older, less efficient lamps and fixture combination typically burns out and needs replacement annually. However, because of the trains' operating schedules, workers are only given between two to six hours at night to repair or replace defective fixtures or install new ones. Therefore, because a repair, replacement, or new installation can take up to 20 minutes per fixture, a four person crew can only handle up to six fixtures in each two hour period.

Metro is currently searching for a "plug and play" technology that can achieve at least one of the following: 1) a reduction in replacement and installation time, 2) a reduction in power and energy usage, and 3) an increase in the life of the lamp and fixture combination. Metro has had discussions with several lighting manufactures, but has not selected a specific technology and does not have specific estimates of the cost or savings per fixture.

Greenhouse Gas Benefits

A more efficient lamp and fixture combination will reduce greenhouse gas emissions associated with the purchase of the grid electricity. Total electricity savings will depend on the number of fixtures within the tunnel and the percentage savings from the more efficient technology. Data from Metro shows that the average lamp and fixture combination uses about 700 kWh of electricity annually, or about 4.1 million kWh for all 5,808 fixtures.

Metro is looking to install lighting that is more efficient, and consistent with the best available technologies in the market. We estimate a new lamp and fixture combination will use 50 watts, for a savings of 37.5% from the current 80 watts.[33] For all 5,808 fixtures, annual electricity usage would decrease to about 2.5 million kWh.

The greenhouse gas benefits are determined by combining the electricity savings with a carbon intensity factor for the Los Angeles Department of Water and Power (LADWP) service territory, in which the tunnel is entirely contained. The weighted average carbon intensity factor is 1228 lbs CO2e per MWh.[34] Based on annual electricity savings of about 1.5 million kWh, the annual emissions reduction would be 850 MtCO2e.

Estimated Greenhouse Gas Benefits for Red-Line Tunnel Lighting

Red-Line Tunnel Lighting	Current	Retrofit
Fixtures	5,808	5,808
Wattage	80	50
Annual hours of operation	8,760	8,760
Annual electricity usage per fixture (kWh)	701	438
Total annual electricity usage (kWh)	4,070,246	2,543,904
Total annual electricity savings (kWh)		1,526,342
Total annual emissions impact (MtCO2e)		850

Cost

At an average rate of nearly $0.11 per kWh, annual electricity costs for the current fixtures are estimated at $439,848. Electricity costs would be $274,905 per year with the more efficient fixtures.

In addition to these electricity costs, the use of more durable and efficient fixtures would reduce Metro maintenance costs. Since each lamp and fixture combination burns out annually, it must be replaced at a cost of $4 per lamp, and an estimated $30 per fixture, for a total cost of $38. For all 5,808 fixtures, the total replacement costs come to $220,704. The annual labor cost for replacing these lighting combinations is estimated at $128,480, based on an average wage of $22 per hour and four hours per day for each member of a four-man crew. Thus, the total annual costs associated with the current Red-Line Tunnel lighting is estimated at $789,032.

The replacement technology is a “plug and play” lamp and fixture combination. We estimate a unit cost of $150, so the total replacement costs would be $871,200. The per unit labor costs for installing the new technology would be about 50% of current labor costs, or $64,240 to replace all units.

Because the lamps contain mercury and cannot be disposed of through the normal municipal waste system, we have included in the calculation the disposal costs for both the current and retrofit technologies.[35] Based on information from Metro, we estimate the disposal costs to be $0.06 per lamp linear foot, with a stop charge, plus energy and security charges of $175 and a 15% fee. Assuming that the lamps are disposed of quarterly (rather than annually), the total costs are estimated at $4,011.

Estimated Disposal Costs for Red-Line Tunnel Lighting

Red-Line Tunnel Lighting	Current / Retrofit
Fixtures	5,808
Lamp length per fixture (feet)	8
Total lamp length	46,464
Total linear feet charges	$2,788
Total stop charges (4x per year)	$700
Total disposal costs (including 15% fee)	$4,011

The lifetime of the replacement lighting is uncertain, and has a significant impact on the cost effectiveness of this strategy. Therefore, we consider two technology lifetime scenarios – two and four years. The upper bound of four years is based on the lamp life of existing technologies.[36]

Cost Effectiveness

To compare greenhouse gas emissions reduction cost effectiveness, we calculate electricity costs, fixture costs, and installation labor costs over a four year period, in order to capture the two different technology lifetime scenarios. Current fixtures would be replaced every year. With a two-year lifetime, the retrofit fixtures would be installed in year 1 and replaced in year 3. With a four-year lifetime, the retrofit fixtures would be installed in year 1 and last for four years.

The table below shows average annual costs over this period, with future costs discounted at 5%. Both retrofit scenarios result in a lower average annual cost than the current lighting fixtures.

Estimated Cost Impacts for Red-Line Tunnel Lighting

	Current	Retrofit with 2-year life	Retrofit with 4-year life
Electricity cost per year	$409,146	$255,885	$255,885
Fixture cost per year	$205,434	$415,351	$217,800
Installation labor cost per year	$119,591	$30,627	$16,060
Disposal cost per year	$3,734	$1,821	$866
Total	$738,174	$703,684	$490,611

The cost effectiveness of this strategy is a $41 savings per ton of greenhouse gas emissions assuming a two-year life, or $291 savings per ton assuming a four-year life.

Cost Effectiveness of Red-Line Tunnel Lighting

	Retrofit with 2-year life	Retrofit with 4-year life
Annual net cost	-$34,490	-$247,563
Annual greenhouse gas reduction (MtCO2e)	850	850
Cost effectiveness (per MtCO2e)	-$41	-$291

The break-even point of this strategy (or the point at which the strategy's cost savings exceeds its costs) depends on the attributes of the technology. Assuming a two-year life, the strategy is cost-effective, compared to the current case, when at least one lamp and fixture combination is replaced with a more efficient combination. With regards to technology life, the strategy is cost-effective when the retrofit technology has a lifetime of 1.94 years, or about one year and eleven months or greater. The installation of a retrofit technology with a life of less than two years would not generate enough electricity and labor cost savings to offset the increased fixture costs.

Strategy: Facility Lighting Upgrades

Description

This strategy reduces energy usage and greenhouse gas emissions by replacing existing lighting and other energy end-use equipment in Metro facilities with more efficient and cost-effective equipment.

Internal energy efficiency audits of Metro's Division 10 and 18 facilities reviewed the quantity and efficiency level of energy-using equipment in the multi-use structure. Nearly two-thirds of the current lighting consists of a fixture with two 40 watt (T12) lamps that operate 24 hours per day. This older, less efficient lamp and fixture combination has a lifetime of 20,000 hours, but typically burns out and needs replacement every two years. Newer, more efficient T8 or T5 lamps and fixture combinations can be installed on a retrofit basis, have a lifetime that ranges from 24,000 to 36,000 hours (between three and four years), and could save Metro about 30% in annual electricity usage and costs.[37] About 10% of the current lighting consists of metal halide fixtures. These could be replaced with more efficient metal halide fixtures or with super-efficient LED fixtures.

