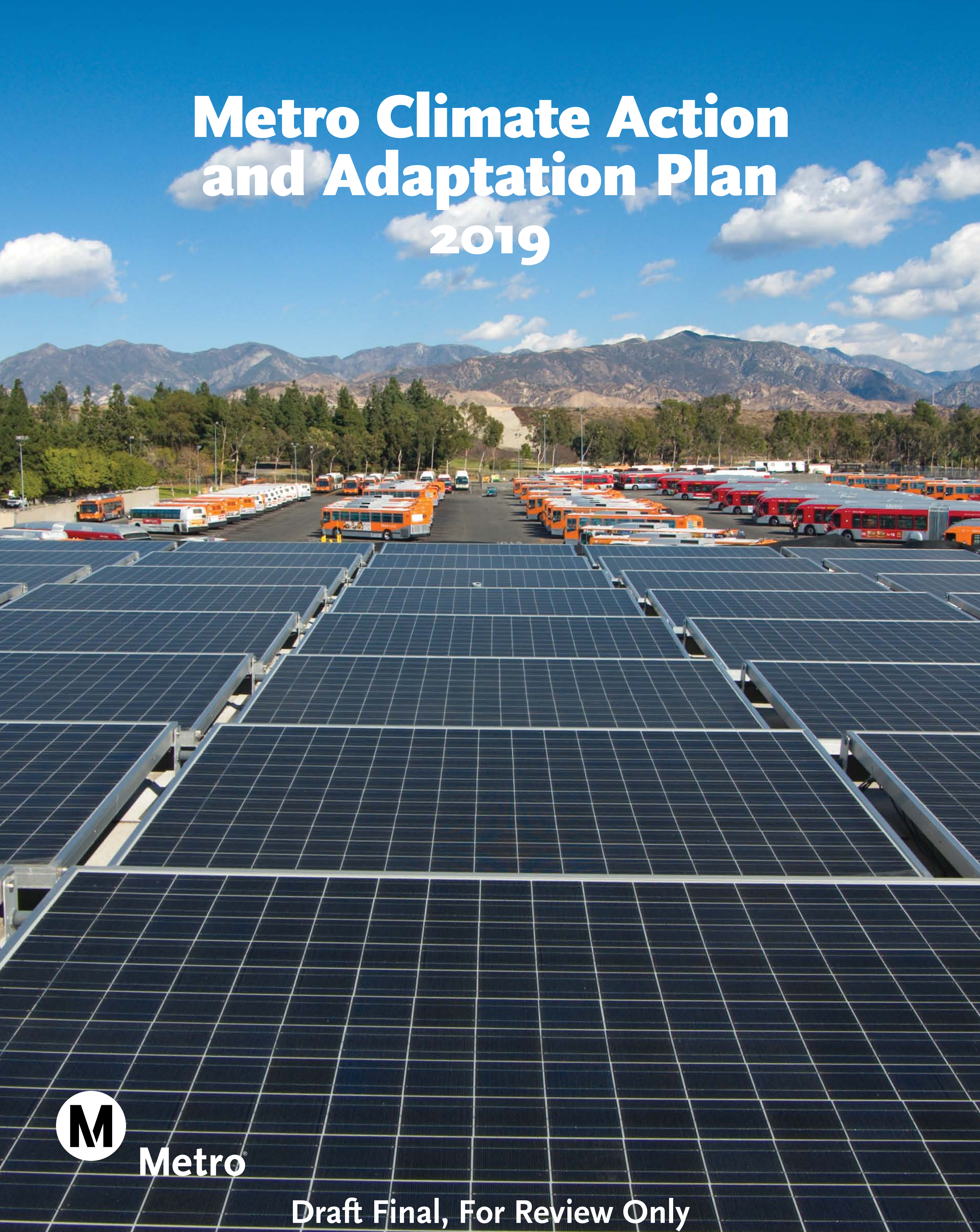
Metro Climate Action and Adaptation Plan 2019



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Acknowledgments

Metro's Environmental Compliance and Sustainability Department (ECSD) led development of this Climate Action and Adaptation Plan, and greatly appreciates the contributions of the following departments at Metro: Enterprise Transit Asset Management, Emergency Management, Safety, Communications, Operations, Engineering, and Countywide Planning and Development.

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Executive Summary

California's changing climate is creating a growing wave of risks to Metro's infrastructure, services, riders and employees. Extreme heat waves, landslides and mudslides, heavy rain and flooding, wildfires, rising sea levels and other hazards are expected to occur with more intensity or frequency as the climate changes. These hazards can in turn disrupt or delay services, threaten health and safety and lead to higher costs related to repair, maintenance and operations.

To ensure Metro can continue to provide vital mobility services to LA County as the climate changes, it is imperative to act now. Recognizing this urgency, this *2019 Climate Action and Adaptation Plan* (CAAP) builds on Metro's existing commitments to environmental and sustainability stewardship by creating a visionary path for minimizing contributions to climate change while building resilience to a changing climate.

Metro is Taking Action

Acting to Limit Climate Change

Metro is already on track to reduce contributions to climate change over the next several decades, but we need to do more to minimize the impact of transit and our operations on the environment. In this 2019 CAAP, Metro commits to reducing our greenhouse gas emissions by 79% relative to 2017 levels by 2030 and 100% (i.e., zero emissions) by 2050.

Achieving these goals will require bold action. Thirteen measures have been identified (see box at right) to reduce emissions from every aspect of Metro's operations. If fully implemented, these measures are projected to **avoid more than 416,000 metric tons of annual carbon dioxide emissions** (see Figure ES-1)–the equivalent of the annual emissions of more than 88,000 passenger vehicles,[1] while also providing net cost savings and environmental co-benefits like air quality and drought resilience.

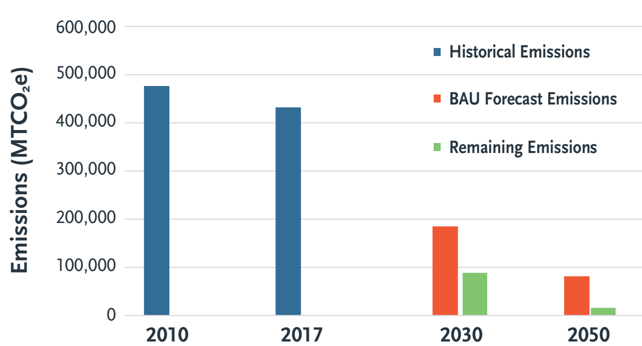
Metro commits to reducing our greenhouse gas emissions by 79% relative to 2017 levels by 2030 and 100% (i.e., zero emissions) by 2050.

Thirteen Measures to Achieve Zero Emissions by 2050

1. Switch directly operated buses to battery-powered technologies
2. Deploy battery-powered buses in the contracted fleet
3. Switch vanpool vehicles to battery-powered vehicles
4. Replace non-revenue vehicles with battery-powered vehicles
5. Install systems to store energy captured from trains
6. Buy 100% renewable energy
7. Install photovoltaic systems
8. Install water-saving fixtures
9. Install non-potable recycled water systems
10. Install LED lights at facilities
11. Install electric heating systems
12. Replace facility appliances with more efficient electric appliances
13. Install electric vehicle charging at Metro facilities and implement an employee electric vehicle outreach plan

Metro's new emission reduction targets build on progress already made. With the release of the first CAAP in 2012, Metro established a framework for reducing our greenhouse gas emissions and building resilience to minimize the impacts of climate change. Since then, Metro has transitioned our bus fuel to renewable natural gas, implemented energy-efficient lighting and expanded our on-site solar power installations. These changes, and an increasingly renewable electricity grid, drove Metro's greenhouse gas emissions down by nearly 12% from 2010 to 2017–despite a nearly 4% increase in service.

Figure ES-1: Forecasted Emissions with Metro's 13 Reduction Measures versus Business as Usual (BAU) Emissions



Thanks to Metro's ongoing efforts to adopt new transportation technologies, plus the impact of state and federal policies to reduce emissions from a variety of sectors, Metro projects emissions will continue to decline to 57% below 2017 levels by 2030 and 81% by 2050.

While this trajectory is substantial, it is not enough. More ambitious targets for greenhouse gas reduction are necessary to do our part to minimize the impacts of climate change. These 13 measures demonstrate major changes that will affect our fleets, energy supply, buildings and employee commuting practices. When combined with activities already planned by Metro and policies at the state and federal levels, these 13 measures will enable Metro to achieve the goals set forth in this CAAP.

[1] Estimated using US EPA's Greenhouse Gas Equivalencies Calculator, epa.gov/energy/greenhouse-gas-equivalencies-calculator.

Building Climate Resilience

Metro needs to plan now to ensure our systems and infrastructure can withstand the climate changes ahead. Building climate resilience is a risk-reduction strategy. Taking actions today can avoid major costs, disruptions to service and safety risks in the future. **Metro's goal is to create a climate-resilient organization and transit system prepared, ready and able to continue to provide services to the people of LA County no matter what the future brings**.

A climate-resilient Metro will plan proactively to reduce impacts due to climate change while ensuring climate resilience is pursued equitably across user groups and communities by: 1) **making climate resilience an organizational priority and integrating it throughout planning and daily operations**, and 2) **establishing a flexible approach to adaptation** that can be monitored and adjusted over time as scientists improve their understanding of climate change and its impacts.

Resilience thinking is already part of Metro's daily business culture. Most planning and building decisions already include climate-resilience implications, but there is more to be done. Metro will ensure climate resilience is considered more thoroughly when making decisions related to planning, designing, construction, procurement, internal protocols and more.

Metro understands that planning for an uncertain future is challenging. Changes in climate projections, population, land use, technology and other factors can influence how the Metro system is planned, used and operated. It is therefore important to develop solutions that can be implemented gradually and modified as new information becomes available, minimizing costs and disruptions to service.

Metro, along with a growing number of other agencies and jurisdictions, is pursuing an approach known as *flexible adaptation pathways,* a conceptual framework that can be used to guide decisions about where, when and how to select adaptation actions, while providing the flexibility to implement changes in the future. Using this approach will require Metro to identify and set thresholds for action, as well as metrics to evaluate system resilience.

The Path to Implementation

This CAAP reflects a major step forward on Metro's path to climate action. However, implementing the greenhouse gas reduction and resilience initiatives described in this Plan will require bold action and the marshaling of intellectual and creative capital, financial resources and cooperation. To effectively manage these changes, the following principles of implementation were developed to guide current and future generations of decision makers toward achieving the CAAP goals:

Metro's goal is to create a climate-resilient organization and transit system prepared, ready and able to continue to provide services to the people of LA County no matter what the future brings.

- Embrace climate leadership
- Secure funding and prioritize resources
- Integrate climate knowledge into existing decision-making processes
- Monitor and evaluate progress
- Engage with community stakeholders

With the support of Agency leadership, Metro staff and external partners, Metro's Environmental Compliance and Sustainability Department will facilitate implementation of the CAAP based on these five principles.

As Metro continues implementation, barriers to implementation and opportunities for improvement and acceleration will be continuously evaluated. Metro will seek out technological changes and innovative solutions that can further reduce greenhouse gas emissions toward a zero carbon emissions goal.

Annual reporting aligned with the goals set forth in this CAAP will provide transparency on Agency accomplishments, progress and timeframes. A robust assessment of the full Plan is scheduled for every five years from this publication.

What Metro's CAAP Means for LA County

Metro's goals—and the actions taken to achieve them—will contribute to a better future for LA County, its residents and the environment. Achieving Metro's greenhouse gas emission reduction goals will help limit climate change—directly through Metro's own actions and indirectly by setting an example for other transit agencies to follow.

Metro's goals to improve resilience will make sure the Agency does our part to ensure that LA County remains resilient to a changing climate through seamless coordination with our stakeholders throughout the County and the country, guided by Metro leadership.

1

Introduction

Metro's mission is to provide a world-class transportation system that enhances quality of life for all who live, work and play within LA County. Metro plays a vital role in reducing congestion on roadways, providing mobility to communities that cannot or choose not to drive to all destinations, and helping to create walkable, bikeable and connected communities. The services that Metro provides are essential to the region's future economic, social and environmental health.

Climate change creates risk for many of Metro's services, affecting communities and businesses that rely on them. More frequent or severe heat waves, flooding, rain, wildfire and other hazards[2] are expected to disrupt service, threaten rider safety and comfort and increase the cost of maintaining the vast Metro system. Therefore, Metro must proactively identify and address these risks and minimize their impact, both now and in the future.

[2]Hall et al. 2018.

This CAAP identifies the actions Metro is currently taking to combat climate change and its effects through two broad strategies:

1. Reducing Metro's greenhouse gas (GHG) emissions, which contribute to climate change, and
2. Making the Metro system more resilient to extreme weather events and long-term climate impacts.

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1.1
Purpose of this CAAP

Why a CAAP?

The CAAP is the cornerstone to achieve a more sustainable and resilient Metro and LA County. Metro has worked to embed climate action into systems, assets and operations to create a resilient and forward-thinking Agency prepared for a changing future. This update sets ambitious goals for the near and long term and contributes to broader efforts to ensure Metro's ability to continue providing essential services regardless of future conditions. This CAAP update also serves to harmonize GHG and resilience goals with broader Agency goals and priorities set forth by other Metro documents, including the *Equity Platform Framework*, *Program Management Plan,* business continuity plans, *Vision 2028 Strategic Plan* and *Long Range Transportation Plan.*

This CAAP seeks to:

> Provide an update on what Metro has accomplished and how approaches to climate action have changed since the 2012 CAAP
> Summarize current and projected GHG emissions from Metro operations
> Describe how climate change could affect Metro's system and operations
> Identify steps to reduce emissions and increase resilience to climate change

CAAP in Context

Metro released the first CAAP in June 2012, establishing a framework for reducing greenhouse gas emissions and building the Agency's resilience to the effects of climate change. Since then, voters passed Measure M (the LA County Traffic Improvement Plan) in 2016 and Metro released *Vision 2028 Strategic Plan* in 2018.

Since 2012, Metro has implemented many of the recommendations from the first CAAP.

Metro is continuously evaluating ways to play an effective role in LA's vitality as the region's needs and challenges evolve over time. This new CAAP will fine-tune Metro's climate action and adaptation efforts, optimizing sustainability and ensuring Metro is ready to handle the impacts of a changing climate.

How Metro Will Use this Plan

The CAAP will guide decision-making, and planning, policy development, staff training, funding and other project priorities including state-of-good-repair maintenance and upgrades. More specifically, Metro will use the CAAP to:

> Inform and align long-range Agency planning, including Metro's *Equity Platform Framework, Program Management Plan, Vision 2028 Strategic Plan, All-Hazard Mitigation Plan* and the *Long Range Transportation Plan*
> Guide the development of processes to ensure implementation of climate actions
> Influence asset and project planning, design, standards and procurement decisions
> Incorporate climate risk mapping into Agency-wide data sharing processes and databases
> Prioritize adaptation efforts in the region's most vulnerable communities
> Lay groundwork for a decision-making process that proactively recognizes challenges and can evaluate decisions based in part on their long-term costs and associated risks
> Leverage opportunities for engagement and collaboration on climate action and adaptation throughout the County
> Educate Metro staff, community partners and riders about the importance of GHG mitigation, climate resilience and the actions Metro is taking in these areas

See Chapter 4 for details on how Metro will execute CAAP goals.

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Who else is this CAAP for?

The CAAP is a tool to establish and communicate Metro's climate change risks and priorities within the Agency, to Agency partners throughout the region and to the broader LA community. This communication aims to raise awareness and understanding, a vital first step toward embedding climate action and adaptation at all levels of the organization.

The CAAP is one way Metro can share priorities for tackling climate change with our stakeholders – riders, surrounding communities and third-party partners – to optimally assess risks, prioritize projects and strategically implement the measures outlined in this Plan.

Building on the 2012 CAAP

The greenhouse gas emissions inventory builds on the methodology used in 2012 to allow direct comparison, but the mitigation and adaptation analyses in this Plan expand on the previous work in several ways. This Plan:

> Considers several new mitigation measures based on industry best practices, robust modeling and stakeholder engagement.

> Evaluates risk from four additional climate hazards.

> Emphasizes flexible adaptation pathways for evaluating and selecting appropriate adaptation actions.

1.2
Metro's Role in Municipal and State Climate Action

California is a leader in advancing progressive policies that set the standard for effective air and climate programs, but transportation remains the state's largest source of GHG emissions.[3] By getting people out of their cars, transit agencies play a unique role in helping to reduce emissions from the transportation sector.

Located in the nation's most populous county, Metro helps reduce GHG emissions from transportation by providing a high-quality transit system that is expanding in size and scope while improving transportation services.

Every molecule of carbon dioxide emitted to the atmosphere remains for an average of 100 years, trapping heat and contributing to climate change. That means every effort to reduce emissions – no matter how small – makes a difference, which is why Metro is committing to a zero-carbon future. Additionally, given that a single bus or train can carry as many people as 50 cars with a fraction of the emissions, Metro also has a responsibility to reduce GHG emissions by increasing ridership as a means to slow future impacts of climate change.

To increase ridership, continuity in service is essential. Therefore, Metro also has a responsibility to prepare for future climate hazards. Los Angeles cannot be resilient if Metro is not resilient.

Metro is taking the necessary steps to integrate GHG mitigation and climate resilience into Agency planning, building, operating and maintaining of infrastructure, assets and human capital.

Reducing Emissions While Expanding Service

Between 2010 and 2017, Metro service levels increased by 4%–yet Metro GHG emissions fell by 12%. By adding more rail, phasing out diesel buses and increasing the use of renewable fuels, Metro has expanded service while reducing emissions.

As part of CAAP development, employees host community outreach to find out what is most important to riders

Metro's activities make it possible to realize broader efforts by the City, county and state to advance action on climate change.

LA County adopted a Community Climate Action Plan as part of the *Los Angeles County General Plan* 2035. In that plan, LA County commits to mitigating GHG emissions from community activities by 11% below 2010 levels by 2020.[4]

California passed climate mitigation legislation to:

> Reduce GHG emissions to 1990 levels by 2020 and 40% below 1990 levels by 2030
> Reduce short-lived climate pollutants like methane by 40 – 50% below 2013 levels by 2030
> Procure 60% of all electricity from renewable sources by 2030 and 100% by 2045
> Raise money through an increased gasoline tax for transportation projects including improvements in efficiency and emission reduction
> Set regional GHG emissions targets and use the regional transportation planning process to achieve reductions in emissions
> Direct at least 25% of state cap-and-trade revenues to projects that benefit disadvantaged communities

[3]CARB mission statement (ww2.arb.ca.gov/about); and CARB 2018.
[4]LACDRP 2015.

The state has also passed resilience-focused legislation to:

> Require publication and regular updates to a statewide climate adaptation strategy, known as the Safeguarding California Plan
> Establish a statewide Integrated Climate Adaptation and Resilience Program
> Require local governments to include adaptation and resilience strategies in general plans
> Require state agencies to account for climate change when planning new infrastructure

In addition to the efforts listed above, the state has established a Climate Change Scoping Plan, Renewables Portfolio Standard, Low Carbon Fuel Standard, Green Building Standard and Greenhouse Gas Reduction Fund.

By reducing transportation emissions, Metro is uniquely positioned to advance and help realize these larger GHG reduction and climate resilience goals.

Resilience at Metro and Beyond

A resilient transit system is the foundation for a resilient community. Metro involvement with local and state resilience initiatives such as the City of LA's Resilience Strategy and the state's Climate-Safe Infrastructure Working Group helps build a resilient LA and California.

1.3
Process for Developing the CAAP

Metro built upon the 2012 CAAP to identify additional mitigation opportunities, better understand areas of vulnerability and take a more systematic approach to resilience. Metro used this information to expand the CAAP in key areas, including:

- Introducing adaptation pathways to help create flexibility in project decision-making (see Section 3.3);
- Expanding stakeholder outreach through the Environmental Management System, the Sustainability Council, Growing a Greener Workforce Program and rider surveys; and
- Improving Agency monitoring of GHG emissions.

Metro will use findings and recommendations described in this CAAP to inform ongoing efforts that relate to climate change mitigation and resilience. The CAAP is just one part of a broader initiative within Metro to promote sustainability, reduce energy use and emissions and increase Agency resilience (see Figure 1-1). Emissions reductions and increased resilience accomplishments will be reported in the next CAAP and tracked closely through Metro's sustainability reports. In this way, Metro can continuously improve systems for the benefit of riders, employees, partners and surrounding communities.

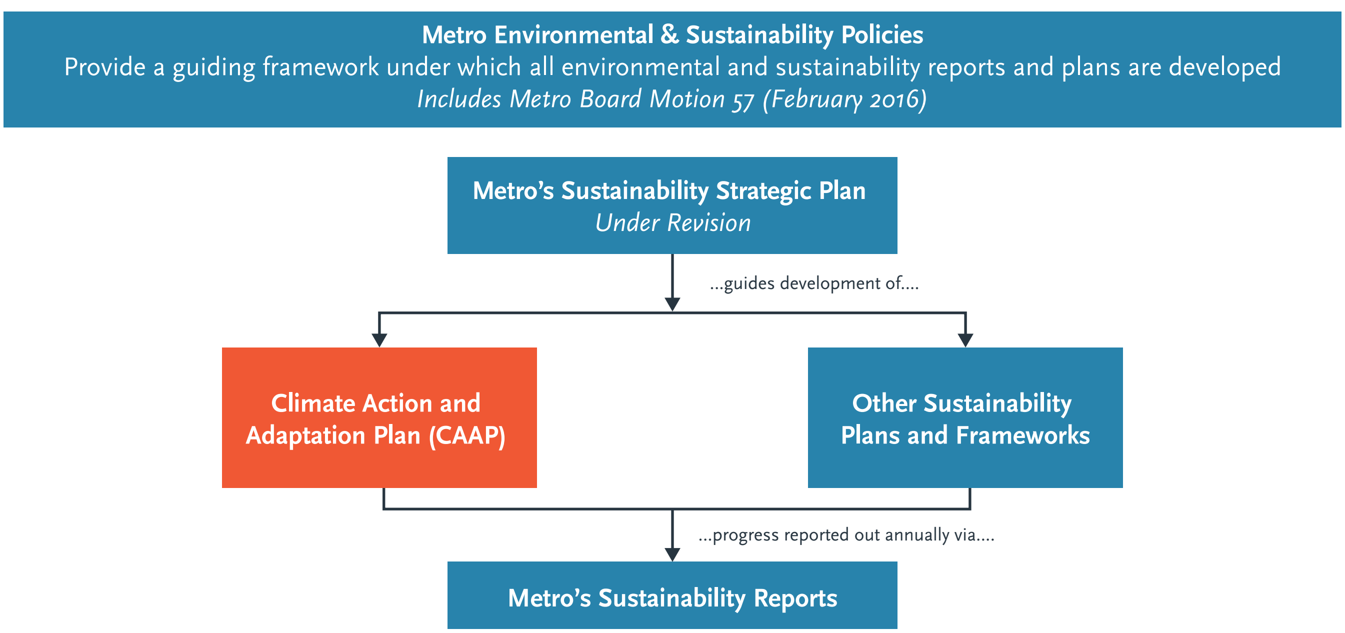
Engaging Riders

In 2019, Metro conducted the first ridership survey on climate change (see Appendix E) asking for impressions and concerns related to climate risks, including information on how extreme weather events affect riders' comfort and convenience. Findings include:

- 61% of respondents thought bus stops need more shade
- Almost half of respondents experienced delays during extreme heat days or heavy rain events
- Riders want Metro to do more to ensure passenger comfort during hot or rainy days

Metro will use these findings to help prioritize future initiatives. Metro plans to conduct similar surveys to ensure riders' concerns and perceptions are received regularly and that efforts to address these concerns are effective.

Figure 1-1: Metro Initiatives Related to Climate Mitigation and Resilience



1.4
What this CAAP Includes

Greenhouse Gas Emissions Inventory, Forecast and Reduction Strategies (Chapter 2)

Inventory: This is an accounting of GHG emissions from Metro activities in 2017, including how emissions have changed since 2010. The inventory also covers the amount of emissions Metro displaces or avoids by providing alternatives modes of transportation in LA County.

Forecast: Description of how Metro emissions are expected to change by 2030 and 2050 under a Business as Usual (BAU) scenario. BAU includes all existing or projected operations based on existing Metro policies and approved plans. The forecast also projects how emissions displaced by Metro might change in the future.

GHG reduction strategies: The GHG reduction analysis evaluates strategies for reducing operational emissions beyond those projected under the BAU scenario. The analysis estimates how much these strategies could reduce emissions, what they would cost, and what co-benefits they could achieve.

Assessing and Planning for Climate Change Risks (Chapter 3)

Risk assessment: Despite global efforts to reduce GHG emissions, the climate is already beginning to change. Scientists have concluded that some degree of climate change is unavoidable in the years and decades ahead. Therefore, a risk assessment identifies where and how the Metro system is at risk to potential and anticipated impacts of climate change.

Flexible adaptation pathways: A description of the flexible adaptation pathways model adopted by the state to help evaluate, select and phase in the most appropriate combination of actions, including local examples.

Implementing Climate Change Action (Chapter 4)

Recommendations for implementing this CAAP include five key principles to guide implementation actions and immediate next steps.

Metro plans to track and monitor progress on CAAP goals and measures through an annual report, the *Energy and Resource Report* (soon to be integrated with *Metro's Countywide Sustainability Planning Policy Annual Report* to create a joint agency-wide sustainability report) with an update to this CAAP every five years to revisit goals and targets over the long term.

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Greenhouse Gas Inventory, Forecast and Mitigation Efforts

GHG inventories are critical tools for reducing emissions. Inventories allow Metro to understand the drivers and sources of emissions, set targets and track progress toward reduction goals. Since 2007, Metro has tracked the GHG emissions generated from our activities as well as regional emissions that are displaced by Metro's transit system. Metro reports these emissions annually in the *Energy and Resource Report*.[5]

Metro's 2012 CAAP identified mitigation actions to reduce emissions and Metro has since taken several steps to reduce GHG emissions, including implementing energy-efficient lighting retrofits, expanding on-site photovoltaic installations and transitioning bus fuel to renewable natural gas (RNG).

Although these actions have contributed to a decrease in emissions, Metro is dedicated to further reducing GHG emissions produced from our own activities. Developing a new inventory and creating a forecast will help us do that.

[5] The 2017 emission results presented in this CAAP differ slightly from the results presented in the 2018 Energy & Resource Report. The differences are largely due to this CAAP's inclusion of additional source categories (i.e., employee commuting and land use) as well as the use of utility-specific consumption data and emission factors rather than a regional electricity emissions factor. In addition, updates were made to the mode shift factor used to calculate displaced emissions, based on updated guidance from the American Public Transportation Association.

2.1
Overview of Inventory Scope and Approach

Metro GHG emissions include those produced by Metro buildings and vehicles and buildings owned by or operated on behalf of Metro. This assessment looks at GHG emissions only and does not quantify changes in other local air pollutant emissions (e.g., nitrogen oxides, particulate matter).

Metro emissions can be understood as two main types:

> **Transit emissions**: Refers to emissions directly associated with moving passengers on Metro's transit system, which includes emissions from rail, bus and vanpool vehicles
> **Non-modal emissions**: Refers to emissions not directly associated with moving passengers, which includes emissions from support "non-revenue" vehicles, facility electricity and natural gas consumption, water consumption, refrigerant use and employee commuting

By providing Angelenos with alternative modes of transportation, Metro avoids GHG emissions. Such displacement utilizes specific processes characterized as:

> **Mode shift**: Represents emissions avoided when access to transit enables moving from the use of private vehicles to public transit
> **Land use**: Represents emissions avoided when access to transit enables denser land use patterns that promote shorter trips, walking and cycling and reduced car use and ownership[6]

Inventory

The CAAP inventory provides data on four main types of GHGs:

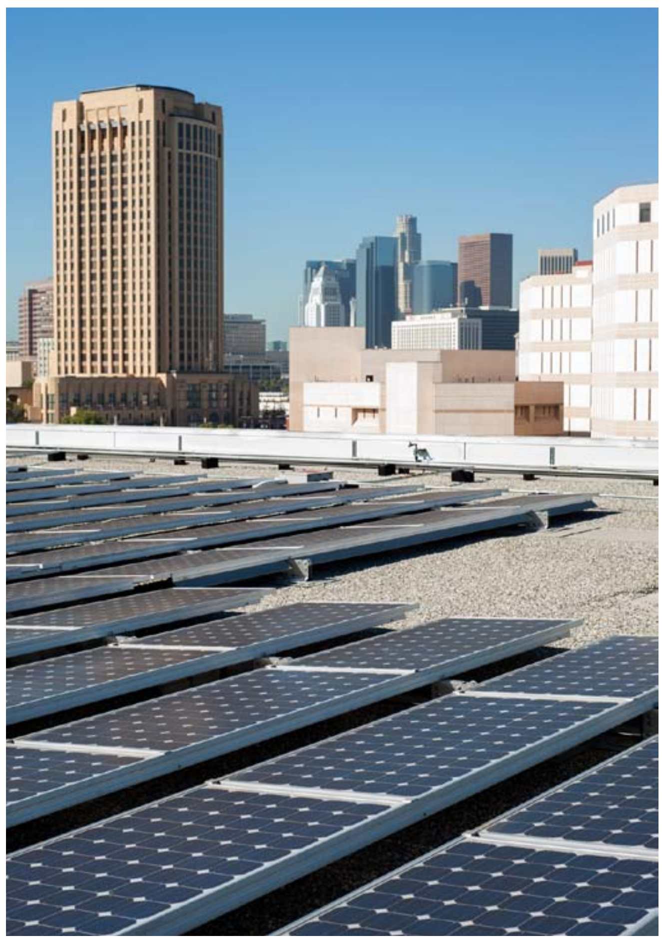
> Carbon dioxide (CO_2)
> Methane (CH_4)
> Nitrous oxide (N_2O)
> Hydrofluorocarbons (HFCs)

Each gas behaves differently in the atmosphere and has a unique impact on climate. For example, 1 ton of CH_4 warms the planet as much as 28 tons of CO_2. Global warming potentials (GWPs) are used to express all gases as an equivalent amount of CO_2. To allow for comparison, emissions for all gases are expressed in terms of metric tons of carbon dioxide equivalent ($MTCO_2e$). Table 2-1 shows the GWPs used in this Plan.

Emissions Not Included in this CAAP's GHG Assessment

The GHG inventory, forecast and mitigation analysis is limited to emissions that are directly controlled by Metro. Therefore, emissions from upstream sources, including from purchased goods such as vehicles, fuel extraction, refining and transportation, waste disposal, construction projects and carbon sinks from tree planting and landscaping are excluded.

Metro will seek opportunities through future sustainability planning efforts to research and analyze these emission sources.



[6]The American Public Transportation Association's Recommended Practice for Quantifying and Reporting Transit Sustainability Metrics does not currently include displacement from land use in its sustainability metric for greenhouse gas emissions. APTA recognizes a third source of displaced emissions, congestion reduction benefits, but currently offers no methodology for measuring such benefits due to a lack of consensus within the industry.

This inventory was developed using the American Public Transportation Association's *Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit*[7] and the Climate Registry's *General Reporting Protocol for the Voluntary Reporting Program*.[8]

Forecast

The emissions forecast is based on a Business as Usual (BAU) scenario that considers projected growth in mobility services currently planned or under construction, accounting for the ongoing transition of Metro's bus fleet to lower-carbon fuel sources and initial efforts to implement zero-emission vehicle (ZEV) technologies.

The BAU scenario takes into account impacts from existing national and statewide policies, highlighting how legislation affects Metro operations. Appendix A provides a detailed description of the methodologies, assumptions and data sources used to prepare the inventory and forecast.

Table 2-1: Global Warming Potentials (GWPs) Used in this Plan

Gas	GWP
CO_2	1
CH_4	28
N_2O	265
HFC-125	3,170
HFC-134a	1,300
HFC-143A	4,800
HFC-32	677

Source: IPCC 2014.
Note: GWPs are for a 100-year time horizon.

Metro's Vehicle Fleets

This CAAP assesses emissions from Metro's diverse fleet both now and in the future. Metro has varying levels of control over our fleet:

> **Directly Operated Bus Fleet**: About 2,400 buses owned and directly operated by Metro

> **Rail Vehicle Fleet**: 104 heavy rail cars and 203 light rail cars operated on six Metro rail lines

> **Non-Revenue Fleet**: 1,500 vehicles that support Metro operations but do not carry transit passengers

> **Contracted Bus Fleet**: 175 buses operating under contract with Metro

> **Vanpool Fleet**: 1,300 vanpool vehicles leased and operated by third parties subsidized through the Metro Vanpool Program

Metro also uses a variety of vehicle types and fuel sources:

> **Internal Combustion Vehicles**: Vehicles using diesel, gas and compressed natural gas (CNG) in operations

> **Electric Vehicles**: Rail vehicles operating on electricity delivered by overhead catenary or third-rail systems, and battery electric buses (BEBs) and battery electric vehicles (BEVs) powered by electricity stored in a battery

[7] APTA 2018.
[8] TCR 2016a.

2.2
Metro's Greenhouse Gas Emissions

This section summarizes Metro's GHG emissions, including a discussion of recent trends and emission projections under the BAU scenario.

2017 Emissions Inventory

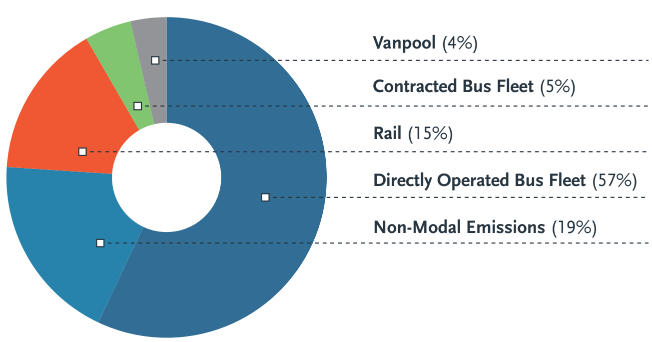
In 2017, Metro emitted an estimated 432,337 $MTCO_2e$ from operational activities. As shown in Table 2-2, transit emissions accounted for the largest portion of emissions, representing 81% of total emissions. The directly operated bus fleet accounted for more than two-thirds of these emissions and more than half of total emissions (see Figure 2-1). Non-modal emissions accounted for the remaining 19% of total emissions.

Table 2-2: 2017 Metro Emissions by Source

Emissions Source	Total Emissions ($MTCO_2e$)	Percent of Total
Transit Emissions	350,065	81%
Rail	67,526	16%
Directly Operated Bus Fleet[a]	246,471	57%
Contracted Bus Fleet	20,365	5%
Vanpool	15,703	4%
Non-Modal Emissions	82,272	19%
Non-Revenue Vehicles	9,730	2%
Facility Electricity	42,575	10%
Facility Natural Gas	5,519	1%
Water Consumption	757	0.2%
Refrigerants	9,844	2%
Employee Commuting	13,847	3%
Total	**432,337**	**100%**

[a] Includes emissions from the electricity consumed for compressed natural gas (CNG) compression.
Note: Totals might not sum due to independent rounding.

Figure 2-1: Metro Emissions by Mode, 2017



2010 to 2017 Emissions Trends

Metro's emissions decreased by approximately 12% (57,998 $MTCO_2e$) from 2010 to 2017, despite a nearly 4% increase in service, measured in vehicle revenue miles (VRM), during the same period. This decline was driven primarily by a reduction in bus VRMs (16%), the phase out of diesel buses and transition to RNG, and a transition to lower-carbon fuel sources used to generate electricity from the grid.

These changes more than offset increases in emissions from building energy use, vanpool service and refrigerants. Table 2-3 summarizes the change in emissions from 2010 to 2017 by source.

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Table 2-3: Changes in Metro Emissions, 2010 to 2017

Emissions Source	2010	2017	Percent Change
Transit Emissions ($MTCO_2e$)	426,710	350,065	-18%
Rail	92,229	67,526	-27%
Directly Operated Bus Fleet[a]	303,215	246,471	-19%
Contracted Bus Fleet	18,965	20,365	7%
Vanpool	12,301	15,703	28%
Non-Modal Emissions ($MTCO_2e$)	49,778	68,425	37%
Non-Revenue Vehicles	8,924	9,730	9%
Facility Electricity[a]	25,051	42,575	70%
Facility Natural Gas	6,771	5,519	-18%
Water Consumption	294	757	157%
Refrigerants	8,722	9,844	13%
Electrical Equipment[b]	16	NE	NA
Total	**476,488**	**418,541**	**-12%**

NE = emissions are not estimated; NA = not applicable.
[a] Emissions from CNG compression in 2010 are captured under facility electricity emissions. Emissions from CNG compression in 2017 are captured under the directly operated bus fleet.
[b] Information on sulfur hexafluoride (SF_6) leakage from circuit breakers owned by Metro was not available for 2017; these emissions are therefore not included in the 2017 estimates.
Notes: Emissions from employee commuting were not previously estimated for 2010 and therefore are excluded from this comparison. Totals might not sum due to independent rounding.

Emissions Forecast for 2030 and 2050

Under the BAU scenario, Metro emissions are projected to decrease by 57% in 2030 (185,225 $MTCO_2e$) and 81% in 2050 (81,529 $MTCO_2e$) relative to 2017. Table 2-4 summarizes emissions in 2017, 2030 and 2050 by source, showing that most reductions are projected to result from decreases in emissions from directly operated bus fleet and rail, which derive primarily from expansion of RNG use through 2020.

Table 2-4: Metro Emissions Forecast by Source

Emissions Source	2017	2030	2050
Transit Emissions ($MTCO_2e$)	350,065	106,469	37,148
Rail	67,526	58,162	–
Directly Operated Bus Fleet[a]	246,471	17,676	8,197
Contracted Bus Fleet	20,365	18,363	18,363
Vanpool	15,703	12,268	10,588
Non-Modal Emissions ($MTCO_2e$)	82,272	78,756	44,381
Non-Revenue Vehicles	9,730	7,146	6,327
Facility Electricity	42,575	37,823	–
Facility Natural Gas	5,519	9,036	14,125
Water Consumption	757	662	–
Refrigerants	9,844	13,407	13,605
Employee Commuting	13,847	10,682	10,324
Total	**432,337**	**185,225**	**81,529**

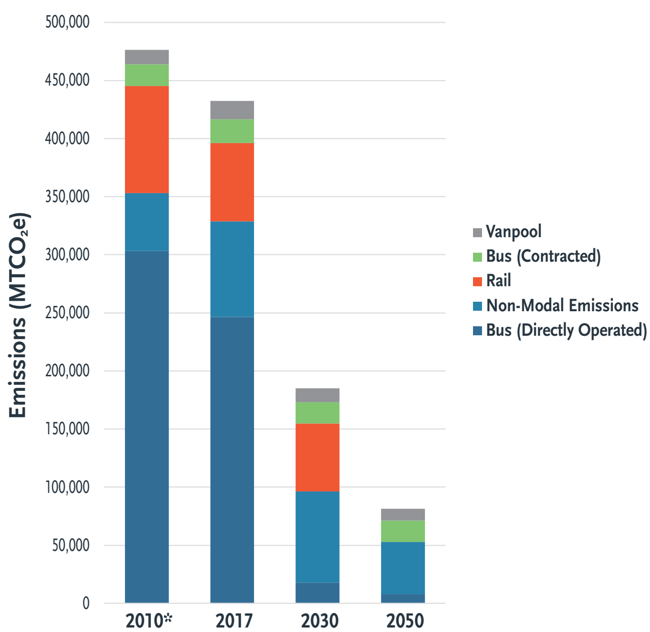
[a] Includes emissions from the electricity consumed for CNG compression.
Note: Totals might not sum due to independent rounding.

Metro's adoption of new technologies alongside both state and federal regulations will continue to play a major role in reducing emissions through 2050. Metro estimates that emissions from rail, facility electricity and water consumption will be zero by 2050 due to compliance with California Senate Bill 100, which requires all retail electricity sales and all state agency electricity procurements to be supplied by eligible renewable energy and zero-carbon resources by the end of 2045.

Under the BAU scenario, Metro emissions are projected to decrease by 57% in 2030 and 81% in 2050 (81,529 $MTCO_2e$) relative to 2017.

Emissions from vanpool, non-revenue vehicles and employee commuting are all projected to decrease based on the federal Corporate Average Fuel Economy (CAFE) standards.[9] Emissions from Metro bus fleets will also decrease as a result of current efforts to transition to lower-carbon fuels and ZEV technologies. Emissions from refrigerants are projected to increase, but are estimated to be lower than they otherwise would be in the absence of California State Bill 1013, which prohibits the future use of HFCs in certain end-uses, including building air conditioners. Figure 2-2 presents emissions for 2010 and 2017, and projected emissions for 2030 and 2050 by mode.

Figure 2-2: Metro Emissions Forecast by Mode under



BAU Scenario

* Emissions from employee commuting were not previously estimated for 2010 and therefore are not included in non-modal emissions for 2010.

[9] EPA and NHTSA 2012.

2.3 How Metro Is Displacing Emissions

Although Metro generates GHG emissions, we also contribute to GHG displacement by providing alternative modes of transportation. This section summarizes current and projected future emissions avoided by Metro's transit services.

2017 Displaced Emissions

Since 2012, Metro has consistently displaced more emissions than we've produced. In 2017, Metro transit services avoided roughly one million $MTCO_2e$. An estimated 20% of these emissions were avoided as a direct result of individuals taking Metro rather than driving. The remaining 80% were avoided as an indirect result of land use patterns resulting from the existence of transit service.

Research indicates that transit systems lead to more compact development, also known as the *land use effect*. This, in turn, results in more walking, cycling and less driving, even by those who do not use transit.[10] When thinking regionally, transit ridership translates to avoided GHG emissions.

