Caltrans Greenhouse Gas Emissions and Mitigation Report

Final Report

August 2020

Caltrans Greenhouse Gas Emissions and Mitigation Report

Final Report

August 2020

Prepared for:

Caltrans

Division of Transportation Planning

1120 N Street

Sacramento, CA 95814

Prepared by:

ICF

980 9th Street, Suite 1200

Sacramento, CA 95814

Under subcontract to WSP USA

Preface

This report was developed by a consultant team based on interviews with approximately 50 Caltrans staff and a review of a wide range of documents. The report is the final product of a consultant project with the following purpose: “document current Caltrans activities that reduce greenhouse gas (GHG) emissions and to identify future opportunities for further reducing GHG emissions.” This document is intended for informational purposes only. The assertions and recommendations contained in this report were developed by the consultant team and do not necessary reflect the views of all Caltrans staff involved in the development of this report.

Contents

List of Tables

List of Figures

Executive Summary

Motor vehicles are a major contributor to the greenhouse gas (GHG) emissions that are causing global climate change, with potentially catastrophic effects on California and the planet. California is already feeling the effects of climate change. Evidence is mounting that climate change has contributed to a variety of recent problems plaguing the state including drought, wildfires, pest invasions, heat waves, heavy rains, and mudslides. Projections show these effects will continue and worsen in the coming years, with major implications for our economy, environment, and quality of life.[1]

In response, the State of California and many local governments have adopted policies to reduce GHG emissions. Given the large contribution of the transportation sector to California's GHG emissions, Caltrans and other state transportation agencies have an important role to play in fostering solutions. Caltrans has influence over a large share of the state's GHG emissions – particularly emissions from persons and vehicles utilizing the State Highway System. As shown in Table 1, vehicles traveling on the State Highway System are responsible for roughly 89 million metric tons (MMT) of GHG emissions annually, equivalent to 21 percent of all California GHG emissions.

Caltrans also has influence over the materials and equipment used by its contractors. The activities associated with the materials and equipment used for Caltrans highway construction and maintenance projects account for roughly 2.5 MMT of GHG emissions per year, or 0.6 percent of statewide emissions.

The emissions from Caltrans internal operations include those produced by Caltrans vehicles and equipment, buildings, highway lighting, and other Caltrans facilities. These emission sources under Caltrans direct control produce roughly 120,000 metric tons of GHG emissions per year – not a trivial amount, but only 0.03 percent of California's total statewide inventory. GHG emissions under Caltrans direct control have declined 45 percent since 2010 due to a variety of factors including improved energy efficiency of buildings and roadway lighting, introduction of more fuel-efficient vehicles, and reductions in the carbon intensity of California's grid electricity and transportation fuels.

Table 1. Caltrans and California GHG Emissions

Source Category	MMT of CO_2-equivalent emissions per year
All California emissions (CARB 2017 inventory) [a]	424
Vehicle travel on the State Highway System (2017) [b]	89
Embodied emissions from Caltrans project materials (2017) [c]	2.5
Caltrans GHG Inventory (2017) [d]	0.12

Sources: a) CARB 2017 GHG inventory. b) On-road vehicle total from CARB 2017 GHG inventory; split of SHS vs. non-SHS travel based on VMT totals as described in Section 2. c) Material usage data from Caltrans 2017 Contract Cost Data; emission factors from literature as described in Section 2. d) Caltrans data submitted to The Climate Registry.

[1] California Air Resources Board, *California's 2017 Climate Change Scoping Plan*, November 2017.

Reducing Emissions from State Highway System Users

It is essential to address the emissions produced by vehicles traveling on the State Highway System if the state is to meet the GHG reduction goal established under AB 32, SB 32, and Executive Order S-3-05. The state's climate change policies recognize that most of the needed transportation sector GHG emission reductions will come from improved vehicle technologies and low carbon fuels, but also that vehicle miles of travel (VMT) reductions are necessary to achieve the targets. The State's Climate Change Scoping Plan identified that some of the necessary VMT reductions would result from the MPO-level GHG reduction actions to meet regional targets established under SB 375, but also that "there is a gap between what SB 375 can provide and what is needed to meet the State's 2030 and 2050 goals."[2] Moreover, recent data shows that statewide VMT and VMT per capita are growing, and that SB 375 is not producing the desired GHG reductions, as made clear in a recent California Air Resources Board (CARB) assessment.[3]

Historically, Caltrans focused its investments towards expanding the highway system to meet the demands of a growing population and economy and increased vehicle ownership and use. Today, expansion of the highway system has slowed, and the focus has shifted to managing the system effectively. This paradigm calls for evaluating new highway projects in terms of their ability to move people rather than vehicles, and to support a multimodal system that offers travel choices and better reliability. The shift in focus away from maximizing vehicle throughput is also reflected in the passage of SB 743, which calls for replacing vehicle delay and level of service as the mechanism for evaluating transportation impacts under the California Environmental Quality Act (CEQA).

Because it plans, builds, and operates most of the state's highway system, Caltrans has some unique opportunities to influence on-road vehicle travel in the state. These opportunities include the provision of multimodal transportation systems that provide viable alternatives to vehicle travel, roadway pricing and other approaches to manage demand, and avoiding new highway capacity additions that result in substantial induced vehicle travel, leading to higher VMT and GHG emissions. The phenomenon of induced vehicle travel is widely accepted and well documented[4,5], and it can often lead to an increase in VMT and GHG emissions when highway capacity is expanded, including through the addition of HOV and express lanes.

---

[2] *California's 2017 Climate Change Scoping Plan*, California Air Resources Board, November 2017.

[3] California Air Resources Board, *2018 Progress Report: California's Sustainable Communities and Climate Protection Act*, November 2018.

[4] Handy, Susan and Boarnet, Marlon, G., "Impact of Highway Capacity and Induced Travel on Passenger Vehicle Use and Greenhouse Gas Emissions," prepared for the California Air Resources Board, 2014. https://ww2.arb.ca.gov/sites/default/files/2020-06/Impact_of_Highway_Capacity_and_Induced_Travel_on_Passenger_Vehicle_Use_and_Greenhouse_Gas_Emissions_Policy_Brief.pdf

[5] Caltrans, Draft Transportation Analysis Framework: Induced Travel Analysis, March 2020. https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/sb-743/2020-04-13-taf-a11y.pdf

Reducing Emissions from Caltrans Internal Operations

In terms of the emissions from Caltrans internal operations, the Department has long been a leader in resource conservation and energy efficiency, and in recent years has implemented numerous strategies to further reduce GHG emissions from its internal operations. These actions include:

- Installation of more than 70 solar power photovoltaic (PV) energy systems at Caltrans buildings
- Purchase and use of more than 250 plug-in electric and fuel cell vehicles
- Reducing water consumption by more than 65 percent compared to 2013 baseline levels
- Converting more than 80 percent of overhead "cobra head" highway lights to light-emitting diode (LED) lights

Pavement strategies appear to offer the most promising opportunities for additional GHG reductions related to internal operations. Use of alternative materials and modifications to construction and maintenance practices can reduce emissions associated with asphalt and concrete pavements as well as structures. Because of the large volume of pavement and structural materials used by Caltrans and its contractors, even small changes in policy can result in significant GHG reductions for the state. However, decisions to promote specific pavement materials and methods in the name of GHG reduction must be supported by careful analysis that considers not only the materials, transport, and construction phases, but also any effects on vehicle fuel economy (pavement smoothness) and durability and lifetime of the pavement.

Some of the other promising opportunities for further reducing Caltrans internal operations emissions include:

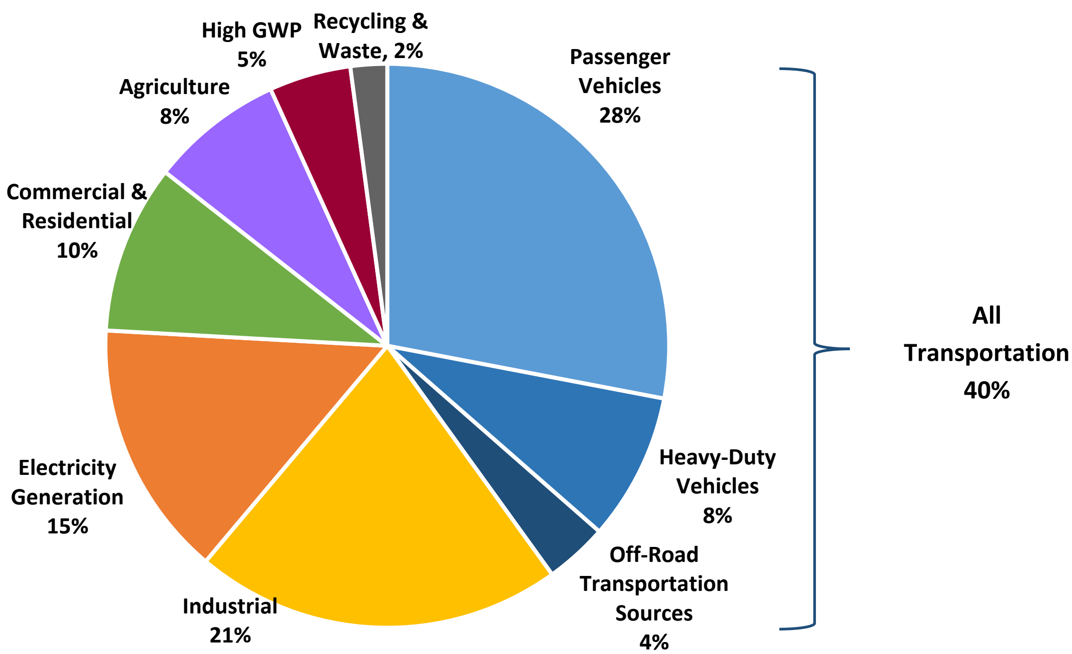
- Increasing renewable energy generation by installing solar power projects in the highway right-of-way
- Purchasing fuels with lower carbon intensities for Caltrans fleet, such as renewable natural gas
- Providing additional programs and incentives to increase transit use, ridesharing, and bicycling for Caltrans employee commuting

Changes to Caltrans' internal operations strategies will not reduce GHG impacts much compared to reducing highway system user emissions. However, they are important because they set an example for other agencies and can help to advance emerging technologies and practices.

1 Introduction

Transportation is a major contributor to greenhouse gas (GHG) emissions in California. In 2017, the transportation sector accounted for 40 percent of the state's total GHG emissions, as shown in Figure 1. On-road vehicles alone accounted for 36 percent of the state total. This reflects just the tailpipe emissions resulting from vehicle fuel combustion. The next largest contributors to the state's GHG emissions were the industrial sector (21 percent) and electricity generation (15 percent). Some emissions associated with transportation, such as refining and processing of fuels and production of asphalt and concrete, are included in these non-transportation sectors.

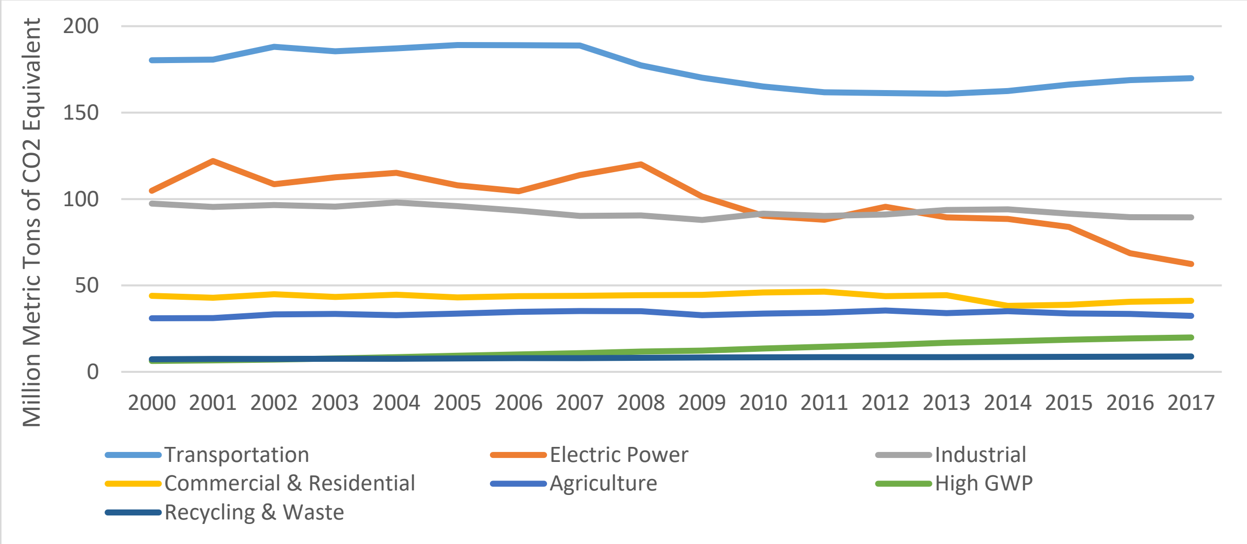
Figure 1. California GHG Emissions by Sector, 2017



Source: California Air Resource Board, California Greenhouse Gas Emission Inventory - 2019 Edition, Available at https://www.arb.ca.gov/cc/inventory/data/data.htm

Moreover, after declining over the period 2007-2013, transportation GHG emissions are increasing again, as shown in Figure 2. Transportation emissions increased 5.6 percent during the period 2013 – 2017. With the exception of high global warming potential (GWP) gases and recycling & waste, all other major economic sectors saw a decline in GHG emissions during this period.

Figure 2. California GHG Emissions by Sector, 2000-2017



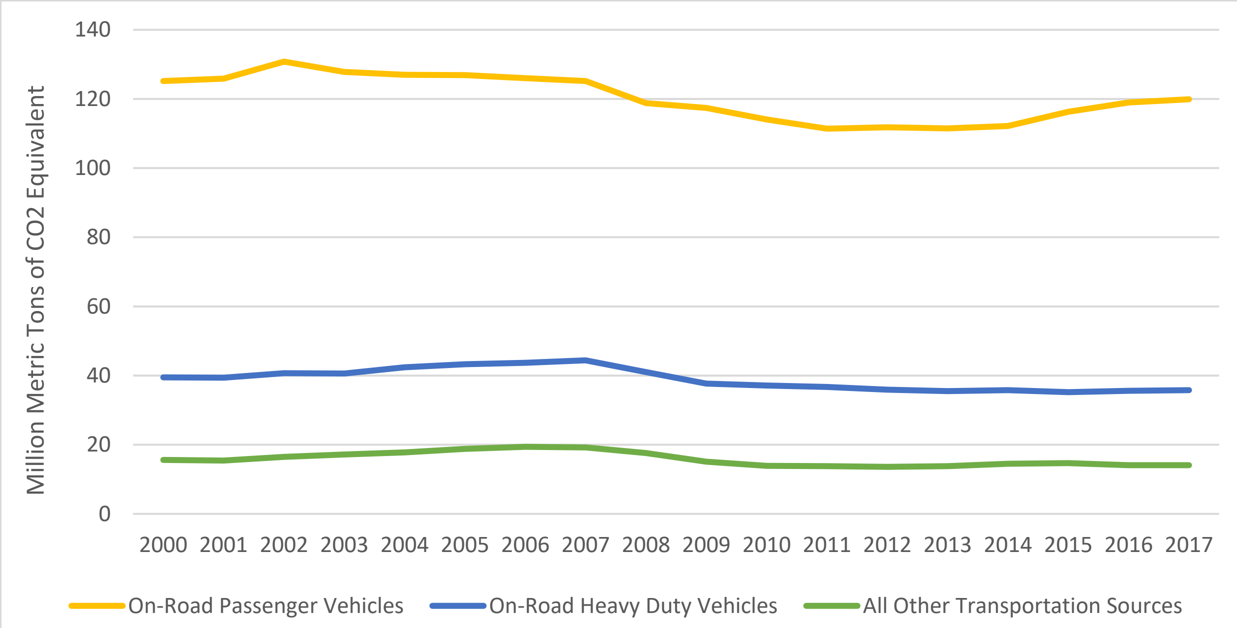
Source: California Air Resource Board, California Greenhouse Gas Emission Inventory - 2019 Edition, Available at https://www.arb.ca.gov/cc/inventory/data/data.htm

Within the transportation sector, about 70 percent of GHG emissions come from on-road passenger vehicles (i.e., light-duty vehicles). Another 21 percent comes from on-road heavy-duty vehicles (i.e., freight trucks and buses). The other sources of transportations emissions each account for a relatively small fraction of the state's GHG emission inventory. Note, however, that the state's GHG emission inventory includes only in-state movement of aircraft and marine vessels; ships and planes engaged in international transport of people and goods are not counted in the inventory.