Lighting Technology Comparison – Divisions 10 and 18

Equipment Type	T12	T8/T5	Metal Halide	Metal Halide	LED
Lighting Type	Linear fluorescent	Linear fluorescent	High intensity discharge (HID)	High intensity discharge (HID)	High intensity discharge (HID)
Efficiency Level	Standard	Efficient	Standard	Efficient	Efficient
Lamps per Fixture	2	2	1	1	1
Total wattage per Fixture	88	48	456	295	60
Usage (hours/year)	8,760	8,760	8,760	8,760	8,760
Annual electricity usage per fixture (kWh)	771	420	3,995	2,584	526
Technology lifetime (hours)	20,000	30,000	20,000	30,000	50,000
Technology lifetime (years)	2.28	3.42	2.28	3.42	5.71
Current fixtures	1,206	417	217	0	0

The facilities also contain HVAC equipment, appliances, and motors and pumps that are used in maintenance, fuel and vacuum, bus wash, and other areas. However, the audit reports were not able to detail the quantity, vintage, and efficiency level of most non-lighting equipment. With this information, Metro could achieve additional energy usage and cost savings by installing high efficiency equipment. Upgrades to equipment other than lighting are typically more cost-effective at the equipment's end of life, rather than while the equipment is still operable.

Division 10's annual electricity usage is about 5 million kWh, and is one of the largest electricity consumers among Metro's buildings in the LADWP service territory. Division 18's annual electricity usage is more than 6 million kWh, and is the largest electricity consumer among Metro's buildings in SCE service territory. In addition, there are at least seven other divisions that operate similarly to Divisions 10 and 18. The total annual electricity usage at these other divisions is about 15 million kWh. Metro plans to conduct audits of additional divisions, and would be able to use this audit data, in addition to the Division 10 and 18 data, to estimate better the potential for electricity savings in all of its buildings.

Greenhouse Gas Benefits

Through energy efficiency retrofits, Metro will reduce greenhouse gas emissions associated with the purchase of the grid electricity. Total electricity savings will depend on the efficiency level of the retrofits and the number of retrofits installed.

The greenhouse gas benefits of this strategy are estimated based on the findings of the Division 10 and 18 energy audits. Metro could replace all of Division 10's 684 T12 fixtures and Division 18's 522 T12 fixtures with more efficient T8 or T5 fixtures. These would save 464,000 kWh per year and reduce greenhouse gas emissions by 204 MtCO2e annually.[38] The audits found that the 92 metal halide fixtures in Division 10 and the 125 metal halide fixtures in Division 18 could be replaced with LED fixtures. These upgrades would save 753,000 kWh per year and reduce greenhouse gas emissions by 302 MtCO2e annually. In total, the upgrades would reduce emissions by 505 MtCO2e annually.

Alternatively, Metro could replace the old metal halide fixtures at Divisions 10 and 18 with more efficient metal halide fixtures. Efficient metal halide lamps are typically more cost-effective at reducing energy use and greenhouse gas emissions than LEDs. If the 217 existing metal halide fixtures were upgraded to more efficient metal halide fixtures, Metro would reduce electricity use by 306,000 kWh annually and reduce emissions by 123 MtCO2e annually. In total, upgrading the fluorescent lamps and metal halide lamps would reduce emissions by 326 MtCO2e annually.

Greenhouse Gas Benefits of Lighting Retrofit

Equipment Type	T8/T5	LED	Metal Halide
Fixtures replaced	1,206	217	217
Annual electricity savings (kWh)	464,455	752,764	306,048
Annual CO2e Savings (Mt)	204	302	123

Electricity use at Divisions 10 and 18 accounts for approximately 14% of Metro's total facility electricity use. If the lighting efficiency improvements described above were implemented throughout Metro's facilities, the total greenhouse gas emissions reduction would be on the order of 2,300 to 3,600 metric tons per year.

Cost

The audits of the Division 10 and 18 facilities contained detailed costs related to the energy efficient retrofits that would be installed. Metro has estimated a unit cost of $153 per fixture to replace a T12 fixture with a T8 or T5 fixture. Metro has estimated a unit cost of $1,314 per fixture to replace a metal halide fixture with an LED fixture.

California's Database for Energy Efficient Resources (DEER), used by the state's investor-owned utilities (IOUs) for energy efficiency program and budget planning, also provides cost estimates for lighting retrofits.[39] DEER estimates a unit cost of $53 per fixture to replace a T12 fixture with a T8 or T5 fixture.[40] DEER estimates a unit cost of $221 per fixture to replace a standard metal halide fixture with a more efficient metal halide fixture.[41] DEER does not provide a cost estimate for LED fixtures.

To offset some of these costs, utilities offer financial incentives for customers to participate in energy efficiency programs and rebates for the installation of efficient equipment. LADWP offers a Commercial Lighting Efficiency Offer (CLEO) program for non-residential customers, with various rebates for lighting retrofits.[42] The rebates begin at $10 per fixture for standard T8 fixtures, and increase up to $30 per fixture for high efficiency T8 fixtures, and $40 per metal halide fixture. LADWP does not offer incentives for LED fixtures.

Southern California Edison (SCE) offers a variety of energy efficiency programs, from programs that deal specifically with certain end uses (lighting, motors, etc.) to programs that are designed specifically for government and other public sector customers.[43] SCE offers an Express Solutions program for non-residential customers, with an average rebate of $36 per T8/T5 lamp and fixture, $75 per metal halide fixture, and $0.05 per kWh for any custom lighting installation, which could be applied to LED fixtures.[44] SCE, through its account representatives, also offers on-bill financing, where energy efficiency improvements are paid for by additional charges to a customer's monthly utility bill. The additional charges do not include interest, and can be paid for over a multi-year period.

While the estimates from Metro and DEER provide a range of retrofit costs, the actual costs incurred will depend on the type of equipment chosen, the selection of a lighting contractor, and the extent to which utility rebates can be utilized. The following table shows retrofit costs based on both the high and low cost estimates. It also includes two scenarios for replacing the existing metal halide fixtures – the first shows replacement with LED fixtures; the second shows replacement with the more efficient metal halide fixtures. Total costs are calculated by averaging the high and low estimates and subtracting rebates from LADWP and SCE. These represent one-time installation costs of lighting upgrades, and do not account for cost savings that will accrue based on the longer lifetimes of the more efficient lamps versus the standard lamps.

Estimated Lighting Equipment Costs for Division 10 and 18 retrofits

	T8/T5 and LED Retrofits	T8/T5 and Metal Halide Retrofits
High Estimate	$469,656	$232,367
Low Estimate	$348,574	$111,284
Rebates	$54,153	$45,527
Total Cost After Rebate	$354,962	$126,298

Cost Effectiveness

Cost effectiveness of the lighting upgrades is calculated over a four year period, based on the average lamp lifetimes noted above. We assume that all retrofits are installed and all costs are incurred in the first year. Electricity cost savings and greenhouse gas emissions reductions occur annually over the analysis period. Annual electricity cost savings were converted to a current-year net present value using a discount rate of 5%.

Cost Effectiveness of Lighting Upgrade (4 Year Lifetime)

	T8/T5 and LED Retrofits	T8/T5 and Metal Halide Retrofits
Installation Cost After Rebate	$354,962	$126,298
Electricity Cost Savings	$493,902	$312,641
Total Costs	-$138,940	-$186,343
Total Electricity Savings (kWh)	4,868,878	3,082,013
Total MtCO2e Reduction	2,022	1,305
Net Cost per MtCO2e	-$69	-$143

Cost effectiveness ranges from $69 cost savings to $143 cost savings per ton of greenhouse gas emissions reduced. Efficient metal halide lamps save more per ton than LED lamps. The technology of efficient metal halide fixtures is well-established, offered in most utility rebate programs, and well-known to lighting contractors. In the longer term, as lighting technologies continue to evolve, LED lamps may become a more cost effective option. At present, LED is still considered an emerging technology.