Forecast of Displaced Emissions for 2030 and 2050

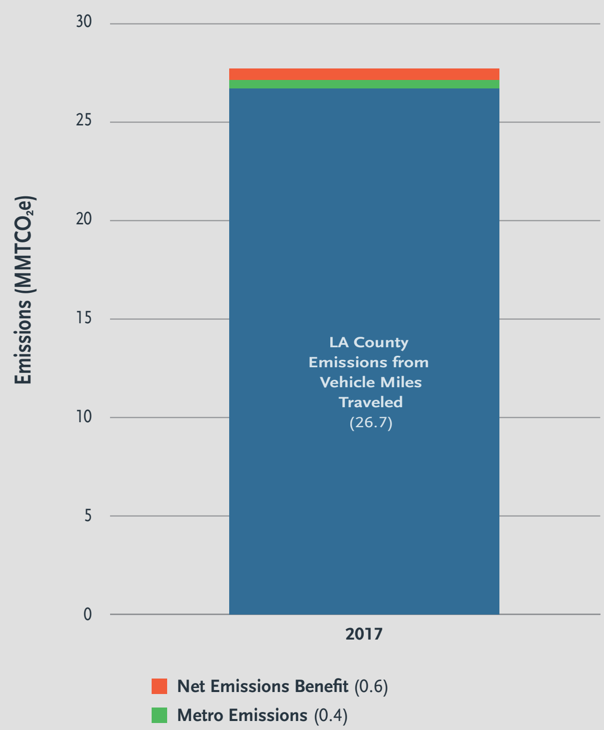
The BAU scenario developed to forecast Metro emissions was also used to forecast emissions displaced by Metro. Metro expects planned system expansion will attract additional ridership (increasing passenger miles traveled by 21% in 2030 and 29% in 2050) and thus contribute to more emissions avoided from mode shift and land use changes. However, because of vehicle fuel efficiency standards for private vehicles, displaced emissions are projected to decrease by 12% in 2030 and 15% in 2050 relative to 2017. Therefore, it is necessary to increase ridership further to keep pace with current GHG displacement. Table 2-5 and Figure 2-4 summarize displaced emissions in 2017, 2030 and 2050 by source.

Metro expects planned system expansion will attract additional ridership, increasing passenger miles traveled by 29% in 2050. However, because of vehicle fuel efficiency standards for private vehicles, displaced emissions are projected to decrease by 15% in 2050 relative to 2017.

Regional Context

Metro's overall emissions impact was compared with emissions from private vehicles in Los Angeles. Private vehicles in LA County emitted roughly 26.7 million $MTCO_2e$ in 2017.[a] However, because Metro has an overall net greenhouse gas benefit, regional emissions from passenger travel (emissions from private vehicles and public transit) in the absence of Metro's transit system would have been 3.7% higher (27.7 million $MTCO_2e$). Thanks to over 300 million Metro riders in 2017, total passenger emissions were only 1.5% higher (27.1 million $MTCO_2e$), a net displacement of roughly 0.6 million $MTCO_2e$.

Figure 2-3: LA County Passenger Transportation Emissions, 2017



[a] Emissions from private vehicles were estimated based on vehicle miles traveled (VMT) data for LA County obtained from the California Department of Transportation (2018).

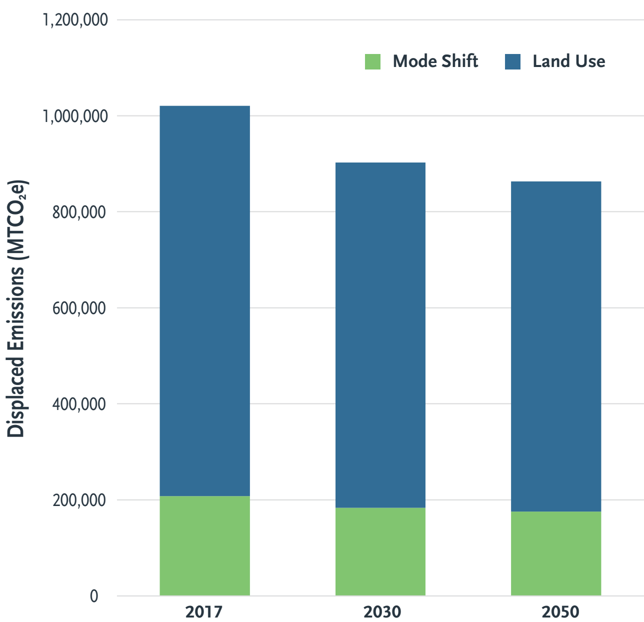
[10] APTA 2018.

Table 2-5: Displaced Emissions Forecast by Source

Displaced Emissions Source	2017	2030	2050
Mode Shift ($MTCO_2e$)	207,374	183,420	175,385
Land Use ($MTCO_2e$)	813,110	719,188	687,679
Total	**1,020,485**	**902,608**	**863,064**

Note: Totals might not sum due to independent rounding.

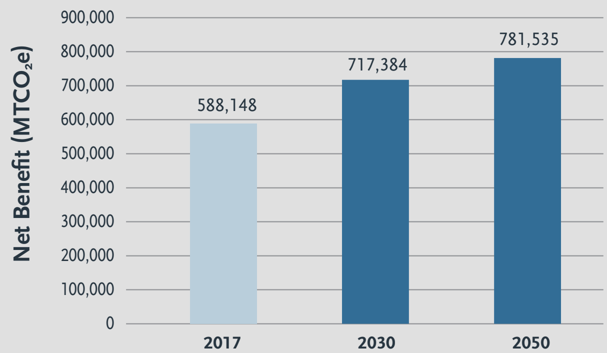
Figure 2-4: Displaced Emissions Forecast by Source



Projected Net Greenhouse Gas Benefits

Displaced emissions are projected to slightly decrease when combined with Metro's emissions. The net benefit (emissions displaced minus direct emissions) is still expected to grow over time. Figure 2-5 shows the net GHG emissions benefit of Metro in 2017, 2030 and 2050.[a]

Figure 2-5: Projected Net Greenhouse Gas Emissions Benefit



[a] This CAAP does not include displaced emissions for 2010 due to methodological changes in the calculation used to estimate displaced emissions relative to that used in Metro's 2012 Climate Action and Adaptation Plan. These changes do not allow for a direct comparison of the results.

2.4 Greenhouse Gas Mitigation at Metro

The CAAP's BAU scenario inventory and forecast indicate that Metro's total emissions will decline 57% by 2030 based on 2017 levels and by 81% by 2050 through a combination of Metro actions and state policies for renewable energy procurement and generation. Metro performed a mitigation analysis to identify opportunities to achieve even greater reductions throughout current and future operations.

Overview of Approach and Mitigation Goal

Metro's mitigation analysis assessed the cost-effectiveness and feasibility of a variety of emission reduction strategies. The general process used for mitigation analysis, shown in Figure 2-6, involved three distinct elements: measure development, inventory and forecast modeling and mitigation modeling. Appendix A details more specifics for this mitigation assessment.

The Process

Thirteen mitigation measures were developed and grouped into categories: vehicle fleets, electricity supply, facility energy use and employee commuting. These measures stem from a review of industry best practices and trends, examination of 2012 CAAP elements, current and proposed Metro initiatives and a significant vetting process with internal and external stakeholders.

Each measure was further analyzed for GHG reduction potential, costs and benefits as compared to the BAU scenario. These scenarios were then used to set ambitious emission reduction goals.

Considerations

While Metro plays an important role in helping LA County avoid emissions from vehicle miles traveled (VMT), VMT reduction was not identified as a mitigation measure. Regional emissions from VMT are driven by a number of factors outside Metro control, including broader decisions about land use, road construction, local street design decisions, fuel and vehicle prices, commuter benefits and much more. Since it is challenging to isolate and quantify GHG emissions from each of these sources, they were not included in the inventory.

Figure 2-6: Metro CAAP Mitigation Process

Measure Development

- Analyzing 2012 CAAP measures
- Assessing other CAPs
- Incorporating Metro policies
- Vetting through internal/external stakeholder collaborations
- Reviewing industry best practices

Mitigation Modeling

- Analyzing GHG emissions and costs/benefits for the final measures
- Using BAU as a baseline for activity and emissions

Goal Setting

- Setting an emission reduction goal

Climate Change Mitigation at Metro

Metro has reduced our GHG emissions in operations through:

> **RNG for buses**: By 2020, all of Metro's directly operated buses will run on renewable natural gas, reducing emissions by almost 300,000 $MTCO_2e$ cumulatively from 2017 to 2019.

> **On-site photovoltaics**: Metro has installed over 2.6 MW of generating capacity which generates 2.9 million kWh annually, saving almost 1,000 $MTCO_2e$ in 2017.

> **Lighting retrofits**: Metro has implemented a number of lighting retrofit projects across its operating facilities. Since 2012, over 5,750,000 kWh of electricity have been saved annually from these retrofits projects, saving over 2,100 $MTCO_2e$ cumulatively through 2018.

Metro will continue to explore opportunities to increase ridership and reduce regional VMT through policies, programs and projects, including our NextGen Bus study, Rail and Bus Rapid Transit (BRT) capital programs and broad range transit-oriented community policies and programs.

Building on the projected reductions found in the inventory and forecast, **this Plan commits to reducing annual emissions to 79% below 2017 levels by 2030 and 100% (i.e., zero emissions) by 2050**. These reductions equate to reducing emissions 52% below BAU scenario projections by 2030 and 100% below BAU projections by 2050. By implementing all 13 analyzed mitigation measures, 2050 goals are within reach, as those measures will reduce Metro's emissions by 96% by 2050. The remaining 4% will be reduced by additional mitigation measures yet to be identified.

Mitigation Assessment Results

Metro performed a mitigation analysis as outlined in Figure 2-6. The following sections summarize the results of that process, as well as the estimated emission reductions and costs for each measure.

Final Mitigation Measures

The 13 mitigation measures are reflected in Table 2-6. The "Measure Code" is a reference applied to each measure, used in tracking mitigation development and used within this document for reference and clarity.

Each measure reflects key assumptions used to guide mitigation modeling. For example, the Battery Electric Bus (BEB) deployment measure (V-1) includes existing goals for converting the directly operated fleet to BEBs by 2030. These goals guided modeling activity and purchasing assumptions. Appendix A provides details on these assumptions and other considerations.

Greenhouse Gas Mitigation Reduction Results

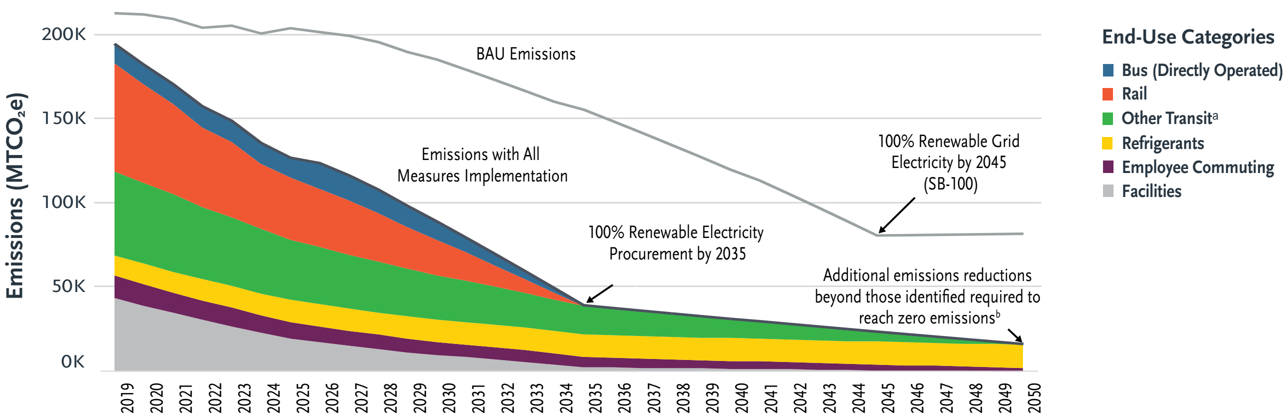
Full implementation of the 13 measures will drastically reduce Metro GHG emissions by 2030, positioning Metro for zero emissions by 2050. (See "Getting to Zero" box on page 22.) Full implementation requires achieving a measure's key goals. For example, electrification of Metro's directly operated bus fleet (V-1) is scheduled to achieve full implementation in 2030 when the entire fleet is composed of BEBs. For contracted buses (V-2), full implementation will occur by 2050 when those fleets are completely electrified. Appendix A includes full details and implementation timelines for each measure.

To examine each mitigation measure in more detail, annual achievable emissions reductions as compared to BAU by general operations categories are graphed in Figure 2-7.

Table 2-6: Final Mitigation Measures by General Sector

Measure Title	Measure Code	Measure Description	Progress to Date
Battery Electric Bus (BEB) Deployment (Directly operated)	V-1	Replace all directly operated buses with BEBs	Metro is currently implementing Phase 1 of the Strategic Plan for the Transition to Zero-Emission Buses (ZEBs): > Transition the Metro Orange Line and Metro Silver Line to ZEBs by 2020 and 2021, respectively > Develop a ZEB Master Plan for a 100 percent ZEB Fleet by 2030 Metro executed $150 million in bus vehicle contracts and is installing charging infrastructure for 105 ZEBs. The ZEB Master Plan is expected in 2019.
BEB Deployment (Contracted)	V-2	Replace all contracted buses with renewable natural gas (RNG) buses and BEBs	Policies and initiatives to directly address GHG emissions from contracted bus fleets have not started.
Battery Electric Vehicle (BEV) Vanpool Deployment	V-3	Replace vanpool vehicles with BEVs	Metro Regional Vanpool Program currently has one all-electric vehicle supplier on its qualified supplier list.
BEV Non-Revenue Vehicle Fleet Deployment	V-4	Replace non-revenue vehicles with BEVs	Metro deployed 10 Chevy Bolts for the non-revenue fleet in 2017. A comprehensive EV Implementation Plan (EVIP) to support expansion of this pilot is in development.
Wayside Energy Storage Substation (WESS) Installation	V-5	Install WESS to store energy from decelerating railcars	Metro installed a 2 MW WESS pilot in 2014 and is verifying long-term energy savings. Energy management plans to assess opportunities for deployment of storage and other distributed energy resources are underway.
Renewable Electricity Procurement	E-1	Expand use of renewable energy in electricity procurement (100% renewable electricity by 2035)	In 2017, 30% of Metro's electricity came from renewable sources. Energy management plans to assess opportunities for increasing renewable supply are being updated.
Photovoltaic Installations	F-1	Increase on-site solar photovoltaic installations	In 2017, Metro produced almost 3,000 MWh from on-site installations. Additional solar capacity will be installed in 2019. A solar preventive maintenance program is in place to optimize system performance. Energy management plans to assess opportunities for increasing on-site renewable resources are being updated.
Water-Saving Fixture Installation	F-2	Install new designs or retrofits of low-water sanitary fixtures that require less water and energy	Metro initiated water conservation pilot projects as part of the Water Action Plan and continues to research opportunities for future implementations.
Water Recycling System Installation	F-3	Install non-potable recycled water systems	Metro is installing recycled water systems along the Orange Line and at Division 3.
Facility LED Lighting Installation	F-4	Replace lighting fixtures with LED lights	Lighting retrofits are identified and implemented annually. Energy-efficient lighting is incorporated into new building design criteria. The energy management plans are being updated to assess opportunities for energy-efficient lighting and advanced lighting controls.
Facility Appliance Electrification	F-5	Replace existing appliances with more efficient electric appliances (compressors, water heaters, kitchen appliances)	Metro analyzed opportunities for energy-efficient equipment, controls and appliance retrofits.
Facility Heating, Ventilation and Air Conditioning (HVAC) Electrification	F-6	Replace existing HVAC systems with electric systems	Energy-efficient HVAC systems are incorporated into new building design criteria. Metro initiated an Agency-wide assessment of HVAC and building management systems to identify opportunities for energy efficiency and building performance.
Employee EV Charging Station Installation	C-1	Install EV charging infrastructure at Metro facilities for employee commuter use	Metro is exploring opportunities to maximize deployment of electric vehicle infrastructure for employees as part of the EVIP.

Figure 2-7: Metro GHG Emissions Forecast by End-use Category



[a] Other transit includes CNG compression, contracted buses, vanpool and non-revenue vehicles.
[b] See "Getting to Zero" on page 22.

Interdependencies of Mitigation Measures

Many of the mitigation measures are interdependent. The degree to which one measure is implemented can influence the GHG mitigation impact of another. Examining each separately can be misleading and omit or reduce the actual compounded impact of these interrelationships.

For example, increasing renewable electricity purchases (E-1) has a profound impact on the mitigation potential of the vehicle electrification measures (V-1, V-2, V-3, V-4). Procuring renewable electricity (E-1) ahead of the implementation of state regulatory requirements (Senate Bill 100) will have a significant effect on Metro's ability to reduce emissions against the BAU scenario. Measure E-1 **would reduce annual emissions by 36% from the BAU in 2030** and would avoid more than 1.2 million $MTCO_2e$ over the analysis period.

The more renewable energy in Metro's electricity mix, the greater the emissions savings from vehicle electrification. In the case of electric vehicles replacing RNG vehicles, Metro needs to procure electricity that has 90% or more renewables to reduce GHG emissions. Metro can improve on the projected BAU emission savings by implementing measure E-1 and shortening the timeline for using 100% renewable electricity. **Bus electrification, when incorporating measure E-1's higher-impact renewable electricity procurement schedule, reduces 10% of BAU emissions by 2050**. The impacts of implementing E-1 are included in Figure 2-8 and in the results presented throughout this Plan.

If Metro chooses not to pursue vehicle electrification (V-1, V-2, V-3, and V-4), the potential benefits of E-1 would be significantly less than projected. Conversely, if E-1 is implemented, the mitigation potential of V-1, V-2, V-3 and V-4 could be significantly greater. The analysis in Figure 2-8 and Table 2-7 shows results when both vehicle measures and E-1 are implemented.

Measure E-1: The Role of Renewable Energy in Metro's Emissions from Buses

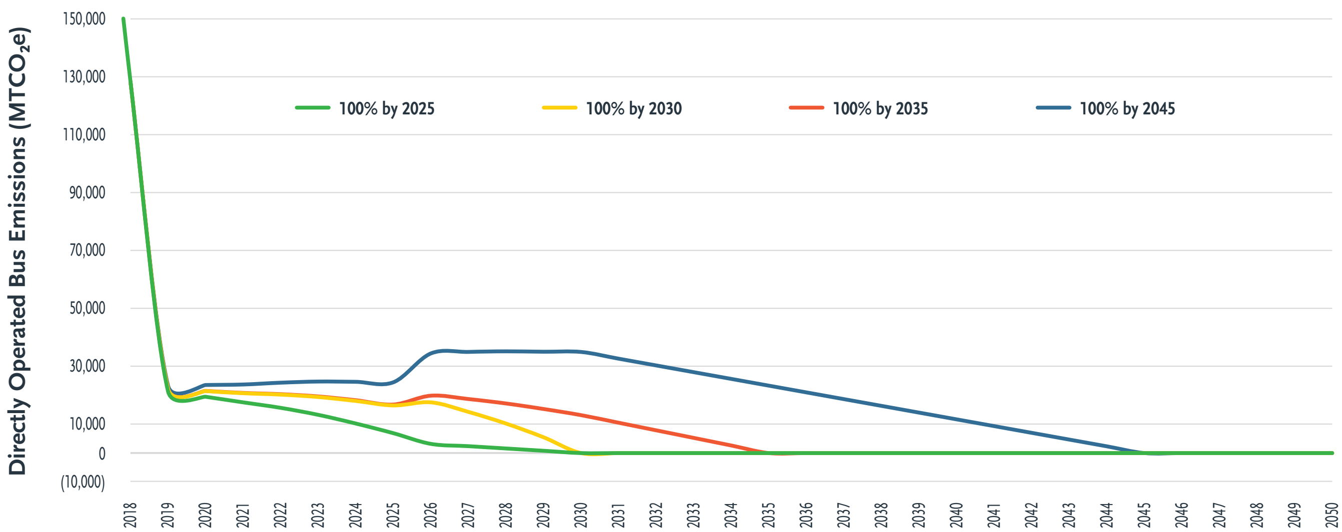
Metro is moving to a zero-emission bus fleet by 2030. This transition provides immediate air quality benefits. The GHG emissions benefits do not fully emerge until California's electricity grid is less carbon intensive than the renewable natural gas Metro is currently supplying to our CNG bus fleet. This is anticipated by 2031.

A renewable electricity procurement measure (E-1) mitigates potential GHG increases from transitioning to a zero-emission bus fleet by setting a goal of 100% renewable electricity for Metro by 2035, 10 years ahead of requirements set forth by SB100.

Moreover, the speed at which E-1 is implemented affects reductions achieved by V-1, V-2, V-3 and V-4 in a given year. See Appendix A for full results on the vehicle electrification and E-1 measures.

Figure 2-8 shows four timelines for procuring 100% renewable electricity and reveals how each timeline affects emissions from Metro's bus electrification (V-1). Using the state's SB100 timeline (100% by 2045) results in 20,000 $MTCO_2e$ more emissions annually than achieving the E-1 procurement timeline (100% by 2035) by 2030. Results presented in this mitigation analysis assume that E-1 (100% renewable energy by 2035) is implemented.

Figure 2-8: Four Renewable Electricity Scenarios and their Impact on Bus Emissions



When incorporating the different 100% renewable electricity timelines from Figure 2-8, Table 2-7 shows the cumulative emission reduction impact for V-1. This information reinforces that failing to adopt a shorter timeline for procuring 100% renewable electricity than that called for in SB100 will result in higher emissions over the analysis period than the BAU.

Table 2-7: Bus Emission Reductions under Four Renewable Procurement Scenarios

Renewable Electricity Procurement Scenario	V-1 Cumulative Emission Reductions from BAU by 2050 ($MTCO_2e$)
SB100 (BAU scenario; 100% renewable electricity by 2045)	(132,438)
E-1 (100% by 2035)[a]	205,562
100% by 2030	269,422
100% by 2025	343,071

[a] This result is different than the V-1 results shown in Figure 2-7 and elsewhere because V-1 in the primary assessment only measures bus fleet emission changes from changes in energy use, whereas the scenarios in this table include bus fleet emission changes from changes in energy use and increased renewable electricity procurement. In Figure 2-8 and elsewhere, E-1 accounts for Metro-wide emission reductions from increased renewable electricity procurement.

Reducing the Cost of E-1

The cost estimate for E-1 is fairly conservative. Using a blended kWh rate, incremental cost increases the base electricity price forecast by 8% through 2050 using the LA County Clean Power Alliance pricing (CPA 2018).

This incremental cost increase might decrease over time. Similar CCA programs in California are now offering 100% renewable options from just under 2% up to 5% incremental cost increase (PG&E 2018).

Whether through a CCA or other means (e.g., power purchase agreement), Metro's ability to procure renewable electricity at lower prices will be the greatest driver in maximizing emission reduction potential while reducing costs.

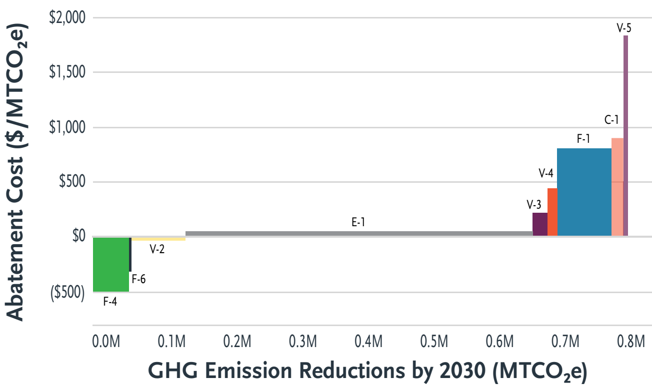
Cost-Effectiveness

The cost-effectiveness of each measure is an important criterion when considering measure prioritization, allocation of funding and the framing of relative costs and benefits of GHG mitigation. Figure 2-9 and Figure 2-10 show the cumulative costs and benefits (net present value) of each measure relative to the total emissions saved for two periods (2019 through 2030 and 2019 through 2050). Renewable electricity procurement measure (E-1) has the highest mitigation potential with a relatively low cost for both analysis periods.

Three of the 13 mitigation measures are estimated to result in cost savings by 2030, and six would result in cost savings by 2050. These cost savings are due to reduced energy or water use. For example, the building lighting (F-4), appliance (F-6) and water efficiency (F-2) measures all provide savings in both the short term and long term, with water and energy savings exceeding capital cost expenses of replacing older, cheaper products.

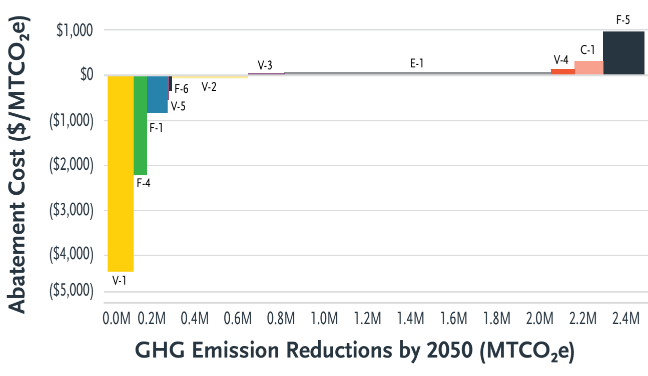
Metro's vehicle electrification measures (both bus and light-duty vehicles) all save costs over the 2019–2050 analysis period as more efficient BEVs replace internal combustion vehicles. However, cost-effectiveness of vehicle electrification measures should be routinely reassessed after implementation as initial electrification initiatives reveal insights into actual costs and savings. For further discussion on the use of financial analysis in GHG mitigation and funding, see Chapter 4, Implementing Climate Action.

Figure 2-9: Marginal Abatement Cost Curve for Mitigation Measures in 2030 [11]



Note: V-1, F-5, F-2 and F-3 have cumulative emission reductions less than 0.02 million $MTCO_2e$ by 2030 and are not shown in the figure above. Please see Appendix A for full results.

Figure 2-10: Marginal Abatement Cost Curve for Mitigation Measures in 2050[11]



Note: F-2 and F-3 have cumulative emission reductions less than 0.04 million $MTCO_2e$ by 2050 and are not shown in the figure above.

Other Considerations

Costs and GHG benefits only tell part of the story when considering the implications of these mitigation measures. The following qualitative criteria evaluate the feasibility and co-benefits of each measure:

- **Sphere of influence** – reflects Metro's ability to directly or indirectly influence a measure's implementation and execution
- **Implementation feasibility** – captures the ease of enacting a measure given Metro resource allocation, availability of funds, financing policy and impact to operations or conflicting priorities
- **Resource security** – gauges benefits from changes in resource consumption that reduce Metro's reliance on purchasing energy and water resources
- **Other environmental benefits** – considers air and water pollution and other non-GHG environmental impacts (e.g., solid waste generation, toxic releases, land use)

The results of this assessment are seen in Table 2-8. Color coding is used to indicate high (green), medium (yellow) and low (red) benefits for each evaluation criterion. Symbols increase in number if the outcome is more desirable (except in the case of costs, where more symbols reflect an undesirable outcome – i.e., increased costs).

Metro should carefully consider the barriers and benefits beyond costs and GHG emissions as the Agency begins implementation of the CAAP. Water-related measures in particular (F-2, F-3) might have low mitigation potential, but provide significant drought resilience benefits and align with existing efforts as articulated in Metro's *Water Action Plan*, resulting in overall greater feasibility. Appendix A provides more information about feasibility and co-benefits.

Costs and GHG benefits only tell part of the story when considering the implications of these mitigation measures.

[11]For each measure, the width of the bar indicates the amount of potential GHG emission reductions ($MTCO_2e$). The height indicates the marginal cost of the carbon emissions abatement ($/$MTCO_2e$). Measures with negative marginal costs are expected to have net cost savings over the analysis period. For full details on operational, capital, annual and cumulative costs, see Appendix A.

Table 2-8: Feasibility and Co-Benefits Matrix

	GHG Mitigation Potential	Net Present Value	Other Environmental Benefits	Sphere of Influence	Resource Security/ Resilience	Implementation Feasibility
V-1: Battery Electric Bus (BEB) Deployment	2	1	3	2	2	1
V-2: BEB Deployment (Contracted)	3	1	3	1	2	1
V-3: Battery Electric Vehicle (BEV) Vanpool Deployment	2	2	3	1	2	2
V-4: BEV Non-Revenue Vehicle Fleet Deployment	2	3	3	2	2	2
V-5: Wayside Energy Storage Substation Installation	1	3	2	3	2	1
E-1: Renewable Electricity Procurement	3	3	2	2	2	2
F-1: Photovoltaic Installations	2	3	2	3	3	2
F-2: Water-Recycling System Installation	1	3	2	3	3	3
F-3: Water-Saving Fixture Installation	1	1	2	2	3	3
F-4: Facility LED Lighting Installation	2	1	3	3	3	3
F-5: Facility Heating, Ventilation and Air Conditioning Electrification	2	3	2	3	1	2
F-6: Facility Appliance Electrification	1	1	2	3	2	2
C-1: Employee EV Charging Station Installation	1	3	2	2	2	2

Setting Mitigation Goals

Metro is charting an ambitious path toward zero emissions by 2050 with an interim GHG mitigation goal of 79% below 2017 levels by 2030.

This represents an annual emissions reduction of 343,000 metric tons by 2030 and 432,000 by 2050 – equivalent to the annual emissions of more than 90,000 passenger vehicles.

By 2050 the implementation of all 13 measures could save Metro over $425 million in 2017 dollars cumulatively over the analysis period. These cumulative savings represent about 6% of Metro's total fiscal year 2019 budget.[12]

A summary of reduced emissions and costs over the analysis period (Table 2-9) shows these measures would reduce emissions nearly to zero by 2050 and save an additional 16,000 metric tons of GHG annually but could increase the potential overall costs of mitigation. See "Getting to Zero" for details regarding Metro's plan to target those remaining emissions.

By examining the feasibility, cost and timeline for implementation of each mitigation measure, Metro is able to better set mitigation goals and achievable targets while being mindful of future opportunities unavailable at this time.

Getting to Zero

Metro recognizes the importance of committing to a 100% reduction target. However, current measures recommended in this Plan fall just short of this target, getting Metro to an ambitious 96% reduction from 2017 levels by 2050. Therefore, additional measures will need to be identified, researched and implemented to address the remaining 4% of emissions.

Metro will explore the use of carbon sinks or sequestration strategies as possible emission reduction measures. Metro could also consider purchasing carbon offsets and explore how offsets could provide regional and local benefits. Additional considerations regarding offsets are included in Appendix A.

Table 2-9: Mitigation Costs and Emission Reductions, 2030 and 2050

	2030			2050		
	Net Present Value ($)	Annual Reduced Emissions from 2030 BAU ($MTCO_2e$)	Annual Emissions Reduced Relative to 2017 ($MTCO_2e$)	Net Present Value ($)	Annual Reduced Emissions From 2050 BAU ($MTCO_2e$)	Annual Emissions Reduced Relative to 2017 ($MTCO_2e$)
All Measures	($125,155,929)	96,421	343,533	$427,273,682	65,632	416,440

Note: positive NPVs reflect savings to Metro and negative NPVs represent costs.

[12] LA Metro 2018f.

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3

Understanding and Preparing for the Risks of Climate Change

Reducing GHG emissions can help slow the pace of climate change, but it cannot stop it. California's climate is already changing, and scientists expect the changes to intensify in the years and decades ahead.[13]

California's Fourth Climate Change Assessment found that the Los Angeles region might experience increases in maximum temperatures, the number of high heat days, precipitation extremes, the frequency of wildfires and sea level rise.[14] The region already experiences many of these hazards, but not at the frequency or severity that scientists project for the future.

These changes pose risks to Metro's infrastructure, services, riders and employees. More extreme climate and weather conditions could interrupt service and cause delays. They could also bring safety risks; increased operation, maintenance and repair costs; and reduce Metro's ability to provide emergency services to other partners in the region.

We need to protect our existing systems from these impacts while also designing and building new infrastructure with the changing future climate in mind.

[13]USGCRP 2018.
[14]Hall et al. 2018.

To determine the best ways to safeguard the system for riders and communities that depend on Metro services, we must first identify which assets are most at risk, and at risk to which climate hazards. Once we understand the risks, Metro can then prioritize the most pressing vulnerabilities and identify actions to prepare and adapt. Increasing the system's resilience to climate change will enable Metro to avoid or reduce the impacts associated with new climate risks, ensuring our ability to continue to provide safe and reliable services to riders.

Adaptation actions range from minor changes in operations and maintenance–such as the pre-seasonal vehicle inspections conducted by Metro Operations and Maintenance–to more large-scale engineering modifications, such as constructing seawalls.

Metro faces a wide variety of climate-related risks that require different types of strategies to address. For example, extreme heat is a key hazard that all people and assets in the region will experience. On the other hand, hazards such as landslides and wildfires are more limited in their reach but could severely affect certain assets and areas of the region. Heat poses health risks and can also impact infrastructure across the region.

This chapter presents the results of a risk assessment that Metro completed to identify potential risks that climate change might pose to our systems and riders. It then discusses opportunities to increase Metro's resilience to climate change.

Risk Assessment in the 2012 and 2019 CAAPs Compared

The risk assessment in this 2019 CAAP expands on the risk assessment in the 2012 CAAP in several important ways:

- The 2012 CAAP considered three climate hazards: extreme heat, heavy precipitation and sea level rise. The 2019 CAAP considers four additional climate hazards, drawing on the latest available data.
- The 2012 CAAP used temperature and precipitation data at individual locations. The 2019 CAAP uses data for the entire Los Angeles region from Cal-Adapt and the Coastal Storm Modeling System.
- The 2019 CAAP analyzes criticality and vulnerability for all of Metro's assets, including additional criticality indicators.
- The 2019 CAAP considers external assets that Metro might depend on, such as city infrastructure, despite these assets not being directly owned and operated by Metro.

3.1
Understanding Risks Associated with Climate Change

To better understand the impact of climate change on infrastructure, Metro completed a comparison between climate hazards and the relative risk of each to an asset. The risk assessment assigned a scaled risk score of 0 to 25 where 25 is the highest risk, based on vulnerability of the asset to each climate hazard and each asset's criticality to Metro's mission.

The section below provides a brief overview of the approach and scope for the risk assessment. This approach allows Metro to compare and prioritize assets requiring adaptation actions.

Risk Components Considered

The risk level assigned to each asset is derived by multiplying vulnerability and criticality ratings for each hazard, as shown in Figure 3-1.

Figure 3-1: Components of Risk

Vulnerability describes how a climate hazard might affect an asset and the likelihood that the asset would experience a negative impact from the hazard, such as damage or disruption. It is scored on a scale of 0 to 5 based on three components:

> **Exposure**: The likelihood that an asset will experience a hazard. For example, coastal assets are more exposed to sea level rise than are inland assets.

> **Sensitivity**: The magnitude of impact resulting from exposure of an asset to a hazard. For example, fires might cause minimal damage to a road, but could devastate an entire building. In this case, a building is considered more sensitive than a road.

> **Adaptive capacity**: An asset's ability to withstand the hazard or recover from it. For example, a bus has higher adaptive capacity than a train in extreme weather because a bus route can be changed before a predicted event. In this context, train tracks and buildings are stationary and would have less adaptive capacity.

Criticality describes the importance of an asset to Metro's ability to fulfill our mission: to provide a world-class transportation system that enhances quality of life for all who live, work and play within LA County. To assess the criticality of an asset, Metro ranked the impact of the loss of the asset to Metro's mission using several metrics. Example metrics include the number of people the asset serves, our ability to connect to other transportation assets and various socioeconomic factors.

Assets and Hazards Considered

Metro relies on a wide range of assets to provide service to riders and recognizes the range of known climate hazards could affect riders in different ways. Assets in the risk assessment include:

> **Public-facing infrastructure maintained by Metro**: this includes buses (BRT and other bus routes), rail (light and heavy rail lines and stations), bikes and bikeshare locations, park & ride locations and customer service centers

> **Non-public-facing infrastructure maintained by Metro**: this includes communication systems and non-public facilities that support public-facing assets, such as bus divisions

> **Other infrastructure not maintained by Metro**: this includes assets Metro relies on for service such as roads and bus stops

Exposure maps include a simplified view of public-facing assets. For the purposes of the spatial analysis, all known assets were mapped.

Metro assessed impacts from projections of seven climate hazards by 2050 including:

> Extreme heat

> Electrical outages

> Wildfires

> Heavy precipitation events

> Riverine flooding

> Landslides and mudslides

> Sea level rise and coastal flooding

What about wind?

The Santa Ana winds are a key feature of LA climate. These winds vary year to year and, currently, scientists don't know a lot about how climate change could affect them in the future. The best available data suggest there might not be a significant change, so a wind risk score was not assigned to each asset. See Appendix B for more details.

Who is affected by the impacts of climate change?

Risks to Metro's system affect all our riders and staff. While Metro serves all of LA County, some populations are particularly dependent on Metro services due to a lack of other accessible transportation options. These transit-dependent populations include car-free households, low income populations and those who do not drive such as senior citizens.

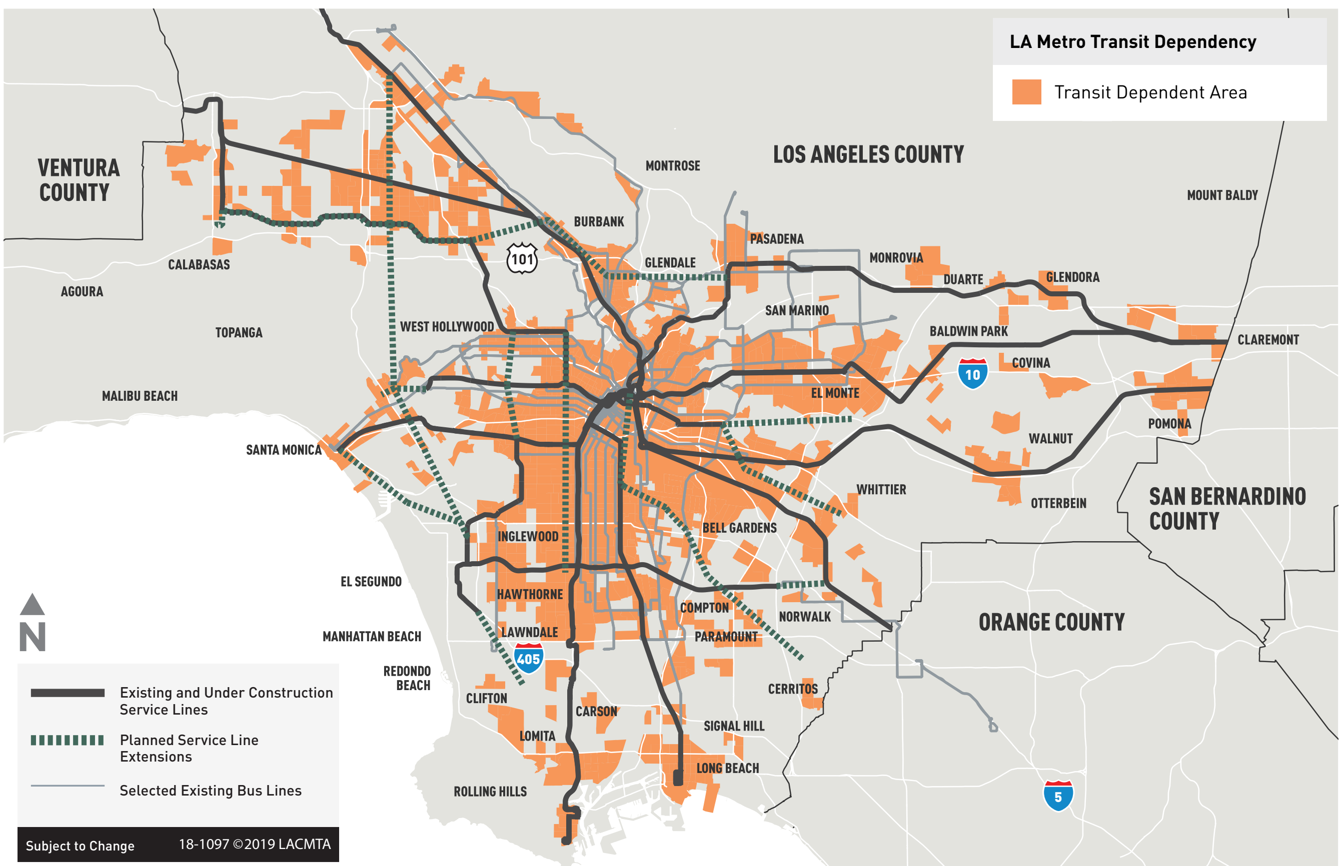
A map of transit-dependent areas in the County overlaid by Metro's rail assets (Figure 3-2) is a powerful tool for ensuring that Metro's system remains resilient to climate hazards in order to meet the needs of its most transit-dependent populations.

Metro is in the process of developing an Equity Platform, an additional tool to define a common basis for Metro and the community to build an agenda around improving equity. This tool will be utilized in the CAAP implementation phase to better prioritize adaptation actions.

Figure 3-2: Transit-dependent Areas in LA County

Transit Dependency

Metro Service Lines



Metro

Note: These areas are potentially most affected by risks to Metro's system. Rail lines are depicted to show their relationship to transit-dependent areas shown in orange. These maps show only selected bus lines to provide a simple visualization of the extent of the bus system.

Key Risk Assessment Findings

Extreme Heat Is the Most Pervasive Risk That Metro Faces

Of the seven climate hazards assessed, extreme heat could affect the greatest number of assets and people.

As extreme temperatures become more common, sensitive systems and equipment can overheat and malfunction. Overhead catenary lines can sag, trackwork can buckle, hydraulic lift systems in elevators can overheat and signal switches and communication systems can malfunction. Each situation results in costly repairs and service disruptions. Those rail and bus assets located downtown are most at risk due to their criticality to the overall system.

Extreme heat events can also pose health hazards for riders and employees. Air conditioning in buses or in rail stations might be unable to provide enough cooling for passenger comfort. Without shade, riders walking to stations or waiting at bus stops could experience heat-related health impacts. Extreme heat often leads to reduced air quality, which further impacts health.

Risk assessment average risk scores (scored out of 25) are listed by asset type and hazard type in Table 3-1. Scores were consistently higher for extreme heat than for any other climate hazard. See Appendix B for more explanation on defining extreme heat days and the risk scoring system.

Nearly all of Metro's assets have a high exposure to extreme heat. Even those areas expected to experience the smallest increase in extreme heat are projected to see at least 14 more extreme heat days annually by midcentury (see Figure 3-3). It is therefore imperative to bolster the system to the impacts of extreme heat systemwide.