The figure below shows that the recent growth in transportation GHG emissions has primarily occurred with passenger vehicles. Between 2013 and 2017, passenger vehicle GHG emissions increased nearly 8 percent, while GHG emissions from heavy-duty vehicles were essentially flat. These trends are the result of a number of different factors. Passenger vehicle travel has been increasing due to population growth and the state's robust economic activity. Between 2013 and 2017, this VMT growth outpaced the improvements in fuel efficiency of the vehicle fleet, leading to a rise in emissions. With heavy-duty vehicles, the percent of biodiesel and renewable diesel in the total diesel blend has grown rapidly in recent years, due in part to the implementation of the Low Carbon Fuel Standard. The increasing market penetration of biodiesel and renewable diesel was able to offset the increase in on-road heavy-duty truck activity and diesel use.[6]

[6] California Air Resources Board, California Greenhouse Gas Emissions for 2000 to 2016: Trends of Emissions and Other Indicators, Available at: www.arb.ca.gov/cc/inventory/pubs/reports/2000_2016/ghg_inventory_trends_00-16.pdf

Figure 3. California Transportation GHG Emissions, 2000-2017



Source: California Air Resource Board, California Greenhouse Gas Emission Inventory - 2019 Edition, Available at https://www.arb.ca.gov/cc/inventory/data/data.htm

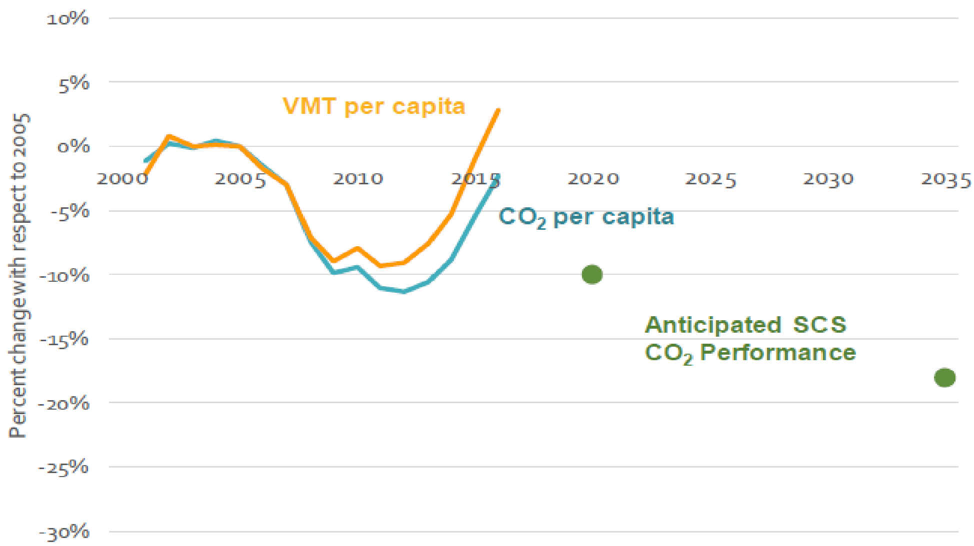
Looking ahead, it is expected that the state will continue to make considerable progress to curb transportation GHG emissions through improvements in fleet-average fuel economy and support for electric vehicle and other alternative fuels. But other developments related to transportation GHG emissions are potentially troubling. Although numerous models of electric vehicles (EVs) are now available, a variety of factors will likely limit their market penetration for some time. Trucks are a large contributor to GHG emissions, and the growth of e-commerce and trade is contributing to increasing heavy-duty vehicle VMT. Many promising technologies to reduce truck emissions are in development, but it may be years before these technologies are cost effective. In addition, while new and emerging technologies related to vehicles, fuels, and system management offer significant potential for reducing GHG emissions from transportation, some other new technologies and services could work against this trend. For instance, recent studies suggest that at least 40 percent of trips by transportation network companies (TNCs) are replacing transit, bicycle, and walk trips, thus generating additional VMT.[7] And autonomous vehicles are widely expected to create additional new vehicle trips and extend the length of trips.

The State's 2017 Climate Change Scoping Plan charts a course for meeting California's 2030 GHG reduction targets. The Scoping Plan recognizes that most of the GHG reductions in the transportation sector will come from vehicle technologies and low carbon fuels, but notes that VMT reductions also are

[7] Rodier, Caroline, "The Effects of Ride Hailing Services on Travel and Associated Greenhouse Gas Emissions," A White Paper from the National Center for Sustainable Transportation, April 2018. https://ncst.ucdavis.edu/wp-content/uploads/2016/07/NCST-TO-028-Rodier_Shared-Use-Mobility-White-Paper_APRIL-2018.pdf

necessary to achieve the 2030 target. Much of this VMT reduction was expected to occur as a result of the transportation and land use planning changes required by SB 375, the Sustainable Communities and Climate Protection Act of 2008. Yet a recent California Air Resources Board (CARB) assessment makes clear that the state "is not on track to meet greenhouse gas reductions expected under SB 375," as illustrated in the figure below.[8]

Figure 4. Statewide CO_2 and VMT Per Capita Trend with Respect to Anticipated Performance of Current SB 375 Sustainable Communities Strategies



Source: California Air Resources Board, 2018 Progress Report: California's Sustainable Communities and Climate Protection Act, November 2018.

Given the large contribution of the transportation sector to California's GHG emissions and the emerging opportunities and challenges associated with GHG emissions from motor vehicles, Caltrans has an important role to play in fostering solutions. Because it plans, builds, and operates most of the state's highway system, Caltrans has some unique opportunities to influence on-road vehicle travel in the state. These opportunities include the provision of multimodal transportation systems that provide viable alternatives to vehicle travel, roadway pricing and other approaches to manage demand, and minimizing highway capacity expansion projects that result in substantial induced vehicle travel and lead to higher VMT and GHG emissions. These efforts align well with broader Caltrans goals of safety, health, sustainability, and system performance.

In addition to influencing the users of the transportation system, Caltrans has numerous opportunities to reduce GHG emissions through its own internal operations and contractors' operations. The maintenance and operation of the State Highway System requires extensive resources such as paving materials, electricity for lighting, water for landscaping, and a large fleet of vehicles. There are proven options for making these resources more energy efficient and less carbon-intensive, many of which

[8] California Air Resources Board, *2018 Progress Report: California's Sustainable Communities and Climate Protection Act*, November 2018.

Caltrans has adopted. Changes to the materials used for roadway construction and maintenance appear to offer the most opportunity for internal operations GHG reduction.

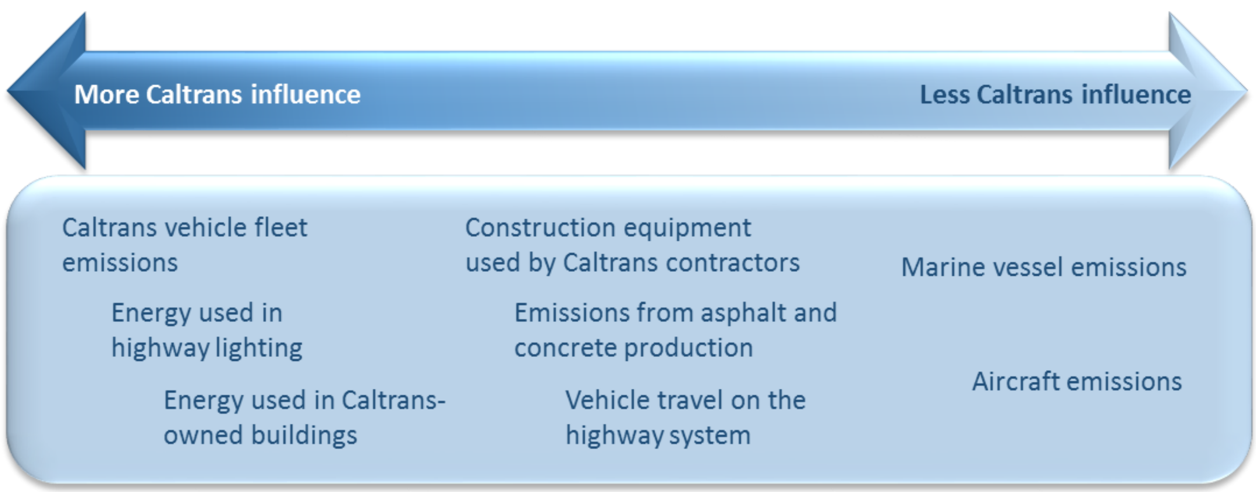
This report describes recent Caltrans actions that reduce GHG emissions, quantifies the magnitude of reductions where possible, and identifies opportunities for the Department to achieve greater emission reductions. Section 2 reviews the sources of emissions that Caltrans can control or influence. Section 3 focuses on reducing emissions from vehicles on the SHS. Section 4 focuses on reducing emissions from Caltrans internal operations. GHG reduction activities are described for the major functional units at Caltrans, which generally align with steps in transportation project delivery – planning, programming, environmental review, design, construction, maintenance, and operations. The identification of recent actions was done primarily through interviews with Caltrans staff and a review of Caltrans publications. Twelve group interviews were conducted at Caltrans Headquarters involving approximately 50 Caltrans staff, along with follow-up telephone interviews and email correspondence. GHG reductions were estimated by gathering data on Caltrans activities and applying standard quantification methods and emission factors.

The assessment of GHG reduction actions provides the foundation for an evaluation of the ways that Caltrans can better support State climate change goals. This report focuses on the GHG reduction strategies that would be most impactful, recognizing that a variety of barriers may currently prevent the implementation of these strategies, such as cost, technology readiness, lack of data for monitoring, staff familiarity, regulatory or policy prohibitions, and potential conflict with other Caltrans goals. The report discusses these barriers and ways to overcome them. The report provides a roadmap for Caltrans as it seeks to align its policies, procedures, plans, and investments so as to maximize the Department's contribution to State GHG reduction efforts.

2 Overview of GHG Emission Sources Influenced by Caltrans

To identify the best opportunities for Caltrans to contribute to California's GHG emission reduction goals and help to mitigate the impacts of climate change, it is important to understand the range of influence Caltrans has on sources of GHG emissions and the magnitude of those emissions sources. As illustrated in the figure below, Caltrans' influence over sources of GHG emissions reflects a continuum. Caltrans has strong influence over the fuel use and emissions from its vehicle fleet and its buildings, although these sources account for only a small fraction of total GHG emissions in California. Caltrans has varying degrees of influence, but less direct control, over a variety of other emission sources, some of which are quite large. These include the emissions from vehicles traveling on the State Highway System and the materials and equipment used by Caltrans contractors. Caltrans has little to no influence over some other sources of transportation emissions, such as marine vessels and aircraft.

Figure 5. Illustration of Range of Influence Caltrans Has on Sources of GHG Emissions



The rest of this section discusses the major sources of emissions that Caltrans can influence.

2.1 Roadway System User Emissions

Because of its role in planning, designing, and operating the State Highway System, Caltrans can influence emissions from vehicles driving on the state's roadways – one of the largest sources of GHG emissions in the state. Fundamentally, travel occurs because of the desire of individuals to reach destinations – for employment, schooling, shopping, recreation, etc. The choice of where, when, and how to travel is based on numerous factors that vary for each individual. When the choice involves traveling by motor vehicle using gasoline or diesel fuel, the result is GHG emissions from fuel combustion. Similarly, businesses make decisions to use the transportation system for the movement of supplies and finished products, which results in GHG emissions.

CARB's statewide GHG inventory shows that on-road vehicles produced 156 million metric tons of CO_2-equivalent emissions in 2017, 37 percent of the state's total emissions. Some of these emissions occur on the State Highway System (SHS) that is owned and operated by Caltrans, and some emissions occur on other roadways.

According to Caltrans, travel on the State Highway System resulted in 195 billion VMT in 2016.[9] For the same period, FHWA estimates 340 billion VMT on the state's entire roadway network.[10] Thus, State Highway System VMT represents about 57 percent of all VMT in California. As a rough order-of-magnitude estimate, applying this ratio to the statewide on-road transportation GHG inventory suggests that State Highway System travel results in 89 million metric tons of directly emitted CO_2-equivalent emissions.

Caltrans influences travel on the SHS through its activities related to planning, programming, design, and highway operations. For example, projects that change the capacity of highways can affect near-term decisions about travel mode as well as longer term land development decisions that can generate or redistribute automobile and truck trips. Investments in bicycle or transit system improvements can encourage travel by non-automobile modes. Activities that change traffic operations can affect roadway congestion levels and the associated vehicle emission rates, as well as decisions about the mode and time-of-day of travel. Section 3 discuses opportunities for Caltrans and partner agencies to reduce highway system user emissions.

Caltrans activities also influence travel on facilities beyond the SHS. Although Caltrans does not own or operate local roadways, personal and business travel decisions are based on the performance of and accessibility offered by the entire transportation system, of which the SHS is a major component. For example, in a built-out urbanized area, projects that improve highway system performance will affect travel on local roadways that are used to access the highway system. On the perimeter of an urbanized area, construction of a new SHS interchange could improve access to the surrounding land, which can spur new development and influence travel to and from the development, even if the travelers do not use the SHS. In addition, Caltrans Local Development-Intergovernmental Review (LD-IGR) program advises other agencies regarding land use and infrastructure plans and projects that may impact the SHS.

2.2 Lifecycle GHG Emissions from Materials and Fuels

In addition to travel by roadway system users, Caltrans can influence emissions associated with the materials and fuels used in highway construction, maintenance, and operation. To describe these emissions requires understanding the concept of a life-cycle assessment (LCA). LCA is an environmental assessment used to determine impacts throughout a product or process's entire lifetime. This holistic approach is often referred to as assessing materials use from "cradle" (e.g., raw materials extraction and

[9] Caltrans. 2018. Historical Monthly Vehicle Miles of Travel.
[10] U.S. Department of Transportation, FHWA. Highway Statistics 2016, 2018. www.fhwa.dot.gov/policyinformation/statistics/2016/

refining) to "grave" (i.e., recycling, reuse, or disposal). Traditionally, an environmental assessment would only incorporate impacts directly related to a product or process's use-phase, such as fuel combusted in operations. LCA ensures that researchers can capture all relevant impacts in associated supply chains both upstream and downstream of use.[11]

LCA is a valuable method for identifying sources of GHG emissions throughout Caltrans asset design and material procurement activities. The large volumes of materials used in construction and maintenance activities can have significant climate change impacts in production, supply, and disposal. Some of the materials used most extensively on highway projects include concrete, asphalt, aggregates, and steel. These materials all have unique supply chain characteristics, but have similar general steps in production and supply. Table 2 summarizes the general life-cycle stages and how each stage relates to common transportation infrastructure materials. When applying LCA, researchers can quantify the associated GHG emissions from energy or material requirements at each life-cycle stage to generate a complete picture of how emissions accumulate throughout a material's lifetime.

Table 2. Typical life-cycle assessment stages for highway materials

	Raw Materials Extraction	Production and Manufacturing	Construction and maintenance	Highway Use	End-of-Life
Concrete	Limestone quarrying	Cement, aggregates, pyroprocessing, batching	Highway construction, maintenance	Vehicle operations by highway users [a]	Material disposal, recycling
Steel	Ore mining	Secondary/primary steel production			
Asphalt	Bitumen extraction and refining	Bitumen feedstock production			
Aggregates	Limestone quarrying	Crushing, sorting			

Note a: Materials influence the fuel economy of vehicles traveling on the highway system. For example, pavement smoothness affects rolling resistance and therefore fuel combustion.

Large volumes of materials are used on Caltrans projects in any given year, offering potential for significant GHG reduction. For example, in 2017 Caltrans projects used more than 1 million cubic yards of concrete, which involved approximately 325,000 tons of Portland cement, a highly GHG-intensive material. Similarly, Caltrans projects used more than 4 million tons of hot mix asphalt and 1 million cubic yard of aggregate in 2017.

[11] U.S. EPA. 2006. Life Cycle Assessment: Principles and Practice. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi/P1000L86.PDF?Dockey=P1000L86.PDF

Developing a LCA-based estimate of the GHG emissions associated with all materials used in Caltrans projects would require an extensive effort and has not been conducted to date. However, a rough order-of-magnitude estimate can focus on the four materials that likely make up the vast majority of roadway construction materials: asphalt, concrete, aggregate, and steel. The amount of these materials used on Caltrans projects can be obtained from the annual Caltrans *Contract Cost Data* report. Recent literature provides lifecycle GHG factors for these materials for the raw materials extraction, materials processing, material transport, and construction phases.[12] This approach suggests that Caltrans highway projects are responsible for roughly 2.5 million metric tons per year of GHG emissions during these extraction, processing, transport, and construction phases – sometimes termed the "embodied" emissions in these materials.

Like the materials used in highway projects as described above, motor vehicle fuels also involve lifecycle impacts beyond the emissions released from the vehicle tailpipe during the use phase. For example, gasoline and diesel fuel require the extraction and transport of petroleum, refining processes, and distribution to retail fuel stations – all of which contribute to GHG emissions. Biofuels create emissions due to the harvesting of feedstocks (e.g., corn or soy), processing, and fuel distribution. Battery electric vehicles produce no tailpipe emissions but require generation of electricity, which typically produces GHG emissions. Estimating the GHG impacts of using alternative fuels requires a life-cycle perspective that considers both tailpipe and "upstream" emissions.

Based on carbon intensity values used by CARB for the Low Carbon Fuel Standard (LCFS) program, the upstream emissions from gasoline and diesel fuel used in California account for about 27 percent of the total lifecycle emissions associated with these fuels. Thus, vehicles operating on the SHS are associated with roughly 32 million metric tons of upstream GHG emissions in addition to the 89 million metric tons of directly emitted tailpipe emissions. These upstream emissions are generally captured under the "Industrial" sector for the purpose of developing a GHG inventory. Note that some of these fuel upstream emissions occur outside California and therefore are outside the boundaries of CARB's statewide GHG inventory summarized in Figures 1 and 2.

2.3 Emissions from Caltrans Internal Operations

The emissions associated with Caltrans internal operations are included in the annual emission inventory that Caltrans prepares and submits to The Climate Registry. In doing so, Caltrans follows standard conventions for defining the organizational and operational boundaries that establish the framework the GHG emission inventory. These conventions recognize the following three types of emissions:

- **Scope 1** emissions include direct emissions from operations, facilities, and sources under Caltrans' operational control. Scope 1 emissions result from activities such as on-site combustion of fossil fuels to generate electricity or heat, use of fleet vehicles, and fugitive GHG emissions from Caltrans-owned refrigeration and air-conditioning equipment.