Additional Steps

In addition to installing energy efficient technologies in Divisions 10 and 18, Metro can further reduce greenhouse gas emissions by commissioning additional audit reports and seeking energy efficiency retrofits where technically and economically feasible. Metro should ensure that future audit reports are similar to the internally-produced audits of Divisions 10 and 18. These reports detail the electricity usage and square footage of each structure within each division, as well as the quantity and efficiency level for each of the major electricity-using equipment.

With electricity usage and square footage data, Metro could develop annual electricity intensities (kWh per square foot) in order to rank comparable facilities. Based on the audit reports, the electricity intensity of Division 10 in 2009 was 73.9 kWh per square foot, down from 74.5 kWh per square foot in 2008. This compares to 71.3 kWh per square foot for Division 18 in 2009. Although the intensities for Divisions 10 and 18 are similar, the intensities for other facilities may be lower or higher, depending on the building types at each facility. For example, the intensity for an office building is probably lower than for a maintenance building within a division. In addition, it is important to note that a facility’s cost savings that results from a reduction in intensity will depend on any changes in electricity rates. Division 10 reduced its intensity by 0.8% from 2008; however, electricity costs increased by 8.5% because the effective electricity rate increased by 9.4%.[45] As electricity prices continue to increase, Metro should incorporate these changes into its cost-effectiveness calculations and long-term project planning.

Metro would then be able to utilize its internal databases or a tool similar to EPA's Portfolio Manager to record and track energy usage over time. Metro could also track project costs to compare the cost-effectiveness of lighting versus other equipment, and with regards to electricity cost savings. As Metro's 2009 Sustainability Report notes, projects in SCE's territory will have a shorter payback and higher return on investment. However, the share of electricity consumed in LADWP's territory is nearly 70% and has been increasing over the last few years, and thus, may provide more project opportunities.

In addition, Metro should continue to follow the blueprint established for the Metro Support Services Center (MSSC) Solar/Energy Efficiency project. This project installed solar photovoltaic panels concurrently with energy efficiency retrofits, including lighting and HVAC equipment. This ensured that the solar project was sized correctly, according to the center's new estimated electricity consumption rather than higher previous consumption.

Strategy: Recycled Water for Bus Washing

Description

Data logging efforts conducted as part of the development of Metro's Water Action Plan revealed that, on average, bus and car washing represents 90 percent of the total water use for Metro. Bus washing includes a preliminary rinse, wash, and final rinse. The water used for the final rinse is treated through a reverse osmosis system to prevent spotting.

This strategy involves the use of recycled water for the preliminary rinse and wash stages for bus washing. The use of recycled water at Metro facilities should be considered on a site-specific basis, considering factors such as the quality of the available recycled water and the retrofit requirements to modify existing plumbing. For this analysis, however, we assume that all bus washing facilities will be retrofitted to accommodate recycled water use.

Based on Metro's Water Action Plan, the estimated water savings for this strategy are presented here in units of acre-feet per year (AFY).[46]

Water Savings of Recycled Water Substitution for Bus Washing

Potable Water Savings (per facility)	27 AFY
Number of facilities	12
Total Potable Water Savings	325 AFY

Greenhouse Gas Benefits

There are a number of steps in the delivery of water to be considered when estimating the greenhouse gas impacts of recycled water use, including: source and conveyance, water treatment, water distribution, and wastewater treatment. We assume that the energy used to distribute the water, regardless of whether it is potable or recycled, is the same. In the case of wastewater treatment, it is a measure of how much water actually makes it into the sewer system, and not a function of how much water is distributed to a particular facility. We assume that the same amount of water from the washing facility will make its way to the sewer system, regardless of if the original water is potable or recycled. The two energy consuming activities that we consider for bus washing with recycled water are: 1) sourcing or conveyance and 2) water treatment.

To estimate the greenhouse gas benefits of using recycled water, we need the following parameters: potable water displaced (acre-feet per year, AFY), the energy intensity of each energy consuming step (kWh/acre-foot), and the emission factors for electricity production (kg/kWh). We use an estimated lifetime of 40 years for the water saving measure.

Based on the estimated water savings, we estimate the electricity requirements to deliver and treat the equivalent amount of potable water and recycled water. Based on the difference in electricity requirements, we estimate annual and lifetime greenhouse gas emission reductions using emission factors associated with electricity production. Our assumptions regarding the energy consuming steps for the potable and recycled cases are as follows:

- Source and Conveyance: This only applies to potable water and is not considered in the recycled water strategy. We estimate a mix of water sources, including: the LA Aqueduct, Metropolitan Water District (MWD), and groundwater. MWD sources include: groundwater, recycled water, water from the State Water Project (SWP), and the Colorado River Aqueduct.
- Recycled: The potable water does not go through this stage of energy consumption, so is excluded from consideration. This factor does apply for recycled water use.
- Water Treatment: This only applies to potable water and is not considered in the recycled water strategy. There is an embedded factor in the recycled water energy intensity which includes treatment.

Note that we did not account for the potential increase in energy required for additional treatment of recycled water in the rinse stage of the bus washing. To avoid spotting, the water is treated using reverse osmosis before rinsing the buses. Note that rinsing only accounts for 2% of the water used during washing, so even if included, the adjustment would be small.

Recycled Water Greenhouse Gas Reduction

	Energy Intensity (kWh/AF)	Electricity (kWh)		GHG Emissions Reduction (MtCO2e)	
		potable	recycled	Annual	Lifetime
Source and Conveyance	1,324	35,867	--	11.65	
Recycled	370	--	10,020	-3.25	
Water Treatment	36	980	--	0.32	
Total		36,846	10,020	8.71	349

Cost

We assume that there is sufficient recycled water available to Metro for the bus washing facilities and that no costs would be incurred for extending existing or constructing new water transmission pipelines. The capital costs include retrofitting the existing facilities, including approximately 600 linear feet of onsite pipelines at each facility that may be required for conversion to recycled water use. We estimate an annual operations and maintenance savings using recycled water based on an assumption of a 20 percent discount for recycled water compared to potable water, shown in the table below. The project would pay for itself within two years and would generate large savings over the lifetime of the project.

Costs of Recycled Water Use at Bus Washing Facilities

	Per Facility	All Facilities
Capital Cost	$ 11,250	$ 135,000
O&M Savings	-$ 7,501/year	-$90,011/year

Cost Effectiveness

The cost effectiveness of using recycled water is calculated by adding the initial (and one-time) capital costs to a discounted lifetime O&M savings, and then dividing by the lifetime greenhouse gas emission reductions. The O&M costs and savings are discounted at 5% over a lifetime of 40 years. This results in a large cost savings, estimated to be $4,007 *saved* per greenhouse gas ton.

Although there are significant cost savings over the lifetime of the project, as indicated by the negative cost effectiveness, it is worth noting that the scale of emission reduction is relatively small – only about 9 tons CO2e per year. Our estimates make a more compelling case for water and cost savings, with greenhouse gas emission reduction as a small bonus. Also note that the cost effectiveness of recycled water use will be highly dependent upon the availability and proximity of existing recycled water infrastructure.