Table 3-1: Average Risk Scores across Metro's System

Asset	Increased Extreme Heat	Increased Electrical Grid Outages	Increased Wildfires	Increased Heavy Precipitation	Increased Riverine Flooding	Increased Land and Mudslides	Sea Level Rise and Coastal Flooding
Bus Rapid Transit	12.6	3.4	4.4	3.4	6.1	5.1	0.5
Light Rail	14.4	10.1	5.1	3.4	6.8	4.9	0.5
Subway	16.3	11.4	8.2	3.8	7.4	5.6	0.0
Commuter and Circulator Buses	11.6	3.2	4.8	3.2	5.6	6.8	0.1
Limited Express Buses	12.0	3.3	5.5	3.3	8.1	8.4	2.7
Local Central Business District Buses	13.6	3.7	5.4	3.7	7.2	7.1	0.3
Local Non-Central Business District Buses	11.6	3.2	5.4	3.2	6.6	5.2	0.6
Rapid Buses	13.4	3.7	6.3	3.7	8.2	7.4	0.5
Highways	6.8	2.9	5.6	2.9	7.7	5.4	0.6
Bike Share Stops	6.6	6.6	2.8	2.8	3.2	2.8	0.0
Metro Bike Hubs	9.1	10.8	2.5	2.5	4.1	2.5	0.0
Cal Trans Park & Ride Lots	9.1	2.1	2.7	2.1	2.6	2.2	0.1
Bus Divisions	9.5	11.2	4.4	2.6	5.6	2.6	0.6
Rail Divisions	10.0	11.8	3.8	2.7	5.1	3.7	1.5
Terminals	12.4	10.6	3.0	2.9	4.5	2.9	0.0
Radio Repeater Stations	8.4	6.9	4.9	2.3	2.3	4.9	0.0
Facilities – Other	9.4	11.2	3.7	2.6	3.1	2.6	0.0
Parcel Lots	6.5	2.8	2.8	2.8	4.1	2.8	0.5
Rail Stations	15.0	11.0	4.6	3.0	4.0	3.0	0.2
All Asset Types	**12.3**	**5.7**	**4.9**	**3.2**	**6.0**	**5.1**	**0.4**

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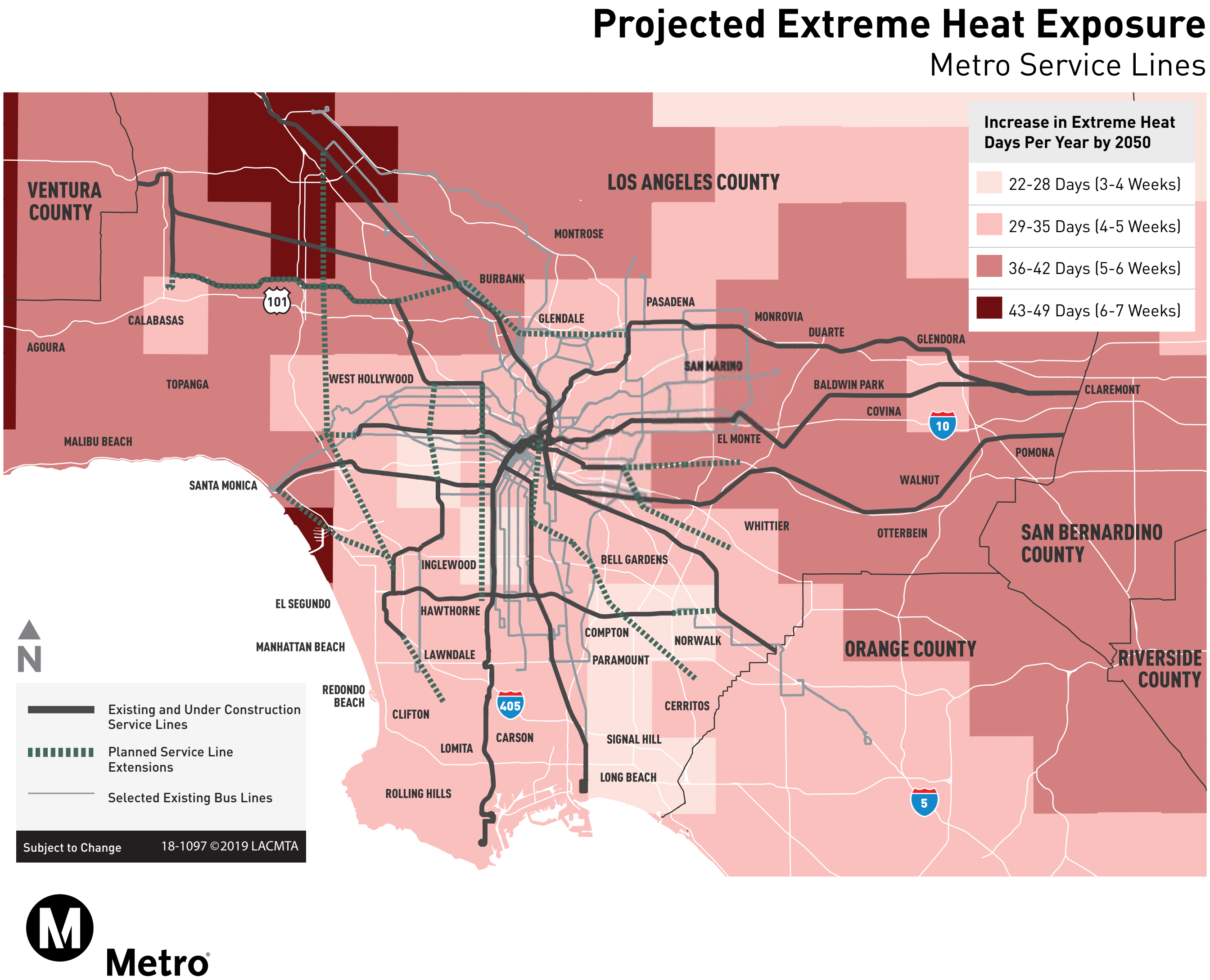
Figure 3-3: Extreme Heat Exposure Map

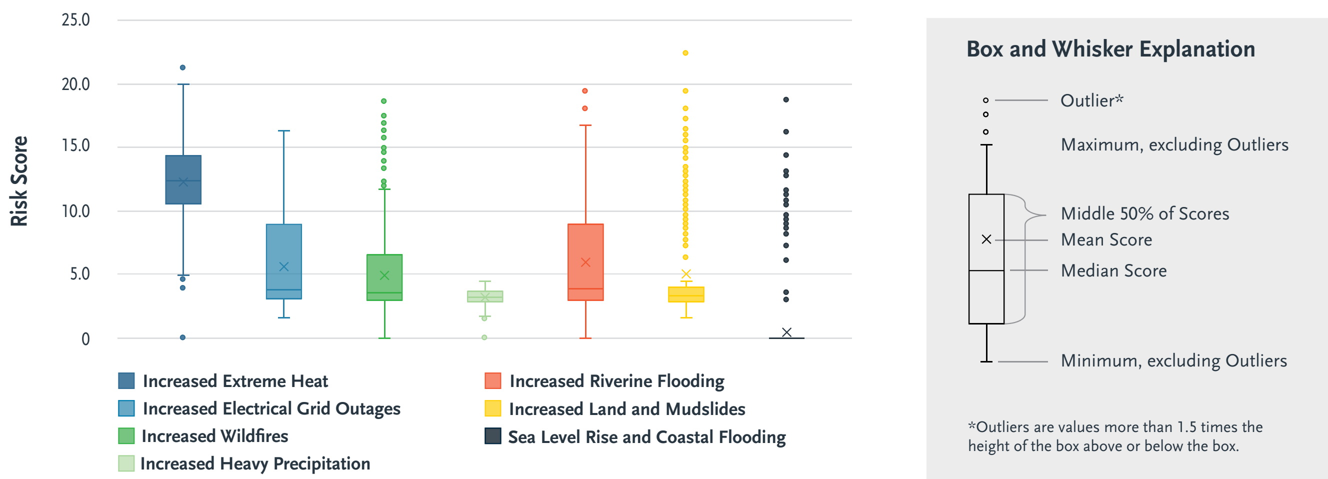


Other Climate Hazards Pose More Isolated Risks

While the risk from climate hazards other than extreme heat might seem low when looking across Metro assets as a whole, they still pose significant risks to certain assets that could affect functioning of the larger system.

The distribution of asset risk scores by hazard (Figure 3-4), presents a more comprehensive picture than the averages displayed in Table 3-1. Besides heat, most hazards pose a lower risk *on average*. However, other hazards pose high risk to at least a few critical assets.

Figure 3-4: Distribution of Asset Risk Scores by Hazard



Note: This chart includes all assets under "Assets and Hazards Considered" on page 25.

The risks from other climate hazards include:

> **Landslides can cause severe damage to rail and bus assets, with nearly 200 assets at high or extreme risk, more than any other hazard except heat**. Landslides and mudslides could occur more often in the future due to increased frequency or severity of wildfires and heavy precipitation events. Almost all aspects of Metro's transportation system are sensitive to landslides, since they can block rails, damage equipment and vehicles and engulf buildings, parking lots and yards. Any of these impacts can cause service delays and require costly and extended repair. Land or mudslides can block roads and disrupt bus routes. Such disruption poses most risk to assets that lie at the foothills of mountains. Catenary lines can be particularly costly to repair or protect from landslide damage.

> **Wildfire poses high risks to the northern and eastern parts of the rail system**. Wildfires can cause costly damage to light rail infrastructure by melting catenary lines, burning sensitive equipment and damaging trackwork. Most parts of the rail system are not highly exposed to wildfire, but the parts that are exposed are at high risk. Wildfire impacts to bus routes are more limited. Roads might close due to wildfires, forcing buses to reroute, but these disruptions are typically temporary. Wildfires can also damage buildings and impact air quality, creating safety and health hazards for passengers, operators and staff.

> **Buildings are particularly vulnerable relative to movable assets**. Because they cannot be moved, buildings can be at high risk from hazards such as wildfire, riverine flooding, land and mudslides. These hazards can damage buildings or reduce their usability. Buildings that have high exposure to these hazards are at higher risk. Impacts to these buildings can have ripple effects throughout the Metro system. For example, if a bus facility is not operating, vehicles cannot get fuel, maintenance is deferred and other key functions may remain unfulfilled. This not only leads to service impacts in the immediate area, but also impacts surrounding facilities used to cover the need.

> **Electrical outages can reduce building functionality and create safety risks**. Metro has electrical redundancy systems for essential functions like running the rail. However, limited backup power is reserved for other electricity-dependent systems, including rail infrastructure or support buildings that power operations behind the scenes. Because high heat can increase the likelihood of power outages, a lack of backup power could affect assets across the Metro system. In addition, power outages could disrupt safety and monitoring equipment at construction sites, creating a safety hazard if not addressed.

> **Sea level rise and coastal flooding could have severe long-term impacts on coastal assets**. Most of Metro's assets are inland, and therefore not at risk to sea level rise and coastal flooding. However, Metro's 18 coastal assets are exposed to this hazard and are at high or extreme risk. The most at risk are rail assets, bus routes and buildings. Sea level rise and coastal flooding can inundate sensitive equipment or close certain buildings and rail stations, causing problems for the communities that rely on Metro to move.

Metro's System Has Several Sources of Inherent Resilience

Analysis revealed several key risks to Metro's system, but it also showed that the Agency is inherently climate-resilient in many ways.

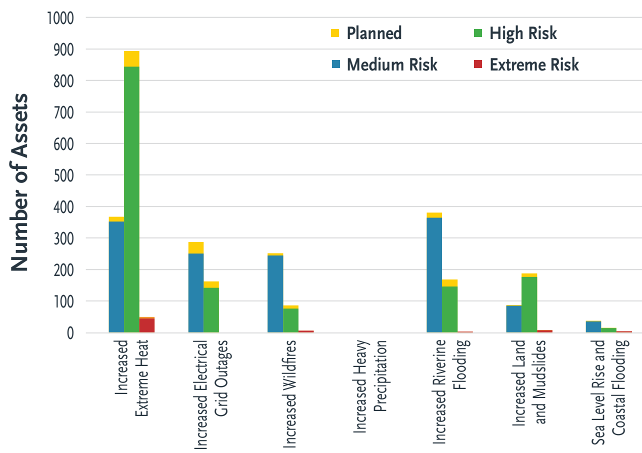
For five of the seven climate hazards (wildfires, heavy precipitation, riverine flooding, land and mudslides and sea level rise and coastal flooding), most assets are in areas with low or negligible exposure. Risks from these hazards tend be concentrated in specific geographic areas and the assessment allowed Metro to identify the limited number of assets most at risk from each of these hazards.

The assessment found that Metro can be flexible, adjusting operations or maintenance practices to address expected impacts due to climate for many types of assets. In other words, many asset types have high adaptive capacity. For example, Metro can relocate or reroute bus services to avoid localized hazards, particularly with enough notice.

Planning Can Help Adapt Future Assets

Most of the assets at high or extreme risk currently exist or are under construction, yet many are still in the planning stage. Figure 3-5 shows the existing and planned assets with at least medium risk. Several of these assets are planned but have not yet been built. If addressed early enough in the planning process, adaptation actions could be incorporated prior to construction in an effort to reduce risk levels. Implementing adaptation actions at this stage tends to be more cost-effective than incorporating them later. Most of Metro's planned assets are at low risk. See Appendix B for more explanation on the assets evaluated.

Figure 3-5: Number of Metro Assets at Risk to Climate Hazards



3.2 Summary of Risks

Metro faces a wide variety of risks due to climate change. Some Metro assets are expected to reach extreme or high risk to certain climate hazards by midcentury. If not addressed, this could lead to widespread operational disruption, higher operating costs or localized infrastructure damage.

Individually and in combination, these risks to infrastructure due to a changing climate have the potential to disrupt or reduce quality of service, riders' access to transit services, or increase repair and maintenance costs. Redirecting funds to repair will take funds away from system enhancements.

Metro needs information about climate risks and their impact on the system to identify and prioritize appropriate adaptation actions, both at the system and individual asset levels. Timely response to address risks will help Metro fulfill our mission and provide services in the face of a changing climate.

3.3 Increasing Climate Resilience at Metro

Metro's critical role is providing mobility to riders throughout the region. It is therefore essential to remain resilient to changes in climate. Metro's goal is to create a climate-resilient organization and transit system, one that is ready and able to provide services to the people of LA County, no matter how the climate changes in the future.

To achieve this goal, Metro will gradually implement a suite of *adaptation actions* to bolster climate resilience. Metro believes that before appropriate adaptation actions can be selected, a broader culture and decision-making process around climate resilience must be established Agency-wide.

A key aspect of Metro's approach is developing a continuous process of building climate resilience, one that needs to be flexible and adaptable as new information, technology or needs become apparent. This process will be integrated throughout the Agency to evaluate climate risks and potential adaptation actions as new information arises in a way that is proactive, cost-effective and coordinated with broader Agency goals and initiatives.

For this type of process to be successful, Metro also must ensure there are mechanisms in place that allow for monitoring of Metro's performance against key metrics, for identifying increases in service disruptions or asset repair, for considering future rather than past climate when making decisions about design and procurement and pursuing adaptation equitably across user groups and communities while being consistent with federal, state and local climate resilience-related initiatives. Flexibility is vital to being able to adapt approaches as new information and technology emerges.

Metro will pursue *flexible adaptation pathways* (see *What are Flexible Adaptation Pathways and why use them?* on page 36) as an approach to resilience that can accommodate these needs.

Metro is already doing a lot to maintain and increase resilience to a variety of natural hazards. However, these efforts have been implemented on a case-by-case basis. Metro is now focused on establishing a more systematic process for evaluating and improving resilience across the Agency.

Metro's goal is to create a climate-resilient organization and transit system.

What Climate Resilience Looks Like at Metro

Metro defines resilience as the ability to provide core functions in the face of threats and to recover quickly from major shocks or changing conditions. Currently, Metro is developing a broad framework for addressing resilience across all hazards (see Figure 3-6), including those hazards that will change as the climate changes.

The CAAP identifies ways Metro can increase our resilience to climate risks.

Figure 3-6: Example Hazards for which Metro is Preparing

What are all hazards?

This CAAP specifically focuses on climate-related hazards that are expected to become more severe or frequent as the climate changes.

However, Metro prepares for a wide range of natural and human-induced hazards beyond those analyzed in this CAAP. The upcoming update to the *Resiliency Indicator Framework*, a tool developed for Metro to assess our resilience, will address the following hazards:

Natural Hazards

- Sea level rise*
- Extreme heat*
- High winds
- Severe storms*
- Tornados
- Drought
- Earthquake
- Flood*
- Landslide*
- Tsunami
- Wildfire*

Human-Induced Hazards

- Dam failure
- Threats to critical infrastructure
- Special events
- Cyberattack and space weather
- Hazardous materials, transportation and radiological incidents
- Public health hazards
- Terrorism and weapons of mass destruction, civil unrest
- Active shooter
- Chemical hazards

*Indicates hazard covered in this CAAP.
This list of natural and human-induced hazards was developed based in part on the hazards covered in the 2018 LA Local Hazard Mitigation Plan, as well as hazards that will be evaluated in Metro's forthcoming All-Hazard Mitigation Plan.

Climate Resilience at Metro: Progress and Accomplishments

Metro has taken actions to adapt the system and increase its resilience to climate hazards, including:

> **New overhead catenary system (OCS) pilot**: Metro Engineering teams conducted field assessments of the OCS during high heat days to determine the impact of extreme heat on operations. High heat days cause the OCS balance weights to hit the ground, causing wire sag, which leads to a slow-down of light rail trains. Metro tested a spring tensioner system along the Gold Line that does not need balance weights, with the goal of eliminating this problem. The pilot technology worked well and Metro plans to replace balance weights with spring tensioners.

> **Permeable pavement pilot**: Metro installed 10,000 square feet of permeable pavement at bus division 4 in Downey, turning our parking lot into a tool to capture and clean stormwater. The pilot can capture more than 130,000 gallons of water in a single rain event. Capturing water to replenish our aquifer provides cleaner water downstream for local flora and fauna. If this pilot is successful, Metro may install permeable concrete at more facilities and stations.

> **Emergency backup alarm pilot**: When a Metro rail division loses power, backup generators are essential for critical operations and equipment needed to keep the trains moving. Generators provide a limited amount of backup power, and after a certain amount of time they must be shut down and refueled. However, during power outages, Metro staff may not know the site is running on backup power since the generators turn on automatically. To increase staff awareness, Metro is piloting a system that triggers a strobe light in the event the backup generator turns on.

> **State of Good Repair system integration**: Many departments in the Agency–including Information Technology Services, Enterprise Transit Asset Management and Maintenance–are replacing the Maintenance and Material Management (M3) system. This effort will add asset management integration while also providing statistical trend analysis. Additionally, the system will be able to integrate weather information like temperature data into existing data sets.

> **Preventive maintenance and flexible operations**: Before summer, Metro Bus Maintenance staff perform preventive maintenance and inspections of the fleet to minimize heat wave season impacts. Air conditioning units are inspected and preventive maintenance performed as early as February in preparation for the summer months. Additionally, the Bus Operation Control Center coordinates with operators when a detour is needed and has "blue water" detours for when a portion of a route has been flooded due to heavy precipitation.

In addition to these existing efforts, Metro has several other efforts underway to help build a culture of resilience:

> **Updating resources**: Metro is currently updating the Resiliency Indicator Framework to reflect lessons learned and areas for improvement under a broader, all-hazards lens.

> **Leveraging existing communication channels**: The Environmental Management System (EMS) is an FTA-endorsed process and communication tool that creates a culture of managing environmental issues. Based on ISO 140001 standards, it includes a set of procedures to reduce an entity's impact on the environment and enhance environmental performance. Metro's EMS ensures that staff at all levels and all sites are aware of environmental goals, know how to act on them, and can communicate what they are doing. EMS includes annual audits and a clear process for corrective action. EMS will be enhanced to further ensure that we are responding to the impacts of climate change in construction and operations.

> **Developing policies**: Metro will establish resilience as a goal with Agency-wide strategies for implementation.

Mitigation as a Form of Resilience

Some GHG mitigation measures have the added benefit of increasing resilience. For example, measures that increase energy efficiency or reduce fuel consumption mean that less money will be spent on procuring energy. The organization might then be more resilient to fuel price shocks.

To create a climate-resilient system, Metro will use a flexible approach to continuously assess our changing risk to climate stressors and evaluate different adaptation actions. The different types of actions that Metro will consider, the flexible approach for evaluating them and key next steps are discussed in the sections that follow.

Increasing Resilience to Climate Change: Understanding Different Types of Adaptation Actions

For a given specific risk, there are often several different feasible actions for addressing the risk. Most adaptation actions fall within these categories:

> **Hardening/protecting infrastructure**: Engineering solutions enable infrastructure to better withstand a climate hazard. Raise a segment of rail that goes through a flood zone above the flood level or protect it with a levee. Incorporate hardening/protecting adaptation actions into the design or planning of new infrastructure, or retroactively apply the actions to existing infrastructure. Include “softer” approaches to protecting infrastructure, like green infrastructure alternatives. Use plantings for erosion control, use wetland and other natural infrastructure to help control flooding, and use vegetation for shading and cooling.

> **Adjusting operations/changing behaviors**: Some risks can be addressed by actions that focus on adapting existing operations, procedures or behavior to minimize their negative impact. If a bus route is known to flood, reroute to avoid the flooded area. Provide better alerts and educate riders about temporary changes in routes and stops. Enhance employee training so that situations requiring temporary operational adjustments are more quickly identified and addressed with minimal impact on riders.

> **Relocating or re-siting infrastructure or services**: When possible, locate assets out of harm’s way to avoid a risk altogether. Permanently move bus routes to avoid areas that might be exposed to floods. Consider impacts of climate on a location before determining the site for the new infrastructure.

Example adaptation actions were identified through collaboration with Metro staff, external partners and riders (Table 3-2). Many are already implemented to varying degrees and can be further improved upon. As the Metro system expands, climate considerations need to be systematically integrated into the decision-making processes.

Communicating with Riders

Communicating climate impacts and resulting service disruptions to riders is key. Metro already makes announcements about changes to service and should work to enhance this communication so that riders can better plan around all disruptions, including climate-driven service abnormalities.

Table 3-2: Example Adaptation Actions

Table Legend			
Type of adaptation action		**Type of process**	
[Harden/protect]	Harden/protect existing or new infrastructure	PD	Planning, Design and Engineering
[Adjust operations]	Adjust operations/change behaviors	P	Procurement
[Relocate]	Relocate existing or design new infrastructure or services to avoid certain areas	AM	Asset Management and Maintenance
		O	Operations
		EM	Emergency Management and Disaster Response

Adaptation Action	Type of Adaptation Action	Type of Process
Implement pre-emptive **inspection/maintenance** and **weather-related monitoring** for bus and rail operations (e.g., AC units, rail catenary inspections, bus windshield wipers)	[Harden/protect] [Adjust operations]	AM, O
Improve **passenger and worker safety conditions** (e.g., making sure bus AC works before revenue service)	[Adjust operations]	AM, O, P
Regularly update **plans and procedures for managing disruptions** caused by weather-related events	[Adjust operations]	O, EM
Track **pervasive maintenance/repair issues** and use to improve practices	[Harden/protect] [Adjust operations]	PD, P, AM, O, EM
Collaborate with municipalities to enhance resilience of vulnerable transit stops and routes	[Harden/protect] [Relocate]	PD, AM
Integrate climate resilience as part of **project planning and design** for new projects	[Harden/protect] [Relocate]	PD
Review Metro **design and procurement criteria** and incorporate thresholds and requirements based on climate change projections	[Harden/protect]	PD, P
Increase **shading** of railway stations and bus stops	[Harden/protect]	PD, P, AM
Implement **erosion and mudslide control devices**	[Harden/protect]	PD, P, AM
Upgrade infrastructure at end of useful life to protect against extreme precipitation and heat	[Harden/protect]	PD, P, AM
Improve **stormwater management** systems	[Harden/protect] [Adjust operations]	PD, P, AM
Increase **pump capacity** to clear flood waters under rail tracks	[Harden/protect]	PD, P, AM
Implement **green infrastructure** to capture and reuse stormwater runoff	[Harden/protect]	PD, P, AM
Plant **trees** around transit stops, parking lots, yards and other open-space areas to provide shading	[Harden/protect]	PD, P, AM
Increase **use of vegetation** in and around Metro spaces to improve air quality, water quality, carbon storage and community health	[Harden/protect]	PD, P, AM
Increase **redundancy in power systems**, installing additional backup generators and establishing micro grids	[Harden/protect]	PD, P, AM, EM
In locations where flooding occurs often, **relocate assets** to other areas, **elevate**, or **incorporate low-impact development** to avoid flood damage	[Harden/protect] [Relocate]	PD

Adaptation Action	Type of Adaptation Action	Type of Process
Ensure Sustainable Acquisition Program accounts for climate resilience of materials (i.e., heat-, water-, fire-resilient materials)		P
Increase climate hazard-related **insurance** coverage		EM
Improve worker emergency management training		O, EM
Enhance **continuity of operations plans** for climate hazards		O, EM
Set up **fund** for emergency response expenses		AM, EM
Ensure adequate **fuel storage** before an extreme climate event occurs		AM, EM
Enhance **communication and monitoring systems** to respond quickly to risks		AM, O, EM
Improve **communication** with riders to spread awareness of redundant bus/rail lines if service is disrupted		AM, O, EM
Ensure weather and asset mapping **data are easily accessible and regularly updated** to aid quick response to risks		EM
Prioritize routes and structures to manage first in case of a climate-related emergency		AM, O, EM
Enhance **internal awareness** on climate change impacts and adaptation		PD, P, AM, O, EM
Designate climate adaptation **roles and responsibilities** to new or existing positions		PD, P, AM, O, EM
Improve **ability to respond** to incidents remotely		O, EM
Develop **external information sharing** mechanisms with relevant agencies for effective joint planning and responses to incidents		PD, O, EM

Each adaptation action has pros and cons in terms of cost, feasibility, effectiveness and rider impacts. The *right* action will depend on a number of situation-specific factors, such as severity of impact, cost, timing, frequency of events, equity considerations and aesthetic or comfort concerns.

Moreover, different actions might be appropriate depending on whether they are part of a **short-term response** or **longer-term planning**. A short-term response usually implies reacting in a way to minimize the impact following infrastructure damage or service disruption. Long-term planning might seek to prevent damage or service disruptions.

Metro must understand each adaptation action in order to determine which is the most appropriate action to take under unique circumstances. Though Metro continues to take measures to address existing extreme weather impacts to the system, what appears to be the right solution now might not be the right solution years from now. Metro is pursuing an approach called **flexible adaptation pathways** to address such situations.

What are Flexible Adaptation Pathways and why use them?

Many of the anticipated climate impacts discussed in this CAAP are expected to be felt by the middle of this century. Over the course of the next few decades, however, more than climate will change. The population and demographics of LA County will change, affecting where and how transit is used.

Flexible Adaptation Pathways: Recommended by State of California

In 2018, the state of California released *Paying It Forward: The Path Toward Climate-Safe Infrastructure in California*. This report discusses how resilience is best achieved through a pathway that has multiple strategies that are evaluated and implemented in different stages over time.

Technology changes also alter the way people travel, as seen with the advancements in self-driving cars, scooter-share programs, GPS and other tracking and communication devices and the rise in telecommuting. However, uncertainty still exists at a local level.

There are big risks in selecting and implementing a suite of adaptation actions all at once. Metro is committed to implementation of adaptation actions inclusive of and beyond those in Table 3-2. We want to plan our adaptation actions thoughtfully and strategically. Metro recognizes there is a risk that actions selected today will not protect the system from challenges down the road. Conversely, there is a risk in taking actions across all asset types beyond what is necessary or that the actions would not be cost-effective.

Metro cannot afford to wait to adapt, as it is more difficult and expensive to make aggressive changes in a short period of time rather than gradually. Flexible adaptation pathways help organizations address climate change and its impacts precisely because they occur over a long period, and often in an unpredictable manner. Metro will use the flexible adaptation pathways as a guide to identify where, when and how to implement adaptation actions such as those listed in Table 3-2.

These pathways visually represent a variety of actions for adapting to a risk and show how different actions can be implemented over time as new information emerges. Adaptation pathways can take different forms, but generally share the following key elements:

> **A clear objective.** A clear statement of the purpose for taking an adaptation action, tied to a specific climate risk.

> **A variety of adaptation actions to meet that objective**. Choosing more than one action such as those listed in Table 3-2 that address the same objective in different ways.

> **Predetermined thresholds or triggers to initiate movement from one pathway to another**. Triggers signal when an adaptation action must be taken to prevent impact escalation. The trigger indicates when to initiate the first adaptation action, as well as when to switch from one action to another. Triggers might be performance metrics (e.g., frequency of service disruptions or approaching end of useful life), impact frequency or cost (e.g., frequency of climate impacts resulting in repair costs, magnitude of annual repair costs). Appropriate and measurable performance metrics that reflect a tangible component of how Metro conducts business will need to be identified.

> **A monitoring system to identify when triggers are met**. The monitoring system tracks performance metrics and could build upon an existing one. Metro already has a management system that keeps track of asset performance relative to expected useful life. The system could be enhanced to track information specifically related to climate-related metrics to help identify when action is needed.

> **Pros and cons of each action within a pathway**. Comparing each pathway enables users to identify the optimal pathway based on considerations like cost, feasibility or service disruptions.

Once this information is identified, components can be organized to show the different potential pathways available for meeting a given objective.

Using the pathways approach has several advantages. It reduces the risk of being unprepared or overpreparing at unnecessary cost. It encourages proactive, rigorous and transparent monitoring to ensure action is taken at the appropriate time, safeguarding against unexpected climate events. It enables identification of a range of potential paths forward, and to better understand the pros and cons of each, creating a flexible and robust approach for enhancing system resilience. In this way, Metro can begin taking steps to ensure we provide safe and reliable service to our riders, while also ensuring efficient fiscal management.

Developing Adaptation Pathways at Metro

Metro will work to integrate the flexible adaptation pathways concept within Metro processes to manage risks identified in the CAAP. This integration began during an internal workshop in January 2019 to introduce the process with a cross-departmental focus group. At this workshop, example pathways were developed, such as the one shown on page 38. For more information on how flexible adaptation pathways will be implemented, see Chapter 4.

Example Flexible Adaptation Pathway: Building Station Elevator Resilience to Extreme Heat

The Issue: Elevator machine rooms on the Red Line can get as hot as 140° F during heatwaves. When this happens, the hydraulic systems that power the elevators become inefficient and eventually stop working. Since many Red Line stations only have one elevator, an elevator outage can lead to significant passenger disruption, particularly for riders with disabilities, older riders and those with strollers and bicycles. Metro currently sets up bus bridges between stations when elevator outages occur.

The Challenge: During the risk assessment, Metro determined the number of high heat days will increase substantially in the future, particularly along certain portions of the Red Line, likely increasing the frequency of elevator outages along the Red Line. Metro could continue to rely on bus bridges during elevator outages, but frequent use could negatively affect the rider experience and add to ongoing operational costs. Moreover, if there are simultaneous outages across multiple stations, bus bridges become more difficult logistically.

Pathway Objective: Ensure rail station accessibility during heat waves through enhanced elevator management

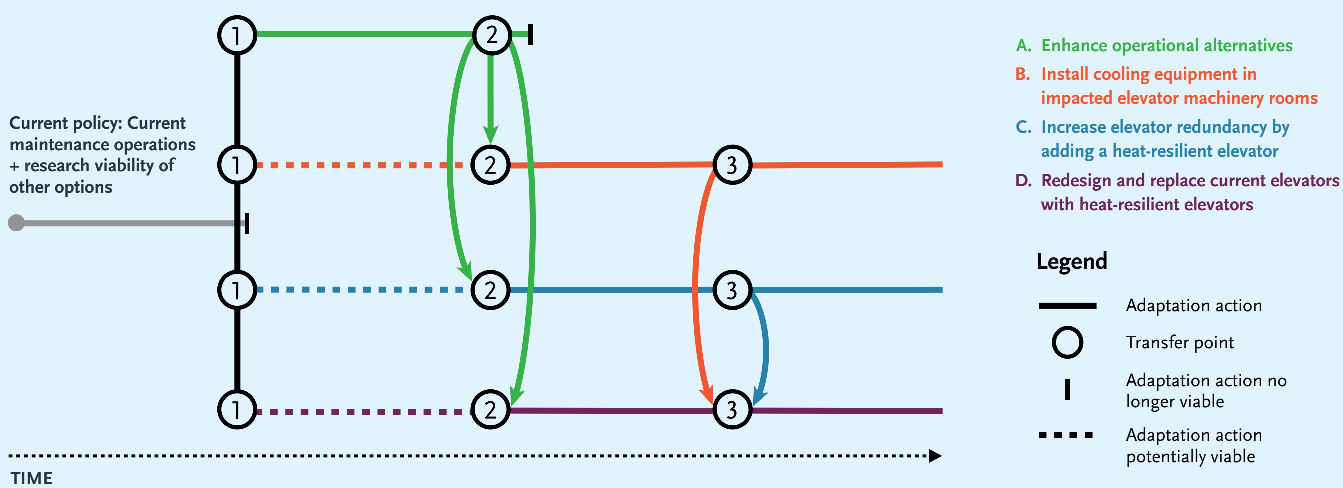
Adaptation Actions That Can Meet That Objective: Metro considered four adaptation actions:

> A: Enhance operational alternatives
> B: Install cooling equipment in impacted elevator machinery rooms
> C: Increase elevator redundancy by adding a heat-resilient elevator
> D: Redesign and replace current elevators with heat-resilient elevators

Pros and Cons of Each Action and Pathway

> Action A is the most economical, easiest to implement and causes the fewest disruptions in the short term. However, this option might not be viable in the long term as heatwaves increase. The rider experience could become too impacted by frequent bus bridges or the rising cost of bus bridges could make this option fiscally undesirable. Moreover, if multiple stations experience simultaneous outages, bus bridges might become logistically infeasible.
> Action B might be more viable than Action A. However, it is more difficult to implement, as some elevator equipment rooms would need reconfiguring to accommodate cooling equipment. Moreover, riders would be inconvenienced in the short term, as elevator outages would be required to install these changes. Thus, Action B might not be technically feasible for all stations.
> Actions C and D are both technically viable at any point, but are very expensive, difficult to implement and would cause rider inconvenience during the time it takes to replace or add elevators. The cost, difficulty and degree of passenger disruption is dependent on the design, and site characteristics of each station, requiring detailed assessment.

Figure 3-7: Pathways Map of Current Policy and Four Adaptation Actions



Transitions from One Pathway to Another

Transfer Point 1

At some point, Metro might determine that providing bus bridges no longer works well. However, to make that determination, Metro would need to first establish clear performance metrics and monitoring procedures. Types of performance metrics Metro could utilize include:

> Number of elevator outages per year
> Number of heat-related elevator maintenance calls per year
> Number of extreme heat days per year
> Number of heat alerts issued by LA County per year
> Cost of providing bus bridges
> Cost of heat-related elevator repairs

Using metrics like these, Metro can identify thresholds at which impacts are no longer acceptable—triggering a switch to another pathway. Once thresholds are identified, Metro can monitor the selected metrics. Nearing a threshold will trigger movement to another pathway. This transition is shown as Transfer Point 1 in Figure 3-7.

While all four adaptation actions are viable at this point, the pathway in the image indicates that adaptation Action A (Enhance Operational Alternatives) is the preferred situation in the near-term. It is likely less expensive and can be a short-term solution before more expensive actions are considered. Ways to enhance operational alternatives include:

> Cooling down elevator machine rooms using portable ice packs or HVAC machines
> Deploying Metro staff to reduce elevator trips by managing riders using elevators, similar to the practices used during special events
> Deploying enhanced bus bridges to improve rider experience

Transfer Point 2

As the number and severity of heatwaves increases, Adaptation Action A might no longer be an optimal option based on performance metrics. As a result, the pathway must transition to Adaptation Actions B, C or D. To determine which action to deploy, Metro must weigh the benefits and costs of each adaptation action.

Transfer Point 3

At some point, the elevator's useful life will end. Because the elevator will need to be replaced, it might make sense to install a more heat-resistant elevator at this point.

Table 3-3 compares the costs and benefits of the sample pathways, including the option of remaining with one action or sequencing in actions over time.

Table 3-3: Example Pathway Pros and Cons

Adaptation Action	Present Value of Cost	Difficulty of Implementation	Passenger Disruption when Implementing Action	Longevity of Option Viability
A	$	+	#	O
B	$$	+++	###	OOO
C	$$$$$	++++	####	OOOOO
D	$$$$$	++++	####	OOOOO
AB	$$$	++++	###	OOO
AC	$$$$	+++++	#####	OOOOO
AD	$$$$	+++++	#####	OOOOO

Note: The action column describes the series of actions within each pathway. The cost column shows relative costs of each pathway, with additional "$" indicating increasing cost. The difficulty of implementation column indicates a greater degree of difficulty associated with more "+." In the disruption column, more "#" represents higher amounts of near-term passenger disruptions due to elevators being taken out of service to implement the action. The longevity of option viability column indicates how long into the future the adaptation option maintains the system within performance metrics, with increasing "O" indicating increasing longevity.

4

Implementing Climate Action

This CAAP has established ambitious goals related to both GHG mitigation and climate resilience (Table 4-1). Meeting these goals will require bold action. To manage change effectively, Metro will need to consider a number of emerging challenges and address potential barriers to action.

Metro will pursue implementation designed around five overarching principles that drive the change process internally and externally. The sections that follow discuss these principles and Metro's immediate next steps.

Table 4-1: Summary of CAAP Mitigation and Resilience Goals

Topic	Goals
GHG Mitigation	> Reduce GHG emissions by 79% below 2017 levels by 2030 > Achieve zero emissions by 2050
Climate Resilience	> Create a climate-resilient organization and transit system: prepared, ready and able to provide consistent services to the people of LA County

4.1
Emerging Challenges

In order to achieve the ambitious goals set forth in this CAAP, Metro identified mitigation measures and an approach for adaptation planning to be implemented over the coming years. Specific actions, technologies and timelines reflect extensive research of industry best practices. However, this field of research constantly evolves. As a result, Metro will face a number of challenges to realizing our goals, including:

- **Resources and prioritization**. Metro has finite resources and competing priorities. Equally critical initiatives constrain the availability of financial, intellectual and creative capital and compete with day-to-day functions for resources. Committing to ambitious goals must be coordinated with service obligations, stakeholder responsiveness and responsible stewardship of taxpayer dollars.
- **Decision-making silos**. Metro departments each have goals and priorities. Accessing critical information needed to make informed decisions about actions that affect GHG emissions and resilience requires interdepartmental coordination and knowledge of available resources. In addition, decisions made from the perspective of one department may not be optimal from another perspective or for Metro as a whole. In some cases, such decisions aimed to meet one priority could conflict with other Agency priorities or performance metric attainment.
- **Emerging technologies and uncertainty**. Achieving the outcomes outlined in this CAAP will require widespread, full-scale adoption of a multitude of new technologies. Many of these technologies will require new equipment, infrastructure, operating procedures, maintenance programs, training, financing and ownership models—a true paradigm shift. Selecting rapidly developing technologies runs the risk of creating stranded assets and costly rework and possible impacts to service. Although pilot projects and the sharing of industry best practices provide valuable insight, a large degree of uncertainty remains to be navigated.

Design Studio rethinks way-finding signage design to reduce maintenance and replacement costs

4.2 Implementation Principles

To address emerging challenges and potential barriers to meeting CAAP goals, Metro has identified five key principles to guide strategy implementation:

Principle 1: Embrace Climate Leadership

Meeting the ambitious goals set forth by this CAAP will require all of us to be champions of climate change. This includes leadership, collaboration and bold action from Metro senior leadership. Metro's entire workforce must embrace, participate in and contribute to an organizational culture of climate leadership and Metro's vast network of stakeholders should be actively engaged in providing critical input and advice.

Establishing clear roles and responsibilities early in the process will lead to successful implementation and outcomes.

Leveraging existing governance structures and forums creates space for collaboration. These structures include: the Environmental Management System (EMS), quarterly Green Working Group meetings that represent over 80 Metro departments, the Sustainability Council, the Transportation Business Advisory Council (TBAC), interdepartmental trainings, discussion groups and electronic communications. Metro's Environmental Compliance and Sustainability Department (ECSD), the principal authors of this Plan, will continue to act as the primary coordinator of climate action across Metro. We can achieve our goals by continuing to promote both rigorous internal collaboration and authentic external engagement with key stakeholders.

Efforts to reduce emissions and increase resilience should be aligned with other Metro priorities, such as equity goals outlined in the *Equity Platform Framework*, infrastructure and operational goals set out in the *Long Range Transportation Plan* and Agency-level goals identified in *Vision 2028 Strategic Plan*. Collective alignment of these goals will require decisive guidance from Metro leadership.

Principle 2: Secure Funding and Prioritize Resources

Metro will need to dedicate adequate resources and prioritize climate actions. While many resources already designated for planning, designing, building and operating the Metro system can be leveraged in pursuit of climate action, additional resources will be required to implement changes identified in this CAAP. Climate action must be reflected across all funding strategies and identified within both department and project budgets.

Wherever feasible, partnerships should be leveraged to jointly support climate-related initiatives. This can be accomplished by identifying external partners that share Metro's vision for climate action and whose decisions collectively impact the sustainability of the region, such as City and County of LA, Caltrans and other state and local agencies.

Many of the risks Metro faces from climate change are risks faced by LA County or the region as a whole. Broad land-use and transportation planning decisions made throughout the LA region affect Metro's ability to offset transportation-related GHG emissions. Metro decisions about service offerings and system planning can affect LA County's future GHG emissions. When it comes to addressing risks from flooding, wildfire and other hazards,

Climate Action Through Collaboration

In 2018, Metro launched a pilot program purchasing 10 all-electric Chevy Bolts for our non-revenue fleet. Metro plans to deploy another 20 Chevy Bolts by the end of 2019. These vehicles reduce fuel consumption, GHG emissions and other air pollutants.

This pilot required extensive collaboration across several Metro departments:

> **Non-Revenue Department** purchases and maintains the non-revenue vehicle fleet;

> **Facilities Maintenance and General Services** installs charging stations; and

> **Environmental Compliance and Sustainability Department** and **Talent Development** produce and deploy training for operators of the vehicles.

it can be more effective to address them collaboratively on a larger scale rather than individual agencies trying to tackle them alone.

Metro must also recognize the potential value of private sector partnerships to maximize financial capital to fund, operate and maintain assets that contribute to impactful climate action. By working together and pooling financial resources, mitigation potential and preparations for climate risks can be optimized.