[12] Lawrence Berkeley National Laboratory, *Life-Cycle Assessment and Co-Benefits of Cool Pavements*, Prepared for the California Air Resources Board and the California Environmental Protection Agency, April 2017.

- **Scope 2** includes indirect emissions from purchased electricity, steam, and chilled water that are consumed within the organizational boundaries of Caltrans. Caltrans can directly control the purchase of electricity but not the process used to generate electricity that results in GHG emissions.
- **Scope 3** includes all indirect emissions that are not included in Scope 2. Similar to Scope 2, Scope 3 emissions are indirect emissions that are a consequence of the Caltrans activities, but the actual emissions are generated by sources not controlled by Caltrans. There are many Scope 3 emission sources. Scope 3 emission sources are typically more difficult to estimate and may be more challenging to reduce due to the lack of direct control over the emission source, but they are often significantly larger than Scope 1 or 2 emission sources and thus provide greater emission reduction potential. Examples of Scope 3 emission sources could include employee commute activity, employee business travel, materials and equipment used by Caltrans contractors, and vehicle travel on the State Highway System.

Like most DOTs and other government organizations, Caltrans includes only Scope 1 and Scope 2 emissions in its submission to The Climate Registry. Also, like most organizations, Caltrans elects to omit small sources of emissions because it is too costly or resource-intensive to gather the necessary data. Some GHG guidance documents, such as the World Resources Institute's *GHG Protocol: Corporate Accounting and Reporting Standard*, define a *de minimis* threshold that allows organizations to exclude small emission sources that together account for no more than 5 percent of their total operational emissions.[13]

Table 3 shows Caltrans' reported GHG inventory for three recent years and 2010. Emissions from all source categories have dropped substantially, with total emissions declining 45 percent since 2010. These reductions are due to a variety of factors including improved energy efficiency of buildings and roadway lighting, introduction of more fuel efficient vehicles, and reductions in the carbon intensity of California's grid electricity and transportation fuels. Caltrans use of renewable diesel in particular has contributed to a decline in vehicle emissions.

Table 3. Caltrans GHG Emission Inventory, metric tons CO_2e

Source Type	2010	2015	2016	2017	Change, 2010-17
Natural Gas	7,585	5,003	5,140	5,000	-34%
Vehicles	118,042	110,998	82,474	76,725	-35%
Purchased Electricity	89,356	48,172	40,829	36,957	-59%
Total Emissions	**214,983**	**164,173**	**128,443**	**118,682**	**-45%**

Source: The Climate Registry

Table 3 excludes some Scope 3 emissions sources that are sometimes included in an organization's emission inventory, such as business travel, employee commuting, contracted solid waste, and

[13] Available at: https://ghgprotocol.org/corporate-standard

contracted wastewater treatment. Some of these sources can be as large as or larger than the Scope 1 and Scope 2 emissions included in Caltrans GHG inventory. For example, commuting by Caltrans employees produces roughly 50,000 metric tons of GHG emissions per year, more than purchased electricity emissions (see below for emissions estimates and sources). Including employee commute emissions in future Caltrans GHG inventories would help to focus attention on opportunities to reduce this source of emissions.

2.4 Summary of Emissions Sources and Caltrans' Influence

Table 4 lists major sources of emissions that Caltrans can influence, and a rough order-of-magnitude estimate of the size of these emission sources. Emission sources under Caltrans direct control or strong influence total roughly 120,000 metric tons of GHG emissions per year – not a trivial amount, but only about 0.03 percent of California's total statewide GHG emission inventory. Caltrans has some influence over much larger sources of emissions – particularly direct emissions from travel on the State Highway System (89 million metric tons[MMT]) and local roads (67 MMT), upstream emissions from State Highway System travel (32 MMT), and embodied emissions in materials used in highway construction and maintenance (2.5 MMT).

Table 4. Summary of Emissions Sources and Caltrans' Influence

Emissions Source Category	Emissions Source	Caltrans Influence: More		Caltrans Influence: Less	Rough order of magnitude annual GHG emissions (thousand metric tons CO2e)	Source	
Direct emissions from California transportation sources	On-road vehicles in Caltrans fleet	●			64	a	
	On-road vehicles used in Caltrans projects		●		N/A		
	On-road vehicles for Caltrans employee commuting		●		53	b	
	Off-road equipment in Caltrans fleet	●			13	a	
	Off-road equipment used in Caltrans projects		●		N/A		
	All on-road vehicles operating on SHS		●		89,000	c	CARB Total Transportation Sector GHG Inventory
	All on-road vehicles operating on local roads		●		67,000	c	
	All off-road equipment operating in CA			●	2,700	d	
	Rail locomotives operating in CA			●	1,800	d	
	Marine vessels operating in CA			●	3,300	d	
	Aircraft operating in CA			●	4,700	d	
	Unspecified transportation sources			●	1,500	d	
Upstream emissions from on-road vehicle fuels used on SHS	Mining/extraction of feedstocks		●		32,000	e	
	Processing/refining of fuels		●				
	Electricity generation (for EVs)		●				
	Distribution of fuels		●				
Caltrans building energy emissions	Electricity used in Caltrans buildings	●			20	f	
	Natural gas used in Caltrans buildings	●			5	f	
	Electricity for pumping water to Caltrans buildings	●			<1	g	
CA highway operations energy emissions	Electricity for roadway lighting	●			17	f	
	Electricity for pumping irrigation water	●			10	h	
Embodied emissions from materials used in Caltrans projects	Mining and extraction		●		2,500	i	
	Production processes		●				
	Transport of materials		●				

Sources for GHG emissions estimates:

a. Vehicle total from Caltrans data submitted to The Climate Registry. Split of on-road vs. off-road calculated by ICF based on Caltrans fleet 2016 annual mileage and fuel use data.

b. ICF estimate using assumptions for average commute length and vehicle fuel economy. Number of Caltrans employees commuting by non-auto modes based on data provided by Districts.

c. On-road vehicle total from CARB 2017 GHG inventory. Split of SHS vs. non-SHS travel based on VMT totals as described in text.

d. CARB 2017 GHG inventory.

e. ICF estimate. On-road vehicle tank-to-wheel (TTW) total for SHS based on CARB 2017 GHG inventory, with split of SHS vs. non-SHS travel based on VMT totals as described in text. Well-to-wheel carbon intensities from CARB Low Carbon Fuel Standard values: CARBOB tailpipe 73.94 g/MJ, CARBOB WTW 100.58 g/MJ, Diesel tailpipe 74.86 g/MJ, Diesel WTW 102.82 g/MJ.

f. Caltrans data submitted to The Climate Registry. Caltrans Fact Booklet, June 2017.

g. ICF estimate based on data originally collected for *Caltrans Activities to Address Climate Change*, 2013, with updates.

h. ICF estimate using annual water consumption provided by Caltrans. Assumes energy intensity of water as an average of 5.4 kWh/1000 gal (Northern California) and 13.0 kWh/1000 gal (Southern California).

i. Annual material usage data for steel, concrete, asphalt, and aggregate from Caltrans, 2017 Contract Cost Data: A Summary of Cost by Items for Highway Construction Projects. Lifecycle GHG emission factors from CARB, Life-Cycle Assessment and Co-Benefits of Cool Pavements, Prepared by Lawrence Berkeley National Laboratory, Contract # 12-314, April 2017.

3 Reducing Emissions from California Highway System Users

Caltrans can influence the emissions from highway system users through its involvement in planning, programming, environmental analysis, design, and operation of the highway system. As discussed in Chapter 2, use of the State Highway System is by far the largest source of emissions that Caltrans can influence. On-road vehicles in California emit approximately 156 million metric tons of GHG emissions annually, and roughly 57 percent of those emissions occur on the State Highway System owned and operated by Caltrans. These emissions dwarf the emissions that result directly from Caltrans internal operations. Given the sheer magnitude of highway system user GHG emissions, it is critical that Caltrans carefully assess all of its opportunities to reduce this emissions source while enabling the movement of people and goods, and prioritize the implementation of strategies that are most effective.

There are three general approaches for Caltrans to reduce GHG emissions on the State Highway System:

- Limit demand for travel by single-occupant vehicles (SOVs), primarily by minimizing induced vehicle travel and through the use of pricing
- Improve facilities that provide alternatives to travel by carbon-intensive modes, particularly SOVs
- Maximize the operating efficiency of vehicles traveling on the State Highway System

Section 3.1 discusses the best opportunities for Caltrans to reduce highway system user emissions. Section 3.2 describes the numerous related on-going activities at Caltrans that support highway user GHG reductions but are unlikely to have major GHG impacts.

3.1 Best Opportunities for Reducing Highway System User Emissions

Caltrans' best opportunities to reduce highway system user emissions would be to focus on revising current planning, programming, and project development procedures to minimize induced vehicle travel, promote greater use of roadway pricing, and facilitate the multimodal system improvements that shift travelers away from automobiles.

Minimize Induced Vehicle Travel

Caltrans, in partnership with local governments and transportation agencies, has a strong influence on the performance of the highway network, which in turn can influence the demand for SOV travel. As a general rule, SOV drivers will shift to an alternative mode only if the alternative is equal to or better than SOV travel in terms of factors such as convenience, travel time, reliability, perceived safety, and cost. Every individual makes travel choices based on these and other decision factors, with variation in the relative importance of each factor. However, even if multimodal options such as transit, rideshare, bicycling, and walking are developed and improved, they are unlikely to attract significant use so long as SOV travel remains faster and cheaper. This explains why more than three quarters of all trips in California are still taken by motorized vehicles.

Highway Capacity Expansion and Induced Vehicle Travel

As population and VMT grow, the roadway network becomes more congested, particularly in urban areas. Projects that expand highway capacity where conditions are congested will induce additional vehicle travel. Capacity additions effectively reduce the "price" of driving, which leads to more driving than would otherwise occur as individuals and businesses become aware of changed conditions. Induced vehicle travel is closely related to the concept of "latent demand," which refers to the travel that would occur if the price were lower (i.e., travel times were faster), or in other words, the travel that does not occur because price is high (i.e., travel times are slow).

The phenomenon of induced vehicle travel is widely accepted and well documented.[14] In the short term, expansion of highway capacity can cause new vehicle trips that would otherwise would not be made, longer vehicle trips to more distant destinations, shifts from off-peak to peak travel hours, and shifts from other modes to driving. Longer term changes can include an increase in more dispersed, low density development patterns that are dependent on automobile travel. As far back as the 1960s, researchers have identified this phenomenon, sometimes dubbed the "Fundamental Law of Road Congestion," which asserts that the amount of vehicle travel will increase in exact proportion to the highway capacity expansion, so that traffic speeds will revert to their pre-expansion levels.[15]

Researchers typically seek to identify induced vehicle travel effects in terms of an "elasticity", which is the ratio of the percentage change in one variable associated with the percentage change in another variable. For example, an elasticity value of 0.5 suggests that a 1 percent increase in roadway capacity is associated with a 0.5 percent increase in VMT, or a doubling (100 percent increase) in roadway capacity is associated with a 50 percent increase in VMT. Table 5 summarizes the results of research on induced vehicle travel, with the elasticity values in the rightmost column. While some of the most well-known studies in this field are 20 years old, more recent research has produced similar findings.

The research has found elasticity values ranging from 0.1 to 0.6 in the short term (typically defined as one year or less) and 0.4 to 1.06 in the long term (5 to 10 years or more). The most recent and comprehensive research (Hymel, 2019) suggests that long-run elasticity is close to 1.0, which means that a 10 percent expansion of highway capacity will lead to a 10 percent increase in VMT. This VMT increase can negate any near-term congestion relief and potentially lead to an increase in GHG emissions, particularly in urbanized areas.

Quantifying induced vehicle travel elasticity is challenging, in part because researchers must account for all the other factors that affect vehicle travel and isolate the effects of capacity expansion. The range of results shown in Table 5 is indicative of different methods and data sources used to study this phenomenon. Induced vehicle travel effects will also vary from region to region and corridor to corridor,

---

[14] Handy, Susan and Boarnet, Marlon, G., "Impact of Highway Capacity and Induced Travel on Passenger Vehicle Use and Greenhouse Gas Emissions," prepared for the California Air Resources Board, 2014. https://ww2.arb.ca.gov/sites/default/files/2020-06/Impact_of_Highway_Capacity_and_Induced_Travel_on_Passenger_Vehicle_Use_and_Greenhouse_Gas_Emissions_Policy_Brief.pdf

[15] Downs, Anthony, "The law of peak-hour expressway congestion," *Traffic Quarterly*, Vol 16, No. 3, 1962.

because of differences in land uses and socioeconomic conditions, the availability of transit and other alternatives to driving, growth rates, and other factors.

Table 5. Research on the Impact of Capacity Expansion on Induced Vehicle Travel

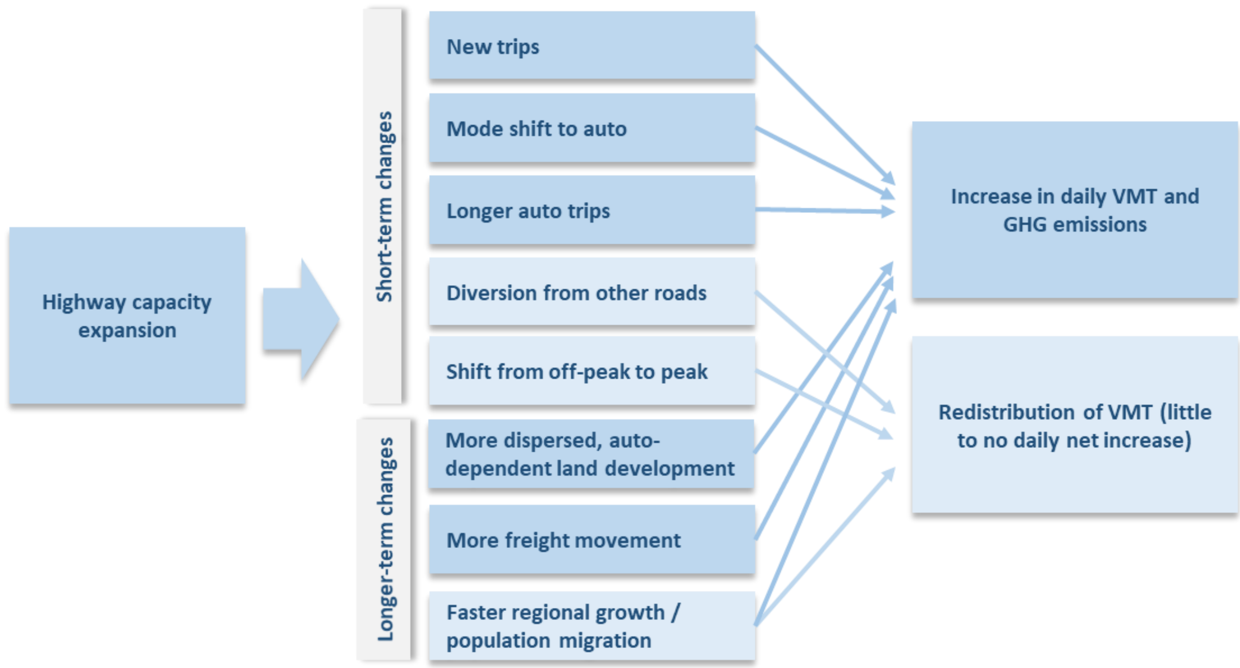
Study	Study Location (and Type)	Study Years	Time Period	Elasticity (change in VMT / Change in Lane- Miles)
Hymel (2019)	U.S (States)	1981-2015	long-term	0.89 to 1.06
Duranton and Turner (2011)	U.S. (MSAs – Interstates)	1983-2003	10 years	0.93 to 1.03 [a]
Cervero (2003)	California (Freeway Corridors)	1980-1994	short-term long-term	0.10 0.39
Cervero and Hansen (2002)	California	1976-1997	short-term intermediate term	0.59 0.79
Noland (2001)	U.S. (States – all roadway types)	1984-1996	short-term long-term	0.30 to 0.60 0.70 to 1.00
Noland and Cowart (2000)	U.S. (Metro Areas – Freeways and arterials)	1982-1996	short-term long-term	0.28 0.90
Hansen and Huang (1997)	California	1973-1990	short-term long-term	0.20 0.60 to 0.90

Source: Handy, Susan and Boarnet, Marlon, G., "Impact of Highway Capacity and Induced Travel on Passenger Vehicle Use and Greenhouse Gas Emissions," prepared for the California Air Resources Board, 2014; Duranton, G., & Turner, M. A., “The Fundamental Law of Road Congestion: Evidence from US Cities,” *American Economic Review*, 101 (6), 2011; Hymel, Kent, “If You Build It, They Will Drive: Measuring induced demand for vehicle travel in urban areas,” *Transport Policy*. Volume 76, pp. 57-66, 2019.

Note a: Duranton and Turner developed several models and elasticities but report 1.03 as the “most defensible estimate.” This total elasticity includes contributions from traffic diversion, which the authors estimate to account for 0 – 10 percent of the total. Because diverted traffic does not generally reflect a net increase in induced vehicle travel, the range shown in Table 5 reflects only the induced vehicle travel that is not diverted traffic.

It is important to recognize that the induced vehicle travel observed on a single highway following capacity expansion is not necessarily equal to a net system-wide increase in VMT and corresponding increase in GHG emissions, as discussed in several of the papers listed above. In the short term, effects such as new trips, mode shift to automobile travel, and longer automobile trips all contribute to a net increase in VMT, while diversion from other roads and shifts from off-peak to peak-period travel primarily redistribute VMT rather than cause a net increase in VMT. In the longer term, effects such as more dispersed, auto-dependent development patterns and freight logistics process reorganization contribute to a net increase in VMT; population migration can at least partially redistribute VMT, potentially from other states, although it can also cause a net increase. The figure below illustrates the short-term and longer-term changes that can result from highway capacity expansion and their relationship to a net increase in VMT and GHG emissions.