Strategy: Low Water Sanitary Fixtures

Description

This strategy involves the replacement of all existing standard flow sanitary fixtures that were installed prior to 1992. The replacement of these fixtures with high efficiency, low flow models has the potential to save a considerable amount of water. The replacements include: dual flushed toilets or low flow toilets (< 1.6 gallons per flush); waterless urinals; infrared sensor sinks or pedal operated; low flow shower heads (< 1.6 gallons per minute); and low flow sinks (< 2.2 gallons per minute). The estimated water savings potential of replacing sanitary fixtures at bus and rail facilities is shown in the table below, in acre-feet per year (AFY).

Water Savings from Sanitary Fixture Replacement

Facility Type	Annual Water Savings
Bus Facilities	38 AFY
Rail Facilities	12 AFY
All Facilities	50 AFY

Greenhouse Gas Benefits

In this strategy, there are two ways in which energy is saved and greenhouse gas emissions are reduced:

- Reduced energy consumption associated with water conveyance, delivery, and treatment
- Reduced energy consumption associated with reduced hot water use at showers and sinks

The greenhouse gas emission reductions for water conveyance, delivery and treatment are estimated based on the estimated amount of water saved by using high efficiency, low flow models, as shown in the table below.

Greenhouse Gas Reduction from Water Conveyance, Delivery, and Treatment

	Energy Intensity (kWh/AF)	Electricity (kWh/yr)	GHG Emissions Reduction (MtCO2e)	
			Annual	Lifetime
Source and Conveyance	1,324	8,198	2.66	
Recycled	36	224	0.07	
Water Treatment	414	2,566	0.83	
Wastewater Treatment	623	3,855	1.25	
Total		14,842	4.82	96

The greenhouse gas emission reductions from hot water savings are achieved through the showers replaced and using faucet aerators at the sinks.[47] We estimate the total number of showers and sinks replaced at both bus and rail facilities to calculate the lifetime emission reduction, shown in the table below. The total lifetime greenhouse gas reduction is about 257 metric tons CO2e.

Greenhouse Gas Reduction from Hot Water Savings

Device	Total Fixtures Replaced		Energy Intensity (kWh/year/device)	Electricity kWh/year	Lifetime GHG Emission Reduction (MtCO2e)
	Bus	Rail			
Showers	72	12	128	10,752	
Faucet Aerators	336	100	32	13,952	
Total	408	112	160	24,704	160

Cost

The capital cost to replace sanitary fixtures at all bus and rail facilities is estimated to be about $250,000, accounting for rebates received by Metro. The annual savings from reduced purchase of water would be about $70,000 per year. We assume the low water fixtures result in no change in operations and maintenance costs compared to conventional fixtures.

	Per Facility		All Facilities
	Bus	Rail	
Capital Cost	$ 15,420	$ 16,820	$ 252,320
Annual Water Purchase Savings	$ 4,413/year	$ 4,159/year	$ 69,593/year

Cost Effectiveness

The cost-effectiveness is calculated by summing the initial capital cost to replace all sanitary fixtures and the lifetime water purchase savings, with future costs and benefits discounted at 5%. We assume replacement fixtures have a life of 40 years. Over this lifetime, water purchase savings offset the initial capital costs. (The break-even point is about 5 years.) Thus, the strategy has a lifetime net benefit of $932,000 and a greenhouse gas reduction cost effectiveness of $3,627 *saved* per ton.

As is the case with the use of recycled water for bus washing facilities, the absolute reduction in greenhouse gas emissions from this strategy is relatively small (only about 6 tons CO2e per year). This strategy is more attractive for its water savings than greenhouse gas reduction.

Strategy: Solar Panels

Description

This strategy reduces energy usage and greenhouse gas emissions by installing solar photovoltaic panels on Metro's buildings and transportation facilities. Metro has previous experience with solar projects, having installed a 1 MW solar panel project on the roof of its Metro Support Services Center (MSSC).

In particular, Metro is considering installing solar panels alongside the I-405 freeway and the Metro Orange Line. The electricity generated by the solar panels would be consumed by nearby Metro stations and facilities. The excess electricity would then be sold to either LADWP or Southern California Edison using a feed-in tariff. A feed-in tariff provides for guaranteed payments over a specified period (ranging from 10 to 20 years) for electricity sold from a customer to the utility.

An example of this type of "Solar Highway" project was completed for Oregon's Department of Transportation (ODOT) in 2008. ODOT facilitated the installation of solar photovoltaic panels alongside its I-205 highway with its local utility, Portland Gas and Electric (PGE), and numerous third-parties, including manufacturers, designers, and contractors. The total cost of the project was $1.28 million, but did not require ODOT to incur any capital costs.

Similar to the ODOT project, for the solar array on the MSSC, Metro did not incur any capital costs, and was able to develop the project from private bank loans, a power purchase agreement with the project developer, Chevron Energy Solutions, and utility rebates. However, both the Freeway and Orange Line projects currently contain barriers to implementation, which would affect project costs and timeline.

One barrier to the Freeway project is that the soundwall structure is owned by the California Department of Transportation (Caltrans), and not by Metro. Metro would first have to develop an agreement with Caltrans regarding project costs and savings sharing.[48] Another potential barrier to both projects is the availability of feed-in tariffs. SCE offers a feed-in tariff based on policies established by the California Public Utilities Commission (CPUC) for the state's investor-owned utilities (IOUs); however, LADWP does not currently have a feed-in tariff. Without a feed-in tariff, Metro must use all of the electricity generated by solar projects, or send it back to the grid without a return payment. Transmission of electricity is also a potential barrier to installation and use of solar panels. To use all of the electricity generated, Metro must consider where the solar panels are sited in relation to the facilities that will use the electricity.

Greenhouse Gas Benefits

By generating carbon-free electricity from solar panels, Metro will reduce greenhouse gas emissions associated with the purchase of grid electricity. Total electricity savings will depend on the size of the solar panel projects and the estimated lifetime of the solar panel projects.

Metro has proposed to install 250 kW of solar cells along the I-405 soundwalls and a 1 MW of solar cells at the Orange Line Park and Ride Stations. The annual electricity savings of these projects was estimated based on the output currently produced by the MSSC project. The greenhouse gas benefits were estimated by combining the electricity savings with carbon intensity factors for LADWP and SCE, since the projects may be located in both service territories. Based on an equal weighting, the carbon intensity factor is 929 lbs CO2e per MWh.[49] Applying this to annual electricity savings of 1,346 MWh would yield annual greenhouse gas benefits of 567 MtCO2e.

Estimated Greenhouse Gas Benefits for Solar Panel Projects

Solar Panel Projects	Annual	Unit
Freeway Soundwall Project	269	MWh
Orange Line Project	1,077	MWh
Total Electricity Savings	1,346	MWh
Total Emission Reduction	567	MtCO2e

In addition, Metro can install solar panels on other buildings and transportation facilities to achieve more greenhouse gas emissions reductions. The agency can expect to achieve reductions proportional to the number of MW of solar arrays installed.