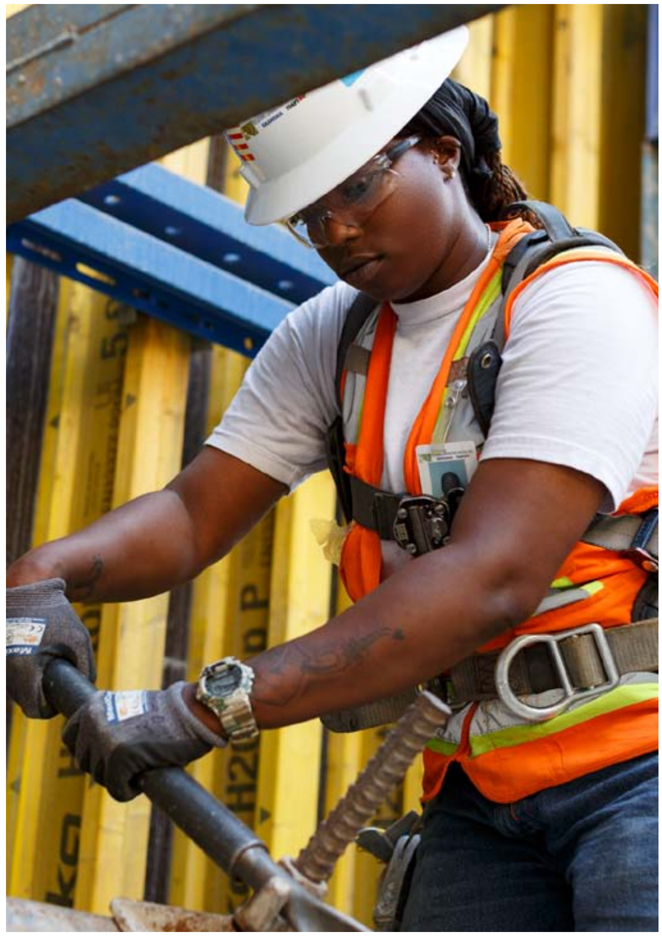
Principle 3: Integrate Climate Knowledge into Existing Decision-Making Processes

Environmental stewardship and sustainability are embedded in all that Metro does. Yet, ambitious goals can only be achieved if climate-forward thinking is seamlessly and rigorously integrated into existing decision-making processes and systems. Key planning, design, construction, procurement and risk mitigation decisions require knowledge about GHG emissions and climate resilience that can be leveraged.

Integrating climate change thinking into Metro operations and processes has already begun in many Metro departments. A framework for sustainable acquisition practices to prioritize procurement decisions aligned with the vision set forth by this Plan is under development. Metro is emphasizing the use of lifecycle costing and other tools that encourage longer-term thinking when making decisions about system designs, construction strategies and maintenance planning. Incorporating climate information and data as inputs when evaluating choices, alternatives and project priorities is the next logical step forward.

Principle 4: Monitor and Evaluate Progress

Metro emphasizes continual improvement in monitoring and evaluating the outcomes of CAAP strategies. Existing reporting processes track, evaluate and report on implementation progress and outcomes in a manner that is transparent and inclusive. For example, GHG emissions and displacement are two of ten sustainability indicators reported annually in the *Energy & Resource Report*. Case studies and program metrics for sustainability planning efforts are simultaneously tracked in the *Countywide Sustainability Planning Policy Annual Report*. In seeking opportunities for collaboration, efficiency and harmonization, Metro will be merging these two reporting documents into a single *Sustainability Performance Report*.



Reporting on GHG mitigation will continue to track the status of pilots, technology assessments, financial analyses, decision-making outcomes and other major planning efforts underway. Reports will not only highlight key successes, but also identify where challenges or barriers persist. Such reports provide an opportunity to reevaluate technology choices, specific mitigation measures and actions, implementation timelines and goals.

To monitor progress toward reducing climate-related risks, it is essential that Metro establish clear metrics and thresholds for climate-related service disruptions, repair, maintenance and customer satisfaction processes.

Principle 5: Engage with Community Stakeholders

Key stakeholders might include state of California agencies (including Caltrans); LA County municipalities and cities; the Southern California Association of Governments

(SCAG); utility partners; contractors that design, build or supply assets; asset owners and operators; existing local committees or organizations addressing climate-related topics; universities; community organizations; and transit patrons.

Metro values input and expertise from staff, riders and other key stakeholders when implementing and evaluating the goals in this CAAP. Regular, inclusive and meaningful involvement across diverse populations helps ensure that Metro's climate actions are well informed and supported. Metro creates opportunities to inform the public about potential risks due to climate changes and wants stakeholders to understand how and why Metro is addressing these risks.

Authentic stakeholder engagement is particularly important because the impacts of climate change affect the region, not just Metro's transportation system. Innovative solutions to persistent challenges can come from anywhere, and often reside in the private sector. Recognizing this and wanting to invite and harness the best thinking available, the Unsolicited Proposal Process and Public Private Partnerships programs at Metro allow anyone to submit innovative ideas to Metro.

Collaboration can bring about greater change than working alone. Metro is a partner in the Transportation Electrification Partnership, an initiative to accelerate progress toward transportation electrification in the LA region in advance of the 2028 Olympic and Paralympic Games. This partnership includes the City and County of LA, Southern California Edison and many other public and private entities and is achieving greater progress toward electrification than any single entity could accomplish on its own.

Increased collaboration could help identify co-benefits or redundancies among partners. Metro's efforts to use green infrastructure to keep stations and bus stops cool might help further local efforts to address the urban heat island effect. The City or County's efforts to improve drainage might result in fewer Metro service disruptions during heavy rain events.

Metro can also leverage many existing engagement mechanisms with new ones for strategic and multi-faceted exchange of information. Existing mechanisms include: ridership surveys, Service Councils, the Sustainability Council, general councils (e.g., Transportation Business Advisory Council), website content, email, social media, local committees, customized trainings and conference presentations. Internal communication channels include MyMetro Headlines section of the Metro intranet portal, department newsletters, employee visual messaging boards at division facilities and employee trainings.

4.3 Looking Ahead

ECSD is the lead department guiding implementation of CAAP goals and will take the following next steps concurrently:

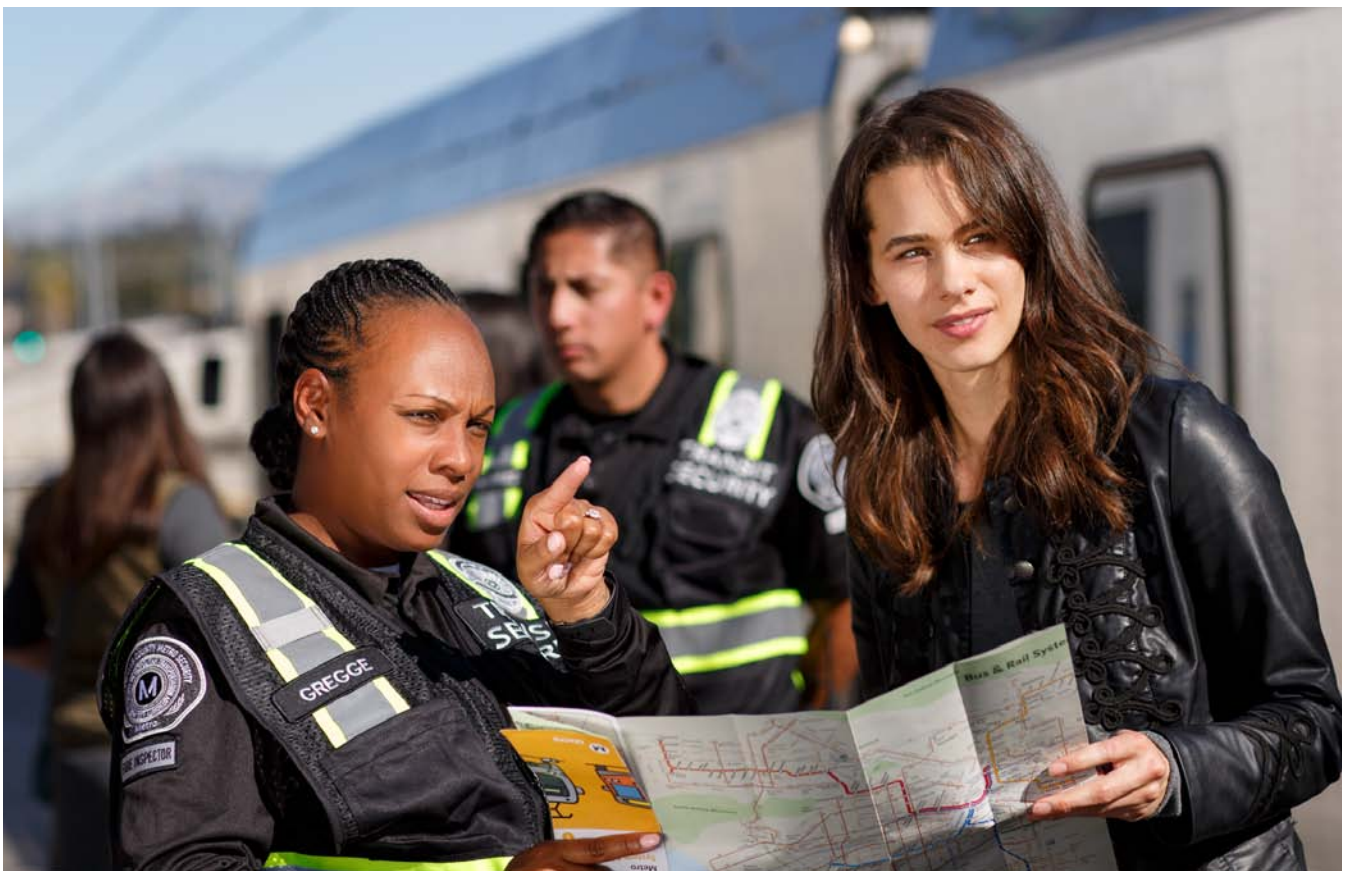
> Oversee implementation of initiatives and strategies detailed in this CAAP
> Work with and support key internal stakeholders toward implementation of CAAP goals
> Provide key departments with technical analysis, project development, lifecycle costing, funding identification, education and training support
> Monitor, track and evaluate progress and outcomes of climate-related initiatives across the Agency

CAAP implementation will include examining planned versus actual implementation timelines and overall program implementation with a keen eye to identify and evaluate potential and realized barriers to implementation, as well as opportunities for improvement. Opportunities for feasible acceleration will be prioritized.

Instituting a robust monitoring system allows Metro to continuously evaluate progress toward our goals and identify opportunities for improvement. This includes evaluating additional measures, such as those to reduce GHG emissions with a goal of zero carbon emissions.

As appropriate, new targets and goals may be established and they may be even more ambitious than those currently set forth.

To maintain transparency and accountability to the goals set in this CAAP and to communicate any new goals and measures, the *Energy & Resources Report* and future sustainability reports will provide an annual update to stakeholders on Agency progress and the status of implementation timeframes.



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Appendices

Appendix A
Methodology for Greenhouse Gas Analyses

Greenhouse Gas Inventory

This section describes the methodologies and data sources used to develop the 2017 GHG inventory estimates for Metro as well as emissions displaced by Metro.

Metro Emissions[15]

Rail. Metro calculated emissions from rail using electricity consumption data for rail propulsion disaggregated by utility, as obtained from the *2018 Energy and Resources Report* Technical Appendix. Metro calculated emissions by multiplying consumption data by utility-specific emission factors obtained from the Los Angeles Department of Water and Power and Southern California Edison. Metro calculated emissions from electricity provided by Pasadena Water and Power (PWP) and other (non-specified) sources by multiplying consumption data by the emission factors for the Western Electricity Coordinating Council California (CAMX) region, obtained from the US Environmental Protection Agency's (EPA's) eGRID tool.

Directly Operated Bus Fleet. Metro calculated emissions from our directly operated bus fleet using CNG and RNG consumption data and vehicle mile data obtained from *the 2018 Energy and Resources Report* Technical Appendix. Metro calculated CO_2 emissions by multiplying fossil CNG consumption by a fuel-specific emission factor obtained from the Climate Registry. Metro calculated CO_2 emissions from RNG using the same method but assumed that these emissions were biogenic, and therefore did not include them in emission totals. Metro calculated methane (CH_4) and nitrous oxide (N_2O) emissions from both CNG and RNG by multiplying the vehicle miles by fuel-specific emission factors obtained from the Climate Registry.

Also included in this source are emissions from the electricity consumed for CNG compression. Metro calculated emissions from CNG compression using electricity consumption data for CNG compression disaggregated by utility, as obtained from the *2018 Energy and Resources Report* Technical Appendix. Metro calculated emissions by multiplying consumption data by utility-specific emission factors obtained from Los Angeles Department of Water and Power (LADWP) and Southern California Edison (SCE).

Contracted Bus Fleet. Metro calculated emissions from Metro's contracted bus fleet using CNG and diesel consumption data obtained directly from the contracted bus operator and vehicle mile data obtained from the *2018 Energy and Resources Report* Technical Appendix. Metro calculated CO_2 emissions by multiplying CNG and diesel consumption by fuel-specific emission factors obtained from the Climate Registry. Metro calculated CH_4 and N_2O emissions from CNG and diesel consumption by multiplying the vehicle miles by fuel-specific emission factors obtained from the Climate Registry.

Vanpool. Metro calculated emissions from the Metro vanpool fleet using gasoline consumption data and vehicle mile data obtained from the *2018 Energy and Resources Report* Technical Appendix. Metro calculated CO_2 emissions by multiplying gasoline consumption by a fuel-specific emission factor obtained from the Climate Registry. Metro calculated CH_4 and N_2O emissions from gasoline consumption by multiplying the vehicle miles by fuel-specific emission factors obtained from the Climate Registry.

Non-Revenue Vehicles. Metro calculated emissions from non-revenue vehicles using diesel and gasoline consumption data and vehicle mile data obtained from the *2018 Energy and Resources Report* Technical Appendix. Metro calculated CO_2 emissions by multiplying diesel and gasoline consumption by fuel-specific emission factors obtained from the Climate Registry. Metro calculated CH_4 and N_2O emissions from diesel and gasoline consumption by multiplying the vehicle miles by fuel-specific emission factors obtained from the Climate Registry.

Facility Electricity. Metro calculated emissions from facility electricity consumption data disaggregated by utility, as obtained from the *2018 Energy and Resources Report* Technical Appendix. Metro calculated emissions by multiplying consumption data by utility-specific emission factors obtained from LADWP and SCE. Metro calculated emissions from electricity provided by PWP and other (non-specified) sources by multiplying consumption data by the emission factors for the CAMX region, obtained from US EPA's eGRID tool.

[15]The 2017 emission results presented in this CAAP differ slightly from the results presented in the 2018 Energy & Resource Report. The differences are largely due to this CAAP's inclusion of additional source categories (i.e., employee commuting and land use) as well as the use of utility-specific consumption data and emission factors rather than a regional electricity emissions factor. In addition, updates were made to the mode shift factor used to calculate displaced emissions, based on updated guidance from the American Public Transportation Association.

Facility Natural Gas. Metro calculated emissions using facility natural gas consumption data. Metro calculated emissions by multiplying consumption data by emission factors obtained from the Climate Registry.

Water Consumption. Metro calculated emissions from electricity consumption embedded in water using water consumption data obtained from the *2018 Energy and Resources Report* Technical Appendix. Metro calculated emissions by multiplying water consumption data by a conversion factor derived using the methodology developed by Hendrickson and Bruguera[16] and data from the *2015 LADWP Urban Water Management Plan* to estimate the amount of electricity embedded in water consumption. Metro then calculated emissions by multiplying the electricity embedded in water consumption by the emission factors for the CAMX region, obtained from US EPA's eGRID tool.

Refrigerants. Metro calculated emissions on a CO_2-equivalent basis using refrigerant emissions data obtained from the *2018 Energy and Resources Report* Technical Appendix. Refrigerant data were not disaggregated for revenue vehicles, non-revenue vehicles and facilities and thus the emissions could not be apportioned specifically to those three sources. Metro multiplied the refrigerant emissions by gas-specific GWPs obtained from the *IPCC Fifth Assessment Report*. For gas mixtures, Metro calculated weighted-average GWP values based on the composition of the mixture.

Employee Commuting. Metro calculated emissions from employee commuting using data from the 2017 Mode Split Commuter Listing and *2017 Average Vehicle Rider Report,* as well as employee data. Metro first calculated total daily employee commuting miles for survey respondents by mode by multiplying the number of daily trips by the average commute distance for trips taken by driving alone, motorcycle and carpool (five persons or fewer). Metro scaled up total daily miles by multiplying the results by the ratio of total employees to the number of respondents to account for miles traveled by non-respondents.

Metro then calculated total annual commuter miles by multiplying the total daily commuter miles by the number of weeks worked per year per employee (assumed 50 weeks) and by the number of days worked per week per employee (assumed five days). Metro calculated fuel consumption from employee commuting by multiplying the total annual commuter miles by the average fuel economy in LA County, assuming all fuel consumed was gasoline. Metro calculated emissions from employee commuting by multiplying gasoline consumption by a fuel-specific emission factor obtained from the Climate Registry. Metro calculated CH_4 and N_2O emissions from gasoline consumption by multiplying the vehicle miles by a fuel-specific emission factor obtained from the Climate Registry.

Displaced Emissions

Mode Shift. Metro calculated displaced emissions from mode shift using a mode shift factor of 0.302, as obtained from the American Public Transportation Association's *Recommend Practice*. Metro estimated VMT displaced by Metro by multiplying the mode shift factor by total passenger miles for the transit system, as obtained from the *2018 Energy and Resources Report* Technical Appendix. Metro estimated the amount of gasoline consumption displaced by multiplying the VMT displaced by the 2017 average fuel economy in LA County, as obtained from the California Air Resources Board (CARB) Emission Factors (EMFAC) model. Metro then calculated emissions using default emission factors obtained from the Climate Registry.

Land Use. Metro calculated displaced emissions from land use using a land use benefits factor of 3.92 (VMT reduction from land use as a ratio of the VMT reduction from the mode shift effect), as obtained from the Transit Cooperative Research Program's (TCRP) Land Use Benefit Calculator. Metro estimated VMT displaced by Metro by multiplying the land use factor by total VMT displaced as a result of mode shift, calculated using the methodology described above to estimate displaced emissions from mode shift. Metro estimated the amount of gasoline consumption displaced by multiplying the VMT displaced by the 2017 average fuel economy in LA County. Metro then calculated emissions using default emission factors obtained from the Climate Registry.

Greenhouse Gas Forecast

This section describes the assumptions used to forecast Metro's GHG inventory and displaced GHG emissions for 2030 and 2050 under a BAU scenario.

Metro Emissions

Rail. Metro forecasted emissions from rail by projecting forward electricity consumption and utility-specific emission factors and applying the same methodology used to estimate 2017 emissions. Metro assumed that the level of service on existing rail lines will not change and that electricity consumption will increase as a result of new planned transit projects. A summary of new rail projects

[16] Hendrickson and Bruguera 2018.

considered in this analysis is provided in Table A-1. Planned project information was gathered through 2018; adjustments or refinements to these planned projects since then are not reflected in this analysis.

Table A-1: New Planned Rail Projects

Name	Rail Type	Projected Service Date	Route Miles
Crenshaw/LAX	Light	2019	8.5
Regional Connector	Light	2021	1.9
PLE1	Heavy	2023	3.9
PLE2	Heavy	2025	2.6
PLE3	Heavy	2026	2.6
Foothill Claremont	Light	2025	12.3
South Bay	Light	2030	4.6
Gold Eastside Exp	Light	2035	9.1
WSAB1	Light	2028	6.0
WSAB2	Light	2041	13.0
East SFV	Light	2027	9.2

Note: Projects in the early planning phase were developed conceptually for the purposes of this analysis. Planned alignments will be determined upon completion of all environmental review and Board approval.

Metro estimated annual VMT for each new project by assuming VMT per route mile will remain consistent with the average VMT per route mile in 2017 for each rail type. Metro then estimated additional electricity consumption that will result from each project by assuming the amount of electricity consumed per VMT will remain consistent with the amount of electricity consumed per VMT in 2017. The additional electricity consumption was then apportioned to each utility based on the percentage of rail propulsion electricity supplied by each utility in 2017.

Metro adjusted utility-specific emission factors by assuming their future generation mix will comply with California Senate Bill 100. In other words, Metro assumed each utility will have 60% renewable energy by 2030, and 100% renewable energy by 2045. Metro adjusted the utility-specific emission factors by applying the ratio of the expected proportion of nonrenewable energy in the utility mix to the 2017 proportion of nonrenewable energy in the utility mix.

Directly Operated Bus Fleet. Metro forecasted emissions from the directly operated bus fleet by projecting forward fuel consumption and vehicle miles and applying the same methodology used to estimate 2017 emissions. Metro assumed that fuel consumption and vehicle miles will increase as a result of new planned transit projects, and that two of the new transit projects will displace existing bus service. A summary of the new bus projects that were considered in this analysis along with the type of service they are assumed to displace is provided in Table A-2. Planned project information was gathered through 2018; adjustments or refinements to these planned projects since then are not reflected in this analysis.

Table A-2: New Planned Bus Projects

Name	Type	Projected Service Date	Route Miles	Displaced Service Type
Noho-Pasadena	BRT	2022	16	Contracted Bus
North SFV	BRT	2023	18	Metro Bus
Vermont Corridor	BRT	2030	12.4	Metro Bus

Note: Projects in the early planning phase were developed conceptually for the purposes of this analysis. Planned alignments will be determined upon completion of all environmental review and Board approval. BRT = bus rapid transit.

Metro estimated annual VMT for each new project by assuming VMT per route mile will remain consistent with the average VMT per route mile in 2017 for BRT. Metro then estimated additional fuel consumption that will result from each project by assuming the amount of fuel consumed per VMT will remain consistent with the amount of fuel consumed per VMT in 2017.

Metro calculated the amount of service displaced by the North San Fernando Valley and Vermont Corridor projects by applying the ratio of annual VMT for Bus Line 501 to the projected annual VMT from the Noho-Pasadena Corridor project. This ratio was applied because the Noho-Pasadena Corridor BRT Project is currently planned to displace the current Bus Line 501, which is part of the contracted bus fleet.

Metro assumed that all buses will transition from CNG to RNG by the end of 2019. In addition, Metro assumed that the Orange and Silver Lines will transition to electric buses by 2020. Metro estimated electricity consumption by multiplying the annual VMT of Orange and Silver Line buses by a 2.2 kWh/mile fuel economy for electric buses. Metro then multiplied total electricity consumption by an emission factor that was calculated using a weighted average of the utility-specific emission factors, adjusted to comply with California Senate Bill 100, based on the proportion of total electricity supplied by utility in 2017.

Metro forecasted emissions from the compression of CNG by projecting forward electricity consumption for CNG compression and applying the same methodology used to estimate 2017 emissions. Metro estimated electricity consumption resulting from CNG compression by assuming the ratio of kWh per therm of CNG consumed by the directly operated bus fleet remains constant relative to that in 2014.

The ratio for 2014 was selected because it was determined to be the best representation of electricity consumption for CNG compression. The electricity consumption was then apportioned to each utility based on the percentage of electricity supplied by each utility for CNG compression in 2017. Metro adjusted the utility-specific emission factors by assuming the future generation mix will comply with California Senate Bill 100.

Contracted Bus Fleet. Metro forecasted emissions from the Metro contracted bus fleet by projecting forward fuel consumption and vehicle miles and applying the same methodology used to estimate 2017 emissions. Metro assumed that the planned Noho-Pasadena Corridor BRT Project will displace existing bus service, and that vehicle miles will otherwise remain constant through 2050. Metro estimated the amount of service displaced by the Noho-Pasadena Corridor BRT Project based on the annual VMT of Line 501 because the Noho-Pasadena Corridor BRT Project is currently planned to displace the current Bus Line 501. Metro also assumed that all diesel buses will be phased out and replaced with CNG buses by 2020. Metro estimated the additional CNG consumption resulting from the phase out of diesel by applying the 2017 ratio of therms per VMT of contracted CNG buses.

Vanpool. Metro forecasted emissions from the Metro vanpool fleet by projecting forward fuel consumption and vehicle miles and applying the same methodology used to estimate 2017 emissions. Metro assumed that vehicle miles will remain constant through 2050. Metro also assumed the fuel economy of the vanpool fleet will improve as a result of the federal CAFE standards. Metro used the CARB EMFAC model to forecast fuel economy. Specifically, Metro obtained the 2030 and 2050 gasoline fuel economy for each of the three vehicle categories (LDT2, LHD1 and MDV) in the vanpool fleet aggregated for all model years in LA County. The adjusted fuel consumption was then calculated based on the average fuel economy weighted by the percentage of each vehicle category in the current vanpool fleet.

Non-Revenue Vehicles. Metro forecasted emissions from non-revenue vehicles by projecting forward fuel consumption and vehicle miles and applying the same methodology used to estimate 2017 emissions. Metro assumed non-revenue VMT will remain constant through 2050. Metro also assumed 28 Chevy Bolts (BEV) will replace retiring Toyota Camry hybrids by 2019, as stated in Metro's *2018 Energy and Resources Report*. Metro estimated electricity consumption by multiplying the 2017 average annual VMT of gasoline non-revenue vehicles by 0.28 kWh/mile, the fuel economy for 2019 Chevy Bolts.

Metro then multiplied total electricity consumption by an emissions factor that was calculated using a weighted average of the utility-specific emission factors, adjusted to comply with California Senate Bill 100, based on the proportion of total electricity supplied by each utility in 2017.

Metro assumed the fuel economy of the remaining vanpool fleet improves as a result of the federal CAFE standards. Metro used the CARB EMFAC model to forecast fuel economy. Specifically, Metro obtained the 2030 and 2050 gasoline and diesel fuel economies for each vehicle category in the non-revenue vehicle fleet aggregated for all model years in LA County. The adjusted fuel consumption was calculated based on the average fuel economy weighted by the percentage of each vehicle category in the current non-revenue fleet.

Facility Electricity. Metro forecasted emissions from facility electricity by projecting forward facility electricity consumption based on the linear trend of historical data and applying the same methodology used to estimate 2017 emissions. The electricity consumption was then apportioned to each utility based on the percentage of electricity supplied by each utility for facility electricity in 2017. Metro assumed there will be no changes to building energy efficiency. Metro adjusted the utility-specific emission factors by assuming the future generation mix will comply with California Senate Bill 100.

Facility Natural Gas. Metro forecasted emissions from facility natural gas by projecting forward facility natural gas consumption based on the linear trend of historical data and applying the same methodology used to estimate 2017 emissions. Metro assumed there will be no changes to building energy efficiency.

Water Consumption. Metro forecasted emissions from water consumption by projecting forward water consumption based on the linear trend of historical data and applying the same methodology used to estimate 2017 emissions. Metro adjusted the CAMX emission factor by assuming the future generation mix will comply with California Senate Bill 100.

Refrigerants. Metro forecasted emissions from refrigerant use by projecting forward emissions by refrigerant type and applying the same methodology used to estimate 2017 emissions. Metro projected emissions of R-134a, which is largely used in motor vehicle air conditioners, based on the projected growth of VMT across all Metro vehicles. Metro projected emissions of R-407C, R-410a and R-438A, all of which are commonly used in building air conditioners, based on the projected growth in building electricity consumption.

Metro grew emissions of these refrigerants based on growth in building electricity consumption through 2023, which is the last year these refrigerants can be used in new equipment under California Senate Bill 1013. Metro also assumed R-22 is displaced by R-438A.

Employee Commuting. Metro forecasted emissions from employee commuting by projecting forward commuting VMT and applying the same methodology used to estimate 2017 emissions. Metro assumed employee commuting VMT will increase consistent with the forecasted employee growth rate of 2% every five years, which is based on the historical trend in employee growth. Metro assumed the average vehicle fuel economy will improve as a result of updated CAFE standards. Metro used the CARB EMFAC model to forecast fuel economy under the CAFE standards.

Displaced Emissions

Mode Shift. Metro forecasted displaced emissions from mode shift by projecting forward passenger miles for the transit system and applying the same methodology used to estimate 2017 displaced emissions. Passenger miles were projected based on the planned transit projects summarized in and Table A-2. Projections for daily weekday boardings by planned project were multiplied by the average passenger miles traveled per boarding by transit mode for 2017. The resulting daily passenger miles were then multiplied by an annualization factor based on the ratio of annual passenger miles to the weekday average passenger miles for 2017. Passenger miles were also reduced based on the planned displacement of existing bus service with new BRT projects. Metro assumed the average vehicle fuel economy will improve as a result of the CAFE standards. Metro used the CARB EMFAC model to forecast fuel economy under the CAFE standards.

Land Use. Metro forecasted displaced emissions from land use by applying the same methodology used to estimate 2017 displaced emissions. Metro assumed the average vehicle fuel economy will improve as a result of updated CAFE standards. Metro used the CARB EMFAC model to forecast fuel economy under the CAFE standards.

Greenhouse Gas Reductions

This section presents the methodologies used to develop measures and estimate costs and GHG emissions. Table A-3 shows detailed results for each mitigation measure.

Table A-4 shows how emission reductions relative to BAU change over time for each measure. Measure E-1 shows by far the greatest savings over time, although by 2050 SB100 has been fully implemented in the BAU scenario (100% statewide renewable electricity) and reduces E-1 emission savings to zero.

Table A-3: Net Present Value and Cumulative Avoided Emissions of All Measures

Measure	2030			2050		
	Net Present Value ($)	Annual Avoided Emissions ($MTCO_2e$)	2018–2030 Cumulative Avoided Emissions ($MTCO_2e$)	Net Present Value ($)	Annual Avoided Emissions ($MTCO_2e$)	2018–2050 Cumulative Avoided Emissions ($MTCO_2e$)
V-1: BEB Deployment (Directly Operated)	($6,503,268)	-1,356	-26,928	$514,834,559	8,197	117,912
V-2: BEB Deployment (Contracted)	$2,501,758	8,294	80,536	$17,917,088	18,363	349,122
V-3: BEV Vanpool Deployment	($4,766,099)	3,330	21,991	($7,674,538)	10,588	166,852
V-4: BEV Non-Revenue Vehicle Fleet Deployment	($6,553,227)	2,461	14,847	($16,811,941)	6,327	106,377
V-5: Wayside Energy Storage Substation Installation	($12,346,643)	654	6,724	$4,538,549	0	8,426
E-1: Renewable Electricity Procurement	($24,604,705)	65,910	514,963	($112,022,344)	0	1,227,887
F-1: Photovoltaic Installations	($64,994,749)	6,539	80,751	$79,012,824	0	94,041
F-2: Water-Saving Fixture Installation	$13,274,605	199	1,834	$35,251,551	0	3,382
F-3: Water Recycling System Installation	($6,225)	19	154	($29,080)	0	385
F-4: Facility LED Lighting Installation	$26,284,350	4,317	52,727	$138,187,420	0	61,872
F-5: Facility Heating, Ventilation and Air Conditioning Electrification	($32,791,222)	2,780	1,474	($186,852,673)	13,419	190,210
F-6: Facility Appliance Electrification	$987,902	397	3,111	$4,542,042	706	13,614
C-1: Employee EV Charging Station Installation	($15,638,405)	2,877	17,348	($43,619,774)	8,032	133,089
Total	($125,155,929)	96,421	**769,533**	$427,273,682	**65,632**	**2,473,168**
BAU Emissions		185,225	*2,419,976*		*81,529*	*4,816,126*
Remaining Emissions		88,804	*1,650,443*		15,897	*2,342,957*

Note: Negative net present value reflects costs while positive net present value reflects savings.

Table A-4: Annual Percentage Emission Reductions for Each Mitigation Measure

	Annual Percent Emission Reduction from BAU				
	2020	2025	2030	2040	2050
Vehicles	**3%**	**4%**	**7%**	**28%**	**53%**
V-1	0%	-1%	-1%	7%	10%
V-2	3%	3%	4%	11%	23%
V-3	0%	1%	2%	6%	13%
V-4	0%	1%	1%	4%	8%
V-5	0%	0%	0%	0%	0%
Renewable Energy Purchases	**8%**	**26%**	**36%**	**33%**	**0%**
E-1	8%	26%	36%	33%	0%
Facilities	**3%**	**6%**	**8%**	**9%**	**17%**
F-1	2%	4%	4%	0%	0%
F-2	0%	0.1%	0.1%	0.1%	0.0%
F-3	0%	0.01%	0.01%	0.01%	0.00%
F-4	1%	2%	2%	0%	0%
F-5	0%	-0.1%	1.5%	8.0%	16.5%
F-6	0%	0.1%	0.2%	0.4%	0.9%
Employee Commuting	**0%**	**1%**	**2%**	**5%**	**10%**
C-1	0%	1%	2%	5%	10%
Total	**14%**	**38%**	**52%**	**74%**	**81%**

Identifying Potential Mitigation Measures

Metro's assessment for this CAAP began by developing a list of possible mitigation measures to guide the emission reduction and cost-benefit analyses. Metro generated an initial list of 37 measures spanning building energy, water and wastewater, vehicle fleets, waste management and refrigerant materials. Metro relied on a variety of sources in developing this list, including:

> **Metro's 2012 CAAP** – Metro reexamined the preliminary mitigation measures list from the 2012 CAAP exercise and integrated the research and results of that effort into generating the initial list of draft measures. Metro incorporated elements of 30 of those measures into the draft measures list.

> **Other Existing Climate Action Plans (CAPs)** – Metro researched and used insights from other jurisdictions' existing CAPs to inform the draft measures. These CAPs consisted primarily of local efforts (i.e., LA County, San Bernardino) and those of other transit agencies (e.g., San Francisco Municipal Transportation Agency).

> **Metro Policies** – Metro wanted to ensure that we accounted for existing policies as part of the measure development. Internal stakeholder interviews and insights helped incorporate policies such as bus electrification, the draft *EVIP* and the *Water Action Plan*. Metro also closely considered the implications of internal policies for expansion, most notably the *Twenty-Eight by '28 Initiative*, and opportunities for GHG mitigation within those policies.

After developing the draft list of measures, Metro conducted extensive internal and external stakeholder engagement to better understand operational context, potential co-benefits, feasibility, how guiding assumptions should be structured and what technologies should be considered. Metro also compared the draft list of measures to the inventory and forecast results to verify that the measures would tackle Metro's largest sources of emissions. Metro then developed a refined list of 13 measures (Table 2-6) for additional stakeholder input and analysis.

Inventory and Forecast

We described the methods and results of the inventory and forecast in Chapter 2 of this CAAP report.

The inventory allowed Metro to verify that the measures it developed would address the largest sources of emissions. The forecasted BAU scenario (see Section 2.1 for BAU description) provided a baseline for both emissions and Metro operational activity data through 2050. Although we could readily compare the forecasted emission assessment with the mitigation potential of the measures to calculate the emission reduction, we used the forecasted activity data (e.g., fuel consumption, VMT, water consumption) to create a cost estimate for the BAU. Metro then used the BAU cost estimate as a benchmark to compare the costs and emissions of the different measures through the analysis period (2019–2050).

Mitigation Modeling

Next, Metro calculated the expected GHG reductions, costs and benefits of each measure. For each measure, we created guiding assumptions over the 2019–2050 analysis period that acted as drivers for energy consumption, purchasing cycles, maintenance costs and other key elements for each measure. Metro drew these guiding assumptions from relevant reports, peer-reviewed literature and expert insights from Metro employees. A key outcome of these assumptions is the expected implementation timeline.

Table A-5 shows how each measure would be implemented gradually over time in the model. For some measures, emission reductions increase after full implementation, primarily because the electricity grid will become decarbonized over time.

Table A-5: Percentage of Each Measure Implemented Through 2050

	Percentage of Measure Implemented			
	2020	2025	2030	2050
Vehicles	**11%**	**22%**	**48%**	**100%**
V-1	8%	20%	100%	100%
V-2	33%	37%	48%	100%
V-3	5%	18%	30%	100%
V-4	6%	20%	35%	100%
V-5	4%	15%	25%	100%
Renewable Energy Purchases (E-1)	**40%**	**70%**	**85%**	**100%**
Facilities	**12%**	**42%**	**71%**	**100%**
F-1	16%	55%	94%	100%
F-2	17%	58%	100%	100%
F-3	6%	19%	33%	100%
F-4	17%	58%	100%	100%
F-5	8%	29%	50%	100%
F-6	8%	29%	50%	100%
Employee Commuting (C-1)	**3%**	**19%**	**36%**	**100%**

The following sections detail the specific approaches and data sources used in the mitigation modeling for both GHG and cost estimates.

V-1: Replace Directly Operated Buses with BEBs

This measure would replace all directly operated buses with BEBs by 2030.

Greenhouse Gas Emissions

Key Assumptions: In the BAU, the analysis assumed that the Orange and Silver Lines are electrified by the end of 2019. For the measure scenario, the analysis assumed that 100% of directly operated buses are electric by 2030.

Methodology: The percentage of total directly operated bus VMT by vehicle type was adjusted from the BAU to reflect 100% electrification by 2030. Total VMT was allocated based on the forecasted percentages. Fuel consumption was calculated based on forecasted VMT by vehicle type using the same fuel efficiencies as in the BAU, and emissions were calculated based on fuel consumption using the same emission factors as in the BAU. The resulting measure scenario emissions were subtracted from the BAU emissions for each year to determine the annual change in emissions from BAU.

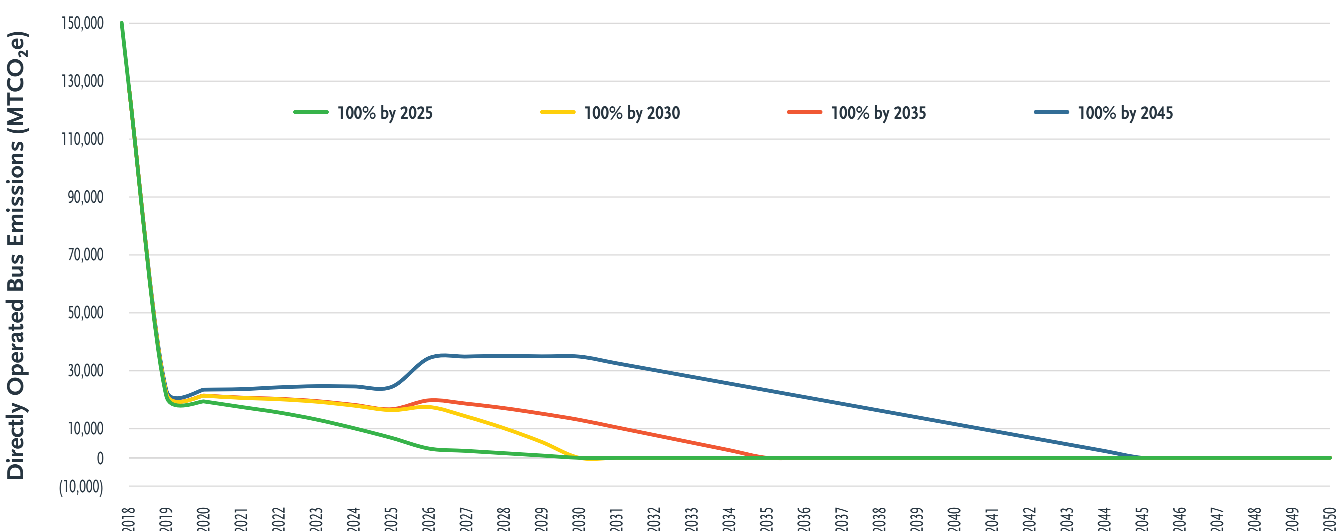
Interaction(s) with Other Measures: The analysis assumed in this measure's emission reduction calculations that Metro will achieve our target of 100% renewable electricity by 2035 (see measure E-1) for electricity emissions associated both with baseline and measure activity.

Comparison of Renewable Energy Procurement Scenarios: The impact of electrifying Metro's directly operated bus fleet is sensitive to the amount of electricity derived from renewable sources.

Figure A-1 below shows the emission reduction impacts of this electrification measure using four different renewable energy scenarios:

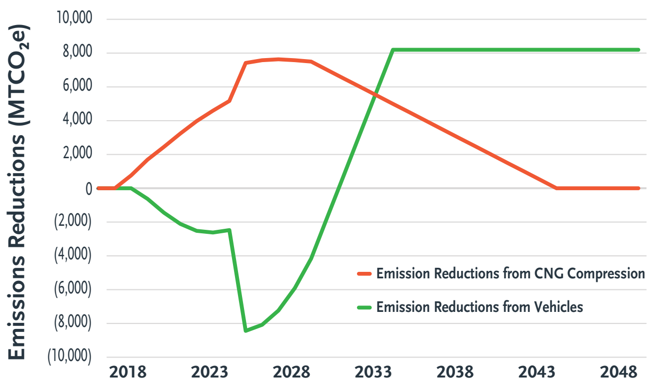
> The first scenario assumes utilities comply with the requirements of SB 100 and achieve 100% renewable energy by 2045.
> The second scenario assumes that Metro procures enough renewable energy to achieve 100% renewable energy by 2035. This is consistent with measure E-1, and it is the default assumption used in the analysis.
> The third scenario assumes that Metro procures enough renewable energy to achieve 100% renewable energy by 2030.
> The fourth scenario assumes that Metro procures enough renewable energy to achieve 100% renewable energy by 2025.

Figure A-1: Emissions from Directly Operated Fleet Electrification using Different Renewable Energy Procurement Scenarios



Emission Reductions in CNG Compression and Vehicle Use: Measure V-1 varies in the source of emission reductions over time. Figure A-2 below shows how emission reductions between CNG compression and direct combustion of fuel for vehicle use are split over the analysis period.

Figure A-2: Emission Reductions from Electrification of Directly Operated Fleet



Note: assumes 100% renewable energy by 2035.

Key Drivers of Emission Reduction Potential:

> Fuel economy improvements in switching to BEBs from CNG buses
> Renewable energy increases in electricity mix
> Phase out of RNG fuel

Costs

Costs Estimated: Capital costs (vehicles and stations), maintenance and repair costs (vehicles and stations), fuel costs and savings from incentives.

Methodology: To estimate the capital costs of purchased buses, the cumulative number of buses replaced to achieve 100% electrification was estimated by dividing the forecasted VMT by the average annual VMT per bus. The annual number of buses purchased was estimated by calculating the difference between the cumulative number of buses replaced in a given year and the cumulative number of buses replaced by the prior year. The annual number of buses purchased was adjusted for the replacement of buses that are at the end of the useful lifetime. The annual number of buses purchased was multiplied by the capital cost per vehicle to determine the capital cost per year of new vehicles. The number of CNG and renewable CNG vehicles that will no longer be purchased under the measure scenario was calculated using the same approach but based on the VMT reductions for these vehicle types.

The capital cost of charging/fueling stations was calculated using the same methodology as that used for vehicle capital costs. The number of new charging stations and number of CNG fueling stations no longer required under the measure scenario were determined based on the number of vehicles that can be charged/fueled per station. Maintenance and repair costs were calculated by applying the annual maintenance and repair cost per vehicle to the cumulative number of BEBs replaced and to the number of CNG vehicles no longer needed under the measure scenario.