Figure 6. Changes Resulting from Highway Capacity Expansion



Recent induced travel research has attempted to distinguish between these different impacts and isolate the net increase in VMT. The research suggests diverted traffic effects are likely small. One of the most comprehensive studies, Duranton and Turner (2011), concludes: "Increasing lane kilometers for one type of road diverts little traffic from other types of road."[16] And a review of literature commissioned by CARB concludes: "Capacity expansion leads to a net increase in VMT, not simply a shifting of VMT from one road to another."[17] The research listed in Table 5 generally seeks to quantify the net increase in VMT.

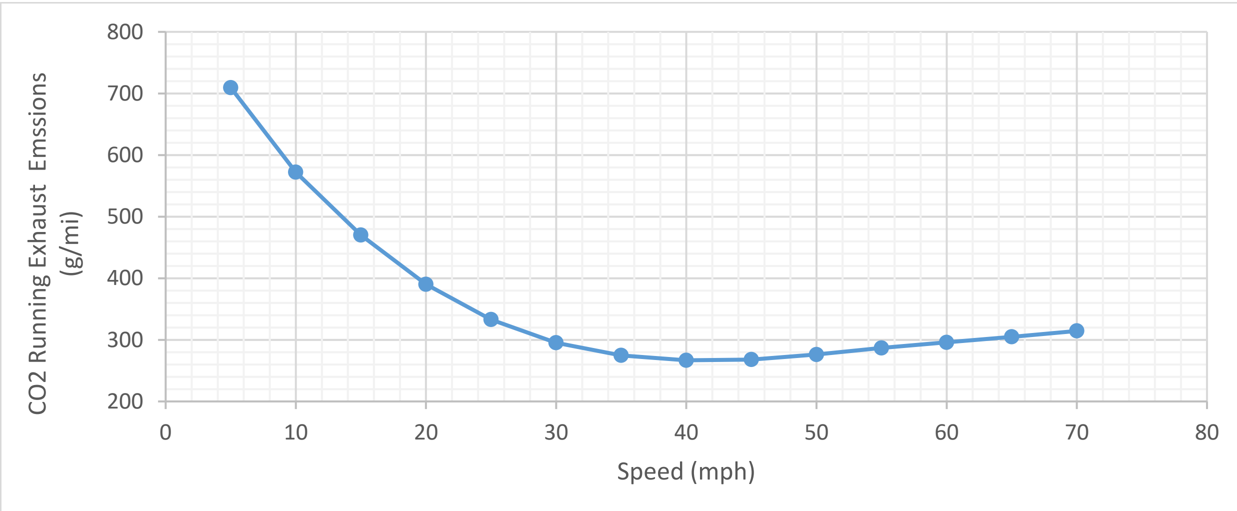
Proponents of highway capacity expansion often claim that the project will reduce emissions because of a reduction in congestion and an increase in vehicle speeds. Vehicle GHG emission rates are lowest between 35 and 55 miles per hour, as show in the figure below. If there is no change in VMT, then a project that increases average vehicle speeds from less than 35 mph to the 35-55 mph range will reduce emissions. However, most highway capacity expansion projects in urban areas will cause an increase in VMT, and the induced vehicle travel can offset some or all emission reduction benefits of congestion reduction. Moreover, any congestion reduction benefits that improve traffic flow and reduce *per vehicle* emission rates are likely to be short-lived, because induced vehicle travel will lead to a return of congested conditions.

This is not to imply that all highway capacity expansion projects will increase GHG emissions. In some circumstances, the emissions benefits of smother traffic flow may be greater than the emissions

[16] Duranton, G., & Turner, M. A., "The Fundamental Law of Road Congestion: Evidence from US Cities," *American Economic Review*, 101 (6), 2011.
[17] Handy, Susan and Boarnet, Marlon, G., "Impact of Highway Capacity and Induced Travel on Passenger Vehicle Use and Greenhouse Gas Emissions," prepared for the California Air Resources Board, 2014.

increase from induced vehicle travel, at least in the short term. The relative magnitude of these two factors will vary by project and vary over time. However, the evidence is clear that induced vehicle travel effects can be substantial, and ignoring induced vehicle travel will produce misleading conclusions about emissions impacts.

Figure 7. California Average Light Duty Vehicle CO_2 Emission Factors by Speed, 2018



Source: EMFAC 2017

Rather than add new highway lanes in name of congestion reduction, operational improvements can sometimes deliver system performance (congestion reduction) benefits at far less cost. These can include ramp metering, reconfigurations to highway ramps to reduce weaving and merge impacts, incident management, and traveler information systems. The GHG impacts of these types of operational strategies are highly context-specific and not well understood, in part because nearly all the research does not consider induced vehicle travel. Traffic operations strategies are discussed in Section 3.2.

Caltrans and its local partners have an opportunity to limit VMT growth and the associated GHG emissions by avoiding highway capacity expansion projects that are likely to result in substantial induced vehicle travel. This approach is consistent with State, regional, and local efforts to mitigate VMT and GHG impacts, and with the Caltrans Strategic Management Plan, which established a goal of reducing statewide per capita VMT by 15 percent relative to 2010 levels.

To limit VMT growth and GHG emissions, consideration of induced vehicle travel is applicable throughout the decision-making process. The development of a highway project begins with identification of the need for the project, which is often framed as a structural or operating deficiency of the existing transportation system. Project needs are identified through Caltrans management systems, master plans, system and regional plans, and prioritizing processes, or by other sponsoring agencies.[18] The project need is documented in a Project Initiation Document (PID). Based on a review of PIDs by the research team, "congestion" is often identified in a PID as a system deficiency, and the identified need for a highway capacity expansion project is to "reduce congestion." Some capacity expansion projects

[18] Caltrans, "How Caltrans Builds Projects," August 2011.

also identify "reduce emissions" as an objective. In some cases, this practice ignores the evidence on induced vehicle travel, since statements in the PID assume that highway capacity expansion will reduce congestion, while the evidence suggests that in urbanized areas, the project may result in little or no congestion relief. The ultimate impact on GHG emissions will depend on the relative speed impacts and induced vehicle travel impacts, as noted above.

Transportation projects must be analyzed for their impacts under the California Environmental Quality Act (CEQA). Despite the evidence documented in literature, the planning and environmental analysis processes have often failed to adequately account for induced vehicle travel.[19] The Governor's Office of Planning and Research provides guidance on the general steps for this analysis.[20] Caltrans has developed the "Transportation Analysis Framework" is to assist Caltrans Districts in identifying the best approach for analyzing VMT (induced travel) under CEQA in various settings and for projects on the SHS.[21] This document identifies two general approaches for assessing induced vehicle travel for SHS projects:

- Use the Induced Travel Calculator developed by the National Center for Sustainable Transportation (NCST) at UC Davis, which applies elasticities from empirical studies discussed above.
- Use a travel demand model, potentially supplemented with off-model post-processing or other adjustments as necessary.

The Caltrans Transportation Analysis Framework discusses in which circumstances these approaches are most appropriate.

HOV Lanes and Express Lanes

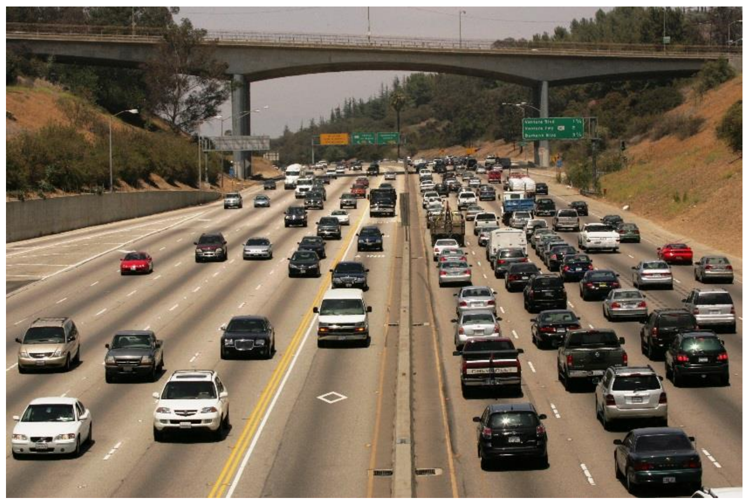
Induced vehicle travel and GHG impacts are also important considerations in decisions regarding high-occupancy vehicle (HOV) lanes and express lanes. Caltrans maintains a network of nearly 1,400 miles of HOV lanes, primarily in the Los Angeles and San Francisco Bay Area metropolitan areas. California law states that the purpose of HOV lanes is "to stimulate and encourage the development of ways and means of relieving traffic congestion on California highways and, at the same time, to encourage individual citizens to pool their vehicular resources and thereby conserve fuel and lessen emission of air pollutants." In theory, HOV lanes can potentially reduce emissions in two ways: (1) by enabling smoother traffic flow that results in a lower rate of fuel use and emissions per vehicle, and (2) by encouraging SOV travelers to shift to carpools, thereby reducing VMT. In reality, however, there is little evidence that expanding highway capacity by adding HOV lanes will reduce GHG emissions, and some research, as discussed below, suggests that HOV lane additions will increase GHG emissions.

In recent years, some HOV lanes have been modified or newly constructed to allow SOVs to use the facility by paying a toll. These facilities were initially termed high occupancy toll (HOT) lanes and are now

[19] Volker, Jamey M. B., Amy E. Lee, and Susan Handy, "Induced Vehicle Travel in the Environmental Review Process," *Transportation Research Record*, Vol. 2674(7), 468–479, 2020.
[20] Office of Planning and Research, Technical Advisory on Evaluating Transportation Impacts in CEQA, December 2018. http://opr.ca.gov/ceqa/updates/sb-743/
[21] Caltrans, Draft Transportation Analysis Framework: Induced Travel Analysis, March 2020.

frequently referred to as "express lanes". California currently has 214 miles of express lanes, with many more facilities in development or planning phases. Express lanes can be a way to introduce the concept of roadway pricing, and pricing can be an effective mechanism for limiting SOV travel demand in some circumstances, as discussed in the following sub-section. Express lanes can also be used by transit vehicles to increase travel time reliability, especially when coupled with dynamic pricing.

Studies have shown that vehicles traveling in HOV lanes emit fewer pollutants than vehicles in mixed-flow lanes, because of smoother traffic flow.[22] However, most of this research simply compares HOV lanes with mixed-flow lanes at a single point in time, rather than looking at travel changes that were caused by the addition of the HOV or express lane. Virtually all the HOV lanes in California have been constructed as new highway capacity, rather than conversion of existing mixed-flow lanes to HOV. Thus, by adding capacity, HOV and express lanes induce new vehicle travel in urbanized areas as described above. The additional VMT will at least partially offset any emissions benefits resulting from smoother traffic flow, and in many cases will completely offset the emissions benefits from traffic flow improvements. These conclusions are supported by regional simulation modeling studies.[23] [24] They are also supported by project-level analyses of emissions impacts of HOV and express lane additions reported in recent project environmental documents.[25] [26]



The impact of HOV lane additions on carpool formation and average vehicle occupancy is uncertain. Surveys of HOV lane carpoolers and vanpoolers conducted in the 1980s and 1990s found that 40 to 50 percent reported previously driving alone.[27] Observations of Southern California freeways that added HOV lanes in the 1990s found that average vehicle occupancy across the entire facility generally increased following the HOV lane opening, although some of the carpools may have simply diverted

[22] "Modeling the Effectiveness of High Occupancy Vehicle (HOV) Lanes at Improving Air Quality," Prepared by Bourns College of Engineering, Center for Environmental Research and Technology, University of California, Riverside, Prepared for Caltrans, 2006.

[23] Johnston, Robert A and Raju Ceerla, "The Effects of New High-Occupancy Vehicle Lanes on Travel and Emissions," Transportation Research Part A, Volume 30, No. 1. 1996.

[24] Dowling, Richard et al, 2005. NCHRP Report 535, Predicting Air Quality Effects of Traffic-Flow Improvements: Final Report and User's Guide. Transportation Research Board. www.trb.org/Publications/Blurbs/155398.aspx

[25] Air Quality Study Report, SR 65 Capacity and Operational Improvements Project, State Route 65, Cities of Roseville, Rocklin, and Lincoln, Placer County, 03-PLA-65-PM R6.2 to R12.8, EA 03-1F170, September 2016.

[26] Sac 50 Phase 2 High Occupancy Vehicle Lanes Project, Draft Initial Study [with Proposed Mitigated Negative Declaration]/ Environmental Assessment with Finding of No Significant Impact. September 2016.

[27] Turnbull, K. H. Levinson and R. Pratt. HOV Facilities – Traveler Response to Transportation System Changes. Transportation Cooperative Research Program Report 95, Chapter 2. 2006.

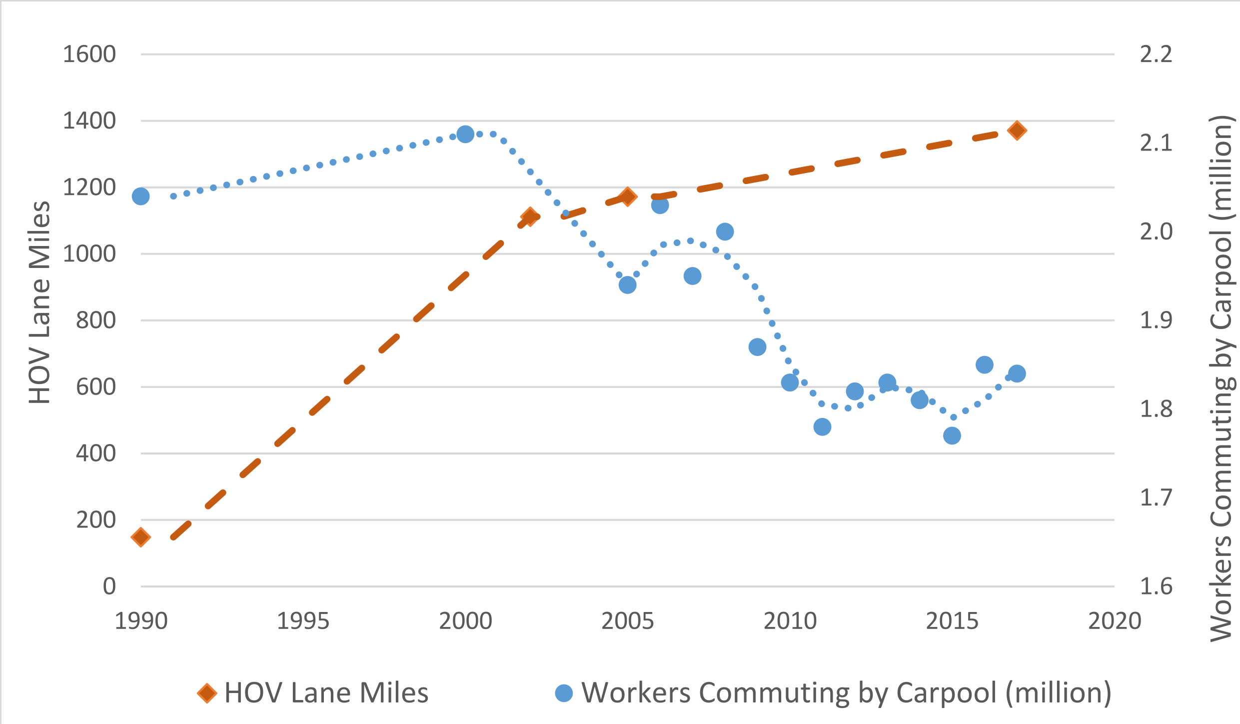
from other facilities.[28] But other studies have found that an individual's decision to drive as an HOV rather than a SOV is not very sensitive to travel time savings, casting doubt on the impacts of HOV lane additions on vehicle occupancy. Forming a new carpool can require additional travel or waiting time, and for most drivers, the time savings afforded by HOV lane travel are not significant enough to overcome the extra burden of forming a new carpool. A 2007 study of California's HOV lanes concluded: "Travel time savings do not provide a statistically significant carpooling incentive."[29]

Other research has shown that most carpool vehicles consist of family members riding together. For example, a study using 2001 data found that 83 percent of carpools for home-based work trips contained only members of the same household.[30] This suggests that carpool formation for work trips depends almost entirely on the work locations of members of the same household.[31]

Observed trends also suggest that HOV lanes have limited influence on carpool formation, or that their influenced is countered by other trends, such as the increased spatial dispersion of workplaces. As shown in the figure below, the number of workers commuting by carpool in California has declined from a peak of 2.1 million in 1990 to around 1.85 million today, a 10 percent reduction, while the number of HOV lane miles in the state has greatly increased. During the same period, the number of SOV commuters in California has increased 36 percent, to 13.5 million. Note, however, that a variety of factors have contributed to the decline in ridesharing, such as the elimination of some mandates for employee trip reductions by larger employers and continued low gasoline prices, so the influence of HOV lanes on broader ridesharing trends is unclear.

[28] Turnbull, 2006.
[29] Varaiya, Pravin, "Effectiveness of California's High Occupancy Vehicle (HOV) System," UCB-ITS-PRR-2007-5, California PATH Research Report, May 2007.
[30] McGuckin, N. and N. Srinivasan. "The Journey-to-Work in the Context of Daily Travel," Paper prepared for the Census Data for Transportation Planning Conference.
http://onlinepubs.trb.org/onlinepubs/archive/conferences/2005/censusdata/resource-journey-to-work.pdf
[31] Variaya, 2007.