Cost

Based on the ODOT project, Metro estimated the cost of both projects at $13.5 million, or $11 per watt. These cost estimates do not include transmission and interconnection costs to connect to either the SCE or LADWP grids. In addition, the cost estimates have not been reduced by any potential utility rebates. By comparison, the cost of the MSSC project was about $9 per watt, inclusive of utility rebates.

Since the projects are likely to generate more electricity than Metro can use, the excess electricity could be sold using a feed-in tariff. One caveat is that a feed-in tariff cannot be used for a project that has received rebates. SCE's current feed-in tariff provides for payment of $0.10 per kWh over a 25 year period for a project that commences operation in 2010. LADWP does not yet have a feed-in tariff, but has proposed one to its Board of Commissions.[50]

If Metro is able to use of all of the electricity that is generated, the project would be eligible for utility rebates. The incorporation of rebates into the costs analysis is also complex because of how the rebates are structured. At the federal level, the government provides for a 2.1 cent per kWh production tax credit (PTC) for the first 10 years for a renewable energy (including solar) project. Because only private firms can receive tax credits (or grants, if the tax liability is zero), Metro would need a third party developer to install and own the project, similar to the MSSC project.

At the state/local level, rebates are provided by the utility through the state's California Solar Initiative. In SCE's territory, rebates for non-residential customers are currently set between $0.22 and $0.32 per kWh per monthly output for five years. In LADWP's territory, rebates are currently set as a one-time payment between $0.11 and $0.14 per kWh per project output. In both utility service territories, the actual rebate amount depends on if Metro or a third party developer chooses to incur the costs and receive the rebates. The higher rebate amounts per kWh correspond to government customers; the lower rebate amounts per kWh are for commercial customers/developers.

Based on an annual output of 1,346 MWh that Metro uses entirely, and assuming both projects are installed in SCE's territory, the annual rebate is estimated at about $300,000 for each of the first five years, for a total of about $1.5 million. If both projects are installed in LADWP's territory, the one-time rebate payment is estimated at about $2.7 million. Both rebate amounts assume that the projects are developed by a third party private firm, and assume the lower rebate amount per kWh.

Estimated Rebates

	LADWP Rebate	SCE Rebate
Rebate Type	One-time payment	Annual payment over 5 years
Rebate $ per kWh	$0.11	$0.22
Annual project output (kWh)	1,346,154	1,346,154
Calculation Factor[51]	18	5
Total Rebate	$2,665,385	$1,480,769

Cost Effectiveness

This analysis assumes that the solar panel projects are installed and project costs incurred in the first year. (In reality, it is likely that project costs will be financed through a loan, similar to the MSSC project). Electricity bill savings and utility rebate amounts are also included. Tax credits are not included because the benefits would go to a third party that would not necessarily share them with Metro. Revenues from feed-in tariffs are not included because the amount of excess electricity is unknown at this time. Electricity bill savings and greenhouse gas emissions reductions occur annually over the project lifetime, which is assumed to be 30 years, owing to the typical lifetime of the solar panel technology.[52]

Depending on the rebates received, Metro can reduce greenhouse gas emissions with this strategy for between $640 and $483 per ton. The inclusion of utility incentives reduced the cost per ton by between 12% and 24% from the gross costs (project costs less electric bill savings). Without rebates, the cost per ton could also be reduced through the use of tax credits and revenue from feed-in tariffs.

Cost Effectiveness by Rebate Scenario

	No Rebate	LADWP Rebate	SCE Rebate
Project Costs	$13,500,000	$13,500,000	$13,500,000
Electric Bill Savings	$2,607,404	$2,607,404	$2,607,404
Rebates	$0	$2,665,385	$1,346,301
Net Total Costs	$10,892,596	$8,227,211	$9,546,295
Cost/ton	$640	$483	$561

5. Other Strategies

Strategy: Wind Energy in Subway Tunnel

Description

This strategy reduces energy usage and greenhouse gas emissions by installing wind turbines at Metro subway stations. The energy generated by the turbines could be used in one of three ways; by individual stations, for propulsion power, or for export back to the electricity grid. The project would also develop a method to store energy. Metro is currently working with a third party firm to develop a proof of concept study.

An example of this type of project is being developed by the Greater Lafayette (Indiana) Public Transportation Corporation (GLPTC). The GLPTC applied for, and received $2.2 million in ARRA funding, as part as the US DOT's Transit Investments for Greenhouse Gas and Energy Reduction program. The grant will go towards the development and installation of wind turbines that is expected to offset most of the GLPTC's electricity use.[53] Using a 20 year lifetime, the GLPTC project has an estimated total cost of $0.15 per kWh (undiscounted). This is nearly twice as high as the project's annual cost savings of $0.08 per kWh.

Greenhouse Gas Benefits

Through a wind turbine project, Metro will reduce greenhouse gas emissions associated with the purchase of grid electricity. Total electricity savings will depend on 1) the quantity and size of the wind energy projects, and 2) the estimated 20 year lifetime of the wind turbines.[54] Metro has not yet estimated the amount of energy that could be generated by the wind turbine project.

Cost

Currently, Metro estimates a total project cost of $20 million. However, this cost estimate does not correspond to a specified power or electricity output. In addition, this cost estimate includes costs related to the proof of concept study and other project costs unrelated to the actual electricity output.

As with Metro's proposed solar projects, one barrier to this project relates to the use of feed in tariffs, which would be used to sell any excess electricity back to the grid, and rebates or incentives. Since the project is unlikely to generate excess electricity, Metro is more likely to want to take advantage of rebates and incentives rather than use a feed in tariff. SCE offers rebates through the state's Self Generation Incentive Program (SGIP) for wind turbine projects between 30 kW and 1 MW. The incentives range from $1.50 to $2 per kW, with the higher incentive amount for a project that includes advanced energy storage. LADWP does not offer rebates or incentives for wind energy projects, which would likely make the project unfeasible in LADWP's territory.

In addition to the state/local rebates, Metro would be eligible for the federal government's 2.1 cent per kWh production tax credit (PTC) for the first 10 years for a renewable energy (including wind) project. Because only private firms can receive tax credits (or grants, if the tax liability is zero), Metro would need a third party developer to install and own the project in order to take advantage of the federal tax credit.

Strategy: Battery Upgrade in CNG Buses

Description

This strategy uses new starting batteries to reduce idling time of CNG buses. Using conventional batteries, CNG buses must be pre-started before operation. This requires approximately two hours of idling time. However, by installing a new Odyssey battery, buses do not need to be restarted, which should reduce idling time and save fuel. Metro installed Odyssey batteries on a portion of its buses in the summer of 2008.

Note that a number of other strategies could reduce energy use and emissions associated with existing bus batteries, including low voltage disconnects and solar chargers to maintain battery health.

Greenhouse Gas Benefits

The Odyssey battery was expected to reduce daily idling by one hour per day or more. At an idling fuel consumption rate of two therms per hour, this strategy could eliminate 4.0 MtCO2e per bus annually. Applied to Metro's entire CNG bus fleet, the total greenhouse gas emissions reduction would be approximately 8,000 MtCO2e annually.

However, data collected by Metro show that there has been no demonstrated fuel savings when using the new batteries. The average fuel economy of the buses with the Odyssey battery, in terms of miles per CNG therm, was found to be nearly identical in the 18 months after installation as compared to the 12 months before installation. The reasons for this are unclear to Metro staff. Thus, we conclude that this strategy results in no greenhouse gas emissions reduction.