Fuel costs were calculated by multiplying electricity and CNG costs by the fuel consumption estimates. Incentives were calculated by applying the incentive amount per vehicle to the number of BEBs purchased and to the number of CNG vehicles no longer needed under the measure scenario.

Key Drivers of Costs:

> Reduced maintenance and repair costs
> Reduced fuel costs
> Capital cost increases for BEBs

Data Sources

Table A-6: Data Sources for V-1

Assumption/Data Point	Source
Vehicle lifetime	ICF 2018
Annual VMT per vehicle	ICF 2018
Vehicle purchase costs	ICF 2018
Vehicle maintenance and repair costs	ICF 2018
Station capital costs	ICF 2018
Station maintenance and repair costs	ICF 2018
EV electricity costs	ICF 2018
CNG costs	ICF 2018
Diesel fuel costs	ICF 2018
Value of incentives	ICF 2018
CNG compression electricity costs	LA Metro 2018b

V-2: Replace Contracted Buses with Zero-Emission Buses

This measure would replace all contracted buses with zero-emission buses by replacing the fleet with renewable CNG and BEBs.[17]

Greenhouse Gas Emissions

Key Assumptions: For the measure scenario, the analysis assumed that 30% of contracted buses will use renewable CNG and 10% will be electric by 2025. Forty percent of contracted buses would be electric by 2035 with the remaining 60% using CNG or renewable CNG, and 100% of contracted buses would be electric by 2050. The

[17]Metro does not directly control or own the contracted bus fleet. For the purposes of the mitigation and cost analysis, we assumed that all costs and impacts from the contracted fleets would be attributed to Metro, similar to how we modeled the directly operated Metro fleet.

analysis assumed in the BAU that the use of diesel would be phased out by 2019 for contracted buses.

Methodology: The percentage of total contracted bus VMT by vehicle type was adjusted from the BAU to reflect that 30% of contracted buses will use renewable CNG by 2025 and that 10%, 40% and 100% of contracted buses will be electric by 2025, 2035 and 2050, respectively. Total VMT was allocated based on the forecasted percentages. Fuel consumption was calculated based on forecasted VMT by vehicle type using the same fuel efficiencies as in the BAU, and emissions were calculated based on fuel consumption using the same emission factors as in the BAU. The resulting measure scenario emissions were then subtracted from the BAU emissions for each year to determine the annual change in emissions from BAU.

Interaction(s) with Other Measures: The analysis assumed for this measure that Metro will achieve our target of 100% renewable electricity by 2035 (see measure E-1) for electricity emissions associated both with baseline and measure activity.

Key Drivers of Emission Reduction Potential:

> Renewable energy increases in electricity mix
> Phase out of CNG and RNG fuel

Costs

Costs Estimated: Capital costs (vehicles and stations), maintenance and repair costs (vehicles and stations), fuel costs and savings from incentives.

Methodology: To estimate the capital costs of purchased buses, the cumulative number of buses replaced to achieve ZEV targets was estimated by dividing the forecasted VMT by the average annual VMT per bus. The annual number of buses purchased was estimated by calculating the difference between the cumulative number of buses replaced in a given year and the cumulative number of buses replaced by the prior year.

The annual number of buses purchased was adjusted for the replacement of buses that are at the end of the useful lifetime. The annual number of buses purchased was then multiplied by the capital cost per vehicle to determine the capital cost per year of new vehicles. The number of diesel, CNG and renewable CNG vehicles that will no longer be purchased under the measure scenario was calculated using the same approach but based on the VMT reductions for these vehicle types.

The capital cost of charging/fueling stations was calculated using the same methodology as is used for vehicle capital costs. The number of new charging stations and the number of diesel/CNG fueling stations no longer required under the measure scenario were determined based on the number of vehicles that can be charged/fueled per station.

Maintenance and repair costs were calculated by applying the annual maintenance and repair cost per vehicle to the cumulative number of BEBs replaced and to the number of diesel/CNG vehicles no longer needed under the measure scenario. Fuel costs were calculated by multiplying electricity, diesel and CNG costs by the fuel consumption estimates. Incentives were calculated by applying the incentive amount per vehicle to the number of BEBs purchased and to the number of diesel and CNG vehicles no longer needed under the measure scenario.

Key Drivers of Costs:

> Reduced maintenance and repair costs
> Reduced fuel costs
> Capital cost increases for BEBs

Data Sources

Table A-7: Data Sources for V-2

Assumption/Data Point	Source
Vehicle lifetime	ICF 2018
Annual VMT per vehicle	ICF 2018
Vehicle purchase costs	ICF 2018
Vehicle maintenance and repair costs	ICF 2018
Station capital costs	ICF 2018
Station maintenance and repair costs	ICF 2018
EV electricity costs	ICF 2018
CNG costs	ICF 2018
Diesel fuel costs	ICF 2018
Value of incentives	ICF 2018

V-3: Replace Vanpool Vehicles with BEVs

This measure would replace all vanpool vehicles with BEVs by 2050.[18]

Greenhouse Gas Emissions

Key Assumptions: For the measure scenario, the analysis assumed that 30% of the vanpool fleet will be electric by 2030, rising to 100% by 2050.

Methodology: The percentage of total vanpool VMT by vehicle type was adjusted from the BAU to reflect that 30% of vehicles will be electric by 2030 and 100% will be electric by 2050. Total VMT was allocated based on the forecasted percentages.

Fuel consumption was calculated based on forecasted VMT by vehicle type using the same fuel efficiencies as in the BAU, and emissions were calculated based on fuel

[18]Metro does not directly control or own the vanpool vehicle fleet. For the purposes of the mitigation and cost analysis, we assumed that all costs and impacts from the vanpool fleets would be attributed to Metro, similar to how we modeled the directly operated Metro fleet.

consumption using the same emission factors as in the BAU. The resulting measure scenario emissions were then subtracted from the BAU emissions for each year to determine the annual change in emissions from BAU.

Interaction(s) with Other Measures: The analysis assumed in this measure that Metro will achieve our target of 100% renewable electricity by 2035 (see measure E-1) for electricity emissions associated both with baseline and measure activity.

Key Drivers of Emission Reduction Potential:

> Renewable energy increases in electricity mix
> Phase out of gasoline fuel

Costs

Costs Estimated: Capital costs (vehicles and stations), maintenance and repair costs (vehicles and stations) and fuel costs.

Methodology: To estimate the capital costs of purchased vehicles, the cumulative number of vehicles replaced to achieve electrification targets was estimated by dividing the forecasted VMT by the average annual VMT per vehicle. The annual number of vehicles purchased was estimated by calculating the difference between the cumulative number of vehicles replaced in a given year and the cumulative number of vehicles purchased by the prior year.

The annual number of vehicles purchased was adjusted for the replacement of vehicles that are at the end of their useful lifetime. The annual number of vehicles purchased was then multiplied by the capital cost per vehicle to determine the capital cost per year of new vehicles. The number of gasoline vehicles that will no longer be purchased under the measure scenario was calculated using the same approach but based on the VMT reductions for these vehicle types.

The capital cost of charging/fueling stations was calculated using the same methodology as that used for vehicle capital costs. The number of new charging stations and number of gasoline fueling stations no longer required under the measure scenario were determined based on the number of vehicles that can be charged/fueled per station.

Maintenance and repair costs were calculated by applying the annual maintenance and repair cost per vehicle to the cumulative number of BEVs replaced and to the number of gasoline vehicles no longer needed under the measure scenario. Fuel costs were calculated by multiplying electricity and gasoline costs by the fuel consumption estimates.

Key Drivers of Costs:

> Reduced maintenance and repair costs
> Reduced fuel costs
> Capital cost increases for BEVs

Data Sources

Table A-8: Data Sources for V-3

Assumption/Data Point	Source
Vehicle lifetime	ICF 2018
Annual VMT per medium-duty/heavy-duty (MDHD) vehicle	ICF 2018
Annual VMT per LD vehicle	LA Metro 2018d
MDHD vehicle purchase costs	ICF 2018
LD vehicle purchase costs	LA Metro 2019
MDHD vehicle maintenance and repair costs	ICF 2018
LD vehicle maintenance and repair costs	DOE 2018
MD and LD EV station capital costs	LA Metro 2019
Gasoline and diesel station capital costs	DOE 2018
MD and LD EV station maintenance and repair costs	LA Metro 2019
Gasoline and diesel station maintenance and repair costs	DOE 2018
EV electricity costs	ICF 2018
Gasoline costs	ICF 2018
Diesel fuel costs	ICF 2018

V-4: Replace Non-Revenue Vehicles with BEVs

This measure would replace all non-revenue vehicles with BEVs by 2050.

Greenhouse Gas Emissions

Key Assumptions: For the measure scenario, the analysis assumed that 60% of non-revenue light-duty and 20% of non-revenue MDHD vehicles will be electric by 2030. 100% of all non-revenue vehicles are assumed to be electric by 2050.

Methodology: The percentage of total non-revenue VMT by vehicle type was adjusted from the BAU to reflect that 60% of light-duty and 20% of MDHD vehicles will be electric by 2030, and 100% of all non-revenue vehicles will be electric by 2050. Total VMT was allocated based on the forecasted percentages. Fuel consumption was calculated based on forecasted VMT by vehicle type and emissions were calculated based on fuel consumption. The resulting measure scenario emissions were then subtracted from the BAU emissions for each year to determine the annual change in emissions from BAU.

Interaction(s) with Other Measures: The analysis assumed in this measure that Metro will achieve our target of 100% renewable electricity by 2035 (see measure E-1) for electricity emissions associated both with baseline and measure activity.

Key Drivers of Emission Reduction Potential:

> Renewable energy increases in electricity mix
> Phase out of gasoline and diesel fuel

Costs

Costs Estimated: Capital costs (vehicles and stations), maintenance and repair costs (vehicles and stations) and fuel costs.

Methodology: To estimate the capital costs of purchased vehicles, the cumulative number of vehicles replaced to achieve electrification targets was estimated by dividing the forecasted VMT by the average annual VMT per vehicle. The annual number of vehicles purchased was estimated by calculating the difference between the cumulative number of vehicles replaced in a given year and the cumulative number of vehicles purchased by the prior year.

The annual number of vehicles purchased was adjusted for the replacement of vehicles that are at the end of their useful lifetime. The annual number of vehicles purchased was then multiplied by the capital cost per vehicle to determine the capital cost per year of new vehicles. The number of gasoline and diesel vehicles that will no longer be purchased under the measure scenario was calculated using the same approach but based on the VMT reductions for these vehicle types.

The capital cost of charging/fueling stations was calculated using the same methodology as that used for vehicle capital costs. The number of new charging stations and number of gasoline/diesel fueling stations no longer required under the measure scenario were determined based on the number of vehicles that can be charged/fueled per station.

Maintenance and repair costs were calculated by applying the annual maintenance and repair cost per vehicle to the cumulative number of BEVs replaced and to the number of gasoline and diesel vehicles no longer needed under the measure scenario. Fuel costs were calculated by multiplying electricity, diesel and gasoline costs by the fuel consumption estimates.

Key Drivers of Costs:

> Increased maintenance and repair costs
> Reduced fuel costs
> Capital cost increases for BEVs

Data Sources

Table A-9: Data Sources for V-4

Assumption/Data Point	Source
Vehicle lifetime	ICF 2018
Annual VMT per MDHD vehicle	ICF 2018
Annual VMT per LD vehicle	LA Metro 2018d
MDHD vehicle purchase costs	ICF 2018
LD vehicle purchase costs	LA Metro 2019
MDHD vehicle maintenance and repair costs	ICF 2018
LD vehicle maintenance and repair costs	DOE 2018
BEB station capital costs	ICF 2018
MD and LD EV station capital costs	LA Metro 2019
Gasoline and diesel station capital costs	DOE 2018
BEB station maintenance and repair costs	ICF 2018
MD and LD EV station maintenance and repair costs	LA Metro 2019
Gasoline and diesel station maintenance and repair costs	DOE 2018
EV electricity costs	ICF 2018
Gasoline costs	ICF 2018
Diesel fuel costs	ICF 2018

V-5: Install Wayside Energy Storage Substations at Rail Stations

This measure would install WESS to store energy from decelerating railcars at all rail stations by 2050.

Greenhouse Gas Emissions

Key Assumptions: For the measure scenario, the analysis assumed that 25% of rail stations will have WESS installed by 2030 and 100% of rail stations will have WESS installed by 2050.

Methodology: The analysis assumed that at full implementation (i.e., when all rail stations have WESS installed), rail electricity consumption from the grid will be reduced by 12%. The reduction in grid electricity consumption increases proportionally to the growth in the percentage of rail stations with WESS installed. The percentage of rail stations with WESS installed was assumed to grow linearly to 25% in 2030 and 100% by 2050.

The percentage reduction in electricity consumption was applied to the BAU electricity to determine the measure scenario electricity consumption. Emission factors were applied to the measure scenario consumption to determine the measure scenario emissions. The resulting measure scenario emissions were then subtracted from the BAU emissions for each year to determine the annual change in emissions from BAU.

Interaction(s) with Other Measures: The analysis assumed in this measure that Metro will achieve our target of 100% renewable electricity by 2035 (see measure E-1) for electricity emissions associated with both baseline and measure activity.

Key Driver of Emission Reduction Potential:

> Reduced grid electricity consumption

Costs

Costs Estimated: Capital costs, maintenance and repair costs and electricity savings

Methodology: To estimate capital costs, the cumulative number of WESS installed was calculated by dividing the reduction in grid electricity consumption by the generation in MWh of each substation. The annual number of substations installed was estimated by calculating the difference between the cumulative number of substations installed in a given year and the cumulative number of substations installed by the prior year.

The annual number of substations installed was adjusted for the replacement of substations that are at the end of their useful lifetime. The annual number of substations installed was then multiplied by the capital cost per substation to determine the capital cost per year of new substations.

Maintenance and repair costs were calculated by applying the annual maintenance and repair cost per substation to the cumulative number of substations installed. Electricity savings were calculated by multiplying facility electricity costs by the electricity generation estimates.

Key Drivers of Costs:

> Capital, maintenance and repair costs of WESS
> Reduced purchased electricity

Data Sources

Table A-10: Data Sources for V-5

Assumption/Data Point	Source
Electricity savings from WESS	Solis et al. 2015
System capital costs	Solis et al. 2015
System maintenance and repair costs	FTA 2015
Electricity generation per system	Solis et al. 2015
System lifetime	Solis et al. 2015
Rail electricity cost	LA Metro 2018b

E-1: Expand Use of Renewable Energy through Power Purchase Agreements, Community Choice Aggregation Providers, etc.

This measure would expand the use of renewable energy through power purchase agreements (PPAs), or engagement with a community choice aggregation (CCA) provider, achieving 100% renewable electricity by 2035.

Greenhouse Gas Emissions

Key Assumptions: For the BAU scenario, the analysis assumed that all grid electricity will be sourced from 100% renewable sources by 2045 per the requirements of SB 100. For the measure scenario, the analysis assumed that Metro will source 70% of our electricity from renewable sources by 2025 and 100% by 2035.

Methodology: In each year, the BAU emission factor was scaled down based on the proportion of renewable to fossil fuels used to generate electricity to calculate a measure scenario emission factor that reflects achievement of Metro's renewables goals. To estimate emission reductions associated with this measure, emissions from BAU electricity consumption were recalculated using the measure scenario emission factors.

The resulting measure scenario emissions were then subtracted from the BAU emissions for each year to determine the annual change in emissions from BAU. Emission reductions from E-1 were calculated based on BAU electricity consumption and those reductions were accounted for in all other measures to avoid double counting of emission reductions.

Interaction(s) with Other Measures: All other measures assume that the renewable energy targets stated in this measure are achieved (i.e., emission reduction estimates for all other measures incorporate emission factors from E-1 to avoid double counting reductions with E-1).

Key Drivers of Emission Reduction Potential:

> Increased electricity from zero-emission sources

Costs

Costs Estimated: Electricity costs

Methodology: The analysis assumed that the cost of electricity sourced through renewable energy procurements is 8% greater than the electricity purchased directly from the utilities. To determine how much electricity is sourced through renewable energy procurements from 2018 through 2034, the measure scenario emissions are subtracted from the BAU emissions to first determine the amount of emission reductions needed to reach the renewable energy targets. The emission reductions needed were divided by the BAU weighted-average emission factor for the given year to determine the amount of electricity that needs to be purchased from renewable sources for that year.

From 2035 to 2044, all electricity consumption is purchased from renewable sources to ensure that 100% of electricity is sourced from renewable fuels. From 2045 to 2050, no electricity is purchased through renewable energy procurements as 100% of utility-sourced electricity is already renewable in the BAU scenario.

The cost estimates for this measure are sensitive to the assumed prices of CCAs, PPAs, etc., which can vary significantly depending on the source(s) of the energy, the energy supplier and the nature of the contractual agreements used to purchase the power. For this analysis, a default increase of 8% was applied to the base electricity price forecasts (CPA 2018), but other sources show 100% renewable options ranging from just under 2% up to 5% (PG&E 2018). Assuming a rate increase as low as 2% would lower the net present value of this measure to $12.9 million, with a cost-per-ton of emission reductions of $10.26/MTCO$_2$e.

Key Drivers of Costs:

> Increased cost of procuring electricity via CCAs, PPAs, etc.

Data Sources

Table A-11: Data Source for E-1

Assumption/Data Point	Source
Electricity rate adjustment	CPA 2018

F-1: Install PV Solar On-Site

This measure would install photovoltaics on-site at facilities.

Greenhouse Gas Emissions

Key Assumptions: For the measure scenario, the analysis assumed that 51.2 MW of new solar PV will be installed at existing facilities by 2030. An additional 1 MW of solar PV will be installed annually at new facilities.

Methodology: Solar PV installations at existing facilities were phased in linearly from 2019 to 2030. Solar PV at new facilities was phased in at 1 MW annually. The newly installed MW of solar PV was converted from DC to AC power and multiplied by the output rate to estimate the annual electricity generated. A 0.8% annual degradation in efficiency was applied to the generation of the PV installations.

Measure scenario emissions were calculated by applying electricity emission factors to the remaining utility-sourced electricity (as forecasted in the BAU). The emission reductions were calculated by subtracting measure scenario emissions from BAU emissions.

Interaction(s) with Other Measures: The analysis assumed in this measure that Metro will achieve our target of 100% renewable electricity by 2035 (see measure E-1) for electricity emissions associated both with baseline and measure activity. Emissions in energy efficiency measures (F-4, F-5, and F-6) were adjusted to account for new on-site solar generation from this measure.

Key Drivers of Emission Reduction Potential:

> Increased electricity from zero-emission sources

Costs

Costs Estimated: Capital costs, maintenance and repair costs and electricity savings

Methodology: Capital costs and fixed maintenance costs were estimated by multiplying the annual MW of installed solar by the capital cost per MW and maintenance costs per MW. Variable maintenance costs were assumed to be zero based on data from the National Renewable Energy Laboratory's (NREL) 2018 ATB Cost and Performance Summary. Electricity savings are calculated by multiplying facility electricity costs by the electricity generation estimates.

Key Drivers of Costs:

> Capital, maintenance and repair costs of PV installations
> Reduced purchased electricity

Data Sources

Table A-12: Data Sources for F-1

Assumption/Data Point	Source
Solar installation potential	LA Metro 2018e
Solar efficiency degradation rate	LA Metro 2018f
Capital cost of PV installations	NREL 2018b
Fixed maintenance and repair costs	NREL 2018b
Variable maintenance and repair costs	NREL 2018b
Cost of electricity offset by solar	LA Metro 2018f
Solar efficiency degradation range	NREL 2012

F-2: Install Retrofits and New Low-Water Fixtures

This measure would install retrofits of low-water sanitary fixtures that require less water and energy in existing buildings and new low-water fixtures in new buildings.

Greenhouse Gas Emissions

Key Assumptions: For the measure scenario the analysis assumed that Metro will achieve a 30% reduction in water consumption in existing facilities by 2030 and that water consumption in new facilities will be 30% below BAU consumption.

Methodology: The annual percentage reduction in water consumption at existing facilities was applied to the BAU water consumption with the percentage reduction phased in from 0% in 2018 to 30% in 2030. A 30% reduction from BAU water consumption was applied to new facility water consumption in every year. Electricity embedded in water consumption for the measure scenario was determined by applying a conversion factor (consistent with BAU methodology) and emissions were calculated by applying the CAMX region average emission factor (EPA 2018) to the embedded electricity consumption. Emission reductions were calculated by subtracting measure scenario emissions from BAU emissions.

Interaction(s) with Other Measures: Reductions in water consumption from this measure are accounted for in the F-3 measure.

Key Drivers of Emission Reduction Potential:

> Reduced lifecycle electricity use embedded in water consumption

Costs

Costs Estimated: Total savings from water fixtures

Methodology: The total savings associated with installation of the fixtures was calculated by applying the savings per gallon to the number of gallons reduced by the measure.

Key Drivers of Costs:

> Cost of low-water fixtures
> Reduced purchased water

Data Sources

Table A-13: Data Source for F-2

Assumption/Data Point	Source
Cost savings from fixtures	Chini et al. 2016

F-3: Install Non-Potable Recycled Water Systems

This measure would install non-potable recycled water systems on existing and new facilities.

Greenhouse Gas Emissions

Key Assumptions: For the measure scenario, the analysis assumed that recycling of non-potable water will reduce overall water consumption by 5% by 2030 and 15% by 2050.

Methodology: The annual percentage reduction in water consumption was applied to the BAU water consumption with the percentage reduction phased in from 0% in 2018 to 5% in 2030 and 15% in 2050. Electricity embedded in water consumption for the measure scenario was determined by applying a conversion factor (consistent with BAU methodology) for recycled and utility water, and emissions were calculated by applying the CAMX region average emission factor to the embedded electricity consumption. Emission reductions were calculated by subtracting measure scenario emissions from BAU emissions.

Interaction(s) with Other Measures: Reductions in water consumption from F-3 are taken into account in the baseline water consumption for this measure.

Key Drivers of Emission Reduction Potential:

> Reduced lifecycle electricity use embedded in water consumption

Costs

Costs Estimated: Total cost of water recycling systems and water savings

Methodology: The total cost of the recycling systems was calculated by applying the cost per gallon to the number of gallons reduced by the measure. Savings from reduced water consumption were calculated by applying the cost of water per gallon to the number of gallons reduced.

Key Drivers of Costs:

> Cost of recycling systems
> Reduced purchased water

Data Sources

Table A-14: Data Sources for F-3

Assumption/Data Point	Source
Cost of systems	Kavaada et al. 2018
Water costs	LA Metro 2018b

F-4: Replace Lighting Fixtures with LEDs

This measure would replace interior and exterior lighting fixtures with LEDs at facilities.

Greenhouse Gas Emissions

Key Assumptions: For the measure scenario the analysis assumed that Metro will achieve a 30% reduction in electricity consumption in existing facilities by 2030 and that electricity consumption in new facilities will be 30% below BAU consumption.

Methodology: The annual percentage reduction in electricity consumption at existing facilities was applied to the BAU electricity consumption with the percentage reduction phased in from 0% in 2018 to 30% in 2030. A 30% reduction from BAU electricity consumption was applied to new facility electricity consumption in every year. Emissions were calculated by applying utility-specific emission factors to the measure scenario electricity consumption. Emission reductions were calculated by subtracting measure scenario emissions from BAU emissions.

Interaction(s) with Other Measures: The analysis assumed in this measure that Metro will achieve our target of 100% renewable electricity by 2035 (see measure E-1) for electricity emissions associated both with baseline and measure activity. This measure takes self-generated electricity from F-1 into account in the baseline electricity consumption.

Key Drivers of Emission Reduction Potential:

> Reduced electricity consumption

Costs

Costs Estimated: Capital costs and electricity savings

Methodology: Based on the Division 18 ASHRAE Audit, the analysis assumed that lighting accounts for 58% of total facility electricity. For both LED and High Intensity Discharge (HID) fixtures, a capital cost per kilowatt-hour was determined based on average cost and wattage. This capital cost factor was multiplied by the corresponding lighting electricity consumption from each bulb type to determine the capital cost each year. Additionally, capital costs resulting from replacing the bulbs at the end of their lifetime were accounted for.

The analysis assumed that only HID bulbs are used in the BAU scenario. In the measures scenario, it was assumed that all new facility energy would be consumed by LED bulbs, whereas existing facilities' HID lighting fixtures were assumed to be replaced with LEDs at a linear rate with 100% LEDs in existing facilities by 2030. Electricity costs were calculated by multiplying the total facility lighting electricity consumption by the cost per kilowatt-hour. To determine total cost savings, capital and electricity costs of the BAU scenario were subtracted from the measure scenario costs.

Key Drivers of Costs:

> Capital cost of LEDs
> Reduced purchased electricity

Data Sources

Table A-15: Data Sources for F-4

Assumption/Data Point	Source
Portion of building electricity used for lighting	LA Metro 2018c
Capital costs of LED fixtures	Average of various retail prices
Capital costs of HID fixtures	Average of various retail prices
Facility electricity costs	LA Metro 2018b

F-5: Install Electric Heating Systems

This measure would install electric heating systems at facilities.

Greenhouse Gas Emissions

Key Assumptions: For the measure scenario, the analysis assumed that 50% of natural gas HVAC systems will be replaced by electric heat pumps by 2030 in existing buildings, and 100% will be replaced by 2050. 100% of HVAC is electric in new facilities.

The analysis also assumed that 95% of BAU facility natural gas consumption is used for space heating.

Methodology: The annual percentage reduction in natural gas consumption for space heating at existing facilities was applied to the BAU natural gas consumption with the percentage reduction phased in from 0% in 2018 to 50% in 2030 and 100% in 2050. Projected natural gas consumption for space heating in new facilities was assumed to be zero for the measure scenario. The reductions in natural gas consumption from BAU were converted to electricity consumption based on a conversion factor determined by the ratio of energy efficiency of the natural gas and electric heating systems.

Emissions were calculated by applying emission factors to the measure scenario electricity and natural gas consumption. Emission reductions were calculated by subtracting measure scenario emissions from BAU emissions.

Interaction(s) with Other Measures: The analysis assumed in this measure that Metro will achieve our target of 100% renewable electricity by 2035 (see measure E-1) for electricity emissions associated both with baseline and measure activity. This measure takes self-generated electricity from F-1 into account in the baseline electricity consumption.

Key Drivers of Emission Reduction Potential:

> Renewable energy increases in electricity mix
> Reduced natural gas consumption

Costs

Costs Estimated: Capital costs, electricity costs and natural gas savings

Methodology: To estimate the capital costs of installed HVAC systems, the cumulative number of systems replaced was estimated by dividing the forecasted electricity consumption for heating by the estimated annual electricity consumption per system. The annual number of systems installed was estimated by calculating the difference between the cumulative number of systems replaced in a given year and the cumulative number of systems purchased by the prior year. The annual number of systems installed was adjusted for the replacement of systems that are at the end of their useful lifetime. The annual number of systems purchased was then multiplied by the capital cost per system to determine the capital cost per year of new systems. The number of natural gas systems that will no longer be installed under the measure scenario was calculated using the same approach but based on the natural gas reductions from replacements.

Maintenance and repair costs were assumed to be equal in the BAU and measure scenarios, so there is no net cost associated with maintenance and repair for this measure. Energy costs were calculated by multiplying electricity and natural gas costs by the energy consumption estimates.

Key Drivers of Costs:

> Capital cost of HVAC systems
> Increased purchased electricity
> Decreased purchased natural gas

Data Sources

Table A-16: Data Sources for F-5

Assumption/Data Point	Source
Portion of building natural gas used for space heating	LA Metro 2018c
Capital cost of electric HVAC	DOE 2015
Capital cost of natural gas HVAC	DOE 2015
Facility natural gas costs	LA Metro 2018b
Efficiency of electric heat pumps	DOE 2019a, Heater Outlet 2019
Base model natural gas to electric water heater conversion	DOE 2019b

F-6: Replace Appliances with Efficient Electric Appliances

This measure would replace appliances with more efficient electric appliances at facilities.

Greenhouse Gas Emissions

Key Assumptions: For the measure scenario, the analysis assumed that 50% of appliances in existing buildings will be replaced with high-efficiency electric appliances by 2030 and 100% will be replaced by 2050. 100% of appliances in new facilities will be high-efficiency electric appliances.

The analysis assumed that energy savings from high-efficiency appliances relative to BAU are 8%, 53% and 33% from air compressors, electric heat pump water heaters and kitchen equipment (refrigerators and dishwashers), respectively.

Methodology: The annual percentage reduction in natural gas consumption for water heating at existing facilities was applied to the BAU natural gas consumption with the percentage reduction phased in from 0% in 2018 to 50% in 2030 and 100% in 2050. Projected natural gas consumption for water heating in new facilities was assumed to be zero for the measure scenario. The reductions in natural gas consumption from BAU were converted to electricity consumption based on a conversion factor determined based on the ratio of energy efficiency of the natural gas and electric water heating systems.

The annual percentage reductions from BAU appliance electricity consumption at existing facilities was applied to the BAU appliance electricity consumption, with the reductions phased in from 0% in 2018 to 50% in 2030 and 100% by 2050. Reductions from BAU electricity consumption were applied to new facility appliance electricity consumption in every year.

Emissions were calculated by applying emission factors to the measure scenario electricity and natural gas consumption. Emission reductions were calculated by subtracting measure scenario emissions from BAU emissions.

Interaction(s) with Other Measures: The analysis assumed in this measure that Metro will achieve our target of 100% renewable electricity by 2035 (see measure E-1) for electricity emissions associated both with baseline and measure activity. This measure takes self-generated electricity from F-1 into account in the baseline electricity and natural gas consumption.

Key Drivers of Emission Reduction Potential:

> Renewable energy increases in electricity mix
> Reduced natural gas and electricity consumption

Costs

Costs Estimated: Capital costs, electricity savings and natural gas savings

Methodology: To estimate the capital costs of installed appliances, the cumulative number of appliances replaced was estimated by dividing the forecasted electricity consumption for appliances by the estimated annual electricity consumption per appliance. The annual number of appliances installed was estimated by calculating the difference between the cumulative number of appliances replaced in a given year and the cumulative number of appliances purchased by the prior year.

The annual number of appliances installed was adjusted for the replacement of appliances that are at the end of their useful lifetime. The annual number of appliances purchased was then multiplied by the capital cost per appliance to determine the capital cost per year of new appliances. For water heaters, the number of old appliances that will no longer be installed under the measure scenario was calculated using the same approach but based on the natural gas reductions from replacements. For air compressors and kitchen appliances, the analysis assumed that for every new appliance purchased, one old appliance no longer needs to be purchased in the measure scenario.

Maintenance and repair costs were assumed to be equal in the BAU and measure scenarios, so there is no net cost associated with maintenance and repair for this measure. Energy costs were calculated by multiplying electricity and natural gas costs by the energy consumption estimates.

Key Drivers of Costs:

> Capital cost of appliances
> Reduced purchased natural gas and electricity

Data Sources

Table A-17: Data Sources for F-6

Assumption/Data Point	Source
Portion of building natural gas used for water heating	LA Metro 2018c
Portion of building electricity used for air compressors	LA Metro 2018c
Portion of building electricity used for kitchen appliances	LA Metro 2018c
Capital costs of electric water heaters	DOE 2015
Capital costs of electric water heaters	DOE 2015
Capital costs of high-efficiency compressors	DOE 2015
Capital costs of standard compressors	DOE 2015
Capital costs of high-efficiency kitchen appliances	DOE 2015
Capital costs of standard kitchen appliances	DOE 2015
Facility natural gas costs	LA Metro 2018b
Facility electricity costs	LA Metro 2018b
Efficiency of appliances	DOE 2015

C-1: Install EV Charging Infrastructure for Employees

This measure would install EV charging infrastructure at Metro facilities.

Greenhouse Gas Emissions

Key Assumptions: For the measure scenario, the analysis assumed that Metro will install 83 new Level 2 ChargePorts per year for employee EV charging.

Methodology: Eighty-three ChargePorts were assumed to be installed annually. In the “Low Utilization” (i.e., default) measure scenario, each ChargePort was assumed to produce 2000 kWh per year. The overall annual increase in electricity consumption was calculated by multiplying the per-station electricity consumption by the cumulative number of ChargePorts installed by that year. The number of VMT by employees using the ChargePorts was estimated based on the electricity consumption and average fuel economy (in kWh/mi) of electric light-duty vehicles.

Gasoline vehicle VMT in the measure scenario was determined by subtracting new EV VMT from BAU gasoline VMT. The measure scenario gasoline consumption was estimated based on the remaining measure scenario gasoline VMT. Emissions from electricity and gasoline were estimated by applying emission factors to the measure scenario energy consumption, and emission reductions were calculated by subtracting measure scenario emissions from BAU emissions.

Interaction(s) with Other Measures: The analysis assumed in this measure that Metro will achieve our target of 100% renewable electricity by 2035 (see measure E-1) for electricity emissions associated both with baseline and measure activity.

Key Drivers of Emission Reduction Potential:

> Renewable energy increases in electricity mix
> Reduced passenger vehicle gasoline consumption

Costs

Costs Estimated: Capital costs, maintenance and repair costs and energy costs.

Methodology: To estimate the capital costs of installed ChargePorts, the annual number of ChargePorts installed was multiplied by the capital cost per ChargePort.

Maintenance and repair costs were calculated by applying the annual maintenance and repair cost per ChargePort to the cumulative number of ChargePorts installed.

Electricity costs were calculated by multiplying electricity costs per kWh by the electricity consumption estimates.

Key Drivers of Costs:

> Capital, maintenance and repair costs of ChargePorts
> Increased purchased electricity

Data Sources

Table A-18: Data Sources for C-1

Assumption/Data Point	Source
LD EV station capital costs	LA Metro 2019
LD EV station maintenance and repair costs	LA Metro 2019
EV electricity cost	ICF 2018

Carbon Offsets

CARB issues GHG emission offset credits for approved projects under several project types, including forest management, destruction of ozone depleting substances, livestock biogas capture and mine methane capture.[19]

Purchase of these offsets is available through the cap-and-trade program established by CARB in 2013. The offset types approved by CARB and their cost per $MTCO_2e$ are summarized in Table A-19.

Table A-20 shows the emissions remaining in 2030 and 2050 (annual and cumulative) when implementing all measures and shows our estimated results for offset purchase costs to reduce these emissions to zero.

Table A-20: Remaining Emissions and Cost to Offset

		2030		2050	
		Remaining Emissions ($MTCO_2e$)	Cost to Offset (USD)[a]	Remaining Emissions ($MTCO_2e$)	Cost to Offset (USD)[a]
All Measures	*Annual*	88,804	$967,074	15,897	$173,117
	Cumulative	1,650,443	$17,973,320	2,342,957	$25,514,804

[a] Cost to offset is assumed to be $10.89/ $MTCO_2e$ based on average ARB approved offsets.

Table A-19: Offset Strategies and Costs

Measure	Description	Cost ($/$MTCO_2e$)
Ozone Depleting Substance Projects	Ozone depleting substances (ODS) are used in a variety of appliances, including refrigerators, freezers and air conditioners, that often leak after disposal, releasing ODS into the atmosphere. ODS projects approved through the ARB often involve working with recyclers of appliances, wholesalers of refrigerants, and other related businesses to aggregate, transport and destroy eligible ODS collected from locations throughout the US.[20]	$11.21
Livestock Projects	Livestock offset projects often involve capturing methane biogas produced by liquid effluent resulting from digested dairy manure. The methane biogas is then piped into generators that produce power.[21]	$10.87
Mine Methane Capture Projects	During mine methane capture projects, methane is captured from the air ventilated from the mine that would otherwise be released into the atmosphere. The captured methane is used to produce energy or destroyed via pipeline injection.[22]	$10.36
US Forest Projects	In California, there are three kinds of forestry offset: afforestation and reforestation, avoided conversion and improved forest management. Afforestation and reforestation offsets create or reestablish acres of forest, whereas conversion offsets aim to retain forests that are likely to experience tree or carbon loss. Improvement of forest management offsets are used to implement sustainable forestry management practices, such as routine maintenance and improved harvest practices to increase forest productivity.[23]	$11.13
	Average	$10.89

[19] CARB 2017a.
[20] ACR 2012.
[21] WTE-Wakker, LLC 2012.
[22] ACR 2002.
[23] CARB 2017b.

Detailed Achievement Targets Matrix

Table A-21 shows the achievement goals for each of Metro's mitigation measures.

Table A-21: Achievement Targets for Greenhouse Gas Mitigation Measures

Mitigation Measure	Achievement Metric	2030	2050
V-1: BEB Deployment (Directly Operated)	Portion of fleet replaced by BEBs (%)	100%	100%
V-2: BEB Deployment (Contracted)	Portion of fleet replaced by BEBs (%)	25%	100%
	Portion of fleet powered by RNG (%)	23%	N/A
V-3: BEV Vanpool Deployment	Portion of fleet replaced by BEVs (%)	30%	100%
V-4: BEV Non-Revenue Vehicle Fleet Deployment	Portion of light-duty vehicles replaced by BEVs (%)	50%	100%
	Portion of medium-duty vehicles replaced by BEVs (%)	20%	100%
V-5: Wayside Energy Storage Substation Installation	Percent of stations with WESS installed (%)	25%	100%
E-1: Renewable Electricity Procurement	Portion of electricity procured from renewable sources (%)	85%	100%
F-1: Photovoltaic Installations	New solar installations on existing facilities (MW)	51	51
	Solar installations on new facilities (MW)	12	16
F-2: Water-Saving Fixture Installation	Reduction in water use in existing facilities (%)	30%	30%
	Reduction in projected water use in new facilities (million gallons)	52	109
F-3: Water Recycling System Installation	Portion of water consumption from recycled non-potable water (%)	5%	15%
F-4: Facility LED Lighting Installation	Reduction in electricity use in existing facilities (%)	30%	30%
	Reduction in projected electricity use in new facilities (GWh)	21	56
F-5: Facility Heating, Ventilation and Air Conditioning Electrification	Portion of currently installed natural gas HVAC replaced with electric HVAC (%)	50%	100%
	Portion of HVAC that is electric in new facilities (%)	100%	100%
F-6: Facility Appliance Electrification	Portion of current appliances replaced with electric and/or high-efficiency appliances (%)	50%	100%
	Portion of appliances that are electric and/or high-efficiency in new facilities (%)	100%	100%
C-1: Employee EV Charging Station Installation	Cumulative number of ChargePorts installed	917	2,577

Detailed Feasibility Matrix

Table A-22: Feasibility Matrix of Mitigation Measures

	GHG Mitigation Potential	Net Present Value	Other Environmental Benefits	Sphere of Influence	Resource Security/ Resilience	Implementation Feasibility
V-1 Metro Bus Electrification	MEDIUM > Increases emissions in short term > Reduces emissions as grid reaches 60% renewables	HIGH Significant savings over time from fuel efficiencies	HIGH Local air quality benefits from avoiding tailpipe emissions from NG	MEDIUM Metro controls procurement of fleet, but might require coordination with utilities/local government in infrastructure and rates	MEDIUM Reduces fuel consumption, but might increase reliability concerns with current grid	MEDIUM Master Plan for bus electrification underway
V-2 Contracted Bus Electrification	HIGH Avoids diesel, fossil CNG use from contracted buses	HIGH Overall savings to Metro in short and long term	HIGH Local air quality benefits from avoiding tailpipe emissions from NG and diesel	LOW Metro can influence contractor, but has less control over fleet and infrastructure decisions	MEDIUM Reduces fuel consumption, but might increase reliability concerns with current grid	LOW Unclear how much contracted fleets can be influenced
V-3 Vanpool Electrification	MEDIUM Greater potential in long-term with cleaner grid and more BEVs	MEDIUM Lower cost option, but no savings to Metro over time	HIGH Local air quality benefits from avoiding tailpipe emissions from NG and diesel	LOW Metro can influence contracted vanpools, but has less control over fleet and infrastructure decisions	MEDIUM Reduces fuel consumption, but might increase reliability concerns with current grid	MEDIUM Metro has begun using EV vanpools, but it is unclear how much contracted fleets can be influenced
V-4 BEV Non-Revenue Vehicle Fleet Deployment	MEDIUM Greater potential in long-term with cleaner grid and more BEVs	LOW Less fuel efficiency savings than buses or vanpool	HIGH Local air quality benefits from avoiding tailpipe emissions from NG and diesel	MEDIUM Metro controls procurement of fleet, but might require coordination with utilities/local government in infrastructure and rates	MEDIUM Reduces fuel consumption, but might increase reliability concerns with current grid	MEDIUM Could be implemented in coordination with Metro EV implementation plan

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	GHG Mitigation Potential	Net Present Value	Other Environmental Benefits	Sphere of Influence	Resource Security/ Resilience	Implementation Feasibility
V-5 WESS Installation	**LOW** Some short-term savings, no long-term savings with cleaner grid	**LOW** Driven by capital costs in short term, annual O&M costs in long term	**MEDIUM** Some energy savings from rail energy storage stations	**HIGH** Metro controlled facilities for WESS installation	**MEDIUM** Reduces electricity procurement requirements	**LOW** Metro has pilot projects in place, but rapid expansion is uncertain and might be difficult to prioritize
E-1 Renewable Electricity Procurement	**HIGH** Major savings through increased grid decarbonization	**LOW** Cost based on higher rate for local Community Choice Aggregation	**MEDIUM** Air quality benefits from avoiding fossil electricity	**MEDIUM** Metro dependent on local CCA rates and availability, but could consider a PPA for more control	**MEDIUM** Reduces reliance on fossil fuel imports for electricity generation	**MEDIUM** Greatest opportunity for Metro to cut overall emissions both in short and long term
F-1 Photovoltaic Installations	**MEDIUM** Variable based on Metro's deployment of PVs	**LOW** Higher costs considering current value of PV electricity generation	**MEDIUM** Air quality benefits from avoiding fossil electricity	**HIGH** Metro controlled facilities for new facility design and existing facility installations	**HIGH** Directly produced electricity enhances reliability and resilience	**MEDIUM** Metro has installations in place with a feasibility study for expanding, but mitigation goals would require rapid expansion of PV in new and existing facilities
F-2 Water Conservation	**LOW** Mitigation relatively low compared to other measures	**LOW** Cost per gallon saved drives overall costs	**HIGH** Improves water efficiency in drought-prone area	**HIGH** Metro controlled facilities for fixture replacement	**HIGH** Reduces reliance on potable water imports in a drought-prone area	**HIGH** Aligned with current Metro strategy for water efficiency
F-3 Water Recycling	**LOW** Mitigation relatively low compared to other measures	**MEDIUM** Low-cost option relative to other measures, but no savings to Metro over time	**HIGH** Avoids use of local or imported water sources in drought-prone area	**MEDIUM** Might require coordination with local water/wastewater utilities	**HIGH** Creates an on-site source for non-potable water, reducing reliance on potable water imports in a drought-prone area	**HIGH** Aligned with current Metro strategy for water efficiency
F-4 LED Lighting	**MEDIUM** > Major energy efficiency benefits in facilities > Emission reductions drops when grid decarbonizes	**HIGH** Significant savings over time from LED energy efficiency	**HIGH** Significant energy savings from LED energy efficiency	**HIGH** Metro controlled facilities for lighting replacement	**HIGH** Significantly reduces electricity procurement requirements	**HIGH** Aligned with current Metro efforts in energy audits, has significant cost savings over time
F-5 HVAC Electrification	**MEDIUM** > Increases emissions in short term > Reduces emissions as grid decarbonizes	**LOW** High cost compared to other measures due to capital costs and cost of electricity.	**MEDIUM** Some energy savings from improved energy efficiency	**HIGH** Metro controlled facilities for HVAC replacement	**LOW** Increases energy requirements in short term, but reduces demands in long term	**MEDIUM** Metro could incorporate efficiency standards in new buildings, but might be less feasible with retrofits due to relatively low-cost benefits
F-6 Appliance Electrification	**LOW** Appliances targeted in measure do not account for significant portions of energy use	**HIGH** Overall savings to Metro in short and long term from energy efficiencies	**MEDIUM** Some energy savings from improved energy efficiency	**HIGH** Metro controlled facilities for appliance replacement	**MEDIUM** Reduces energy and electricity procurement requirements	**MEDIUM** Metro could incorporate efficiency standards in new buildings, but might be less feasible with retrofits due to relatively low-cost benefits
C-1 EV Charging for Employee	**LOW** Increasing savings over time with increased installations of EV chargers	**LOW** Driven by EV infrastructure capital costs	**MEDIUM** Local air quality benefits from avoiding tailpipe emissions from NG and diesel	**MEDIUM** Might require coordination with local utilities in rates, time of use considerations	**MEDIUM** Reduces fuel consumption, but might increase reliability concerns with current grid	**MEDIUM** Could be implemented in coordination with Metro EV implementation plan

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Appendix B
Methodology for Risk Assessment

This appendix provides the detailed methodology for the risk assessment presented in Chapter 3.