Figure 8. Change in California HOV Lane Miles and Workers Commuting by Carpool, 1990 – 2017



Source: Commute data from US Census Bureau, Decennial Census & American Community Survey; HOV lane mile data from Caltrans, *High Occupancy Vehicle Guidelines* (various years) and May, Adolf D., Lannon Leiman, and John Billheimer, "Determining the Effectiveness of HOV Lanes," California PATH Research Report, UCB-ITS-PRR-2007-17, November 2007.

The impacts on carpooling of converting HOV lanes to express lanes appears to vary widely. One recent study concluded that HOV to HOT lane conversion generally reduces the prevalence of carpooling.[32] However, previous research came to different conclusions. In San Diego, for example, the number of HOVs increased significantly in the seven years after the I-15 HOV lanes were modified to allow SOV buy-in.[33]

For HOV lanes to effectively encourage carpooling, they must offer a significant travel time savings and better reliability as compared to general purpose lanes. Yet the free-flow conditions on the state's HOV lane system has been declining. More than half of HOV lanes in the state exhibit "degraded" performance, defined as having average traffic speed during the morning or evening weekday peak commute hour is less than 45 miles per hour for more than 10 percent of the time.[34] Improving HOV lane performance though better enforcement and potentially higher occupancy requirements (e.g., 3+

[32] Burris, Mark, "The impact of HOT lanes on carpools," *Research in Transportation Economics*, Volume 44, June 2014.

[33] Turnbull, K. H. Levinson and R. Pratt. HOV Facilities – Traveler Response to Transportation System Changes. Transportation Cooperative Research Program Report 95, Chapter 2. 2006. www.trb.org/Publications/Blurbs/158237.aspx

[34] Caltrans, "2016 California High-Occupancy Vehicle Lane Degradation Determination Report," October 2017.

occupants) can help to maximize their potential to boost ridesharing. Use of dynamic pricing can also significantly improve travel time reliability on express lanes, making them more attractive to carpoolers.

HOV lanes are most effective when they carry large numbers of transit buses and vanpools. In these cases, the passenger throughput of the HOV lane can be significantly higher than general purpose lanes. For example, the I-395 HOV lanes in the Northern Virginia and Washington DC area carry large numbers of buses and vanpools. The observed average vehicle occupancy on this facility in the AM peak was 3.1, and HOV lane peak-hour person throughput was approximately 5,600, compared to 2,000 for the general purpose lanes.[35] Buses that use properly functioning HOV lanes can see reduced travel times and better schedule adherence, which can help to attract new bus riders and enhance transit cost effectiveness.

It should be noted that HOV lanes have played a role in encouraging adoption of low emission vehicles in California. Since 2000, the State has issued decals that allow HOV lane access by certain low- or zero-emission vehicles. There is evidence that, for some vehicle owners, this HOV lane access has been a motivating factor in the choice of purchasing a low- or zero-emission vehicle.[36]

Because most California highway capacity projects today involve HOV or express lanes, and because the GHG impacts of building these facilities are uncertain, it is important to carefully study the likely impacts of proposed projects and avoid premature assumptions about VMT or emission reductions. This acknowledgement should begin during planning and programming when projects are first proposed for congestion reduction purposes. Based on interviews conducted for this report, many Caltrans and local partner staff continue to believe that all HOV lane projects reduce emissions. For example, a recent Caltrans website for a proposed project to add HOV lanes in a major metro area stated: "This project will also benefit transit ridership/ ridesharing by providing less delay and a more reliable traveling option and air quality is expected to improve due to decrease in delay and vehicle miles traveled (VMT)." These types of assertions, made before careful traffic and emissions studies have been performed, can contradict the findings of research on induced vehicle travel effects and the simulation modeling performed for recent Caltrans projects. Without properly recognizing the uncertainty and potential for induced vehicle travel and GHG emissions increases, projects may be advanced that are inconsistent with State and local GHG reduction targets and do little to alleviate congestion.

Roadway Pricing

As an alternative to capacity expansion, roadway pricing provides a mechanism for reducing the demand for SOV travel and improving network performance. Roadway pricing in the form of tolls has been in place for many years. Examples include the tolled bridges in the Bay Area and tolled highways in California and other states. Road pricing is being introduced widely as part of the development of

---

[35] Turnbull, K. H. Levinson and R. Pratt. HOV Facilities – Traveler Response to Transportation System Changes. Transportation Cooperative Research Program Report 95, Chapter 2. 2006.

[36] Tal, Gil and Michael A. Nicholas, "Evaluating the Impact of High Occupancy Vehicle (HOV) Lane Access on Plug-In Vehicles (PEVs) Purchasing and Usage in California," Institute of Transportation Studies, University of California, Davis, Working Paper UCD-ITS-WP-14-01, 2014.

express/HOT lanes, as discussed above. Tolls or pricing in these examples have been implemented in part to raise revenue for facility construction and/or maintenance.

Roadway pricing can be applied explicitly for the purpose of reducing congestion in urban areas and for mitigating associated adverse environmental impacts. For example, London, Stockholm, and Singapore impose a charge for vehicles entering the city center. In all these cities, vehicle travel and congestion dropped significantly following the implementation of the pricing scheme. For example, the central London congestion charging scheme, coupled with transit service improvements, resulted in a 20 percent reduction in vehicle traffic and a 30 percent reduction in peak-period congestion delay, while transit ridership increased.[37] These cities have robust public transit systems, and the introduction of roadway pricing was typically coupled with transit service improvements. Also, the price level necessary to significantly deter vehicle travel must be relatively high, as compared to the lower price level of tolling as typically applied for the purposes of funding roadway construction and maintenance.

Increasingly, roadway pricing is being considered as an alternative to roadway capacity expansion and a mechanism to curb congestion and reduce VMT. For example, the investment strategy for the Metropolitan Transportation Commission's *Plan Bay Area 2040* includes a new cordon pricing zone in downtown San Francisco. A study by the Southern California Association of Governments found that implementing a cordon pricing scheme for the Los Angeles Westside area ("Mobility Go Zone") would reduce daily VMT by 8 percent, increasing transit and non-motorized travel, and yield a benefit-cost ratio of 3:1.[38] Other metropolitan areas that are actively considering urban area roadway pricing include New York City, Seattle, Portland, Oregon, and Vancouver, British Columbia.

Caltrans has identified expanding the use toll lanes or development of other pricing strategies as one type of project alternative that can potentially minimize, or avoid altogether, the additional VMT from capacity-increasing projects.[39]

By increasing the cost of SOV travel, roadway pricing will encourage travelers to consider other modes, most of which are less carbon intensive such as walking, bicycling, transit, and ridesharing. Thus, road pricing works best when paired with improvements to non-SOV travel options, discussed in the next section. Like many forms of behavior change, the most effective approaches to changing travel choices involve both "carrots" (more attractive alternative modes) and "sticks" (SOV price increases).

Impacts on VMT

The potential for road pricing to reduce VMT depends on the magnitude of the charges, among other factors. As the price of driving increases, VMT will decrease as divers shift to other modes, shorten trips, or forego discretionary trips altogether. Research on fuel price elasticity can provide a starting point for

---

[37] Litman, Todd, "London Congestion Pricing: Implications for Other Cities," Victoria Transport Policy Institute. November 24, 2011. www.vtpi.org/london.pdf

[38] Southern California Association of Governments, *Mobility Go Zone & Pricing Feasibility Study: Final Report*, March 2019.

[39] Caltrans, Draft Transportation Impacts Analysis under CEQA for Projects on the State Highway System, March 1, 2020.

estimating VMT effects. A report published by the Federal Highway Administration (FHWA) synthesized several prominent studies on travel demand relative to fuel cost, finding a wide range in elasticities, ranging from -0.1 to -0.63.[40] These values imply that doubling the cost of driving would reduce VMT by 10 to 63 percent. However, motorists' response to roadway pricing may differ from the response to a change in fuel price. On one hand, roadway pricing could result in a larger VMT reduction because the impacts are more immediate and closely tied to the vehicle trip as compared to fuel prices. On the other hand, in some situations, some drivers may be able to avoid highway charges by using surface streets, limiting impacts of roadway pricing on VMT. Actual impacts are likely to vary widely depending on the context.

A study of increased peak period tolls on the San Francisco-Oakland Bay Bridge in 2010 estimated a traffic elasticity of -0.23, meaning that doubling toll rates would reduce traffic by 23 percent. The study notes that this relatively low elasticity value is "an indication that peak period motorists were fairly insensitive to pricing and a reflection of the nondiscretionary nature of many peak hour journeys." The study also showed a high reduction in carpool vehicles once carpools change from free to tolled, even at a discounted rate.[41]

In the absence of real-world examples of comprehensive roadway pricing schemes in the United States, modeling studies provide the best estimates of impacts. As one example, the City of Seattle commissioned in 2009 a study of various regional tolling options. The study estimated a drop in per capita VMT from 24.1 (2009) to 22.7 (2030), a 6 percent reduction, with the variable priced tolling on all freeways in the Seattle metropolitan area. Such a tolling scheme would collect $1.9 billion in revenue annually.[42]

Where possible, the application of roadway pricing to existing travel lanes can be an effective strategy for Caltrans and partner agencies to manage congestion and reduce VMT, rather than highway capacity expansion that will include new vehicle travel. At present, however, Caltrans and its partner agencies have only limited ability to implement road pricing. Federal law prohibits tolling of Interstate highway general purpose lanes, with the exception of a small number of pilot programs. Federal law does allow charging of tolls for SOV use of HOV lanes.

Equity Concerns

Objections to roadway pricing are often centered around equity concerns. Pricing road travel could make it too expensive for low-skilled workers to get to their jobs. Tolls or other forms of road user charges would consume a larger share of income for poor drivers as compared to wealthy drivers. The actual social equity impacts of any specific roadway pricing scheme are complex and depend on many

[40] Dong, J., Davidson, D., Southworth, F., Reuscher, T. 2012. *Analysis of Automobile Travel Demand Elasticities with Respect to Travel Cost.* FHWA. www.fhwa.dot.gov/policyinformation/pubs/hpl-15-014/TCElasticities.pdf
[41] Cervero, Robert, "Traffic Impacts of Variable Pricing on the San Francisco-Oakland Bay Bridge, California," *Transportation Research Record*, No. 2278, 2012.
[42] Seattle Department of Transportation, *Seattle Variable Tolling Study,* 2009. www.seattle.gov/Documents/Departments/SDOT/About/DocumentLibrary/Reports/FINALTollingStudyreportrevised6.25.10.pdf

factors. While equity concerns should in no way be dismissed, it is worth noting that much of the literature on the subject finds that road pricing is not as inequitable as commonly believed.

Observations of existing priced highway lanes in urban areas finds that a large portion of users of these facilities are low- and middle-income drivers. When examining HOT lanes, researchers have found that, even if they don't use the facility regularly, lower income drivers value the option to bypass congestion because they may have less flexibility in their schedules and pay a greater penalty for arriving late. This is borne out in public opinion surveys, which consistently find that support for road pricing does not vary substantially by income group.[43]

When pricing is used to generate revenue for roadway improvements, it must be compared against alternative revenue generation approaches. In California, sales taxes are often used to fund highway improvements, and research finds that a transportation sales tax "disproportionately favors the more affluent at the expense of the lower-income."[44]

Roadway pricing equity concerns can potentially be addressed in several ways. "Lifeline" programs could be used to provide discounted access to toll roads, similar to utility programs available to low-income households. The distribution of road pricing revenue can also be used to fund services that benefit low-income travelers. If equity is a prominent factor in the design and implementation of a roadway pricing program, the results can benefit disadvantaged communities through improved public transit, safer pedestrian and bicycle routes, and reduced environmental burdens.[45]

Improve Alternatives to SOV Travel

Caltrans plans, designs, constructs, and operates facilities that provide alternatives to SOV travel. Caltrans decisions can support these alternatives even when Caltrans does not directly control the facilities. As shown in the table below, SOVs typically produce the highest emissions per passenger mile among major modes surface of transportation, although the results depend on vehicle fuel type, vehicle occupancy, and other variables. The emission factors shown below were developed using fuel-based carbon intensity values from CARB's LCFS program, which account for the emissions resulting from the production and distribution of the various fuel types and all associated tailpipe exhaust emissions.[46]

[43] FHWA, "Income-Based Equity Impacts of Congestion Pricing: A Primer," 2008. https://ops.fhwa.dot.gov/publications/fhwahop08040/cp_prim5_00.htm
[44] Schweitzer, Lisa, and Brian D. Taylor, "Just Pricing: The Distributional Effects of Congestion Pricing and Sales Taxes," *Transportation*, Vol 35, No. 6, 2008.
[45] TransForm, *Pricing Roads, Advancing Equity*, January 2019. www.transformca.org/transform-report/pricing-roads-advancing-equity
[46] California Air Resources Board. 2018. California Climate Investments Quantification Methodology Emission Factor Database. Available at: www.arb.ca.gov/cc/capandtrade/auctionproceeds/cci_emissionfactordatabase.xlsx

Table 6. GHG Emissions by Surface Transportation Mode

Transportation Mode	Fuel Type	Grams CO_2e per vehicle mile	Assumed Vehicle Occupancy	Grams CO_2e per passenger mile [a]
Single-occupancy vehicle	Gasoline	492 [b]	1	492
	Electric	123 [c]	1	123
Carpool	Gasoline	492 [b]	3	164
	Electric	123 [c]	3	41
Vanpool	Gasoline	1,292 [b]	8	161
Transit Bus *(80% occupied)*	Diesel	2,512 [b]	36	66
	Electric	893 [d]	36	25
Transit Bus *(20% occupied)*	Diesel	2,512 [b]	9	263
	Electric	893 [d]	9	99
Passenger Rail	Diesel	24,954 [e]	203	123
	Renewable Diesel	8,696 [e]	203	43
Light Rail	Electric	7,795 [e]	121	65
Streetcar	Electric	8,297 [e]	29	285

Notes:

[a] Grams per passenger mile calculated by dividing the grams per vehicle mile by the assumed vehicle occupancy for each mode.

[b] GHG emission factors developed by multiplying vehicle fuel consumption rates from CARB's EMFAC2017 model by CARB's LCFS fuel-based carbon intensity values. The following vehicle types were assumed to represent the transportation modes: light-duty automobile (LDA)/light-duty truck (LDT)/medium-duty vehicle (MDV) = SOV and carpool; light-heavy duty vehicle (LHD1) = vanpool; and urban bus (UBUS) = transit bus. The EMFAC modeling was performed at the statewide level for calendar year 2016.

[c] Assumes an electricity consumption rate of 0.326 kilowatt-hours per vehicle mile, based on the average efficiency for top selling U.S. electric vehicle brands in 2015 (U.S. Department of Energy 2016). This rate was multiplied by CARB's LCFS carbon intensity for grid electricity (CARB 2018).

[d] Assumes an electricity consumption rate of 2.36 kilowatt-hours per vehicle mile, based on the average efficiency of King County Metro 40-foot battery electric buses (Federal Transit Administration 2018). This rate was multiplied by CARB's LCFS carbon intensity for grid electricity (CARB 2018).

[e] GHG emission factors were obtained directly from CARB (2018).

VMT Reduction Strategies

A variety of programs and services are available to encourage alternatives to SOV travel, reduce reliance on the private automobile, and thereby reduce VMT and GHG emissions. Examples are listed in the table below. Many of these strategies are categorized as transportation demand management (TDM). In some cases, Caltrans can lead the implementation of these strategies, while in other cases, Caltrans would play a supporting role to MPOs, local governments, large employers, or other organizations.

Table 7. Examples of VMT Reduction Strategies

Strategy Category	Strategies for which Caltrans has a Support Role	Strategies for which Caltrans has a Lead or Support Role
Bicycle, Pedestrian, and Urban Design Strategies	Bikeshare	Bikeway network expansion Bike lane/path development Pedestrian facility network expansion Pedestrian facility development Street connectivity
Transit Strategies	Transit system expansion Transit frequency improvements Transit travel time improvements Transit reliability improvements Transit fare reduction	
Land Use and Parking Strategies	Land use mixing Higher density development Transit oriented development Destination accessibility Parking management and pricing	
Transportation Demand Management Strategies	Employer alternative commute option programs Rideshare Carsharing programs Telework Community-based travel marketing	Park and ride lots

California's 18 MPOs lead the planning for VMT reduction measures at the regional scale. Most MPOs have been pursing these types of strategies for decades due to air quality planning requirements, often working with regional air quality management districts. The passage of SB 375 added the requirement that MPOs demonstrate that their long-range transportation plan will achieve light-duty vehicle per-capita GHG emission reduction targets set by CARB. In some cases, the GHG reduction targets can be achieved through future land use plans that result in VMT reduction. However, most MPOs have also analyzed and adopted additional TDM strategies for VMT and GHG reduction. For example, MTC's Plan Bay Area 2040, adopted in 2017, includes the following strategies to reduce VMT[47]:

- Commuter Benefits Ordinance
- Car Sharing
- Vanpools and Employer Shuttles
- Smart Driving Program
- Targeted Transportation Alternatives (i.e., community-based travel marketing)

[47] Metropolitan Transportation Commission. 2017. Plan Bay Area 2040: Final Travel Modeling Report. http://2040.planbayarea.org/sites/default/files/2017-07/Travel_Modeling_PBA2040_Supplemental%20Report_7-2017_0.pdf

- Trip Caps
- Bike Share
- Bicycle Infrastructure

The MTC plan also includes three strategies to promote accelerated deployment and use of clean vehicles: a Regional Electric Vehicle Charger Network, a Vehicle Buyback and EV Incentive Program, and a Clean Vehicles Feebate Program.