Cost

The Odyssey battery costs approximately 3.5 times more than a conventional battery ($250 versus $70); it lasts four times longer (4 years vs. 12 months). Thus, the net cost of this strategy is approximately zero – over four years, the cost of purchasing one Odyssey batter is nearly identical to the cost of purchasing four conventional batteries.

Strategy: Battery Electric Buses

Description

This strategy replaces conventional CNG buses with alternative technology, battery-electric buses (BEBs), in order to increase fuel economy and decrease energy use and greenhouse gas emissions. Electric vehicles have no tailpipe emissions and use less energy per mile than diesel or CNG buses.[55] In addition, the electricity used to charge BEBs can be derived from renewable energy sources. However, the technology has certain limitations that may limit its functionality in revenue service. One critical issue is the bus range. Metro buses require an operating range of

300 – 400 miles; the BEB technology currently being considered by Metro has a range of less than half that.

Since BEB technology is immature, there is insufficient data to analyze its cost-effectiveness quantitatively; instead this discussion will present a qualitative description of the technology's pros and cons. BEBs are currently being tested in a pilot program at Foothill Transit, with results expected in the near future.

Greenhouse Gas Benefits

Since BEBs are powered by an electric motor and battery pack, and are recharged using grid electricity rather than gasoline or diesel like hybrid electric buses, they have at least two advantages over CNG buses in reducing greenhouse gases. While quantitative tests have not confirmed these benefits in revenue service, these benefits can be expected based on the nature of each underlying technology and similar results in light-duty vehicle tests.

First, the fuel economy of BEBs, measured in miles per therm-equivalent, can be much higher than that of CNG buses. This is due to the efficiencies of vehicle operation, especially the engine's efficiency in converting fuel to mechanical power. While internal combustion engines such as those found in CNG buses are typically less than 40% efficient, electric motors achieve greater than 80% efficiency in operation. This difference can result in much greater fuel economy for BEBs than CNG buses, and is borne out in tests on pilot BEBs reported by the manufacturer, Proterra, which showed that its prototypes can achieve up to 17.5 miles per gallon of diesel equivalent.

Second, because BEBs are powered by grid electricity rather than natural gas, their carbon footprint will largely be determined by the carbon intensity of the electricity source. If the electricity is produced from renewable energy sources, such as wind or hydro-electric power, the greenhouse gas emissions of BEBs could be very low. However, the source of electricity is largely outside of Metro's control, and depends largely on decisions made by the electricity provider. In fact, if the electricity is sourced from high-carbon generation, the greenhouse gas benefits of BEBs may be entirely negated. The extent of Metro's influence on electricity providers is likely limited to locating BEB depots in areas that are serviced by cleaner utilities such as Southern California Edison.

Cost

Since BEBs are an emerging technology, their costs of ownership are extremely high, and are not indicative of the long-run costs once the technology becomes established. However, the long-run costs can be expected to be high for the following reasons:

- Capital costs will be dominated by the battery cost. In order to achieve the necessary range for revenue service, BEBs will require a large battery pack that will be prohibitively expensive at current prices.
- Periodic maintenance may be higher than CNG buses. The cost of maintaining the battery pack will be expensive. In order to maintain vehicle range, the battery pack will likely require replacement halfway through the bus' lifecycle.

- Operation costs may be high. Depending on fluctuations in the prices of electricity and natural gas, the costs of “fueling” BEBs may be much higher than that of conventional vehicles.

As a result of these factors, BEB capital, maintenance, and operation costs may be significantly higher than that of conventional CNG buses.

Cost Effectiveness

Because the benefits and costs of BEBs cannot be quantified at this time, it is not possible to calculate the cost-effectiveness of the technology. However, based on the possible cost impacts described above, the cost-effectiveness of BEBs is likely to be worse (greater $ per MtCO2e reduced) than existing mature technologies.

However, as an emerging technology battery-electric buses may still hold promise. The performance of newer-generation BEBs should be monitored for future application in Metro’s fleet.

Strategy: Hydrogen/CNG Blend in Buses

Description

This strategy retrofits conventional CNG buses to operate on a new fuel blend consisting of 80% natural gas and 20% hydrogen. These modified buses, dubbed hybrid hydrogen-compressed natural gas (HCNG) buses, have been shown to significantly reduce criteria pollutants such as NO_X. However, this technology is likely to have a larger carbon footprint than conventional CNG buses, due to the methods used to produce hydrogen fuel. Since HCNG bus technology has been primarily tested in the laboratory instead of in revenue service, and since it has not matured to the point of market penetration, it is difficult to accurately quantify its cost-effectiveness. Instead this discussion will present a qualitative description of the technology’s pros and cons.

Greenhouse Gas Benefits

HCNG buses are powered by a blend of CNG and hydrogen gas. This blend, and the accompanying engine modifications, has been demonstrated to reduce criteria pollutants such as NO_X. However, the greenhouse gas benefits of HCNG are likely to be negative.

From a tailpipe perspective, the fuel blend reduces CO2 emissions from the vehicle in operation. Since hydrogen gas is carbon free, its combustion does not produce CO2 as a waste product. As such, the blending of hydrogen with a carbon-rich fuel such as CNG will dilute the level of CO2 emissions.

However, the total greenhouse gas impacts of hydrogen fuel depend greatly on how it is produced. If the fuel is produced using a method known as electrolysis in combination with renewable electricity generation sources, then the carbon intensity of the fuel could be low. However, if the fuel is produced using traditional steam methane reformation methods, in which natural gas is combined with water to produce hydrogen and CO2, the carbon footprint is much higher than that of natural gas alone. According to the Argonne National Laboratory GREET model, hydrogen from steam methane reformation (SMR) is 35% more carbon intensive per therm of energy than natural gas.

Using current technology, nearly all large-scale hydrogen production uses steam methane reformation. Electrolysis is only used in small installations primarily for demonstration or light-duty use. If Metro were to invest in a fleet of HCNG buses with great hydrogen fuel demands, then it would likely source hydrogen using steam methane reformation methods. Under this scenario, greenhouse gas benefits evaporate – while the vehicle is consuming hydrogen in place of CNG, the hydrogen is produced from natural gas in the first place.

As such, the HCNG strategy would result in greater, not fewer, greenhouse gas emissions.

Cost

The HCNG strategy involves a mix of capital and infrastructure costs. On a per-vehicle basis, the up-front costs are low, since existing conventional CNG vehicles can be modified to run on HCNG. While the buses require a new fuel storage system, they can use the same engines, keeping costs relatively low.

However, any introduction of HCNG buses will require a source of hydrogen fuel. If Metro met this need by installing new hydrogen fueling structure, then the costs would be very high. However, if Metro could procure fuel from existing hydrogen facilities, or roll out this technology in conjunction with other hydrogen initiatives, then the infrastructure costs could be reduced or eliminated.