Each Metro asset received an overall risk score for each of the seven climate hazards. The scores were based on underlying data about each asset, representing indicators of the different components of risk. For this risk assessment, Metro evaluated risk as a function of two overarching components: vulnerability and criticality.

Vulnerability describes how a certain climate hazard might affect an asset, whereas **criticality** describes the importance of that asset to Metro's ability to fulfill our mission.

Metro measured vulnerability, in turn, as a function of three components: exposure (whether the asset might experience the hazard), sensitivity (whether the asset would be affected by the hazard) and adaptive capacity (an asset's ability to withstand the hazard or recover from it).

We measured criticality based on eight indicators of the asset's role in contributing to our mission.

Figure B-1 shows an illustrative example of how Metro combined a variety of information about each asset to create an overall risk score on a scale of 1 to 25. The details of how we selected, evaluated and scored each indicator and component are provided in the sections that follow.

Figure B-1: Example Extreme Heat Risk Score Build-up for an Asset

Underlying Indicators	Value	Score (1-5)	
Expected increase in very hot days	32 more hot days by 2050	5	Vulnerability Score 4.3
Sensitivity to extreme heat	High; may be severely damaged or subject to costly and extended repair	5	
Adaptive capacity to extreme heat	Medium; Minor engineering modification to asset possible to avoid impact	3	
			×
Ridership	5 million boardings	5	Criticality Score 3.5
Serves transit-dependent populations?	Yes	5	
Connectivity	52 connections to other modes	5	
Lack of redundancy	43 replacement assets	1	=
Role in emergency response?	Yes	5	
Joint development site near asset?	No	1	Risk Score 15.2 (High)
Jobs served	1,000	5	
Serves priority economic zone?	No	1	

The risk assessment analyzed risks to Metro assets from a variety of climate hazards. The full scope of asset types and climate hazards included is shown in Table B-1. The assessment covered 1,341 Metro assets from Metro's Enterprise Transit Asset Management (ETAM) database. These assets are both existing and planned, and include assets owned and operated by Metro as well as those Metro depends upon for service. The assets included in this assessment might not include every single known Metro asset or other assets that affect Metro (such as green infrastructure across LA County) due to data limitations and the fact that there are many different ways to define what constitutes an asset.

Though Metro's ETAM database includes over 25,000 individual assets, this analysis developed a simplified, streamlined approach to asset identification and categorization, as explained later in this section.

Table B-1: Asset Types and Hazards Included in Risk Screen

Asset Types Included	Climate Hazards Included
> Bus Rapid Transit > Light Rail > Subway > Bus Routes • Commuter and Circulator Buses • Limited Express • Local Central Business District Buses • Local Non-Central Business District Buses • Rapid > Highways > Bike Share Stops > Metro Bike Hubs > Cal Trans Park & Ride Lots > Division – Bus > Division – Rail > Terminals > Radio Repeater Stations > Facilities – Other > Parcel Lots > Rail Stations **Total: 1,341 assets**	> Increased extreme heat > Increased electrical grid outages > Increased wildfires > Increased heavy precipitation > Increased riverine flooding > Increased land and mudslides > Sea level rise and coastal flooding

Exposure

The first step in the vulnerability assessment was to determine which, and to what extent, Metro assets might be exposed to various climate change hazards. We also considered exposure to loss of electricity, as that loss could be caused by several different climate-related and non-climate hazards. In all, we considered a total of eight hazards, although the wind hazard was ultimately eliminated from the vulnerability assessment because wind is not projected to increase in the study area during the study timeframe. These eight hazards are:

> Extreme heat
> Electrical outages
> Wildfire
> Precipitation
> Flooding
> Land and mudslides
> Sea level rise and coastal flooding
> Wind

The methodology Metro used to evaluate exposure to these hazards is described in the subsections that follow.

Exposure to each hazard was scored on a scale of 1 to 5. For sea level rise and coastal flooding, however, certain assets received an exposure score of 0, indicating no exposure. This is because it is very clear that sea level rise has potential to affect only assets near the coast. Assets farther inland are too far away to be potentially exposed, even under the most extreme scenarios. In contrast, for other hazards we determined a strong likelihood of low exposure, but due to uncertainties in climate science we cannot definitively say that there would be *no* exposure.

The risk analysis examined future exposure to climate hazards; however, Metro has taken a comprehensive risk management approach for future vulnerabilities and current exposure. Metro has conducted interviews with employees across a wide range of departments and specialties to collect data on current climate vulnerabilities, particularly the risks identified in the 2012 CAAP and progress made toward addressing these risks. These discussions supplement the risk analysis and provide important information on incorporating current climate risks with future projections.

For some hazards, the future risk analysis also informs current risk. For example, future projections cover approximately the same area as current risk for spatially constrained hazards such as wildfire, flooding, sea level rise and mud and landslides. For hazards such as heat, risk is expected to increase throughout the entire County, especially in the areas that are already highly exposed to heat.

Because these changes aren't as well known to Metro or the public, it is important to highlight them as key areas for adaptation. The assets included in the following exposure maps are high-level examples of asset types analyzed; exposure maps with all existing and accounted-for assets were generated for this analysis but are not available as they contain sensitive asset location information.

Extreme Heat

For purposes of this study, Metro defined extreme heat as the number of additional days that exceed the historical 95th percentile threshold. Depending on location, this ranged in temperature from 72 to 107 Fahrenheit across the region, with coastal areas tending to be cooler than inland areas.

People and systems are usually somewhat already adapted to their local climate, so it is important to understand the increase in extreme heat days relative to what people and systems are used to. That is, a 110-degree day might have very different implications for a coastal area than for an inland area that is more accustomed to these temperatures.

Metro calculated these values by first identifying the temperature at which only 5% of the days in an average year (about 18 days each year) would exceed that temperature.

To calculate extreme heat days, we used data from Cal-Adapt, a data resource developed and recognized by the state of California (it is generally considered best practice to use Cal-Adapt for California-based climate change exposure analyses). When downloading and processing the Cal-Adapt data, we made the following decisions:

> We defined the baseline as the period covering 1986–2005. This is the period used in Cal-Adapt as the baseline. It is important — and a widely recognized best practice — to average across 20–30 years to determine the average climate for a range of time. We therefore looked at historical temperature data for each year within the range 1986–2005 and averaged the outputs to determine the temperature threshold at which 5% of days in an average year would exceed that threshold.
> We defined the projection period as 2041–2060, again averaging across these years. These two decades represent the midcentury timeframe. Although some climate change analyses look further out to the end of the century, that timeframe is often considered too far into the future for informing meaningful action today. Looking that far in advance not only introduces increased uncertainty in the climate change projections themselves, but also introduces major uncertainty in other factors such as demographics and technology.
> We pulled data from the four climate models recommended by the state of California for the state's Fourth Climate Change Assessment. It is generally considered best practice to use an average of several

models when looking at climate projections (except in specific instances where a single climate model might be better suited to the location, hazard or goals of an analysis), and the state of California issued guidelines recommending use of those four models in particular. The four models are also the models used as defaults in Cal-Adapt: HadGEM2-ES, CNRM-CM5, CanESM2, MIROC5.

> When considering GHG emissions, we used the Representative Concentration Pathway (RCP) 8.5. (For a technical explanation of RCPs, please see: van Vuuren et al. (2011) The Representative Concentration Pathways: An Overview. Climatic Change, 109 (1-2), 5-31.) In basic terms, RCPs are commonly used representations of how the concentration of GHGs could change in the atmosphere as time goes on, based on assumptions on how quickly global GHG emissions increase or are reduced over time. RCP 8.5 is considered a high but realistic scenario.

Once we obtained and processed the climate data, we calculated the number of *additional* days above the baseline 95th percentile threshold at each asset location. Then, for each asset, we assigned an exposure score according to the scoring system in Table B-2.

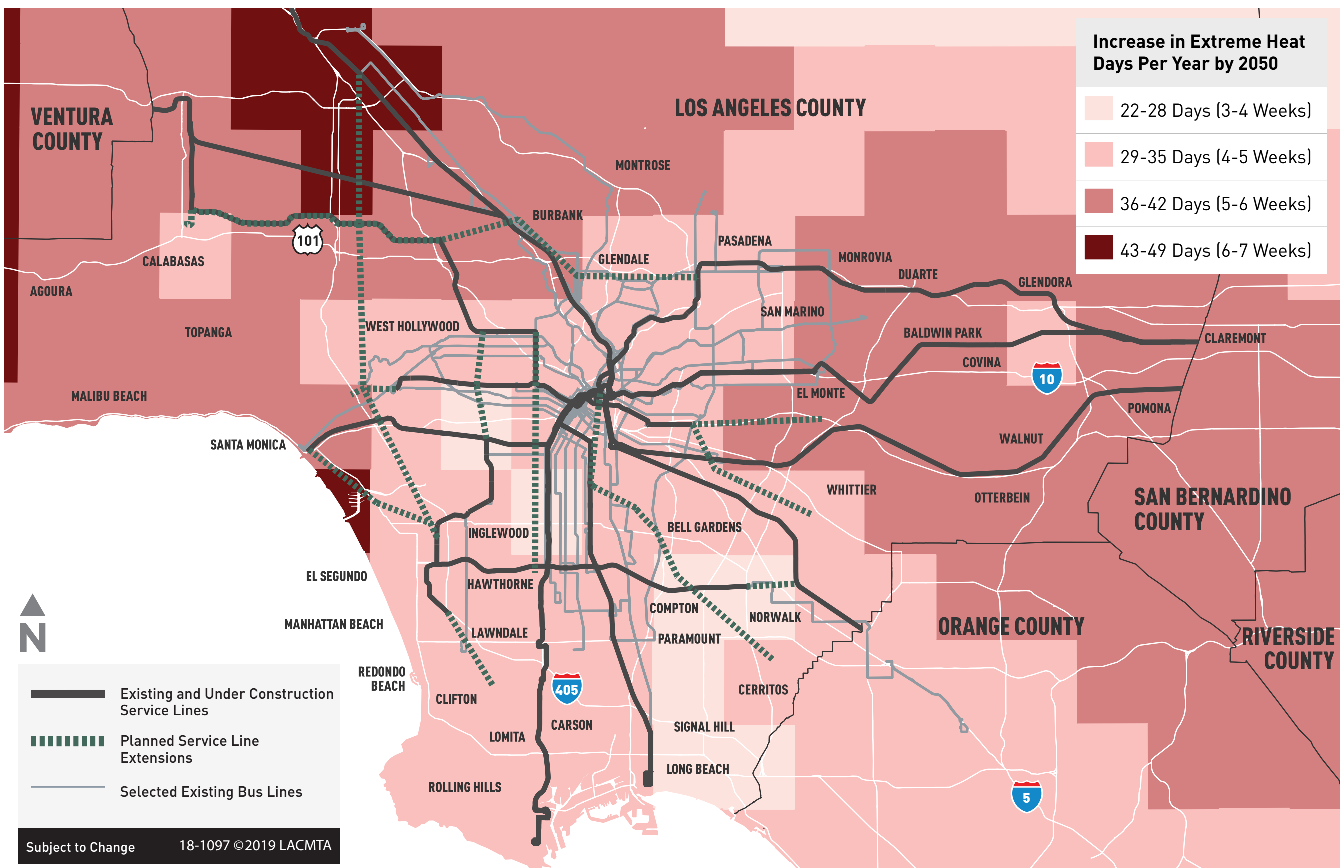
Table B-2: Extreme Heat Exposure Scoring

Exposure Score	Number of Additional Extreme Heat Days per Year
5	More than 28 additional days
4	22–28 additional days
3	15–21 additional days
2	8–14 additional days
1	1–7 additional days

The exposure analysis results for extreme heat are shown in Figure B-2. Nearly all Metro assets have high exposure to extreme heat.

Figure B-2: Extreme Heat Exposure Map

Projected Extreme Heat Exposure
Metro Service Lines



Metro

Note: These maps show only selected bus lines to provide a simple visualization of the extent of the bus system.

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While the global climate models used to conduct the heat exposure analysis show a broad projection of extreme heat in the future, they do not incorporate more local temperature profiles. For example, the urban heat island effect in Los Angeles results from a combination of factors such as low tree canopy, albedo (reflectivity) and a large surface area of heat-absorbing infrastructure.[24] This effect might amplify existing effects from increasing temperatures, creating an even higher projection of extreme heat days in certain parts, especially highly urban sections, of LA County. This has human health implications for disadvantaged communities, who are more likely to live in highly urbanized areas.[25]

In addition, extreme heat might be exacerbated by drought; the combination of these two hazards can strain water resources, affect soil moisture balance and damage vegetation and green space.[26] Climate change might make droughts in the Los Angeles region longer, more severe and more frequent. Conditions conducive to causing drought, such as persistent regions of high pressure in the northeast Pacific Ocean, have become more frequent in recent decades, and there is increasing probability that low-precipitation years coincide with warm years, worsening the impact of droughts.

Climate models also predict a high probability (over 80%) that a multidecadal drought in the Southwest will occur this century under RCP 8.5. To understand more clearly the characteristics of future droughts on a local scale in the Los Angeles region, additional research is needed.

Electrical Outages

It is critical to measure potential exposure to electrical outages, as some assets are dependent on electricity and loss of electricity could occur through a number of different means–including several of the natural climate hazards included in this assessment (e.g., extreme heat or wildfires).

For electricity, Metro assigned a binary score of exposed/not exposed, based on whether the asset type needs electricity to operate, as shown in Table B-3.

Table B-3: Asset Type Electricity Needs

Asset Type	Needs Electricity to Operate?	Exposure Score
Bus Rapid Transit	No	1
Light Rail	Yes	5
Subway	Yes	5
Commuter and Circulator Buses	No	1
Limited Express Buses	No	1
Local Central Business District Buses	No	1
Local Non-Central Business District Buses	No	1
Rapid Buses	No	1
Highways	No	1
Bike Share Stops	Yes	5
Metro Bike Hubs	Yes	5
Cal Trans Park & Ride Lots	No	1
Bus Divisions	Yes	5
Rail Divisions	Yes	5
Terminals	Yes	5
Radio Repeater Stations	Yes	5
Facilities - Other	Yes	5
Parcel Lots	No	1
Rail Stations	Yes	5

[24]Haider et al. 2018
[25]Hall et al. 2018.
[26]Hall et al. 2018.

Note that sensitivity and adaptive capacity of assets needing electricity are separate concepts, the evaluation of which is described in subsequent sections of this appendix. For example, the existence of backup power sources is considered under sensitivity.

Wildfire

Metro obtained wildfire data from Cal-Adapt, using the same climate models, RCP and other assumptions discussed under the methodology for extreme heat. The scoring system takes into account both the current acreage burned as well as the projected increase in area burned. Both current and projected acres burned are factored into the scores because looking at only the increase in change could over- or understate the risk.

For example, a climate model grid cell might show a large increase in wildfire but have a very small baseline and thus would be rated as a higher overall exposure than a grid cell with a large baseline but a more modest increase. To address this possibility, we considered both current and projected exposure. Areas that have both higher current exposure and higher projected changes scored higher, as shown in the scoring system in Table B-4.

Table B-4: Wildfire Exposure Scoring

Exposure Score	Exposure Description
5	Top 66% in current area burned + > 20% change
4	Top 66% in current area burned + <= 20% change
3	Top 33% in current area burned + > 20% change
2	Top 33% in current area burned + <= 20% change
2	Bottom 33% in current area burned + > 20% change
1	Bottom 33% in current + <= 20% change

The two components (current and projected) of the wildfire exposure analysis are illustrated in Figure B-3 and Figure B-4. Northern and eastern LA County currently experience the greatest area burned by wildfire as well as the largest projected increase in area burned. About a fourth of Metro's assets are in areas that are projected to have more areas burned by wildfires in the future.

Figure B-3: Wildfire Exposure: Current Area Burned

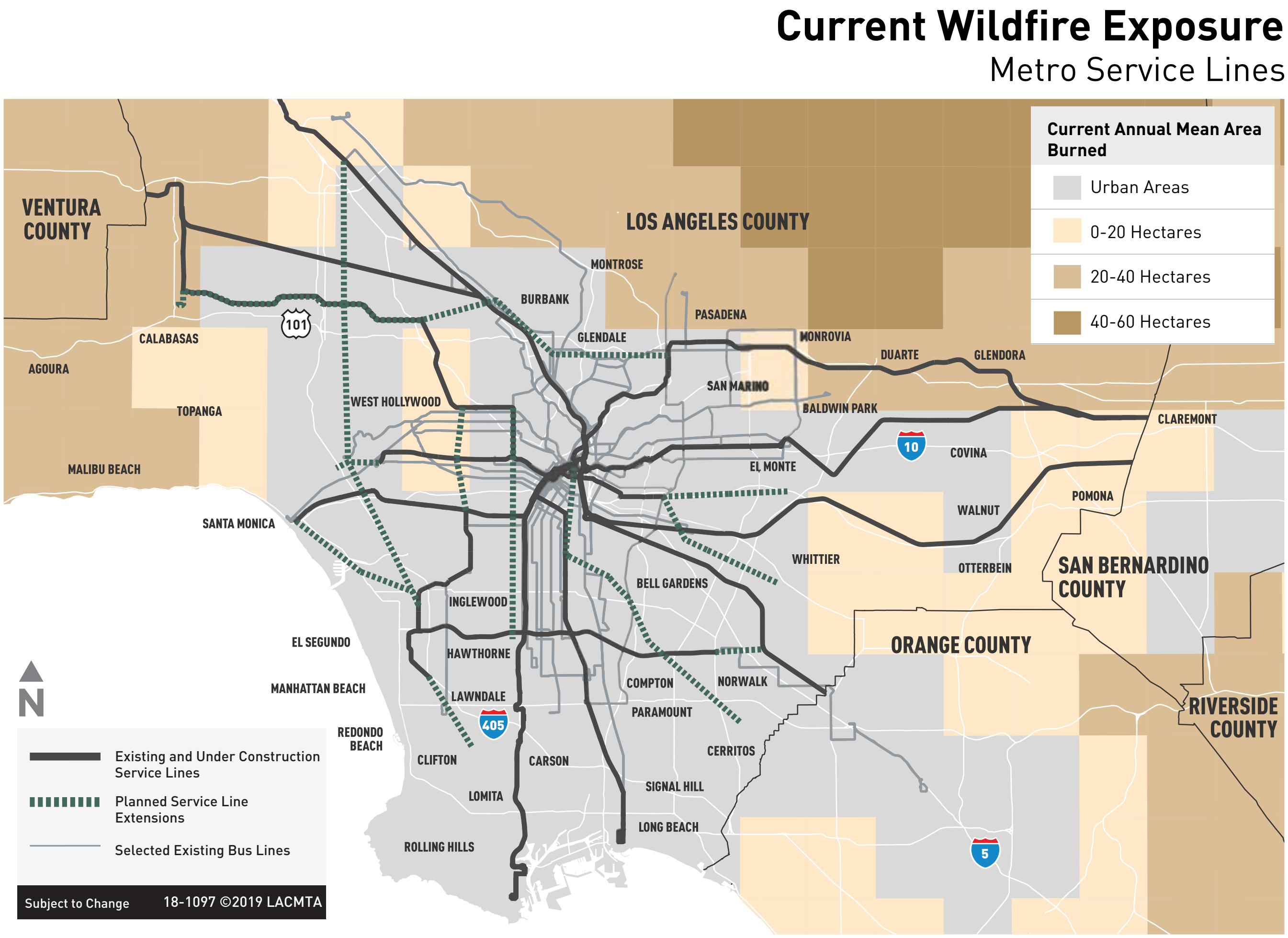

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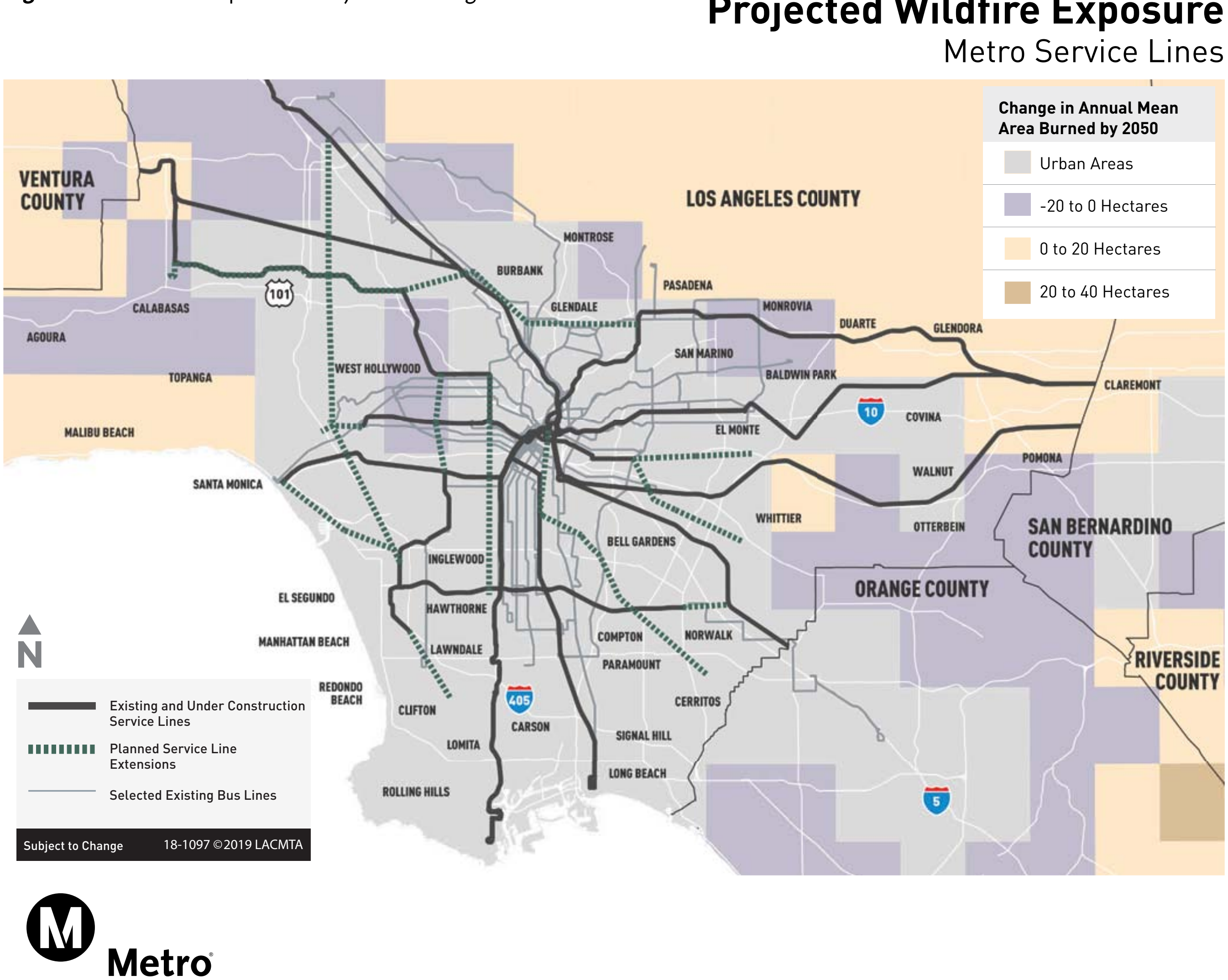
Figure B-4: Wildfire Exposure: Projected Change in Area Burned



Wildfires in Southern California become more dangerous due to the combination of drought, which creates dry fuels to feed wildfires, and regional Santa Ana winds, which further spread fires.[27] Droughts are expected to increase in length, frequency and severity in the Los Angeles region as highlighted in the "Extreme Heat" section of this appendix.

Heavy Precipitation

Projections for the Los Angeles region show the possibility of an increase in extreme precipitation events as well as an increase in intensity during the wettest days of the year. Heavy precipitation can flood tracks and underground infrastructure, damage electrical equipment, erode and flood roads and damage buildings and facilities. Heavy precipitation events can also make vehicle operations dangerous due to decreased visibility for operators or might overwhelm Metro's system with passengers.

To estimate precipitation exposure, Metro took a similar approach to that described for extreme heat: by identifying the threshold for daily inches of rainfall that only 5% of days with rain exceed in an average year (i.e., the fifth percentile daily rainfall amount). We considered the days that experienced precipitation that exceeded this threshold to be extreme precipitation days. Again, this threshold varies by location, which is important because locations are already somewhat adapted to normal precipitation patterns for that location. Then, using the same model assumptions described above for heat, we calculated the *additional* number of days that would exceed this threshold by midcentury. We assigned each asset an exposure score based on the approach shown in Table B-5.

Table B-5: Heavy Precipitation Exposure Scoring

Exposure Score	Number of Additional Extreme Precipitation Days per Year
5	More than 28 additional days
4	22–28 additional days
3	15–21 additional days
2	8–14 additional days
1	1–7 additional days

[27] Hall et al. 2018.

The exposure analysis results for heavy precipitation are shown in Figure B-5. All of Metro's assets show a low exposure to an increase in extreme precipitation events. However, because such events can result in safety concerns and costly impacts, identifying vulnerable assets is still critical. Future improvements could consider how expected precipitation change could contribute to localized stormwater flooding.

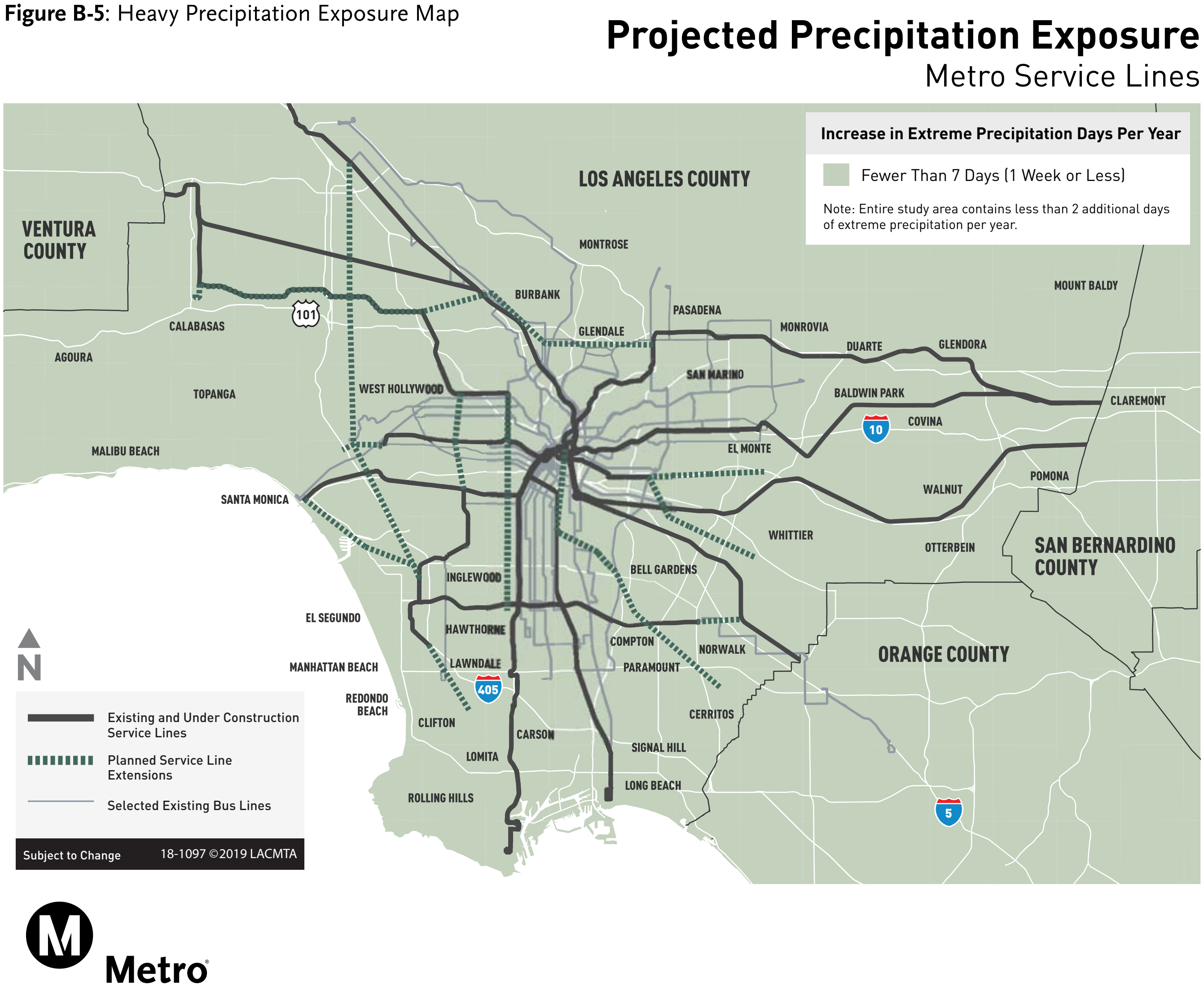
This precipitation analysis does not predict whether precipitation-related flooding might occur in a given spot–for example, whether a road floods at a particular location. That is because this sort of short-term, localized flooding depends not only on precipitation but also on other factors such as the capacity of the surrounding stormwater management systems and the area covered by impervious surfaces.

However, looking at the increase in extreme precipitation events can be a proxy indicator for whether stormwater-related flooding might increase in frequency. That is, if there are areas already known to flood during heavy rains, and more days of heavy rains are projected to occur, then those flood-prone areas might experience flooding events more often in the future.

In addition, when looking at changes in precipitation patterns on a percentage basis instead of the number of days with heavy rain, more notable increases can be calculated. For example, Hall et al. found that by the end of the century in the Los Angeles region, the wettest day of the year could increase in intensity by up to 25–30% and precipitation during atmospheric river events could increase up to 40% under RCP 8.5.[28]

While these potential changes are notable, using a percentage to convey changes has limitations when the baseline is a small number to start with: relatively small absolute increases can translate to large percentage increases. Furthermore, the projected changes are less dramatic when considering the midcentury timeframe, which, as discussed earlier, is the timeframe for this analysis.

Figure B-5: Heavy Precipitation Exposure Map



[28]Hall et al. 2018.

Hall et al. did also find that the peak season of atmospheric rivers is projected to lengthen, which might extend the flood hazard season.[29]

Riverine Flooding

Riverine flooding risks are similar to and brought about by heavy precipitation risks. Excessive rainfall can cause a river to exceed its capacity, resulting in flooding risks to nearby assets. To evaluate riverine flooding exposure, Metro considered whether assets were located within or near floodplains defined by the Federal Emergency Management Agency (FEMA). Metro downloaded flood zone spatial layers from FEMA's National Flood Hazard Layer[30] and evaluated whether each asset was within the 100-year or 500-year floodplain.

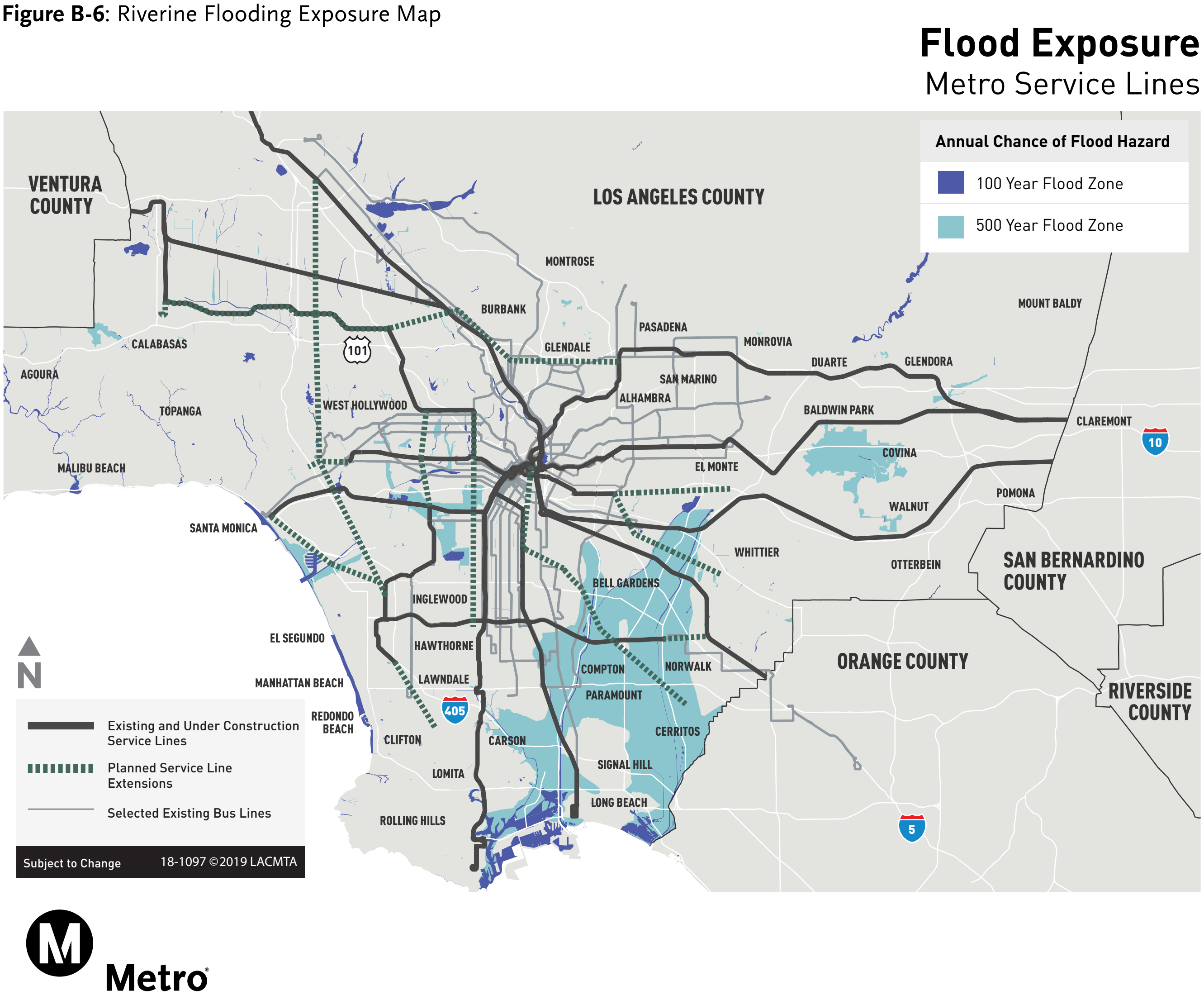
However, these FEMA layers represent the current floodplains, and quality data on how the floodplains might change in the future are not available. Therefore, we also looked at a 100-yard buffer around each floodplain to determine whether an asset was close to the floodplain. This buffer is meant to capture assets that are not currently within a floodplain but that could be exposed if climate change causes more extreme riverine flooding. Table B-6 shows the scoring system for riverine flooding exposure.

Table B-6: Riverine Flooding Exposure Scoring

Exposure Score	Relation to FEMA Floodplains
5	Within 100-year flood zone
4	Within 100 yards of 100-year flood zone
3	Within 500-year flood zone
2	Within 100 yards of 500-year flood zone
1	>100 yards away from 500-year flood zone

The flood zone maps are shown in Figure B-6. Over 500 Metro assets lie at least within 100 yards of one of the flood zones, rendering them exposed to riverine flooding events.

Figure B-6: Riverine Flooding Exposure Map



[29]Hall et al. 2018.

[30]Spatial layers available at fema.gov/national-flood-hazard-layer-nfhl. Downloaded in December 2018.

Land and Mudslides

Metro used available geospatial data on landslide zones to determine land- and mudslide exposure. We downloaded landslide zones from Los Angeles Geohub.[31] These spatial layers allowed us to determine whether assets are in current landslide zones. Because landslide risk might not be as binary as being in or out of a zone, we used a small buffer zone around the landslide zones to capture areas that could have some risk even though they are not considered to be in the zone. See the scoring system depicted in Table B-7.

Table B-7: Land and Mudslide Exposure Scoring

Exposure Score	Location Relative to Landslide Zone
5	In landslide zone
4	Within 50 feet of landslide zone
3	Within 100 feet of landslide zone
2	Within 150 feet of landslide zone
1	More than 150 feet from landslide zone

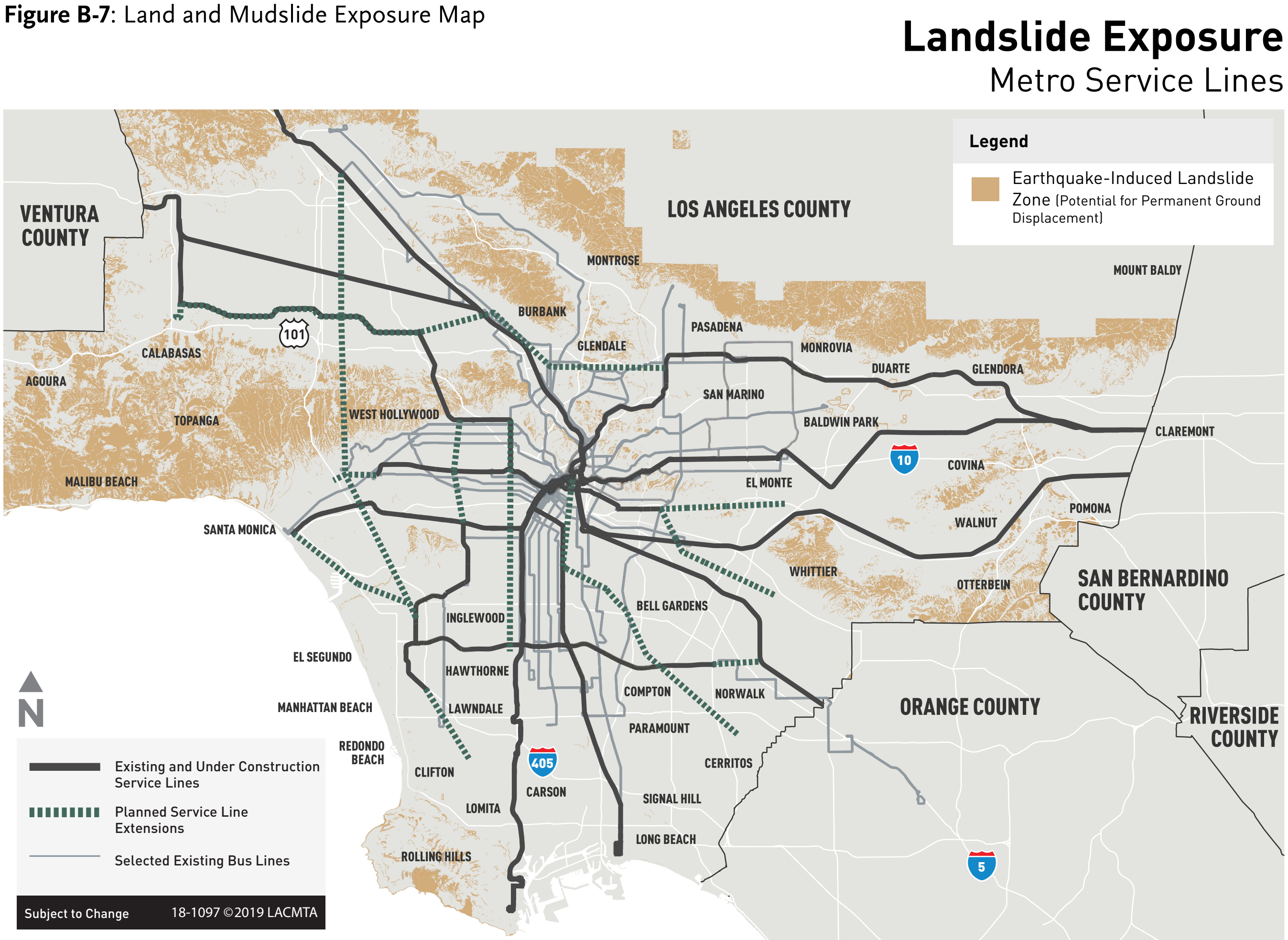
The exposure analysis results for land and mudslides are shown in Figure B-7. Land and mudslide events mostly affect assets that lie at the foothills of mountains, so Metro's assets situated along slopes have higher exposure to mudslides, whereas assets on flat land have lower exposure.