Bicycle System Improvements

Walking and cycling are forms of active transportation that do not generate any GHG emissions. Caltrans can support active transportation by expanding bike and pedestrian infrastructure and improving the safety of existing facilities. New bicycle lanes can reduce GHG emissions by encouraging the replacement of auto trips with bicycle trips, which reduces VMT.[48,49] The amount of emission reductions achieved by new bicycle facilities depends on many variables, including regional connectivity, length of the facility, average daily traffic (ADT) on the parallel roadway, proximity to activity centers, and the extent to which cycling trips are replacing auto trips. Bicycle facilities are most effective at reducing VMT and GHG emissions when they improve the connectivity of a regional bicycle network, improve access to popular destinations, and are perceived as safe and convenient by cyclists.

The table below presents an illustrative example of potential GHG and VMT reductions that may be achieved by three hypothetical Class 2/Class 4 bike lane projects. The research team assumed the three facilities have different characteristics, as described below, in order to identify a range of low, medium, and high GHG reductions. GHG and VMT reductions for each facility were quantified by the research team using CARB's Active Transportation Program GHG Emission Reduction Calculator.

- Facility 1: less than 1-mile bike lane parallel to a roadway with less than 12,000 ADT located in a town with less than 250,000 people. The new facility would be within 0.5 mile of three activity centers.
- Facility 2: 1- to 2-mile bike lane parallel to a roadway with 12,000 to 24,000 ADT located in a university town with less than 250,000 people. The new facility would be within 0.5 mile of three to seven activity centers.
- Facility 3: longer than 2-mile bike lane parallel to a roadway with 24,000 to 30,000 ADT located in a town with more than 250,000 people. The new facility would be within 0.25 mile of more than seven activity centers.

[48] Matute, Juan, Herbie Huff, Jamie Lederman, Diego de la Peza, and Kevin Johnson (2016). Toward Accurate and Valid Estimates of Greenhouse Gas Reductions from Bikeway Projects. California Department of Transportation, Report CA 17-2919. www.lewis.ucla.edu/wp-content/uploads/sites/2/2016/08/UCCONNECT-Matute-Final-Report-with-Appendices.pdf

[49] Handy, S., Tal, G., and Boarnet, M. (2014). Impacts of Bicycling Strategies on Passenger Vehicle Use and Greenhouse Gas Emissions - Policy Brief. California Air Resources Board. www.arb.ca.gov/cc/sb375/policies/bicycling/bicycling_brief.pdf

Table 8. Potential VMT and GHG Reductions from New Bicycle Lanes

Facility	Auto VMT Reduction (miles per year)	GHG Reduction (metric tons CO_2e per year)
Facility 1	8,100	4
Facility 2	64,260	30
Facility 3	127,980	59

Notes: The calculator uses CARB's "Methods to Find the Cost-Effectiveness of Funding Air Quality Projects for Evaluating Motor Vehicle Registration Fee Projects and Congestion Mitigation and Air Quality Improvement Projects" to quantify VMT and GHG reductions. The GHG reductions account for emissions resulting from the production and distribution of the displaced fuel, as well as all associated tailpipe exhaust reductions.

While new bicycle facilities can reduce auto VMT and associated emissions, the GHG reduction potential is relatively low, in part because any resulting mode shift tends to replace only short automobile trips. Based on the analysis presented above, more than 15,000 bicycle lanes with characteristics like "Facility 3" would need to be constructed to reduce 1 percent of annual GHG emissions on the State Highway System (89 million metric tons, as shown in Table 1).

Transit System Improvements

System improvements that make transit more reliable and attractive as an alternative to SOV travel can increase transit ridership and reduce automobile VMT and GHG emissions.[50] There are a variety of mechanisms for improving transit service, including:

- Increasing the frequency of transit service, which reduces wait times for riders
- Improving transit travel speed and reliability through treatments such as transit signal priority, bus-only signal phases, queue jumps, curb extensions to speed passenger loading, and dedicated bus lanes.
- Expanding transit service by developing new routes, which can improve transit access to residents and businesses
- Reducing transit fares to make transit travel more competitive with auto travel

Caltrans does not operate public transit service so would rely on local partners to lead transit service improvements. However, Caltrans can support public transit in several ways. Caltrans administers a number of transit programs, including the Transit and Intercity Rail Capital Program (TIRCP), created in 2014 to provide grants from the state's Greenhouse Gas Reduction Fund to fund transit capital improvements that will reduce GHG emissions. Caltrans can also influence transit operations that occur on the State Highway System. For example, Caltrans can permit buses to operate on freeway shoulders to increase transit speeds and reliability, particularly during peak-hours or heavy congestion. Buses are

[50] Handy, S., Lovejoy, J., Boarnet, M., and Spears, S. (2013). Impacts of Transit Service Strategies on Passenger Vehicle Use and Greenhouse Emissions – Policy Brief. California Air Resources Board. www.arb.ca.gov/cc/sb375/policies/transitservice/transit_brief.pdf

currently permitted to operate on the shoulders of I-805 in San Diego County. In some situations, Caltrans may also be able to improve transit efficiency by creating dedicated bus-only lanes on the State Highway System.

The table below presents an illustrative example of potential GHG reductions that may be achieved by three hypothetical transit improvement projects under various ridership assumptions. The inputs were developed by the research team, and the GHG reductions were quantified using CARB's Transit and Intercity Rail Capital Program calculator. These examples assume that because transit-only and transit-priority lanes would likely be implemented in areas with existing transit service, they are not likely to significantly increase bus VMT. Accordingly, the analysis presented below does not assume any expansion to transit operations. There are many other ways to improve transit service, as noted above; some transit improvement options would increase bus VMT which would at least partially offset the GHG benefits of mode shift from autos.

Table 9. Potential GHG Reductions from Improved Transit Service

Project [a]	Additional Annual Ridership to Existing Transit Service [b]	GHG Reduction (metric tons CO_2e per year)
Transit Service 1	103,323 (Low)	407
Transit Service 2	206,646 (Medium)	814
Transit Service 3	516,614 (High)	2,035

Notes:

[a] All transit projects were analyzed as long-distance bus service in Sacramento County during calendar year 2020. Analysts also assumed all transit vehicles were model year 2015 and an average transit trip length of 10.23 miles (CARB 2017). No changes in transit VMT are assumed.

[b] For illustrative purposes, the low, medium, and high ridership levels represent a 1, 2, and 5 percent increase, respectively, in Sacramento Regional Transit's 2017 annual ridership (SacRT 2017).

Compared to new bicycle facilities, improved and productive transit service has a higher potential to reduce automobile VMT and associated GHG emissions (e.g., mode shift from SOVs to transit), although the illustrative reductions presented above are still relatively low compared to annual GHG emissions on the State Highway System.

Bicycle and Transit Project Impacts in Relation to Induced Vehicle Travel Impacts

Overall, Caltrans investments in projects that improve facilities for transit, bicycles, pedestrians, and other SOV alternatives are important components of the state's GHG reduction efforts. The co-benefits of these projects can be substantial, including public health improvements from more physical activity and safety improvements for the most vulnerable travelers (e.g., pedestrians and bicyclists). However, it is important to consider the magnitude of the GHG reductions from these projects in relation to the emissions impacts of induced vehicle travel. Typically, GHG emissions increases from induced vehicle travel will far outweigh any reductions from improvements to non-SOV facilities. Thus, based on this analysis, the inclusion of multi-modal improvements to a highway project will not “offset” the vehicle emissions impacts.

3.2 On-Going and Recent Actions

A variety of recent and on-going activities at Caltrans support reductions in highway system user GHG emissions. These actions, described below, are primarily led by the Division of Transportation Planning, the Division of Environmental Analysis, and Division of Traffic Operations. These actions can complement and support the high impact approaches discussed in the previous section, but are not likely to result in major GHG reductions by themselves.

Statewide Policy and Planning

Transportation planning at Caltrans articulates a long-term vision for California’s transportation system and implements statewide transportation policy through partnerships with state, regional, and local agencies. Transportation planning at Caltrans also includes the first phases of the project delivery process, including the development of project initiation documents (PIDs), which are prepared by the Division of Transportation Planning. The products and services of transportation planning support and guide transportation investment decisions. Programming is the commitment of transportation funds to be available over a period of several years to particular projects. Caltrans supports the preparation of several programming documents as required under State and Federal law, including the State Transportation Improvement Program (STIP) and the State Highway Operation and Protection Program (SHOPP). Nearly all these plans and programming documents can affect VMT in the state and therefore can influence GHG emissions.

Strategic Management Plan

Caltrans adopted a Strategic Management Plan in 2015 in order to provide clear direction for meeting statewide objectives, create and deepen strategic partnerships, and provide performance measures to monitor success. The Strategic Management Plan provides a definition of sustainability by identifying the following objectives for Caltrans Goal #3:

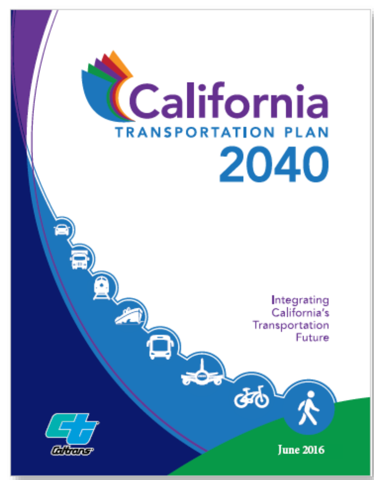
- PEOPLE—Improve the quality of life for all Californians by providing mobility choice, increasing accessibility to all modes of transportation and creating transportation corridors not only for conveyance of people, goods, and services, but also as livable public spaces.
- PLANET—Reduce environmental impacts from the transportation system with emphasis on supporting a statewide reduction of greenhouse gas emissions to achieve 80 percent below 1990 levels by 2050.
- PROSPERITY—Improve economic prosperity of the State and local communities through a resilient and integrated transportation system.

The Strategic Management Plan contains a number of sustainability performance measures and targets, several of which directly or indirectly relate to GHG reduction. These performance measures are shown in the table below.

Table 10. Sustainability Performance Measures in Strategic Management Plan

Performance Measure	Targets
Per capita vehicle miles traveled (Reported statewide by District)	By 2020, achieve 15% reduction (3% per year) of statewide per capita VMT relative to 2010 levels reported by District.
Percent reduction of transportation system-related air pollution for GHG emissions	15% reduction (from 2010 levels) of GHG to achieve 1990 levels by 2020.
Percent reduction of GHG emissions from Caltrans design, construction, operation, and maintenance of transportation infrastructure and building	By 2020, reduce Caltrans' internal operational pollutants by District from 2010 levels (from planning, project delivery, construction, operations, maintenance, equipment, and buildings) including: • 15% reduction by 2015 and 20% reduction by 2020 of Caltrans' GHG emissions per EO-B-18-12.

California Transportation Plan



Senate Bill 391 (2009) requires Caltrans to develop a statewide long-range transportation plan every five years that aligns with and supports California's GHG reduction targets as specified by AB 32. California Transportation Plan 2040 (CTP 2040), released in 2016, was the first CTP developed under this mandate. As a statewide transportation plan, CTP 2040 provides a framework for meeting the State's mobility and GHG goals and considers all transportation modes. Caltrans incorporated information from the statewide modal plans (described in subsequent sections) and regional transportation plans.

CTP 2040 is California's first statewide transportation plan that included modeling scenarios to measure potential GHG reductions. In the first scenario, Caltrans used the regional transportation plans for the state's four largest metropolitan planning organizations (MPOs), the State modal plans, and California Air Resources Board's Advanced Clean Cars program to model the GHG reductions from key existing plans and policies. The second scenario starts with the first scenario and adds in efficiency strategies (e.g., increased car and rideshare, improved multimodal options, driving pricing, and improved operations) that help reduce transportation-related GHG emissions. The third scenario assumes fuel and vehicle technology improvements (e.g., increased biofuel availability, zero emission vehicle deployment, and rail and aviation efficiencies) on top of the second scenario to help meet the transportation sector's share of the State's GHG reduction target of 80 percent emission below 1990 levels by 2050.

Caltrans has now started the development of the next statewide long-range transportation plan, CTP 2050. This effort will include development of a range of tangible future transportation scenarios, and then modeling of those scenarios to determine their potential impact on GHG emissions and other CTP performance objectives in compliance with adopted CTP Guidelines.

Caltrans Modal Plans

Caltrans develops statewide plans for individual transportation modes. These plans vary in structure and level of detail, but generally describe a vision for improving the performance of modal-specific transportation systems. When successful, improvements to non-highway travel modes can help to reduce travel by on-road vehicles (autos and/or trucks) and associated GHG emissions. Recent modal plans developed by Caltrans include the following:

- Toward an Active California: State Bicycle + Pedestrian Plan
- California State Rail Plan: Connecting California
- California Statewide Transit Strategic Plan
- California Freight Mobility Plan

A description of each of these plans is included in Appendix A.

Sustainable Freight

Caltrans created a Sustainable Freight Branch in 2016, primarily to implement the state’s Sustainable Freight Action Plan. The Sustainable Freight Action Plan was produced by a partnership of state agencies in response to Executive Order B-32. The Plan includes 9 major actions and 73 sub-actions; Caltrans is the assigned lead for 25 of the sub-actions. Other key implementation partners are the California Air Resources Board, the California Energy Commission, and the Governor’s Office of Business and Economic Development. Several of the actions led by Caltrans can reduce GHG emissions. These include:

- **Truck Parking Availability**. Because of a shortage of truck parking spaces and need for drivers to comply with federal hours of service limits, truckers can spend circling to search for an overnight parking space. This contributes to unnecessary truck VMT and possibly excessive idling. Increasing the availability of truck parking in key locations would improve system efficiency and reduce emissions.

- **Electric Charging Infrastructure for Parked Trucks**. Long-haul freight trucks often need to idle their diesel engines during overnight stops in order to provide truck cab comfort and amenities. With appropriate electrical service at truck parking facilities, trucks can minimize fuel consumption and GHG emissions. In addition, refrigerated trucks can potentially use electrical service instead of diesel engines to operate cooling units. Caltrans is leading coordination and feasibility assessments to encourage investment in electric charging infrastructure for public truck parking facilities along the freight network. A first step is to identify where these type of parking facilities can be located, if possible. Longer term, this infrastructure could also help to shift vehicles to zero emission technologies. District 11 recently worked with a private vendor to provide electric infrastructure at a truck parking facility along SR 76.

- **Truck Platooning**. Several research teams have demonstrated the operation of Class 8 line-haul trucks using semi-automated platooning. UC Berkeley, in partnership with Caltrans, has demonstrated two linked vehicles. Other prominent demonstrations have occurred in Virginia.[51] Using vehicle-to-vehicle communication, radar, and active braking, two or more trucks can operate at high speeds in close proximity, which reduces aerodynamic drag. Recent tests by the National Renewable Energy Laboratory using two trucks in platoon showed fuel savings of up to 5.3% for the lead truck, up to 9.7% for the trailing truck, and a net savings of up to 6.4% for the platooned pair. Caltrans DRISI is supporting pilot projects in California to further explore this strategy.
- **Marine Highway 580**. Caltrans is supporting an assessment of the use of waterways to move freight between the Port of Oakland and Central Valley locations such as the Port of Stockton. Currently many shipping containers imported through the Port of Oakland are transported inland via truck on I-580. If tugs and barges were to transport these containers using the Sacramento River Delta, it could potentially reduce fuel consumption and emissions, while also mitigating highway congestion. The feasibility of this service depends on private sector interest, as barge travel adds significantly to the travel time. Caltrans will be sponsoring a network optimization study for the corridor to assess feasibility. Ultimately, achieving emission reductions through the use of a "Marine Highway 580" may also necessitate efficiency and emission control improvements to the tugs that propel the barges.
- **Supportive Local Development Decisions**. Caltrans is considering how to support sustainable freight movement through the Local Development-Intergovernmental Review (LD-IGR) process, discussed below. Caltrans is also considering how its guidance for complete streets projects can accommodate freight. With the growth of e-commerce and urban package delivery, there may be more conflicts between complete streets features and the parking needs of delivery trucks. Without parking options, double-parked delivery trucks can hinder transit service and contribute to excessive delay and idling among all vehicles using the street.

Smart Mobility and Active Transportation

Complete Streets Program

Caltrans Complete Streets Program promotes roadways that provide safe mobility for all users, including bicyclists, pedestrians, transit vehicles, truckers, and motorists, appropriate to the function and context of the facility. The program responds to Deputy Directive 64-R2, first signed in October 2008 and renewed in October of 2014, which directs Caltrans to implement complete streets:

[51] Loftus, Jeff, "Truck Platooning: The State of the Industry and Future Research Topics," presentation at the 2018 Transportation Research Board 97th Annual Meeting. https://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/docs/safety/395146/loftus-tershak-truck-platooning-final-508c.pdf

> "The Department provides for the needs of travelers of all ages and abilities in all planning, programming, design, construction, operations, and maintenance activities and products on the State Highway System."

Caltrans efforts that increase use of bicycle, pedestrian, and transit modes will typically result in a reduction in VMT and associated GHG emissions.