Cost Effectiveness

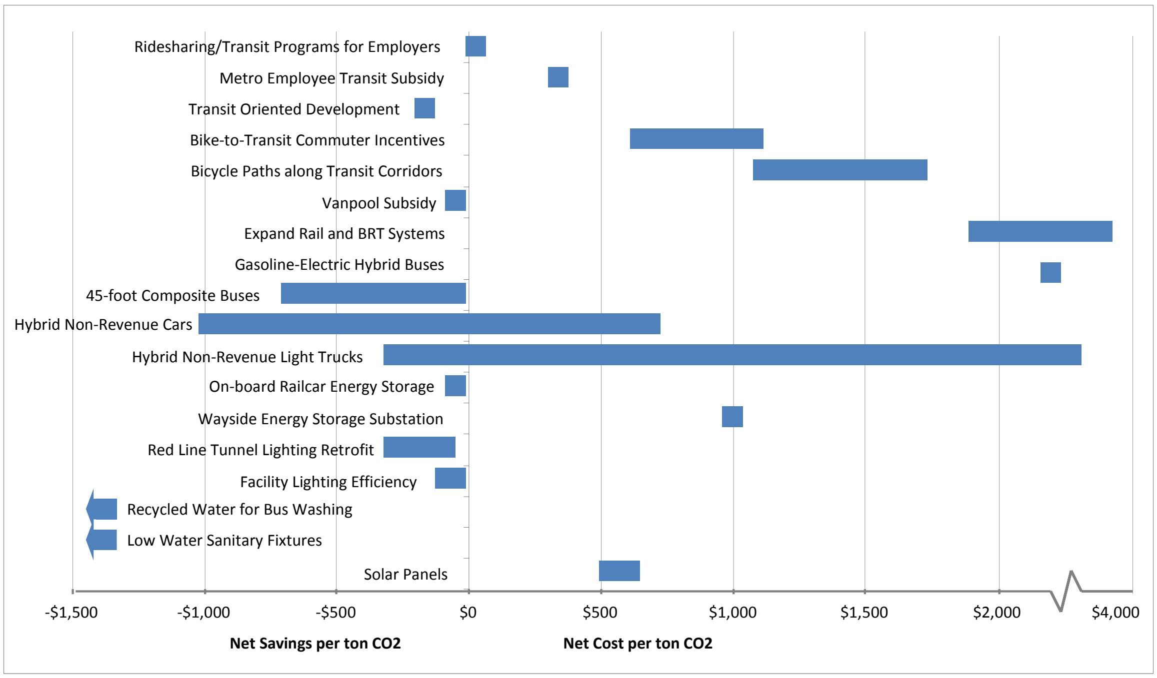
The viability of the HCNG strategy primarily depends on how hydrogen fuel is produced: if it is created using traditional SMR methods, then the technology will have a larger carbon footprint than conventional CNG buses. However, if the fuel is produced by electrolysis using electricity generated from renewable sources, then HCNG blends may have greenhouse gas benefits.

However, depending on the need for new hydrogen fueling infrastructure, the cost effectiveness of this strategy could be poor.

6. Summary of Results

The figure below shows the greenhouse gas reduction cost effectiveness of the strategies that could be quantified. For some strategies, the results are sensitive to a single parameter with a high degree of uncertainty. For these strategies, we estimated cost effectiveness as a range, depicted with solid long bars in the figure.

Summary of Greenhouse Gas Reduction Cost Effectiveness by Strategy



The figure shows that a variety of strategies can potentially reduce greenhouse gas emissions for Metro at low cost or a net savings. The most cost effective strategies appear to be:

- Ridesharing/transit programs for employers
- Transit oriented development
- Vanpool subsidy
- 45-foot composite buses
- Hybrid non-revenue cars
- On-board railcar energy storage
- Red Line tunnel lighting retrofits
- Facility lighting efficiency
- Recycled water for bus washing
- Low water sanitary fixtures

For strategies that result in a *net savings* to Metro, the cost effectiveness ratio can be misleading and should not be compared across strategies. In particular, it should not be assumed that a strategy with a $/ton ratio that is "more negative" than another is necessarily better. Consider, for example, two strategies that each save $1,000. Strategy A eliminates 10 tons of emissions, while strategy B eliminates 20 tons of emissions. In this case, Strategy B is preferable, even though its cost effectiveness (-$50/ton) is closer to zero than that of Strategy A (-$100/ton).

The table below groups the 17 strategies according to cost effectiveness and maximum emission reduction potential. As described in Section 4, the maximum emission reduction potential assumes expansion of some strategies that have, to date, targeted only a subset of Metro vehicles or facilities. For strategies that have a range of cost effectiveness values, we used a median cost effectiveness for the purposes of this table. The most desirable strategies are those that achieve a net savings and offer large greenhouse gas reductions.

Summary of Greenhouse Gas Reduction Cost Effectiveness and Maximum Annual Emission Reduction

	Cost Savings/ Cost Neutral	Moderate Cost ($300 - $900 per ton)	High Cost (> $1,000 per ton)
Large GHG Benefit (> 10,000 MtCO2e/year)	• Ridesharing/Transit Programs for Employers • Transit Oriented Development • Vanpool Subsidy • On-board Railcar Energy Storage		• Expand Rail and BRT Systems • Wayside Energy Storage Substation
Moderate GHG Benefit (1,000-10,000 MtCO2e/year)	• 45-foot Composite Buses • Facility Lighting Efficiency	• Metro Employee Transit Subsidy	• Bicycle Paths along Transit Corridors • Gasoline-Electric Hybrid Buses
Small GHG Benefit (< 1,000 MtCO2e/year)	• Red Line Tunnel Lighting Retrofit • Hybrid Non-Revenue Cars • Recycled Water for Bus Washing • Low Water Sanitary Fixtures	• Solar Panels • Bike-to-Transit Commuter Incentives	• Hybrid Non-Revenue Light Trucks

Endnotes

1 Los Angeles County Metropolitan Transportation Authority, "Moving Towards Sustainability: 2010 LACMTA Sustainability Report," June 2010.

2 American Public Transportation Association, "Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit" (2009).

3 Based on 2.07 billion passenger miles traveled and a mode shift factor of 47%, according to APTA, "Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit" (2009). Light-duty vehicle emission factors from EMFAC.

4 Baxandall, Phineas Tony Dutzik, and Joshua Hoen Frontier Group, A Better Way to Go: Meeting America's 21st Century Transportation Challenges with Modern Public Transit, California's Public Interest Research Group (CALPIRG) Education Fund, 2008

5 Southern California Association of Governments, "State of the Commute Report: 2006." (The commute mode share does not vary significantly between people working in LA County and people living in LA County, according to SCAG staff).

6 Southern California Association of Governments, "State of the Commute Report: 2006." Figure for LA County residents.

7 According to Table 8-3 and Table 6-6 of SCAG 2003 Model Validation and Summary, the average miles per vehicle trip in Los Angeles County is 205,104,000 VMT/20,081,851 trips =10.2 miles per trip

8 Los Angeles County Metropolitan Transportation Authority, "Towards a Sustainable Future: June 2010 Baseline Sustainability Report"

9 The actual fraction of Metro commuters is probably slightly higher to the extent that some subsidy recipients use other transit operators and then transfer to Metro service.

10 Source: Metro Joint Development Program

11 ICF International for U.S. EPA, "Evaluation of Compact Development as a GHG Reduction Strategy: 7 Case Studies", 2010

12 According to Table 8-3 and Table 6-6 of SCAG 2003 Model Validation and Summary, the average miles per vehicle trip in Los Angeles County is 205,104,000 VMT/20,081,851 trips =10.2 miles per trip

13 Pitkanen, Whitney, "MyGo-Pasadena: Demonstrating Small Electric Vehicles as Transit Connectors," 2008.

14 An initial survey of 24 participants found that 58% had previously driven for the entire trip. (Source: Pitkanen, Whitney, "MyGo-Pasadena: Demonstrating Small Electric Vehicles as Transit Connectors," 2008.)