Note that this exposure analysis considers today's landslide zones. It does not attempt to account for how these landslide zones will change in the future, simply because quality projections on future landslide risk do not exist. However, landslide risk in Southern California is projected to increase in the future due to the projected increase in extreme precipitation and wildfire events.[32]

Sea Level Rise and Coastal Flooding

To evaluate exposure to sea level rise, Metro used the US Geologic Survey (USGS)'s Coastal Storm Modeling System

Figure B-7: Land and Mudslide Exposure Map



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[31] Los Angeles Geohub 2016.
[32] Hall et al. 2018.

(CoSMoS) v3.0 Phase 2. CoSMoS provides spatial layers of projected sea level rise and related coastal flooding events. Metro looked at exposure of assets for 50-centimeter (cm) sea level rise (which could occur by midcentury) as well as 200-cm sea level rise (which could occur by the end of the century).

In this area of the country, it is more appropriate to discuss extreme events tied to storms and/or tidal events rather than storm surge. Therefore, Metro also considered exposure to the 1-in-100-year coastal event, also obtained from CoSMoS.

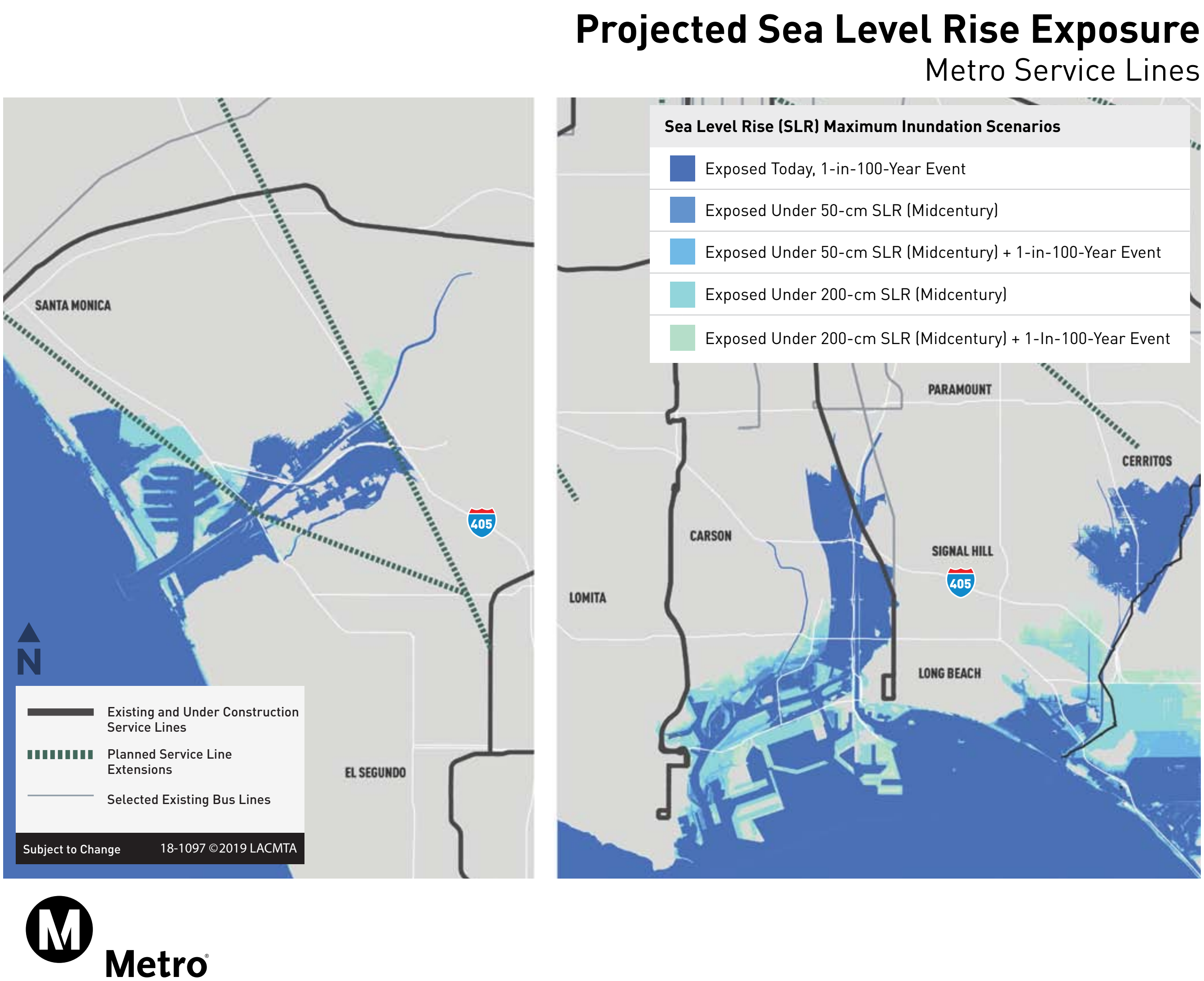
Combining the two sea level rise scenarios with the 1-in-100-year scenario allowed us to assign exposure scores for each asset, as shown in Table B-8.

Table B-8: Sea Level Rise and Coastal Flooding Exposure Scoring

Exposure Score	Exposure Description
5	Exposed today, 1-in-100-year event
4	Exposed under 50-cm SLR (midcentury)
3	Exposed under 50-cm SLR (midcentury) + 1-in-100-year event
2	Exposed under 200-cm SLR (midcentury)
1	Exposed under 200-cm SLR (midcentury) + 1-in-100-year event
0	Not exposed

The locations exposed to sea level rise and coastal flooding according to this analysis are shown in Figure B-8. Most of Metro's assets are not exposed at all to sea level rise and coastal flooding, since these hazards would only affect infrastructure near the coast.

Figure B-8: Sea Level Rise and Coastal Flooding Exposure Map



Wind

In the *California Fourth Climate Change Assessment* report on the Los Angeles region, Hall et al. (2018) found an overall uncertainty in predicting future changes for Santa Ana wind events, as studies differ in their results discussing the direction and magnitude of change.[33,34] Future research might provide better detail on how these winds respond to climate change and how that impact might affect the Los Angeles region.

Preliminary analysis for wind exposure used data from Cal-Adapt.[35] This analysis evaluated whether maximum wind speeds are projected to increase in the Metro region by midcentury and determined that wind speeds are projected to decrease throughout the Metro region by midcentury. Therefore, wind hazards were not analyzed further in this CAAP.

Sensitivity and Adaptive Capacity

The sensitivity of an asset describes the magnitude of impact a hazard would have on it, whereas the adaptive capacity relates to the asset's ability to withstand the hazard or recover from it.

Metro assessed sensitivity and adaptive capacity for each asset class, or the lowest level of an asset at which there is key differentiation in these factors. For example, a subway station is an asset type, but the specific trackwork in that station is an asset class. While some individual assets within a class could be more sensitive than others, Metro conducted the assessment at the asset class level. Figure B-9 shows an example of the hierarchy of asset types and asset classes.

For each asset class, Metro rated its sensitivity and adaptive capacity to each of the seven climate hazards on a scale of 1 to 3 (where 3 is more vulnerable).[36] These ratings were based on the following hierarchy of sources:

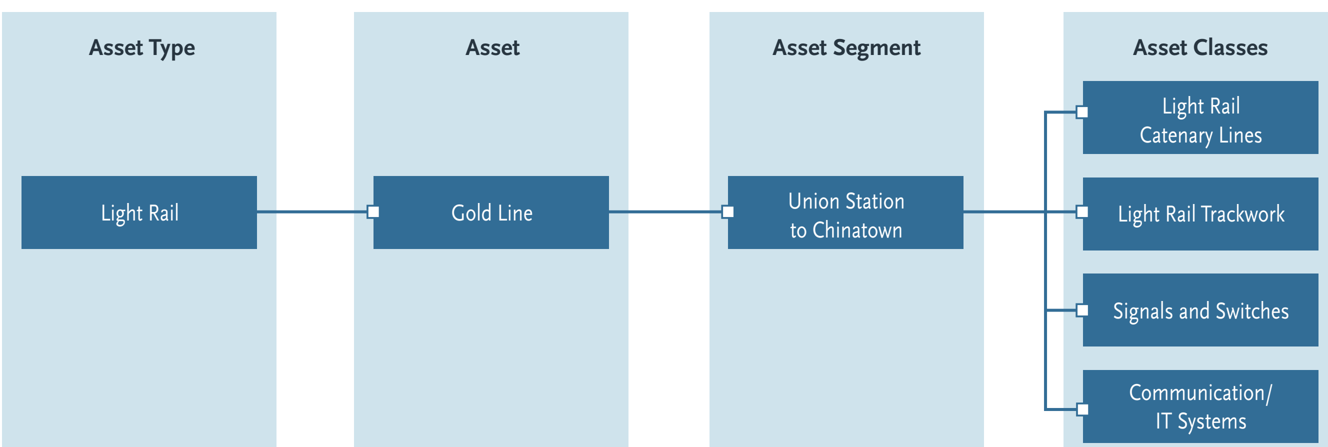
1. Interviews with Metro staff
2. Sensitivity and adaptive capacity relationships documented in the Federal Transit Administration *Flooded Bus Barns and Buckled Rails* report[37] on transit climate vulnerabilities
3. Sensitivity relationships documented in the US Department of Transportation's *Transportation Climate Change Sensitivity Matrix*[38]
4. Targeted research on specific gaps after going through the first three sources
5. Metro expert judgment to fill remaining gaps

If information was not available from the first source, Metro sought information from the second, and so on through the end of the list. For each asset class-hazard pair, Metro provided a justification and documentation for the rating.

Metro stakeholders then reviewed and refined these ratings.

An example subset of the matrix is shown in Figure B-10.

Figure B-9: Asset Hierarchy Example with Gold Line Segment



[33]Guzman-Morales et al. 2016.
[34]Hughes, Hall, and Kim 2011.
[35]LSA 2018.
[36] Metro used a three-point rating scale for sensitivity and adaptive capacity, which was appropriate to capture the granularity of the ratings across assets. Metro subsequently converted these ratings into the five-point scoring scale used for all other risk components for input into the vulnerability score calculation.
[37] US Department of Transportation 2011.
[38] US Department of Transportation 2015.

Figure B-10: Example of Sensitivity and Adaptive Capacity Matrix

Asset Category	Asset Class	Increased Wildfires				Increased Heavy Precipitation			
		Sensitivity		Adaptive Capacity		Sensitivity		Adaptive Capacity	
		Rating	Justification	Rating	Justification	Rating	Justification	Rating	Justification
Underground Tunnel Railways (Subways)	**Subway Trackwork**	1	Underground tunnel is a controlled environment. No considerable impact from outside heat is expected [10]	1	N/A [10]	3	Flooding impact [1], unsure to what extent impact would be to power equipment under cars + how it can affect underground tracks [10]	2	Pumps help keep water out but may be overwhelmed [3], can install resilient rail fasteners to provide smoother ride [7]; Metro Rail Operating Rules do address rail operations on a flooded track [10]
	Subway Stations	1	Possible air quality issues if HVAC draws from outside and ash gets in [10]	1	Metro has air filters inside the subway system [10]	3	Flood risk [3]	2	Pumps help keep water out but may be overwhelmed [3], enhance drainage [7], Metro Rail Operating Rules address rail operations on a flooded track [10]
	Third Rail Power	1	No impact [10]	1	N/A [10]	2	Potential to cut off power if water level from rain reaches third rail [2]; however, deluge would reach vehicles first [10]	2	Must shut off if water reaches it [3]; Third Rail must be de-energized by the ROC to cut off power to trains in advance of potential threats; no significant potential damage to Third Rail itself [10]
	Subway Rolling Stock	1	Possible air quality issues if HVAC draws from outside and ash gets in; subway cars can withstand 1 hr of flame underneath due to layers and design of flooring [10]	1	Metro has air filters inside the subway system; fire extinguishers on board if fire gets into cars; regarding repairs, assets can be moved from one track to another (i.e. Blue line is connected to Expo line, so Blue line cars could be run into maintenance shop) [10]	2	Water could get in motors and require repair; could be overwhelmed with passengers, stranding some [3]; elevated water levels could reach vehicles with potential short-circuits in the power equipment underneath them [10]	1	Damaged rolling stock could be replaced, or with enough advanced warning rolling stock could be moved to higher ground [6]

Note: This matrix illustrates the impact of wildfires and heavy precipitation on underground tunnel railways. Justifications adjacent to the rating give evidence to support the score and include citations to external references.

Vulnerability

To determine vulnerability, Metro combined scores for the exposure, sensitivity and adaptive capacity of each asset to the seven climate hazards identified. Scores for exposure were pulled on the asset level from the spatial analysis. To calculate sensitivity and adaptive capacity scores for each asset (as opposed to asset class), Metro assigned each asset type a set of asset classes that corresponded to those analyzed in the sensitivity and adaptive capacity matrix. Table B-9 presents the distribution of these asset classes.

Table B-9: Asset Types and Classes

Asset Type	Asset Classes
Highway	> Bus Routes
Cal Trans Park & Ride	> Parking Lots
Bus Routes (BRT, Commuter and Circulator, Limited Express, etc.)	> Buses > Bus Routes
Division – Bus	> Storage and Maintenance Yards > Buses > Other Buildings and Structures (Non-Station)
Division – Rail	> Storage and Maintenance Yards > Light Rail Engines and Cars > Subway Cars > Other Buildings and Structures (Non-Station)
Light Rail (Station)	> Station Structures > At-Grade Communication/IT Systems > Parking Lots > Elevators, Escalators and Other People Movers > Signals and Switches
Light Rail (Segment)	> Light Rail Catenary Lines > Light Rail Trackwork > Signals and Switches > Communication/IT Systems > Light Rail Engines and Cars
Other Facilities	> Buildings and Structures > Stormwater Collection Systems
Parcel Lots	> Stormwater Collection Systems
Radio Repeaters	> Communication/IT Systems
Subway (Station)	> Subway Station Structure > Signals/Switches > Parking Lots > Elevators, Escalators and Other People Movers > Communication/IT Systems
Subway (Segment)	> Subway Trackwork > Third Rail Power > Subway Cars > Signals and Switches > Communication/IT Systems
Terminal	> Parking Lots
Metro Bike Hubs	> Buildings and Structure > Stormwater Collection Systems
Bike Share Stop	> Metro Bike Share Bicycles > Bike Share Stations > Bike Paths

Each individual asset is assigned component asset classes based on asset type. In some instances, individual assets have different asset class designations than others in their asset type. For example, some light rail segments run underground, and so would be scored based on the underground trackwork asset type. Each asset received the highest sensitivity and adaptive capacity score of its component asset classes. This is based on the idea that the "weakest link" asset class in an asset type should be highlighted. This might result in cases in which, for example, the sensitivity of a subway station is based solely on the sensitivity of its elevators and escalators rather than the trackwork that is unique to the subway station. However, Metro addresses such cases later in this analysis.

We averaged the exposure, sensitivity and adaptive capacity of each asset to create vulnerability scores on a scale of 0 to 5. If an asset had an exposure score of 0 (not exposed), it also received a vulnerability score of 0.

Criticality

Defining Criticality

Metro followed Caltrans guidance for transit emergency preparedness in defining whether an asset is "critical," which means its loss would either endanger human life or affect the Agency's ability to meet our mission.[39] Metro's mission is to provide a world-class transportation system that enhances quality of life for all who live, work and play within LA County.

This criticality assessment includes eight indicators of each asset's contribution to Metro's ability to fulfill our mission:

> Ridership
> Transit Dependency
> Connectivity
> Lack of Redundancy
> Role in Emergency Response
> Joint Development Site
> Economic Impact
> Priority Economic Zone

These eight indicators also align with Metro's multiple long-range planning documents, including our *Vision 2028 Strategic Plan* and *2009 Long Range Transportation Plan*. For example, Table B-10 shows how the criticality indicators align with goals from the Strategic Plan.

[39]Caltrans 2007.

Table B-10: Criticality Indicators Aligned with Strategic Plan Goals

Strategic Plan Goals	Ridership	Transit Dependency	Connectivity	Lack of Redundancy	Role in Emergency Response	Joint Development Site	Economic Impact	Priority Impact Zone
Provide high-quality mobility options that enable people to spend less time traveling	✓	✓	✓	✓		✓		
Deliver outstanding trip experiences for all users of the transportation system		✓	✓	✓	✓	✓		
Enhance communities and lives through mobility and access to opportunity	✓	✓	✓	✓	✓	✓	✓	✓

Criticality Indicators and Rating Details

Ridership

This indicator measures how many users rely on each asset. The more users who would be affected by loss of the asset, the more critical it is. Metro used the following datasets showing ridership metrics for this analysis:

> **Dataset #1 (line-level ridership of all assets)**: shows monthly and fiscal-year-to-date boardings + average daily and monthly passenger miles through January 2018
  – Applies to: Light Rail (Blue Line, Green Line, Gold Line, Expo Line), Heavy Rail/Subway (Red Line, Purple Line), BRT (Orange Line, Silver Line) and other bus (Metro Bus, Contracted Bus and Combined Bus, but not individual bus lines)

> **Dataset #2 (station-level ridership of rail assets)**: shows average daily and fiscal year 2017/2018 boardings and alightings, plus direction of travel
  – Applies to: Light Rail (Blue Line, Green Line, Gold Line, Expo Line) and Heavy Rail/Subway (Red Line, Purple Line)

> **Dataset #3 (line-level ridership of bus assets)**: shows monthly boardings and passenger miles in 2016 only
  – Applies to: all directly operated and purchased transportation bus lines

> **Dataset #4 (Metro bike share data)**: shows quarterly boardings from 2016 Q3 to 2018 Q3, also includes other data such as station use
  – Applies to: all bike share stops

> **Dataset #5 (new planned assets)**: shows projected daily and annual boardings, route miles and passenger miles traveled for new planned Metro BRT, light rail and heavy rail assets
  – Applies to: Crenshaw LAX Transit, Regional Connector Transit, Purple Line Extension, Gold Line Foothill Extension, South Bay Light Rail, Gold Line Eastside Corridor, West Santa Ana Corridor, North Hollywood-Pasadena Corridor, North San Fernando Valley Transit Corridor, East San Fernando Valley Transit Corridor, Vermont Corridor

Based on the data Metro had available, we determined ridership for the following assets:

> **Buses, BRT**: *line*-level data for the year 2016, using number of boardings; this draws from Dataset #1 (for BRT) and #3 (for other buses)

> **Light rail and heavy rail**: *line*-level data for the year 2016, using number of boardings; this draws from Dataset #1
  – **Note**: dataset #1 aggregated ridership data for the Red and Purple Lines, so Metro used Dataset #2 to gather data on ridership for each line individually

> **Light rail and heavy rail stations**: *station*-level data for the year 2016 (determined by averaging the fiscal year 2016 and fiscal year 2017 values), using number of boardings; this draws from Dataset #2

> **Bike share stops**: *system*wide data for the year 2017 (full-year bike data were not available for 2016 as the program launched during 2016), using number of trips; this draws from Dataset #4

> **CalTrans park & rides**: data were available for these assets but did not align with the asset inventory, so their ridership was not analyzed

> **Planned assets**: *line*-level data, using annual number of projected boardings; this draws from Dataset #5

To calculate ridership for each line, Metro used the "number of boardings" metric across all assets, including lines, stations and bike share stops.

Metro calculated ridership across all assets except bike share stations for calendar year 2016.[40] This is the most recent year for which data were available for all asset types. All assets were scored based on 20% percentiles. For example, the assets in the 80th to 100th percentile of ridership received a 5, assets in the 60th to 80th percentile received a 4, and so on.

Transit Dependency

This indicator measures whether the asset serves populations who are dependent on transit for mobility. These assets are critical to ensure mobility across LA County for all residents.

[40] For bike share stations, Metro scored assets for the year 2017, since the bike share program launched in mid-2016.

Consistent with the 2014 Short Range Transportation Plan, populations in LA County are defined as transit-dependent if the population met one or more of the following criteria:[41]

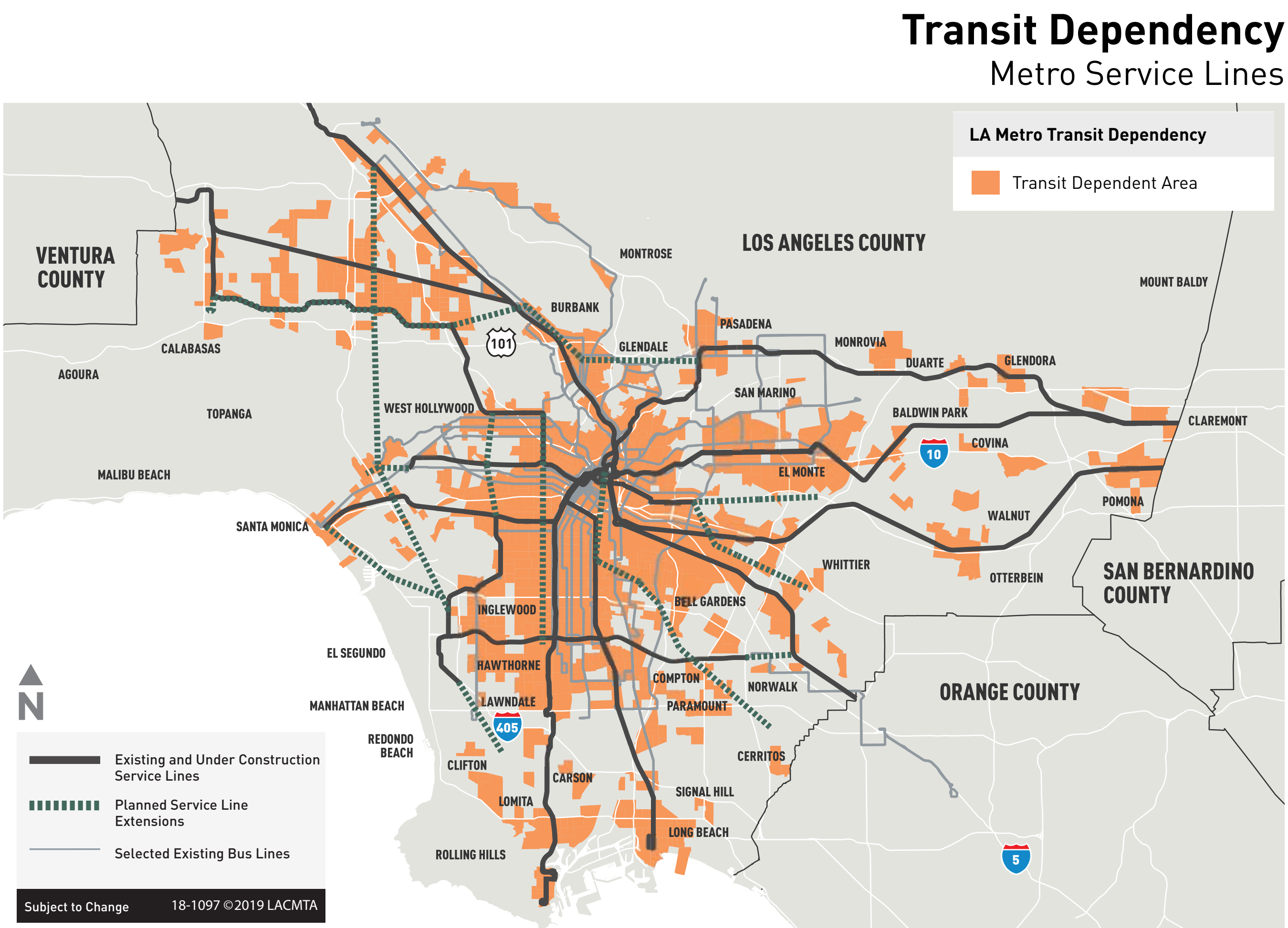
> **Zero car ownership**: 10% or more of the households do not own a car;
> **Low income**: 26.7% or more of the households have income of $25,000 or less (in 2010 dollars); or
> **Senior citizens with medium-low income**: 11% or more of the households include individuals aged 65 or older, and median household income is less than $53,762.

Metro filtered census data from the 2015 American Community Survey five-year estimates according to the above criteria to create a base map of census tracts deemed to be transit-dependent (see Figure B-11). Metro bus and rail/BRT lines within 0.5 mile of these census tracts were identified as critical for these populations.

Connectivity

Connectivity measures how many different transportation options are accessible from a given asset, which represents its criticality to the overall mobility of the region. Assets with more connectivity are more critical, because their loss would have a greater disruption to mobility than would the loss of assets that are not connected to other parts of the system.

Figure B-11: Transit-dependent Populations in LA County



Metro

[41] LA Metro 2018.

Metro measured the number of connections based on the following geospatial analysis for each asset type:

> **Rail stations, bike share stops and park & ride lots**: the number of other assets within 0.5 mile from each station or asset location.
> **Light rail and subway segments**: the number of other assets within 0.5 mile from either end of each segment.
> **Bus lines**: the number of other assets within 0.25 mile from each bus route. Bus lines have a smaller connectivity buffer than other asset types due to their length and to reflect realistic conditions. For the other asset types, the 0.5-mile buffer was designated as a reasonable distance for people to walk from one asset to another to continue their trip. However, since bus lines are so long, the 0.5-mile buffer picked up many more connections than was realistic, so Metro reduced the buffer.

Metro scored connectivity on a scale of 1 to 5 based on 20% percentiles for the whole system. For example, the assets in the top 20% of connectivity ratings received a 5, and so on.

Lack of Redundancy

This indicator measures whether other assets could serve a similar function to the asset—loss of those assets that are "irreplaceable" would create a greater disruption to Metro's ability to provide service and mobility.

To measure redundancy, a geospatial analysis was used to calculate the number of available replacement assets. Replacement asset types and the relevant distance varied by asset type, as shown in Table B-11.

Metro also has other facility types, including customer service centers, maintenance facilities and wayside systems, Harbor Transitway and office space; individual replacement assets were identified for each asset.

Table B-11: Redundancy Rating Approach and Rationale

Asset Type	Approach	Replacement Asset Types		Rationale
BRT Segment	Number of "replacement assets" within 0.5 miles	> BRT Station (different line) > Light Rail Station	> Subway Station > Bus Route	Not all nearby routes will be adequate replacement routes (e.g., they might head in different directions), but the more options available, the more likely the rider will be able to reach his/her destination
BRT Station	Number of "replacement assets" within 0.5 miles	> BRT Station > Light Rail Station	> Subway Station > Bus Route[a]	
Light Rail Segment	Number of "replacement assets" within 0.5 miles	> BRT Station > Light Rail Station (different line)	> Subway Station > Bus Route	
Light Rail Station	Number of "replacement assets" within 0.5 miles	> BRT Station > Light Rail Station	> Subway Station > Bus Route[a]	
Subway Segment	Number of "replacement assets" within 0.5 miles	> BRT Station > Light Rail Station	> Subway Station > (different line) > Bus Route	
Subway Station	Number of "replacement assets" within 0.5 miles	> BRT Station > Light Rail Station	> Subway Station > Bus Route[a]	
Bus Route	Number of "replacement assets" within 0.5 miles	> BRT Station > Light Rail Station	> Subway Station > Bus Route (different line)	
Bike Share Stop	Number of "replacement assets" within 0.5 miles	> Bike Share Stop		The more options available, the more likely the rider will be able to park the bike and reach their final destination on foot
CalTrans Park & Ride	Number of "replacement assets" within 1 mile	> CalTrans Park & Ride		The more options available, the more likely the driver can find an alternate park & ride location within a reasonable driving distance
Division – Bus	Number of "replacement assets" within 16 miles[b]	> Division – Bus		
Division – Rail	Number of "replacement assets" within 5 miles	> Division – Rail		
Other Facilities	Number of "replacement assets" within 5 miles	> Varies by Asset		
Parcel Lots	Number of "replacement assets" within 5 miles	> Varies by Asset		
Radio Repeater Stations	Number of "replacement assets"	> Varies by Asset		
Terminals	Number of "replacement assets" within 1 mile	> Terminals		

[a] This assumes that there will be a bus stop within reasonable walking distance along the bus route (bus stop would be more appropriate, but data were not practical to analyze).
[b] Based on a recent incident where one division, 16 miles away from another, was able to serve as a replacement.

Role in Emergency Response

This indicator captures whether loss of the asset would hinder Metro's ability to provide emergency response services in the event of an incident. This was based on whether the asset is identified as having a role within one of two designated emergency planning documents:

> County of Los Angeles All-Hazard Mitigation Plan[42]
> Metro Continuity of Operations Plan (COOP)[43]

The *County All-Hazard Mitigation Plan* did not identify specific assets but called out the critical role of Metro in supporting emergency transportation services. The COOP then identified specific assets that are "mission essential."

Assets with a role in emergency response received a 5 and those without received a 1.

Joint Development Site

This indicator captures whether an asset serves a designated "joint development" site that is part of Metro's Joint Development program through which Metro collaborates with developers to build transit-oriented communities on Metro-owned properties.[44] These joint development sites are critical to Metro's ability to contribute to the sustainability of the region, as well as to attract new riders.

Each asset received a score of 5 if it is located within 0.5 mile of any completed, active and opportunity joint development projects. A database of these sites was accessed through Metro's Joint Development Project Sites Map available on the Metro website.

Jobs Served

This indicator measures the number of jobs served by any given Metro asset, which represents the asset's contribution to economic opportunity in the region. Metro pulled the number of jobs from block-level census data and summed the number of jobs within 0.5 mile of each asset.[45] If a block was only partially within the 0.5-mile buffer, the fraction of that block within the buffer was applied to the number of jobs.

Metro scored this indicator on a scale of 1 to 5 based on 20% percentiles.

Priority Economic Zone

This indicator captures whether an asset serves a designated priority economic zone, which reflects how much the asset contributes to enhancing economic opportunity in the region. Areas designated through the California Enterprise Zone program represent "economically distressed areas" that the County has targeted for economic development.[46]

[42] County of Los Angeles 2014.
[43] LA Metro 2016.
[44] LA Metro 2018.
[45] US Census Bureau 2017.
[46] LAEDC 2013.

LA County has eight designated areas:

> Compton, expires: 7/31/2022
> Harbor Gateway Communities, expires: 4/30/2027
> Long Beach, expires: 1/7/2022
> Los Angeles (East), expires: 1/10/2023
> Los Angeles (Hollywood), expires: 10/14/2021
> Pasadena, expires: 4/10/2022
> Santa Clarita Valley, expires: 6/30/2022
> South Gate/Lynwood, expires: 10/14/2021

Metro assets located within 100 feet of a designated Enterprise Zone received a 5, and all others received a 1 for this indicator. LA County provided GIS data with Enterprise Zone boundaries.

Overall Criticality Score

Each asset received a rating of 1 to 5 for each indicator based on the data as described above. An average of these ratings was computed to develop an overall criticality score for each asset.

Risk

Finally, a risk score was computed for each asset as the product of its vulnerability score and criticality score, by hazard. Vulnerability was measured on a scale of 0 to 5 and criticality was measured on a scale of 1 to 5, giving a maximum possible risk score of 25.

Table B-12 and Table B-13 illustrate the resulting risk matrix, as well as the risk rating assigned to each score.

Table B-12: Risk Score Matrix

Criticality \ Vulnerability	0	1	2	3	4	5
5	0	5	10	15	20	25
4	0	4	8	12	16	20
3	0	3	6	9	12	15
2	0	2	4	6	8	10
1	0	1	2	3	4	5

Table B-13: Risk Rating Matrix

Risk Score Range	Risk Rating
Risk = 0	Negligible
1 ≤ Risk < 6	Low
6 ≤ Risk < 11	Medium
11 ≤ Risk < 17	High
Risk ≥ 17	Extreme

Appendix C
Glossary

TERM	DESCRIPTION
Adaptation	Actions taken to adjust to the effects of climate change
Adaptive capacity	An asset's ability to withstand a hazard or recover from it
Asset	Individual component of Metro infrastructure or operations; examples include bus routes, subway segments, buildings and buses
Battery electric vehicle	A vehicle powered by electricity that is stored in a battery after charging
Bus rapid transit	A bus-based transit system that improves transit efficiencies through dedicated bus lanes and other operational efficiencies
Business as usual	A scenario developed for this CAAP that forecasts Metro greenhouse gas emissions through 2050 based on current and planned operations
Climate Action and Adaptation Plan	A plan that incorporates both climate mitigation and adaptation into processes
Cal-Adapt	A data resource developed by the state of California that spatially shows California-based climate change exposure analyses
Coastal Storm Modeling System	A spatial analysis tool created by the US Geological Survey to project sea level rise and coastal flooding events
Contracted vehicles	Vehicles or vehicle fleets that Metro contracts with external parties for providing transit services
Criticality	A component of risk and the importance of an asset to Metro's ability to fulfill our mission
Directly operated	Vehicles or vehicle fleets directly controlled and operated by Metro
Displaced emissions	Emission reductions that are achieved as a result of the diversion of trips from private vehicles to transit (mode shift) and when transit enables denser land use patterns that promote shorter trips, walking and cycling and reduced car use and ownership (land use effect)
Exposure	The likelihood that an asset will experience a hazard
Flexible adaptation pathways	An adaptation planning approach offering multiple options for adaptation action; accounting for the fact that climate change and its effects will occur over a long period of time, often in an unpredictable manner, this approach provides flexibility to respond to new information or changing factors
Global warming potential	A value that describes the total warming impact of a greenhouse gas relative to carbon dioxide
Greenhouse gas	A gas from human or natural source that absorbs thermal infrared radiation; examples include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), and hydroflurocarbons (HFCs)

TERM	DESCRIPTION
Hazard	Impacts to assets, operations, employees and riders from natural or human sources; examples of impacts include physical damage to assets, increased health damages to riders and employees, and disruptions to transit services
Internal combustion vehicle	A vehicle that burns fuel in an internal engine
Land use effect	When transit enables denser land use patterns that promote shorter trips, walking and cycling and reduced car use and ownership
Lower-carbon fuels or energy sources	Fuels or energy sources with significantly lower associated greenhouse gas emissions in production and use than fossil fuels, such as RNG and biodiesel
Mitigation	Actions taken to reduce greenhouse gas emissions
Mode shift	The diversion of trips from private vehicles to public transit
Non-modal emissions	Emissions from operational activities that are not directly associated with moving passengers; examples include emissions from support "non-revenue" vehicles, facility electricity and natural gas consumption, water consumption, refrigerant use and employee commuting
Power purchase agreement	An agreement or contract between a consumer and generator for supplying electricity
Renewable natural gas	Natural gas produced from biogenic sources, such as landfills or agricultural sources
Resilience	The ability to provide core functions in the face of threats, and to recover quickly from major shocks or changing conditions
Risk	The likelihood and consequence of a hazard; calculated as a product of vulnerability and criticality
Risk assessment	An analysis used to determine the risk different hazards pose to a system or assets
Sensitivity	The extent to which an asset is affected due to exposure of a hazard
Transit emissions	Emissions from operational activities that are directly associated with moving passengers, such as emissions from rail, bus and vanpool
Trigger	In adaptation pathways, a metric that signals transition from one pathway to another
Vehicle miles traveled	A measure of distance (in miles) traveled by a vehicle or vehicle fleet
Vehicle revenue miles	A measure of miles traveled by Metro revenue-generating vehicles
Vulnerability	A component of risk, composed of an asset's exposure, sensitivity and adaptive capacity to climate hazards; it signifies how an asset might be affected by climate change
Zero-emission vehicle	A vehicle with no tailpipe emissions (air pollutants or greenhouse gases) during use

Appendix D References

Inventory/Forecast

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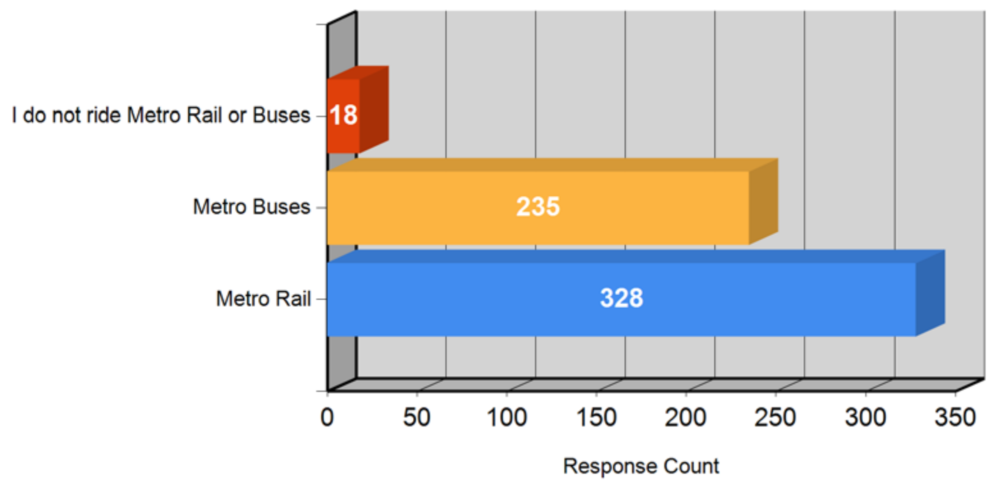
Appendix E
Rider Survey

Chapter: opening
Which of the following Metro services do you ride?

Total Respondents:	373
Total Skipped:	0

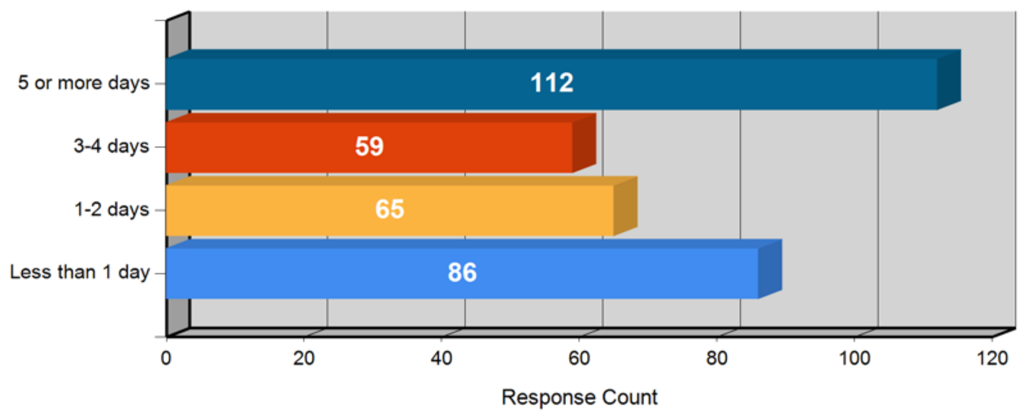


	Choice	Response Percent	Response Total
1	Metro Rail	87.94 %	328
2	Metro Buses	63.00 %	235
3	I do not ride Metro Rail or Buses	4.83 %	18

Analytics	
Mean	1.466
Standard Deviation	0.558
Standard Error	0.023
Variance	0.311

Chapter: Rail
How many days a week do you usually ride Metro Rail?

Total Respondents:	322
Total Skipped:	0

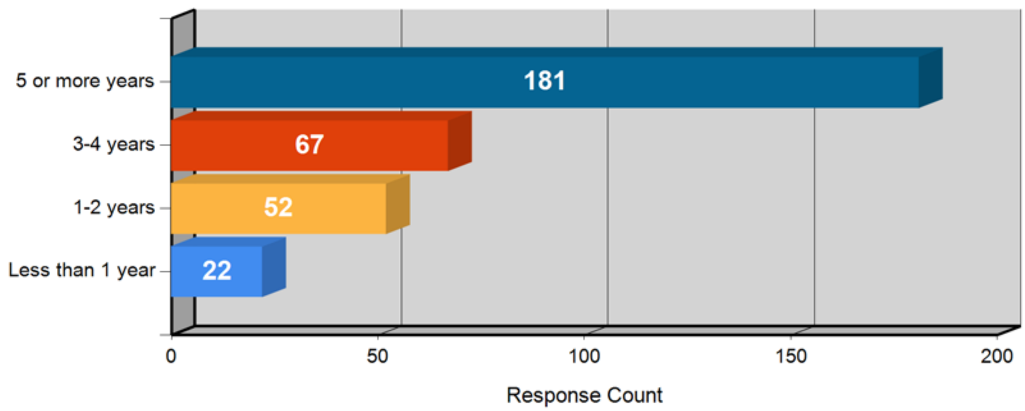


	Choice	Response Percent	Response Total
1	Less than 1 day	26.71 %	86
2	1-2 days	20.19 %	65
3	3-4 days	18.32 %	59
4	5 or more days	34.78 %	112

Analytics	
Mean	2.612
Standard Deviation	1.211
Standard Error	0.068
Variance	1.467
Top 2	46.89%
Bottom 2	53.11%

Chapter: Rail
How many years have you been riding Metro Rail?