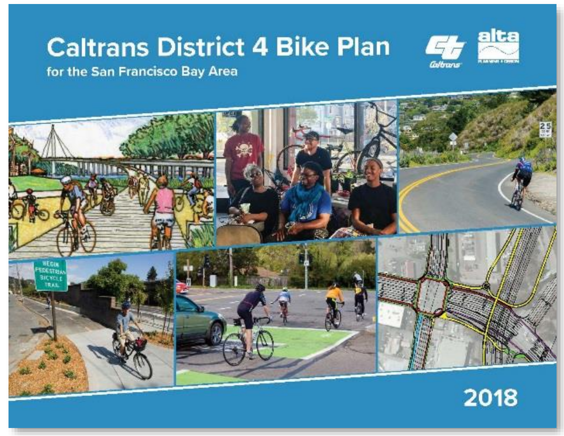
One outcome of this program has been the development of the Complete Streets Elements Toolbox. The Toolbox provides detailed information about specific roadway elements that can be designed and constructed to provide multi-modal mobility and access. Approximately 40 elements are included in the Toolbox, focusing on bicycle, pedestrian, and transit travel. For each of these elements, the Toolbox provides definitions and benefits, links to design guidance, and project examples. In addition, the Toolbox describes how Caltrans staff can quantify each Complete Streets element for entry into the SHOPP Tool. This is a critical step for securing funding for bicycle, pedestrian, and transit improvements as part of SHOPP projects. Project Initiation Documents (PIDs) developed for the 2018 and 2020 SHOPP cycles are required to consider complete streets elements.

Other Caltrans achievements related to Complete Streets include:

- Incorporation of active transportation projects into the Cal-B/C model. The Cal-B/C model is used by Caltrans staff to perform a life-cycle benefit/cost analysis for proposed state highway and public transit projects. The spreadsheet model was enhanced to include bicycle and pedestrian projects. The tool calculates benefit of these projects in terms of journey quality, travel time, safety auto accident and emissions, and public health. The project benefits are monetized (translated into dollar terms), which can then be compared to project costs as part of a benefit-cost analysis.
- Development of a Complete Streets brochure. The full-color brochure describes Complete Streets at a high level and includes examples and photos of Complete Streets projects on Caltrans facilities.
- Complete Streets overview training course. Caltrans contracted with UC Berkeley Tech Transfer to develop and deliver a Complete Streets overview training course specifically for Caltrans employees in all functional units. The course was delivered 12 times in 2014 – 2016.

District-Level Active Transportation Planning

Following on the publication of the statewide bicycle and pedestrian plan, Caltrans Districts are developing plans and leading related active transportation efforts. The first of these plans was released by District 4 in April 2018 – a Bike Plan for the San Francisco Bay Area. In addition to the plan, District 4 created a separate on-line mapping tool that offers a comprehensive interactive map of the projects in the plan.[52] Clicking on specific projects brings up details of those projects. Other District-level plans are under development.



Smart Mobility Framework

The Smart Mobility Framework (SMF) was introduced in 2010 is an important part of Caltrans efforts to achieve goals such as reduced vehicle travel and GHG emissions, better multimodal accessibility and safety, improved public health, and efficient use of resources. One of the core principles of Smart Mobility is location efficiency, which refers to the integration of transportation and land use at both the neighborhood scale and the regional/statewide scale. When these two dimensions of location efficiency are both strong, communities can achieve the full extent of smart mobility benefits in terms of higher levels of non-motorized travel, reduced vehicle trip making, and shorter vehicle trips. The Smart Mobility 2010 document provides high-level tools for applying the Framework. One is a set of Place Types and corresponding recommendations for planning activities, transportation projects and programs, and land development projects and programs. The second tool is a set of 17 Smart Mobility performance measures, intended for use in decision making at both the planning and project level to evaluate progress toward implementing the Smart Mobility principles and attaining Smart Mobility benefits. More recently, Caltrans developed a Smart Mobility Framework Guide, which provides more detailed instruction to Caltrans staff who are interested in implementing Smart Mobility strategies.

Local Development Intergovernmental Review (LD-IGR) Program

Caltrans coordinates and consults with local jurisdictions and Tribal Governments when proposed local land use planning and development may impact the State Highway System. Through the LD-IGR process, Caltrans advises Lead Agencies on what these impacts might be and ways to avoid, minimize, and/or mitigate adverse impacts. Caltrans also identifies land use and design strategies that may enhance connectivity and access to destinations.[53] Caltrans issued LD-IGR Interim Guidance in September 2016 to respond to recent legislation such as SB 743 and recent planning guidance such as the Smart Mobility Framework and the California Transportation Plan 2040. In the past, LD-IGR practices primarily used vehicle Level of Service to identify impacts to the State Highway System, and often limited

[52] Available at:
https://caltrans.maps.arcgis.com/apps/webappviewer/index.html?id=91f1bb4eb7ff418092977b762b459d01

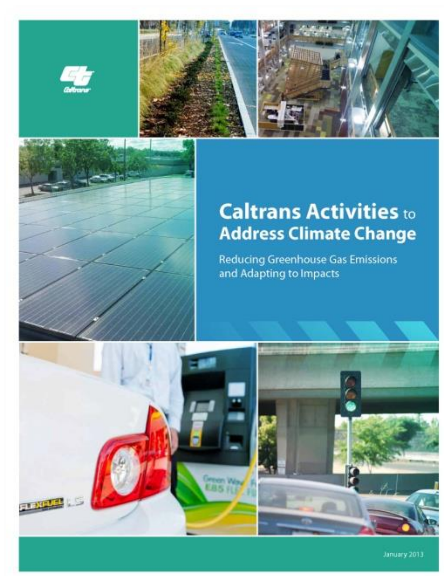
[53] Caltrans, Local Development Intergovernmental Review Program Interim Guidance, Approved – September 2, 2016

recommended mitigation to traditional road improvements. The 2016 Interim LD-IGR Guidance document is intended to ensure that all Caltrans comments on growth plans, development projects, and infrastructure investments align with state policies through the use of efficient development patterns, innovative demand reduction mitigation strategies, and necessary multimodal roadway improvements. Specifically, the Interim Guidance calls for Caltrans reviewers to include the following elements in their reviews:

- Reviewers should comment on vehicle miles traveled resulting from the land use project
- Provide recommendations that strive to reduce VMT generation; improve pedestrian, bike, and transit service and infrastructure; and which don't induce additional VMT.
- Reviewers should use the terms "transportation impact study" rather than "traffic impact study" and note that the study should analyze all modes.
- Comments related to impacts to the State Highway System (SHS) will be focused on VMT impacts not delay or effects on road capacity.

The Interim Guidance includes a flow chart and associated guidance to determine whether to comment on site-specific projects and what types of comments to make based on the type of project and its location. This guidance references the Smart Mobility Framework place types to help reviewers determine which comment guidance is most relevant for a given project.

Climate Change Program



The Climate Change Branch in Caltrans' Division of Transportation Planning is responsible for overseeing the development, coordination, and implementation of the Department's climate change policies. The Branch also serves as a Caltrans-wide resource for technical assistance, training, information exchange, and partnership-building. The Branch is focused on both GHG reduction efforts and climate change impacts and adaptation efforts. In 2013, the Branch published the report *Caltrans Activities to Address Climate Change: Reducing Greenhouse Gas Emissions and Adapting to Impacts*. The Branch also develops Caltrans annual GHG inventory for reporting to the Climate Registry and California EPA.

Project Planning

A transportation need is identified through Caltrans or partner agency planning processes or asset management programs. A transportation need can be a structural or operating deficiency of the existing transportation system or a response to planned land use changes. Caltrans and local agencies use a Project Initiation Document (PID) for determining the type and scope of project that will be developed to address the transportation need. The PID is a record of the purpose and need for the project, and the approach that will be taken to meet or reduce transportation deficiencies. The most important function of the PID is to establish a project as a viable candidate for Federal, State, regional, and local funds. A Project Study Report (PSR) is the most common type of PID.

For projects recommended for inclusion in the SHOPP, Caltrans requires an estimation of GHG emissions where possible. This requirement stems from Executive Order B-30-15, which states:

> *7. State agencies' planning and investment shall be guided by the following principles:*
>
> > *-Priority should be given to actions that both build climate preparedness and reduce greenhouse gas emissions;*

Caltrans has issued guidance for including GHG emissions calculations in SHOPP PIDs.[54] The guidance includes the following direction:

> "Under the new requirements of Executive Order B-30-15, Caltrans will need to define project-level performance in the Project Initiation Document (PID) work plan and SHOPP Tool, and PIDs must demonstrate project-level performance to be eligible for programming into the 2018 SHOPP. Project level performance needs to include a definition of condition improvement, complete streets components, climate change mitigation/adaptation elements, system performance, operational improvements, safety improvements or other tangible project level benefits." Kome Ajise, Chief Deputy Director-January 22, 2016

The guidance calls for use of the FHWA Infrastructure Carbon Estimator (ICE) Tool to perform the GHG estimation. The ICE Tool is specifically designed for estimation of GHG emissions at the planning stage, when all that may be known about a project is the type of work, the length of the project, and the number of lanes. The types of infrastructure that can be analyzed using the ICE Tool are:

- Roadway projects, including new facility, lane additions, lane widening, shoulder improvements, pavement rehabilitation and resurfacing.
- Parking facilities
- Bridges
- Rail line construction
- BRT construction
- Bicycle facilities
- Pedestrian facilities

The ICE Tool evaluation is typically performed by a District level project engineer (PE), who must sign off on the PID. The Caltrans guidance strongly encourages the PE to use the mitigation feature of the ICE Tool and document mitigation measures that can be employed in the project. Mitigation measures in the tool include concrete and asphalt pavement alternatives, alternative fuels and vehicle hybridization, and vegetation management. If the PID includes GHG mitigation, then the project with mitigation elements should be advanced to the California Transportation Commission for inclusion in the SHOPP, which increases the likelihood that the mitigation will be carried forward to design and construction.

[54] Caltrans, District Guidance for Including Greenhouse Gas (GHG) Emissions Calculations For 2018 & Future State Highway Operations and Protection (SHOPP) Project Initiation Documents (PIDs), November 2017- Version 4.

Sometimes at the environmental stage, a more detailed GHG analysis tool is used because there is more project detail by that stage (See Section 3.2 for more information). If so, then that GHG analysis will supersede the ICE analysis.

One of the benefits of GHG quantification and use of the ICE Tool at the SHOPP PID stage is the increased awareness on the part of Project Engineers. Project Engineers may not fully understand the GHG benefits of strategies like alternative concrete mixes, warm mix asphalt, etc. Caltrans has seen a difference in this GHG mitigation awareness in the two years they have been requiring use of the ICE Tool. And once a project is programmed in the SHOPP, these same engineers often do the project design, and they can continue to incorporate GHG mitigation at that stage. One challenge is that Caltrans project engineers often cannot specify a particular asphalt or concrete mix; they can only specify pavement performance characteristics and compliance with Caltrans standard specifications. Thus, there is currently a gap between the knowledge of pavement GHG reduction strategies (discussed in Section 4.2) and the ability of Caltrans to promote those strategies.

Planning Grants

In addition to developing policies and plans, Caltrans provides grants to support local planning for GHG reductions and other sustainability goals. Two current grant programs, Sustainable Communities Grants and Adaptation Planning Grants, were funded through Senate Bill 1 (SB 1, 2017), which allocated funding for transportation improvements. The Strategic Partnership Grant program is funded by FHWA and administered by Caltrans. Descriptions of these grant programs is included in Appendix A.

Environmental Analysis

Caltrans Division of Environmental Analysis administers Caltrans' responsibilities under federal and state environmental law. These laws include the National Environmental Policy Act (NEPA), the California Environmental Quality Act (CEQA), and a variety of other environmental laws and regulations. The Division of Environmental Analysis develops and maintains Caltrans environmental standards, policies, procedures, and practices that are implemented by the 12 District Environmental Branches. Program staff work with the districts to identify and assess the effects of Caltrans projects on California's natural and cultural environments and on the climate, and identify ways to avoid or mitigate those effects.

Caltrans has developed Environmental Document Annotated Outlines in order to provide a consistent document format for the presentation of required content in NEPA and CEQA documents. The actions of the Division of Environmental Analysis do not by themselves reduce GHG emissions. However, the environmental documentation produced by the Division can help to Caltrans staff make more informed decisions about project design in ways that can lead to GHG reductions.

Implementation of SB 743 places a new emphasis on reducing VMT and highlights the nexus between VMT reduction and the State's climate change goals. Governor Jerry Brown signed SB 743 on September 27, 2013, which mandated a change in the way that public agencies evaluate transportation impacts of projects under CEQA, focusing on VMT rather than level of service (LOS) and other delay-based metrics. SB 743 states that new methodologies under CEQA are needed for evaluating transportation impacts that are better able to promote the state's goals of reducing GHG emissions and traffic-related air pollution, promoting the development of a multimodal transportation system, and providing clean, efficient access to destinations. Amendments to the CEQA Guidelines shifting the focus of the transportation impact analysis from automobile delay to VMT were adopted in January 2019.

While the 2019 CEQA Guideline Amendments do not change the GHG impact analysis considerations, they bring CEQA transportation analyses into closer alignment with statewide policies on GHG emissions and smart growth. To facilitate implementation of the 2019 CEQA Guideline Amendments, the Governor's Office of Planning and Research (OPR) published the *Technical Advisory on Evaluating Transportation Impacts in CEQA* (Technical Advisory), which includes recommended VMT thresholds for various types of land use projects. These thresholds connect the level of VMT reduction to the State's emissions goals. The Technical Advisory does not currently provide a numeric VMT threshold for transportation projects, but notes that "a transportation project which leads to additional vehicle travel on the roadway network… would need to quantify the amount of additional vehicle travel in order to assess air quality impacts [and] greenhouse gas emissions impacts".[55]

Caltrans has prepared guidance documents addressing the Department's transportation analysis and CEQA procedures consistent with SB 743. These include:

- **Transportation Analysis Framework** (TAF): This document provides guidance for CEQA transportation/traffic analysis for projects on the SHS, including direction to Caltrans Districts related to selecting methods for VMT analysis (including induced travel demand) in project-level environmental documents reflecting both project type and context (urban vs. rural).
- **Transportation Analysis under CEQA for Projects on the State Highway System** (TAC): The TAC provides methodologies for CEQA practitioners to evaluate the transportation impacts of projects on the SHS, including how to determine significance of those impacts, and identifies potential mitigation measures.

Project-level GHG Analysis for Operational Emissions

For projects that provide congestion relief or otherwise increase roadway capacity (including operational improvement projects that are expected to address future demand volumes), Caltrans guidance calls for developing a quantitative analysis of GHG emissions using either the CT-EMFAC2014 or CT-EMFAC2017 model. The Annotated Outlines provide instructions for this analysis, as follows:

> *[C] conduct separate model runs for existing/baseline conditions (existing conditions at the time of the Notice of Preparation [NOP] or existing conditions at the time the environmental analysis began), and the design-year for both the build and no-build alternatives. It is also helpful to include an intermediate year such as the open-to-traffic year. Summarize this information in a table that includes the VMT projections used for the CT-EMFAC model run and the resulting annual metric tons of CO_2e. A sample table format is provided for your convenience. Please modify it to fit the proposed project.*

[55] Governor's Office of Planning and Research. *Technical Advisory on Evaluating Transportation Impacts in CEQA*. December 2018. http://opr.ca.gov/docs/20190122-743_Technical_Advisory.pdf

Table ##: Modeled Annual CO_2 Emissions and Vehicle Miles Traveled, by Alternative

Alternative	*CO_2 Emissions (Metric Tons/Year)*	*Annual Vehicle Miles Traveled*
Existing/Baseline 20XX	*XX*	*XX*
Open to Traffic 20XX		
No Build	*XX*	*XX*
Build Alternative 1	*XX*	*XX*
Build Alternative 2	*XX*	*XX*
20-Year Horizon/Design-Year 20XX		
No Build	*XX*	*XX*
Build Alternative 1	*XX*	*XX*
Build Alternative 2	*XX*	*XX*

Project analyses should also identify applicable policies from the local RTP/SCS and analyze whether the project is consistent with regional goals to reduce VMT, congestion and delay, and vehicle-related GHG emissions. The analysis should discuss how modal choice was considered in the early planning phases of the project and explain how transit-only or multi-modal alternatives were assessed and/or eliminated. Existing transit infrastructure and how it connects with the project should also be discussed.

For non-capacity-increasing projects, Caltrans guidance recommends performing a qualitative analysis that describes why an increase in operational GHG emissions is unlikely. Examples of projects that are likely to have minimal or no increase in operational GHG emissions are listed below. OPR's Technical Advisory includes additional example project types for reference. The Technical Advisory also notes that transit and active transportation projects, including all passenger rail projects, bus and bus rapid transit projects, and bicycle and pedestrian infrastructure projects, generally reduce VMT.[56]

- Pavement rehabilitation
- Shoulder widening
- Culvert/drainage/storm water work
- Landscaping
- Closed-circuit television (CCTV)
- Maintenance vehicle pullouts
- Minor curve corrections

Caltrans' Annotated Outlines further identify ramp metering and signalization projects as potentially eligible for a qualitative assessment of operational GHG emissions. The analysis should discuss traffic-soothing effects and the extent to which the signal or meter provides for smoother traffic flow. However, if the ramp or signal creates lengthy traffic queues, a quantitative emissions analysis should be conducted using CT-EMFAC.

[56] Governor's Office of Planning and Research. *Technical Advisory on Evaluating Transportation Impacts in CEQA*. December 2018. http://opr.ca.gov/docs/20190122-743_Technical_Advisory.pdf.

Project-level GHG Analysis for Construction Emissions

Construction GHG emissions must be calculated for all projects per the requirements of EO B-30-15. The Annotated Outlines call for using the Sacramento Metropolitan Air Quality Management District's Road Construction Emissions Model or the Caltrans Construction Emissions Tool (CAL-CET) to quantify the expected construction-related GHG emissions related to a proposed project.