15 Fehr & Peers, Metro Orange Line Mode Shift Study (draft), June 2010

16 See: http://www.seattlepi.com/business/63174_bend21.shtml

17 A 20 year lifetime is the average of typical lifetimes for bicycle/pedestrian facilities and for pavements, as provided in other studies. (Source: TRB Special Report 264)

18 American Public Transportation Association, "Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit" (2009).

19 To estimate how many of the trips are new to transit, we look at Metro's experience with opening new fixed guideway transit segments in the past. Metro conducted surveys of new riders on the Gold Line (2003) and the Orange Line (2006) after those lines opened. On average, 44% of trips on those two

lines represented a car trip removed from the road. In the absence of modeled estimates of mode shift, we assume that the new projects proposed would eliminate car trips at the same rate. This figure is comparable to the default mode shift factor that APTA proposes for large urban areas, 47%. (APTA, "Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit" (2009). The average rail trip length is calculating using data on passenger miles traveled and boardings on Metro's rail service in 2009, and assuming that the average rail trip includes 1.5 trip lengths (NTD 2009).

[20] Fuel savings estimate from Texas Transportation Institute, 2009 Annual Urban Mobility Report. Calculated according to APTA, "Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit" (2009).

[21] BASE Energy Inc., "Energy Efficiency Assessment of Bay Area Rapid Transit (BART) Train Cars," March 2007.

[22] Does not consider the possibility of these projects to transmit electricity directly to the rail lines. We estimate that the two solar panel projects would produce 1,346 MWh of electricity per year. In 2009, Metro's rail lines used 184 million kWh of electricity.

[23] In other studies of emission reduction strategy cost effectiveness, rail transit systems have been assumed to have a lifespan of 30-35 years. (Source: TRB Special Report 264)

[24] Weekday Vehicle Revenue Miles traveled by Metro's directly operated buses (Source: NTD 2009) * 50%. 50% of weekday vehicle revenue hours are scheduled between 6:40-9:00 AM and 3:00-6:40 PM. (Source: Trips in Motion database as of 4/13/10).

[25] We apply a mode shift factor of 47%, according to APTA's guidance for large urban transit systems. (Source: APTA, "Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit", 2009).

[26] Metro operates 2,084 buses at its maximum service level. (Source: NTD 2009).

[27] The capital cost of 2,084 buses amortized over the buses' lifetime at an interest rate of 5%.

[28] Average operating and maintenance cost for Metro's directly operated buses is $8.70 per mile (Source: NTD 2009).

[29] Average fare per passenger mile traveled is 19 cents (Source: NTD 2009).

[30] National Transit Database 2009.

[31] Turner, David et al, "Assessing and Measuring Benefits of Wayside Energy Storage Substations for the LACMTA Metro Gold Line," APTA Rail Conference, Chicago, June 14 – 18, 2009.

[32] BASE Energy Inc., "Energy Efficiency Assessment of Bay Area Rapid Transit (BART) Train Cars," March 2007.

[33] Based on existing efficient T8 and high-efficient T5 technologies. For more information, see http://www.cee1.org/com/com-lt/lamps-ballasts.xls

[34] Available at http://www.climateregistry.org/resources/docs/PUP_Metrics-June-2009.xls

[35] More information is available at http://www.dtsc.ca.gov/HazardousWaste/Mercury/upload/HWMP_FS_Fluorescent_Tubes_Trash.pdf

[36] Available at http://www.lrc.rpi.edu/programs/nlpip/lightingAnswers/t8/05-t8-lamp-life.asp

[37] More information is available at http://www.pge.com/includes/docs/pdfs/mybusiness/energysavingsrebates/incentivesbyindustry/agriculture/pge2001mo_collateral_factsheets_t8fluorescents.pdf

[38] Electricity supplied by LADWP, in whose service territory Division 10 is located, emits 1228 lbs CO_2 per MWh.

[39] Available at http://www.deeresources.com/

[40] DEER estimates the average unit cost of a T8/T5 lighting retrofit to be $52.60; this estimate includes materials costs of $20.93 and a labor cost of $31.67. The labor cost is estimated based on average wage of about $73 per hour, and an installation time of 0.43 hours, or slightly less than 30 minutes per fixture.

[41] DEER estimates the unit cost to be $220.50; this estimate includes material costs of $148.33 and a labor cost of $72.17 (based on 0.98 hours of labor).

[42] More information is available at http://www.ladwp.com/ladwp/cms/ladwp000572.jsp

[43] SCE currently offers a rebate of $5.50 per lamp (or $11 per two lamp fixture) for T8/T5 lighting retrofits. SCE also offers a rebate of $75 per fixture for the replacement of a 400 watt metal halide lamp and fixture with a more efficient fixture rated up to 250 watts. Similar to LADWP, SCE does not offer a specific incentive for an LED light fixture, but does offer a custom incentive for other lighting measures of 5 cents per kWh saved.

[44] Available at http://www.sce.com/NR/rdonlyres/369FBD31-31F6-4337-90DE-CCEFBD5ACB07/0/100125_SolutionsDirectory_Single.pdf

[45] More information is available at http://www.ladwpnews.com/posted/1475/ECAF_Board_Presentation_042910.527247.pdf

[46] 1 acre-foot ≈ 326,000 gallons of water

[47] From *Energy Down the Drain*, Pacific Institute and *Guide to Data & Methods for Cost-Effectiveness Analysis of Urban Water Conservation Best Management Practices*, California Urban Water Conservation Council. Note that we adjusted the energy intensity of facility showers to reflect an assumption that they are used 50% less than residential showers.

[48] Metro develops projects through a “design/build” mechanism, whereas Caltrans does not.

[49] Available at http://www.climateregistry.org/resources/docs/PUP_Metrics-June-2009.xls

[50] More information on this, and on feed-in tariffs in general, is available at http://labusinesscouncil.org/online_documents/2010/Designing-an-Effective-Feed-in-Tariff-for-Greater-Los-Angeles-040110.pdf The proposal consists of two tariff options, both of which are based on market prices. The first is a floating tariff that varies by time of day, day of week, and season. The second is a fixed tariff that provides a specified price per kWh for output over a 20 year period.

[51] LADWP’s calculation factor is the product of the project lifetime (set at 20 years) and the system degradation factor (set at 0.9). SCE’s calculation factor is the rebate payment period (set at 5 years).

[52] More information is available at http://www.oregon.gov/ODOT/HWY/OIPP/docs/solar_panel_lifecycle.pdf

[53] More information is available at http://citybusnews.blogspot.com/2009/09/citybus-awarded-grant-for-wind-energy.html

[54] More information is available at http://www.urbanwind.net/pdf/technological_analysis.pdf

[55] Transit Cooperative Research Program, “Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Operations,” TCRP Report 38, 1998.

Los Angeles County
Metropolitan Transportation Authority

One Gateway Plaza
Los Angeles, CA 90012-2952

213.922.9200 Tel
213.922.5259 Fax
metro.net

Metro®