Total Respondents:	322
Total Skipped:	0

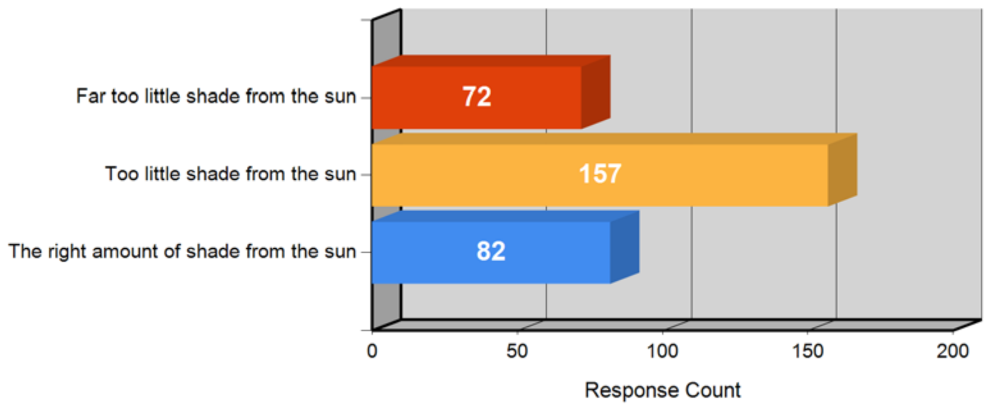


	Choice	Response Percent	Response Total
1	Less than 1 year	6.83 %	22
2	1-2 years	16.15 %	52
3	3-4 years	20.81 %	67
4	5 or more years	56.21 %	181

Analytics	
Mean	3.264
Standard Deviation	0.963
Standard Error	0.054
Variance	0.927
Top 2	22.98%
Bottom 2	77.02%

Chapter: Rail
Overall, do you think Metro above ground rail stations provide:

Total Respondents:	311
Total Skipped:	0

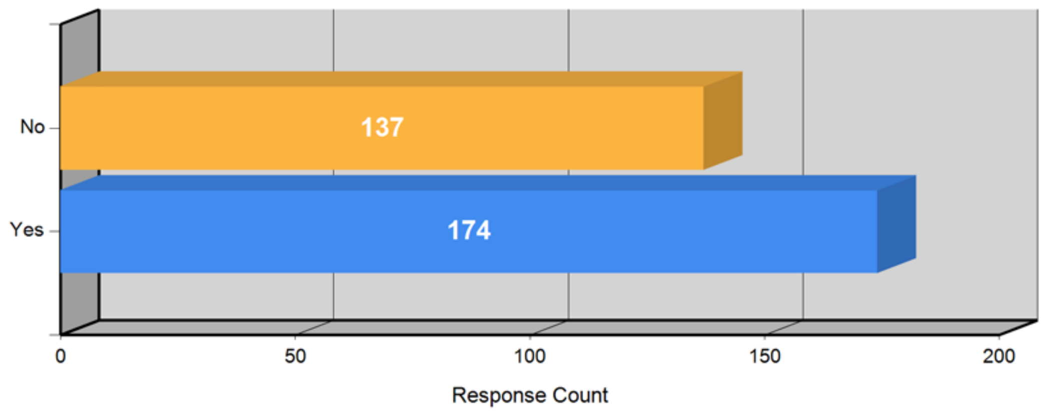


	Choice	Response Percent	Response Total
1	The right amount of shade from the sun	26.37 %	82
2	Too little shade from the sun	50.48 %	157
3	Far too little shade from the sun	23.15 %	72

Analytics	
Mean	1.968
Standard Deviation	0.703
Standard Error	0.040
Variance	0.494

Chapter: Rail
Have you ever experienced air conditioners out of order on Metro Rail?

Total Respondents:	311
Total Skipped:	0

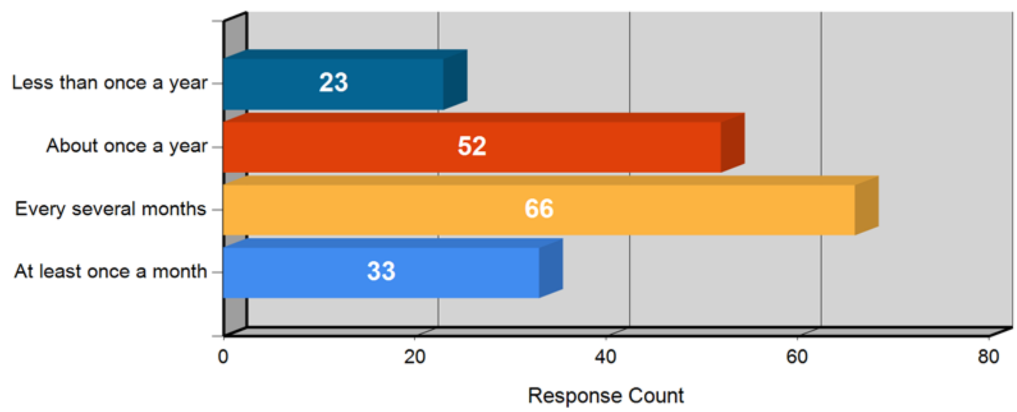


	Choice	Response Percent	Response Total
1	Yes	55.95 %	174
2	No	44.05 %	137

Analytics	
Mean	1.441
Standard Deviation	0.496
Standard Error	0.028
Variance	0.246

Chapter: Rail
About how often do you experience air conditioners being out on Metro Rail?

Total Respondents:	174
Total Skipped:	0

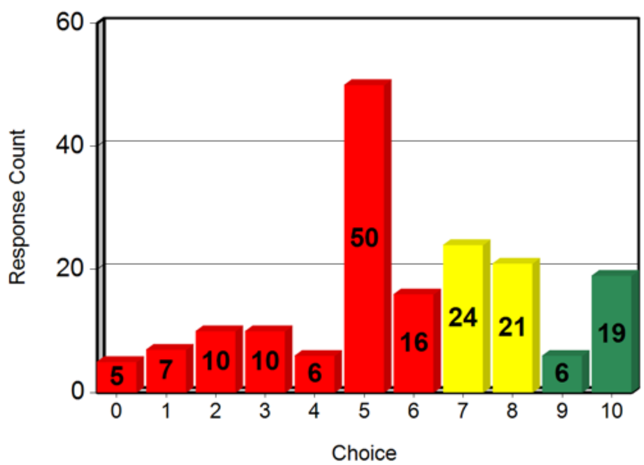


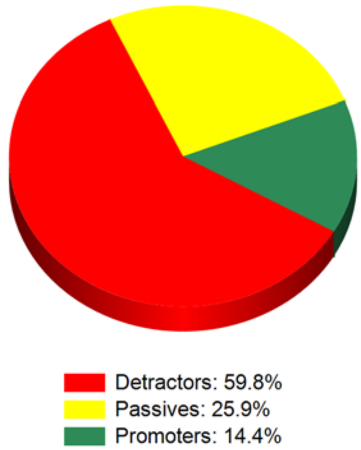
	Choice	Response Percent	Response Total
1	At least once a month	18.97 %	33
2	Every several months	37.93 %	66
3	About once a year	29.89 %	52
4	Less than once a year	13.22 %	23

Analytics	
Mean	2.374
Standard Deviation	0.937
Standard Error	0.071
Variance	0.878
Top 2	56.90%
Bottom 2	43.10%

Chapter: Rail
On a scale of 1-10, how much does this affect your experience using Metro?

Total Respondents:	174
Total Skipped:	199





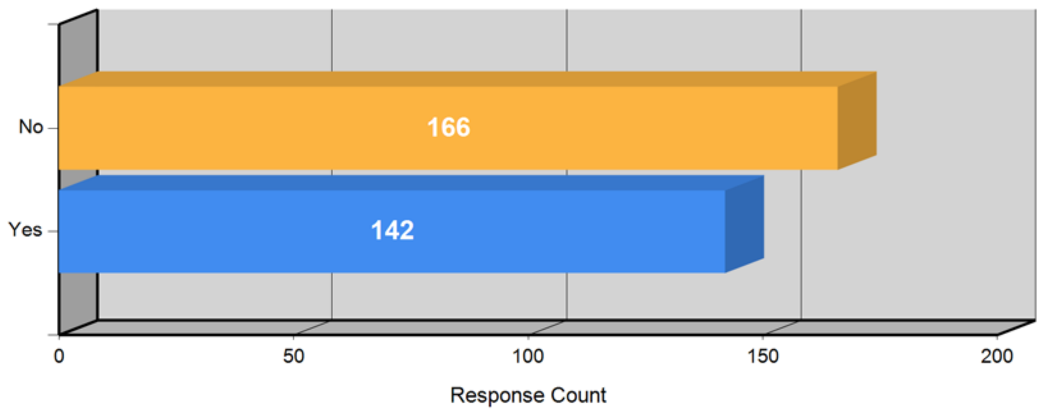
Choice	Response Percent	Response Total
0	2.87 %	5
1	4.02 %	7
2	5.75 %	10
3	5.75 %	10
4	3.45 %	6
5	28.74 %	50
6	9.20 %	16
7	13.79 %	24
8	12.07 %	21
9	3.45 %	6
10	10.92 %	19

Net Promoter Values	
Detractors (0 to 6)	104
Passives (7 and 8)	45
Promoters (9 and 10)	25
Net Promoter Score	-45.40 %

Analytics	
Mean	5.787
Standard Deviation	2.556
Standard Error	0.194
Variance	6.535

Chapter: Rail
Have you ever experienced Metro trains slowing down during heat waves?

Total Respondents:	308
Total Skipped:	0

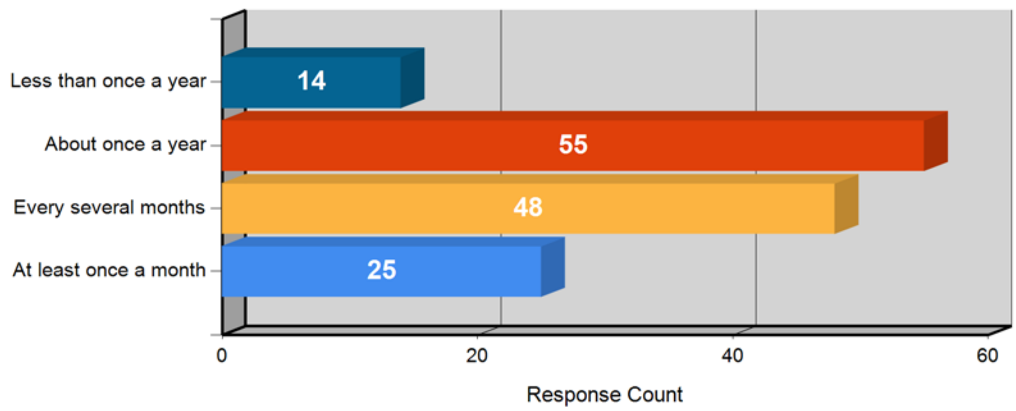


	Choice	Response Percent	Response Total
1	Yes	46.10 %	142
2	No	53.90 %	166

Analytics	
Mean	1.539
Standard Deviation	0.498
Standard Error	0.028
Variance	0.248

Chapter: Rail
About how often do you experience trains slowing down during heat waves?

Total Respondents:	142
Total Skipped:	0

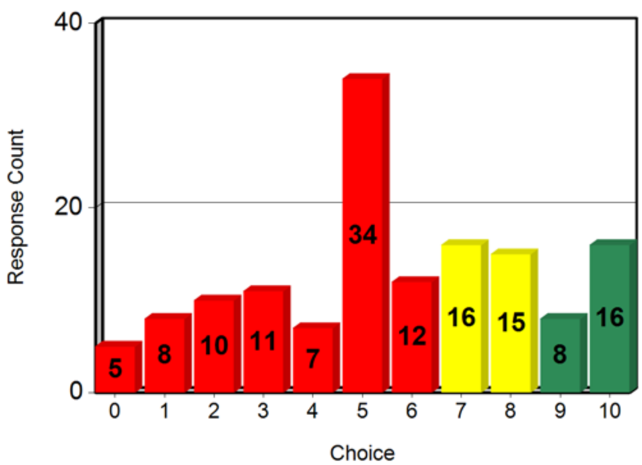


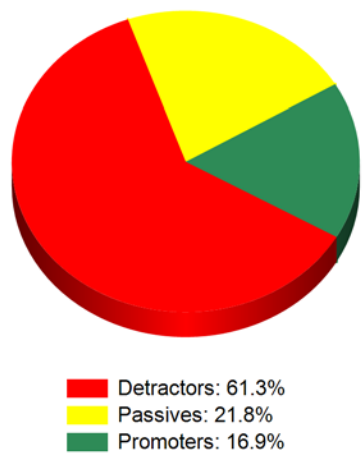
	Choice	Response Percent	Response Total
1	At least once a month	17.61 %	25
2	Every several months	33.80 %	48
3	About once a year	38.73 %	55
4	Less than once a year	9.86 %	14

Analytics	
Mean	2.408
Standard Deviation	0.889
Standard Error	0.075
Variance	0.791
Top 2	51.41%
Bottom 2	48.59%

Chapter: Rail
On a scale of 1-10, how much does this affect your experience using Metro?

Total Respondents:	142
Total Skipped:	231





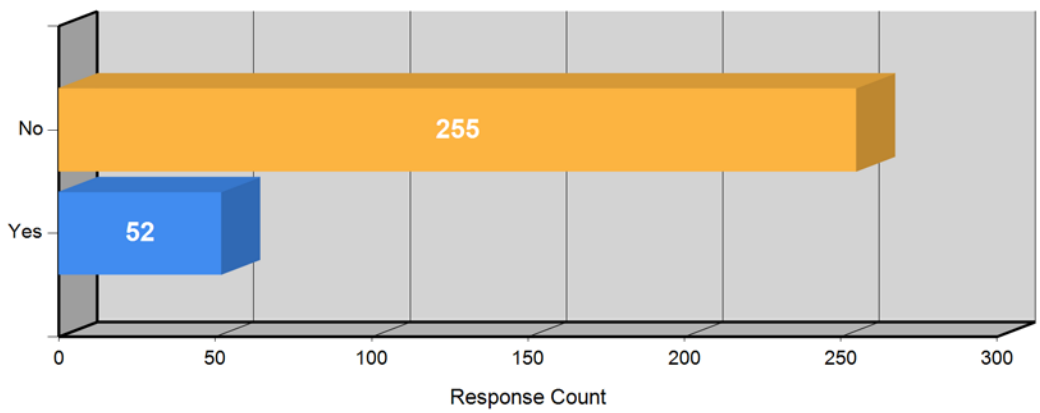
Choice	Response Percent	Response Total
0	3.52 %	5
1	5.63 %	8
2	7.04 %	10
3	7.75 %	11
4	4.93 %	7
5	23.94 %	34
6	8.45 %	12
7	11.27 %	16
8	10.56 %	15
9	5.63 %	8
10	11.27 %	16

Net Promoter Values	
Detractors (0 to 6)	87
Passives (7 and 8)	31
Promoters (9 and 10)	24
Net Promoter Score	-44.37 %

Analytics	
Mean	5.599
Standard Deviation	2.761
Standard Error	0.232
Variance	7.621

Chapter: Rail
Have you ever experienced Metro Rail service delays on windier than usual days?

Total Respondents:	307
Total Skipped:	0



	Choice	Response Percent	Response Total
1	Yes	16.94 %	52
2	No	83.06 %	255

Analytics	
Mean	1.831
Standard Deviation	0.375
Standard Error	0.021
Variance	0.141

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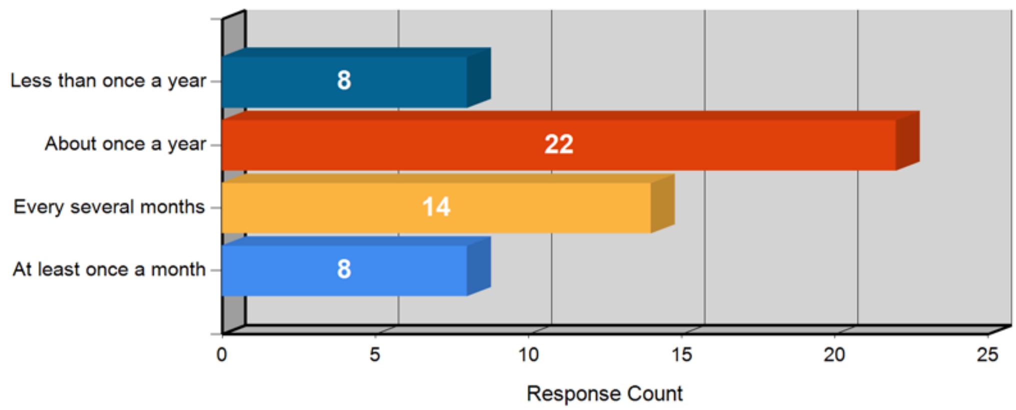
Chapter: Rail
About how often do you experience service delays due to high winds?

Total Respondents:	52
Total Skipped:	0



	Choice	Response Percent	Response Total
1	At least once a month	15.38 %	8
2	Every several months	26.92 %	14
3	About once a year	42.31 %	22
4	Less than once a year	15.38 %	8

Analytics	
Mean	2.577
Standard Deviation	0.927
Standard Error	0.129
Variance	0.859
Top 2	42.31%
Bottom 2	57.69%

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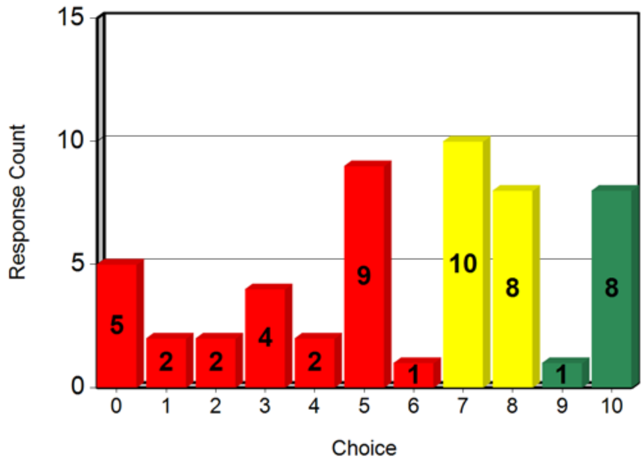
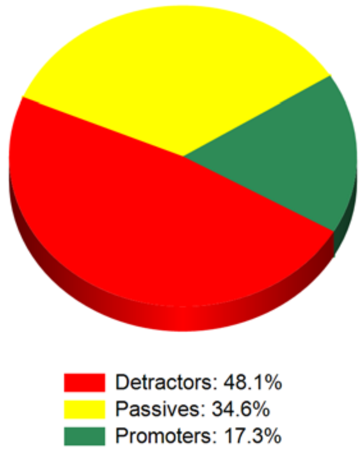
Chapter: Rail
On a scale of 1-10, how much does this affect your experience using Metro?

Total Respondents:	52
Total Skipped:	321





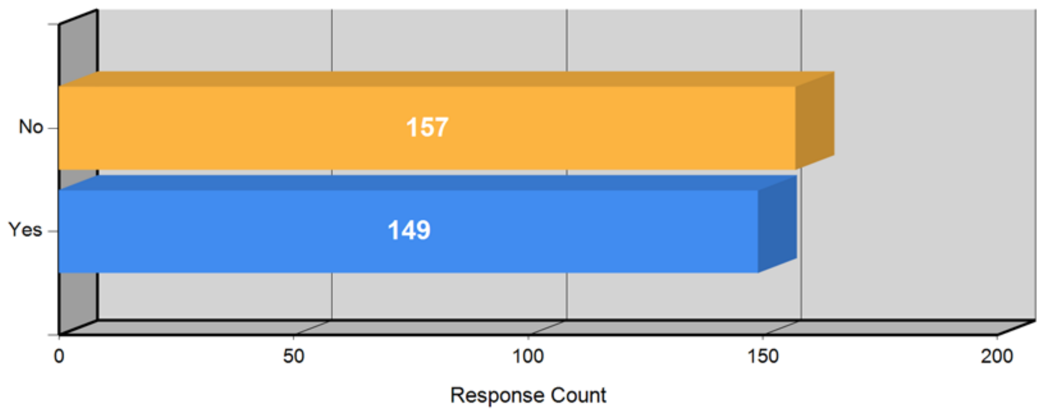
Choice	Response Percent	Response Total
0	9.62 %	5
1	3.85 %	2
2	3.85 %	2
3	7.69 %	4
4	3.85 %	2
5	17.31 %	9
6	1.92 %	1
7	19.23 %	10
8	15.38 %	8
9	1.92 %	1
10	15.38 %	8

Net Promoter Values	
Detractors (0 to 6)	25
Passives (7 and 8)	18
Promoters (9 and 10)	9
Net Promoter Score	-30.77 %

Analytics	
Mean	5.769
Standard Deviation	3.074
Standard Error	0.426
Variance	9.447

Chapter: Rail
Have you ever experienced Metro Rail service delays on days with heavy rain?

Total Respondents:	306
Total Skipped:	0



	Choice	Response Percent	Response Total
1	Yes	48.69 %	149
2	No	51.31 %	157

Analytics	
Mean	1.513
Standard Deviation	0.500
Standard Error	0.029
Variance	0.250

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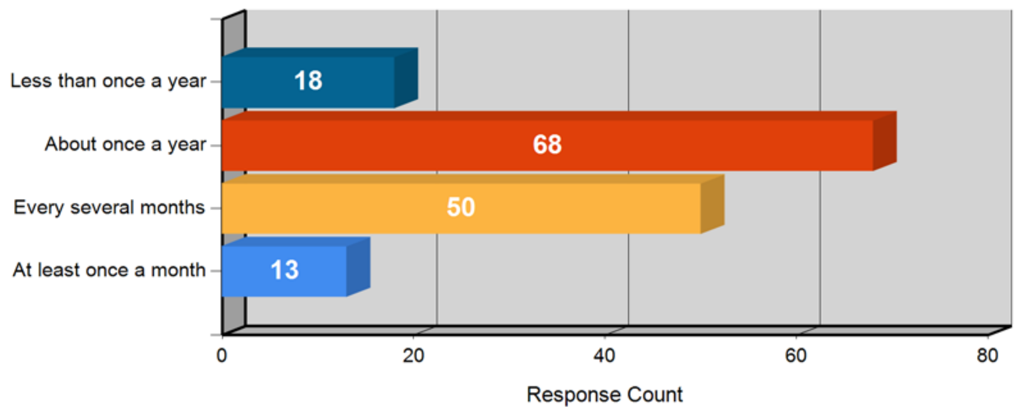
Chapter: Rail
About how often do you experience service delays due to heavy rain?

Total Respondents:	149
Total Skipped:	0

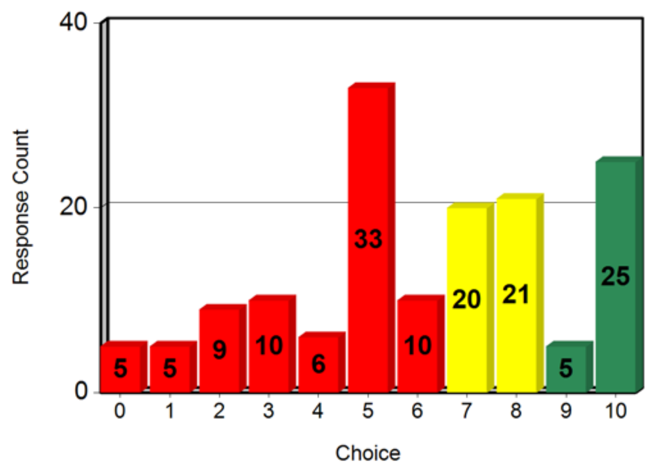


	Choice	Response Percent	Response Total
1	At least once a month	8.72 %	13
2	Every several months	33.56 %	50
3	About once a year	45.64 %	68
4	Less than once a year	12.08 %	18

Analytics	
Mean	2.611
Standard Deviation	0.809
Standard Error	0.066
Variance	0.654
Top 2	42.28%
Bottom 2	57.72%

Chapter: Rail
On a scale of 1-10, how much does this affect your experience using Metro?

Total Respondents:	149
Total Skipped:	224



Detractors: 52.3%
Passives: 27.5%
Promoters: 20.1%

Choice	Response Percent	Response Total
0	3.36 %	5
1	3.36 %	5
2	6.04 %	9
3	6.71 %	10
4	4.03 %	6
5	22.15 %	33
6	6.71 %	10
7	13.42 %	20
8	14.09 %	21
9	3.36 %	5
10	16.78 %	25

Net Promoter Values	
Detractors (0 to 6)	78
Passives (7 and 8)	41
Promoters (9 and 10)	30
Net Promoter Score	-32.21 %

Analytics	
Mean	6.074
Standard Deviation	2.771
Standard Error	0.227
Variance	7.679

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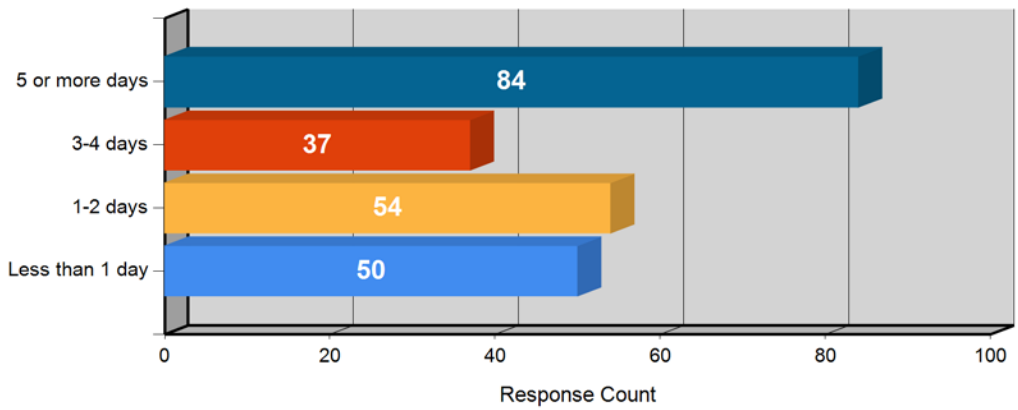
Chapter: bus
How many days a week do you usually ride a Metro Bus?

Total Respondents:	225
Total Skipped:	0

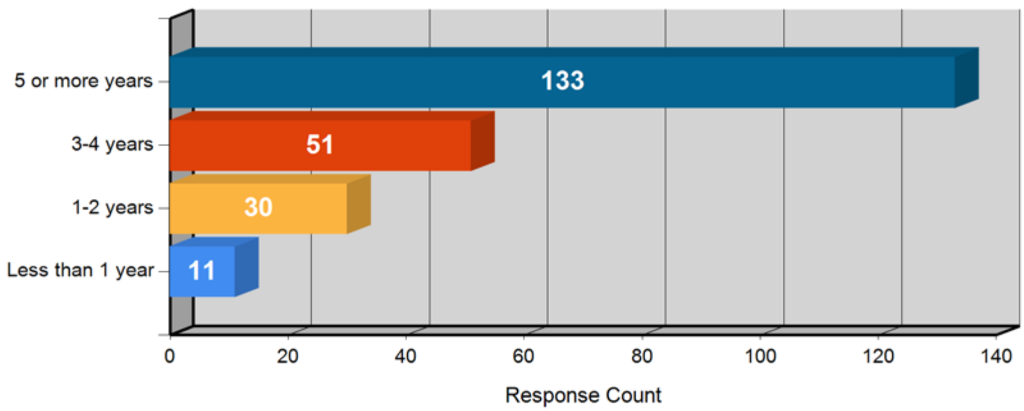


	Choice	Response Percent	Response Total
1	Less than 1 day	22.22 %	50
2	1-2 days	24.00 %	54
3	3-4 days	16.44 %	37
4	5 or more days	37.33 %	84

Analytics	
Mean	2.689
Standard Deviation	1.186
Standard Error	0.079
Variance	1.405
Top 2	46.22%
Bottom 2	53.78%

Chapter: bus
How many years have you been riding Metro Buses?

Total Respondents:	225
Total Skipped:	0

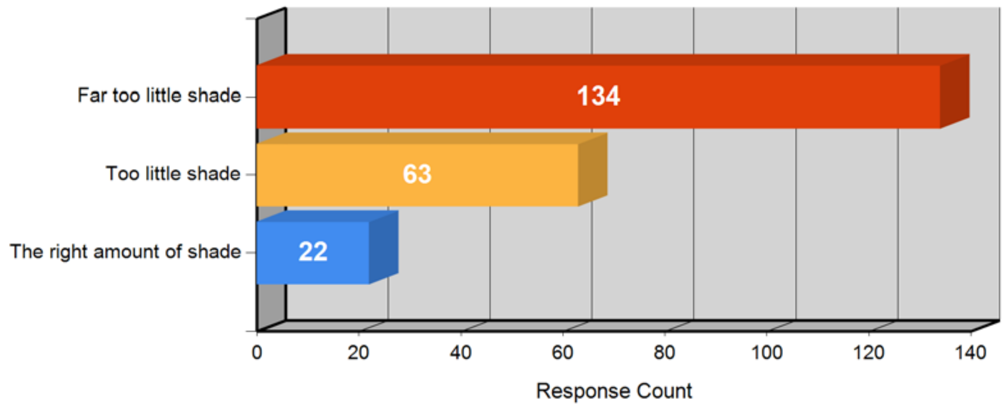


	Choice	Response Percent	Response Total
1	Less than 1 year	4.89 %	11
2	1-2 years	13.33 %	30
3	3-4 years	22.67 %	51
4	5 or more years	59.11 %	133

Analytics	
Mean	3.360
Standard Deviation	0.889
Standard Error	0.059
Variance	0.790
Top 2	18.22%
Bottom 2	81.78%

Chapter: bus
Overall, do you think Metro bus stops provide:

Total Respondents:	219
Total Skipped:	0



	Choice	Response Percent	Response Total
1	The right amount of shade	10.05 %	22
2	Too little shade	28.77 %	63
3	Far too little shade	61.19 %	134

Analytics	
Mean	2.511
Standard Deviation	0.671
Standard Error	0.045
Variance	0.451

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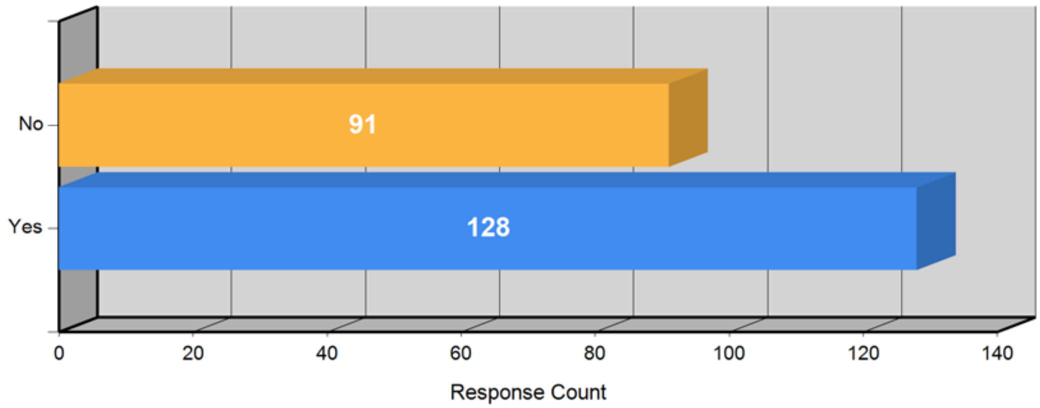
Chapter: bus
Have you ever experienced air conditioners out of order on any Metro bus lines?

Total Respondents:	219
Total Skipped:	0



	Choice	Response Percent	Response Total
1	Yes	58.45 %	128
2	No	41.55 %	91

Analytics	
Mean	1.416
Standard Deviation	0.493
Standard Error	0.033
Variance	0.243

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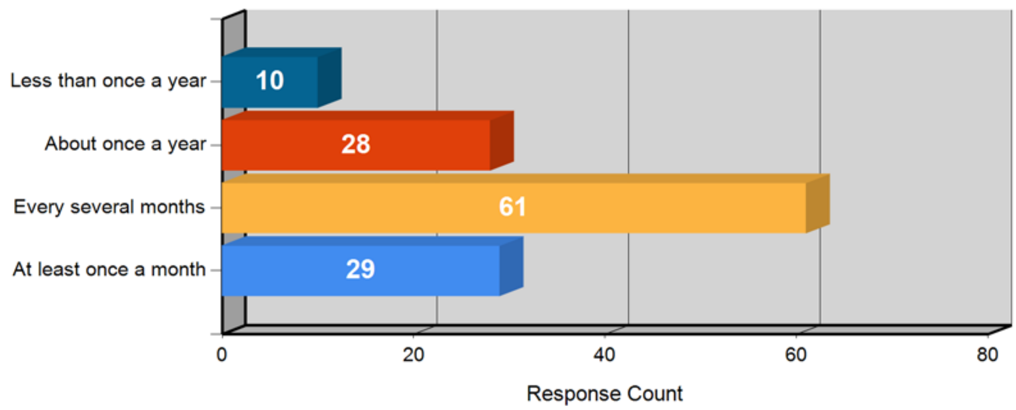
Chapter: bus
About how often do you experience air conditioners being out on Metro bus lines?

Total Respondents:	128
Total Skipped:	0

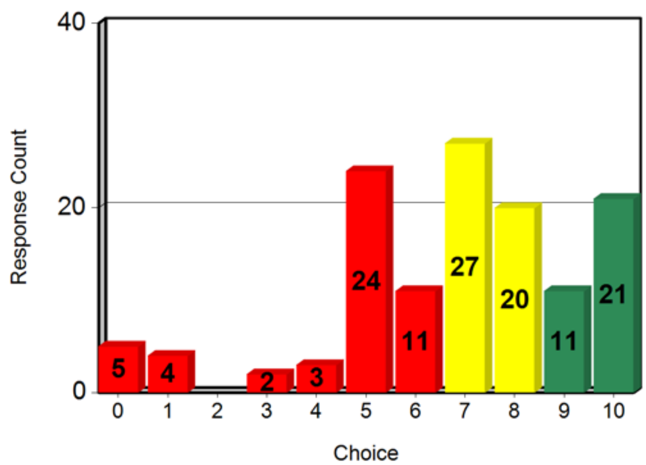


	Choice	Response Percent	Response Total
1	At least once a month	22.66 %	29
2	Every several months	47.66 %	61
3	About once a year	21.88 %	28
4	Less than once a year	7.81 %	10

Analytics	
Mean	2.148
Standard Deviation	0.858
Standard Error	0.076
Variance	0.736
Top 2	70.31%
Bottom 2	29.69%

Chapter: bus
On a scale of 1-10, how much does this affect your experience using Metro Buses?

Total Respondents:	128
Total Skipped:	245



Choice	Response Percent	Response Total
0	3.91 %	5
1	3.13 %	4
2	0.00 %	0
3	1.56 %	2
4	2.34 %	3
5	18.75 %	24
6	8.59 %	11
7	21.09 %	27
8	15.63 %	20
9	8.59 %	11
10	16.41 %	21

Net Promoter Values	
Detractors (0 to 6)	49
Passives (7 and 8)	47
Promoters (9 and 10)	32
Net Promoter Score	-13.28 %

Analytics	
Mean	6.766
Standard Deviation	2.502
Standard Error	0.221
Variance	6.258

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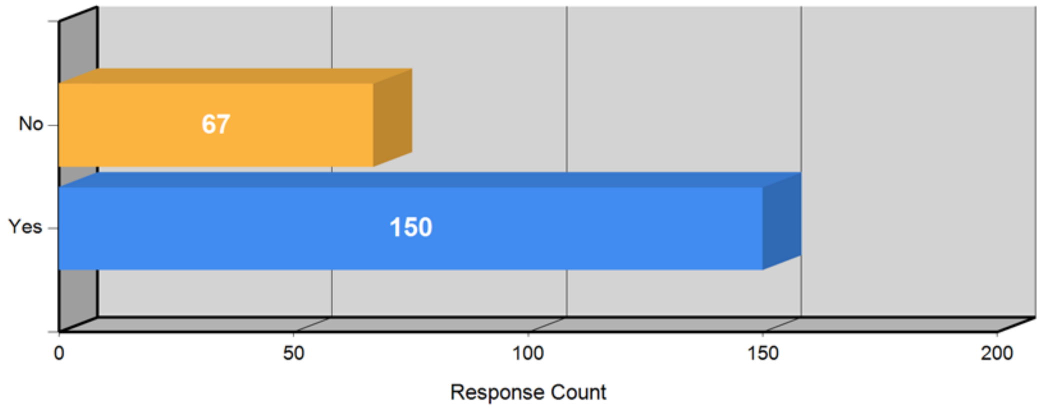
Chapter: bus
Have you ever experienced Metro bus service delays on days with heavy rain?

Total Respondents:	217
Total Skipped:	0



	Choice	Response Percent	Response Total
1	Yes	69.12 %	150
2	No	30.88 %	67

Analytics	
Mean	1.309
Standard Deviation	0.462
Standard Error	0.031
Variance	0.213

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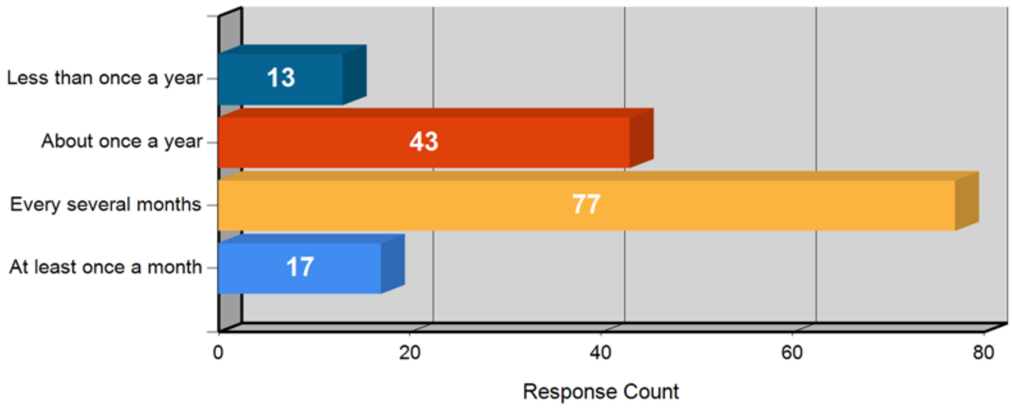
Chapter: bus
About how often do you experience service delays due to heavy rain?

Total Respondents:	150
Total Skipped:	0



	Choice	Response Percent	Response Total
1	At least once a month	11.33 %	17
2	Every several months	51.33 %	77
3	About once a year	28.67 %	43
4	Less than once a year	8.67 %	13

Analytics	
Mean	2.347
Standard Deviation	0.792
Standard Error	0.065
Variance	0.626
Top 2	62.67%
Bottom 2	37.33%

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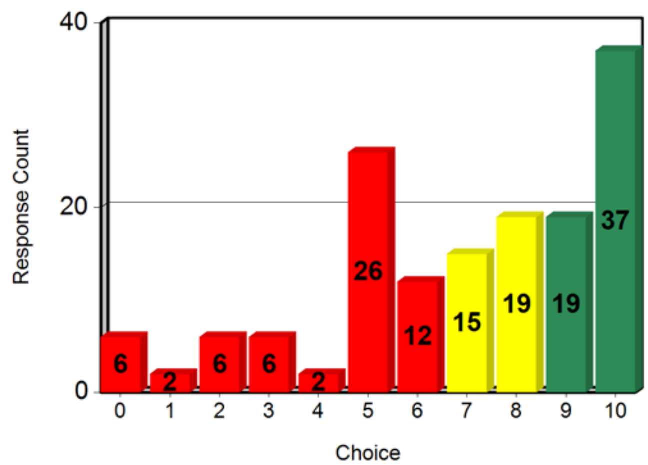
Chapter: bus
On a scale of 1-10, how much does this affect your experience using Metro?

Total Respondents:	150
Total Skipped:	223



Choice	Response Percent	Response Total
0	4.00 %	6
1	1.33 %	2
2	4.00 %	6
3	4.00 %	6
4	1.33 %	2
5	17.33 %	26
6	8.00 %	12
7	10.00 %	15
8	12.67 %	19
9	12.67 %	19
10	24.67 %	37

Net Promoter Values	
Detractors (0 to 6)	60
Passives (7 and 8)	34
Promoters (9 and 10)	56
Net Promoter Score	-2.67 %

Analytics	
Mean	6.933
Standard Deviation	2.797
Standard Error	0.228
Variance	7.822

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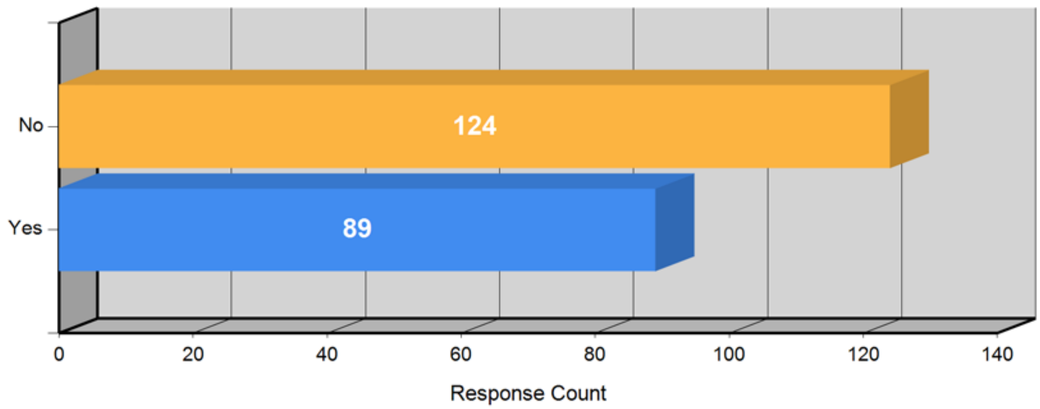
Chapter: final comments
In the past, have you received notice of delay due to a specific extreme weather event through our communications channels? (Twitter/The Source/Facebook/Go Metro app)

Total Respondents:	213
Total Skipped:	0

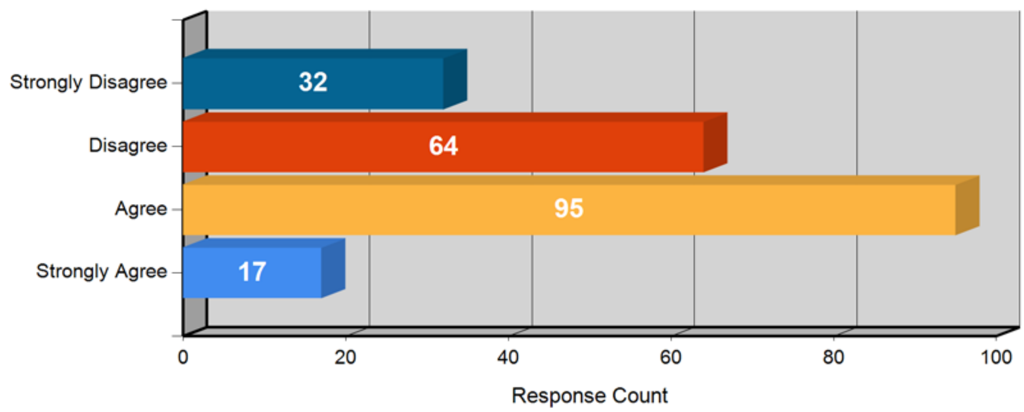


	Choice	Response Percent	Response Total
1	Yes	41.78 %	89
2	No	58.22 %	124

Analytics	
Mean	1.582
Standard Deviation	0.493
Standard Error	0.034
Variance	0.243

Chapter: final comments
How much do you agree with the following statement? "Metro provides timely and adequate notice of delay due to extreme weather events."

Total Respondents:	208
Total Skipped:	5



	Choice	Response Percent	Response Total
1	Strongly Agree	8.17 %	17
2	Agree	45.67 %	95
3	Disagree	30.77 %	64
4	Strongly Disagree	15.38 %	32

Analytics	
Mean	2.534
Standard Deviation	0.849
Standard Error	0.059
Variance	0.720
Top 2	53.85%
Bottom 2	46.15%

Metro
One Gateway Plaza
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