The Road Construction Emissions Model requires users to enter information about the project, including:

- Project type (new road construction, road widening, bridge/overpass construction, or other linear project type)
- Project length and area
- Volume of soil and asphalt brought to or from the construction site
- Use of water trucks (for dust control)

Using these inputs and emission factors from EMFAC, the model calculates emissions resulting from the movement of construction equipment.

GHG Reduction Strategies in Environmental Documents

When environmental analyses determine that a project or program will result in significant GHG impacts, the impacts must be mitigated. Strategies to reduce GHG emissions generated during construction and operation of a transportation project must be specific and enforceable. The environmental analysis must describe, either quantitatively or qualitatively, the expected GHG reduction benefits of each measure. Due to the global nature of GHG emissions, mitigation to reduce an individual project's GHG impacts may be implemented on the project site or at an offsite location. Successfully reducing project-generated GHG emissions requires early consideration of relevant reduction measures and strategies, preferably during the initial project planning and design.

Caltrans Division of Environmental Analysis has developed lists of strategies that could be used for mitigating potentially significant GHG impacts from construction and operation of transportation projects.[57] Individual projects should carefully evaluate the feasibility of any reduction strategy before it is required as project-specific mitigation. In addition to project-specific reduction measures, Caltrans guidance also recommends discussing all applicable Standard Specifications, Standard Special Provisions, Nonstandard Special Provisions, and measures from other resource topics (e.g., air quality) that will reduce GHG emissions.

GHG Analysis Tools

Because of its responsibility to quantify GHG emissions as part of environmental documents, the Division of Environmental Analysis maintains the most comprehensive understanding of GHG emissions analysis tools and methods within Caltrans. Staff from the Division of Environmental Analysis actively

[57] Caltrans, GHG Reduction Measures Toolbox for Internal Use in Caltrans Project Development, January 2020.

monitor improvements to existing tools and development of new tools. The Division has compiled a list, summarized below, of GHG analysis tools current used by Caltrans in some form.

Table 11. GHG Emissions Analysis Tools Used by Caltrans

Tool Name	Developer	Description
Cal-B/C Tool	Developed by Caltrans Transportation Economics Branch and consultants	A PC-based spreadsheet model. Can be used to analyze many types of highway construction and operational improvement projects, some Intelligent Transportation System (ITS) and transit projects, bike and pedestrian projects, park-and-ride lots, and intermodal freight projects.
SB-1 Emissions Tools	Developed by Caltrans Transportation Economics Branch and consultants using similar methodology developed by the CARB for California Freight Investment Program	Excel-based tool that estimates emissions from changes in VMT, service-miles, ton-miles, and speeds. Users enter the input data and model will calculate emission reduction results. Tool should only be used to analyze projects that do not fall under any project category types in Cal-B/C tool.
SMAQMD Roadway Construction Emissions Model (RCEM)	Developed by Sacramento Air Quality Management District (SMAQMD)	Excel-based tool to estimate construction equipment emissions for roadway projects. Requires detailed project design and construction inputs to estimate construction equipment usage and the resulting emissions. The required information is mostly only available at the PA&ED or later phases of the project development process. Recommended for use on Caltrans projects for environmental analysis during PA&ED.
FHWA Carbon Infrastructure Estimator (ICE) tool	Developed by U.S FHWA	Excel-based tool that estimates the lifecycle energy and GHG emissions from the construction and maintenance of transportation facilities. Requires limited data inputs and is designed to inform planning and pre-engineering analysis. Allows users to create “ballpark” estimates of energy and GHG emissions using limited data inputs. Tool is current being updated and expanded as part of a pooled fund study. Caltrans uses ICE to calculate GHG Emission for 2018 and future SHOPP PIDS.
EMission FACtors (EMFAC)	Developed by CARB	The mobile source emission tool that CARB developed to assess emissions from on-road vehicles in California. EMFAC provides emission rates to calculate project emissions. EMFAC is required for air quality analyses in compliance with transportation conformity, NEPA, and CEQA as a part of the Environmental Document (PA&ED).

Tool Name	Developer	Description
CT-EMFAC	Developed by Caltrans Headquarter, Division of Environmental Analysis (HQ DEA), Air Quality Program	Caltrans DEA created the CT-EFMAC to expedite and streamline the efforts required to complete project-level emission analyses.
GHG Emissions Calculator	Developed by Caltrans HQ DEA, Air Quality Program	Excel-based tool to estimate GHG emissions from on-road vehicles in California. Because EMFAC2014 includes only CO_2 and CH_4 emission rates, the GHG Emission Calculator expand on EMFAC2014 data to include N2O, black carbon, and hydrofluorocarbons (HFCs).
Caltrans Construction Emissions Tool (CAL-CET)	Developed by Caltrans HQ DEA, Air Quality Program	Excel-based tool to estimate construction equipment emissions on Caltrans highway projects. The tool utilizes engineering economic principles based on construction Forced Account calculations to estimate equipment usages and the resulting emissions. CAL-CET was created based on data collected from Caltrans construction projects.
Climate Registry Information System (CRIS)	The Climate Registry	Online emissions calculator that converts energy, material, and fuel consumption into GHG emissions (CO_2e) using the latest international reporting protocols and emissions factors (IPCCC's Fifth Assessment Report). The tool includes all seven recognized GHG pollutants in their calculation of CO_2e. This is the required tool for Caltrans' annual GHG report to CalEPA – the "State Agency Greenhouse Gas Reduction Report Card".

Promoting Alternative Fuel Use on the State Highway System

In response to the Governor's ZEV Action Plan, Caltrans is installing EV charging for public use along the State Highway System. One part of this program is focusing on installation of DC fast charge stations at Department-owned, publicly accessible locations. Caltrans is developing 11 DC fast charging projects at 37 locations consisting of 49 individual charging units. The projects are located throughout the state at 28 safety roadside rest areas, 5 maintenance stations, 2 District offices, and 2 park-and-ride lots. The proposed DC fast charging locations will address gaps in the state's EV charging infrastructure, since the vast majority of fast charging stations are currently located in urbanized areas and do not serve long-distance travelers. Caltrans estimates that most of the units will be operational by summer or fall of 2020. Operational status will be dependent upon the ability of electric utilities to provide the needed electrical service upgrades.

Traffic Operations

Caltrans Traffic Operations Program performs a variety of activities intended to maximize the mobility and safety of travelers on the State Highway System. While these programs do not reduce VMT, when they result in smoother traffic flow and reduced delay, they can reduce GHG emissions. As discussed in Section 3.1 and illustrated in Figure 6, motor vehicles exhibit their lowest CO_2 emission rates around 40 mph. Vehicles in congested traffic, with queuing and stop-and-go conditions, produce much higher emissions per mile of travel, so systems operations improvements that reduce or eliminate these conditions can reduce GHG emissions. However, emission rates start to increase as speed increases above 40 mph, so not all delay reduction necessarily equates to GHG reduction.

The emissions impacts of traffic operations strategies are complex and not well understood. One reason for this is that evaluating the impacts of traffic operations strategies using controlled field experiments is difficult and costly. Thus, most studies use simulation models, which inherently raises questions about how well these models reflect actual conditions. In addition, when traffic operations strategies succeed in reducing delay, they can also induce new vehicle travel, which can potentially offset the emissions benefits of speed improvements.

The available research is insufficient to make definitive statements about the conditions under which traffic operations strategies will reduce emissions and by how much. Nearly all of the published research does not consider induced vehicle traffic effects, so reports of GHG emissions benefits are generally overstated.[58] The remainder of this section discusses some specific traffic operations programs at Caltrans and the available research on their GHG impacts.

Traffic Signal Management

Caltrans works to refine signal synchronization to improve traffic flow and reduce idling time. Caltrans Headquarters works with Districts to coordinate their signals. As individual signals are synchronized, they are connected to a central signal control system. Centralized signal control increases efficiency, as a decentralized system requires that GPS units maintain the timing on each individual signal. Using a remote traffic signal management surveillance system, Caltrans aims to control roughly 5,000 of its traffic signals remotely, which reduces the need for staff to physically go to a signal to monitor and improve signal timing, conduct maintenance, or fix failed signals.

The impact of traffic signal coordination on GHG emissions is highly context-specific and has not received extensive research attention. A meta-analysis conducted for CARB identified four studies that estimated GHG impacts of signal coordination, three of them outside the U.S.[59] The estimated GHG

[58] Rodier, Caroline, Susan Handy, and Marlon Boarnet, "Impacts of Traffic Operations Strategies on Passenger Vehicle Use and Greenhouse Gas Emissions, Technical Background Document, Prepared for the California Air Resources Board, 2014. https://ww2.arb.ca.gov/sites/default/files/2020-06/Impacts_of_Traffic_Operations_Strategies_on_Passenger_Vehicle_Use_and_Greenhouse_Gas_Emissions_Technical_Background_Document.pdf

[59] Rodier, Caroline, Susan Handy, and Marlon Boarnet, "Impacts of Traffic Operations Strategies on Passenger Vehicle Use and Greenhouse Gas Emissions – Policy Brief," 2014. https://ww3.arb.ca.gov/cc/sb375/policies/tsm/tos_brief.pdf

reductions ranged from 1 to 10 percent. Note that none of these studies considered the potential for induced vehicle travel.

Ramp Metering

Caltrans uses ramp metering to improve freeway traffic flow in many congested corridors. Caltrans is currently seeking to increase use of adaptive ramp metering, whereby ramp meters are adjusted dynamically in response to traffic conditions, as opposed to pre-timed or fixed time rates. This feature allows system managers to actively control the rate of vehicles entering the freeway and prevent back-up queues from spilling onto local roads.

The effects of ramp metering on fuel consumption and GHG emissions are complex and not well understood. When ramp metering improves highway traffic flow by eliminating bottlenecks around entrance ramps, the result will be a reduction in GHG emission rates for vehicles on the highway. However, ramp metering can cause an increase in stop-and-go traffic at the ramps, increasing emissions and fuel consumption. Furthermore, by improving highway travel speeds, ramp metering has the potential to induce new vehicle traffic (discussed in Section 3.1), which could offset GHG emissions benefits of traffic flow smoothing. The net GHG emissions impact resulting from these different effects will vary from project to project, making it difficult to generalize about the GHG impacts of ramp metering.

Bay Area Ramp Meter (source: MTC)

Very few research studies have reported on the system-wide GHG emissions impacts of ramp metering. One of the only such studies used simulation modeling to estimate the CO_2 emissions effects of ramp metering on a South Korean highway, finding a 7.3 percent emission reduction.[60] However, this study

[60] Bae S., T. Heo, and B. Ryu. "An Evaluation of the Ramp Metering Effectiveness in Reducing Carbon Dioxide Emissions," Society for Modeling and Simulation International, Korea, 2012.

did not consider induced vehicle travel. A meta-analysis conducted for CARB identified no other relevant research and noted that any reported impacts could not be generalized beyond the particular region or time period of the study.[61]

Traffic Incident Management

Caltrans works with the California Highway Patrol and local and regional transportation agency and public safety partners to implement traffic incident management programs in the state's large metropolitan areas. Traffic incident management programs are intended to quickly respond to vehicle crashes and other highway incidents. Clearing a freeway following an incident will reduce the associated congestion and vehicle emissions. FWHA estimates that about half of all congestion is non-recurrent congestion attributable to temporary disruptions, and one-quarter is caused by traffic incidents in particular.[62]

Like other traffic operations strategies, the GHG emissions impacts of traffic incident management programs are not well understood. Research typically relies on traffic simulation models to estimate the impact of incidents on traffic speeds, and the corresponding benefits of more rapid incident clearance. A meta-analysis conducted for CARB identified three studies that estimated GHG impacts of incident management programs, with fuel use or GHG benefits ranging from 0.07 percent to 4 percent.[63] The most relevant of these studies examined clearance of lane blockages on a highway corridor in Montgomery County, Maryland, during the AM peak, finding a 4 percent reduction in CO_2 emissions.[64] MTC claims its freeway service patrol program reduces "auto carbon emissions by approximately 67,000 tons annually".[65] The existing research on incident management program impacts does not consider induced vehicle travel, and therefore likely overstates GHG benefits.

Roundabouts

Caltrans' Intersection Control Evaluation policy encourages consideration of roundabouts. Historically, if an uncontrolled intersection experienced a history of collisions, the default approach was to install a traffic signal. Now, Caltrans considers the intersection needs more holistically, which could involve a variety of options. One result is the more frequent use of roundabouts. Roundabouts can offer several benefits over signalized intersections in some circumstances. They can reduce the number and severity of crashes, eliminating head-on or broadside collisions.[66] Roundabouts can also reduce maintenance costs because they do not require periodic retiming or electrician visits in the event of a signal outage.

---

[61] Rodier, C., Handy, S., and Boarnet, M., Impacts of Traffic Operations Strategies on Passenger Vehicle Use and Greenhouse Gas Emissions – Policy Brief, 2014. https://ww3.arb.ca.gov/cc/sb375/policies/tsm/tos_brief.pdf

[62] FHWA, https://ops.fhwa.dot.gov/program_areas/reduce-non-cong.htm

[63] Rodier, C., Handy, S., and Boarnet, M., Impacts of Traffic Operations Strategies on Passenger Vehicle Use and Greenhouse Gas Emissions – Policy Brief, 2014. https://ww3.arb.ca.gov/cc/sb375/policies/tsm/tos_brief.pdf

[64] Avetisyan, H. G., Miller-Hooks, E., Melanta, S., & Qi, B. (2014). Effects of vehicle technologies, traffic volume changes, incidents and work zones on greenhouse gas emissions production. Transportation Research Part D: Transport and Environment, 26, 10-19.

[65] MTC, Bay Area Freeway Service Patrol, www.fsp-bayarea.org/About-us

[66] FHWA, Office of Safety, "Roundabouts" https://safety.fhwa.dot.gov/intersection/innovative/roundabouts/

Roundabout on Route 138 in Palmdale

The GHG emissions impacts of roundabouts depends on how the devices affect traffic flow, particularly traffic speeds, acceleration, and deceleration. The emissions impacts also depend on what a roundabout is compared against: an uncontrolled intersection, stop signs, or traffic signals. Because they create less vehicle delay and idling, roundabouts have the potential to lower fuel use and emissions in some cases. Available research suggests that roundabouts can reduce emissions in some circumstances but increase emissions in others. A study in Sweden found that replacement of a signalized intersection with a roundabout reduced fuel consumption by 28 percent, but a study in Maryland found a 5 percent fuel increase and a 1 percent CO_2 increase from a similar replacement. A meta-analysis conducted for CARB concludes: “Given the wide range of estimated impacts, it is not possible to conclude that roundabouts will reduce fuel consumption and GHG emissions in all cases.”[67]

Other Traffic Operations Strategies

Caltrans has a variety of other strategies to improve traffic flow, including:

- Reversible lanes, which Caltrans is testing along the Coronado Bridge on I-15 in San Diego.
- Work zone strategies to reduce traffic delay.
- Working with a private vendor, Pre-Pass, Caltrans allows heavy vehicles that are preregistered to bypass open weigh stations legally. Doing so reduces truck delay at these stations and the associated emissions.
- Integrated corridor management (ICM), which uses advanced technology to monitor and actively manage traffic through an entire highway corridor. Key features of ICM can include adaptive ramp metering, incident management, enhanced traffic signal control, transit signal priority, and system integration
- Traveler information systems, which enable drivers to select routes and travel times to avoid unnecessary delay. The Caltrans QuickMap is a web page and mobile app that presents several types of real-time traffic information layered on a Google Map, including traffic speed, lane and

[67] Handy, Susan and Marlon Boarnet, “Impacts of Roundabouts on Passenger Vehicle Use and Greenhouse Gas Emissions: Policy Brief,” Prepared for the California Air Resources Board, 2014. https://ww3.arb.ca.gov/cc/sb375/policies/rndabt/roundabout_brief.pdf

road closures due to construction and maintenance activities, incident reports, changeable message sign content, camera snapshots, and active chain control requirements.

There is little to no information on the GHG impacts of these types of traffic operations strategies.

4 Reducing Emissions from Caltrans Internal Operations

Caltrans has the vast responsibility of planning, designing, building, operating, and maintaining the State Highway System – a network of more than 50,000 lane miles and more than 12,000 bridges. To carry out these activities, Caltrans employs more than 19,000 workers, many located in the Caltrans Sacramento Headquarters or in one of the 12 District offices. Other staff work from the approximately 250 Caltrans maintenance stations, equipment shops, and transportation management centers. Caltrans operates a fleet of more than 7,000 automobiles and light trucks and more than 1,000 heavy-duty vehicles. Caltrans also operates 86 Safety Roadside Rest Areas across the State. These activities and facilities offer numerous opportunities to reduce GHG emissions resulting from Caltrans own internal operations.

Caltrans has been working to conserve energy and natural resources for more than three decades. The Department has already taken a variety of actions that reduce GHG emissions from its internal operations, including deploying electric vehicles and other alternative fuels in its fleet, installing energy efficient lighting along roadways and in buildings, generating renewable energy with solar power, conserving water, and using recycled materials.

Actions that can achieve additional GHG emission reductions primarily involve expansion of or modification to existing efforts, including:

- Increasing renewable energy generation, focusing on solar power in the highway right-of-way
- Using the latest pavement lifecycle assessment research to modify highway construction and maintenance practices to maximize GHG reduction
- Reducing emissions associated with employee commuting by offering more attractive programs and incentives to encourage travel by less carbon-intensive modes

The remainder of this section describes actions to reduce Caltrans internal operations emissions – both on-going activities and opportunities for additional reductions. The descriptions are organized according to major Caltrans functional areas:

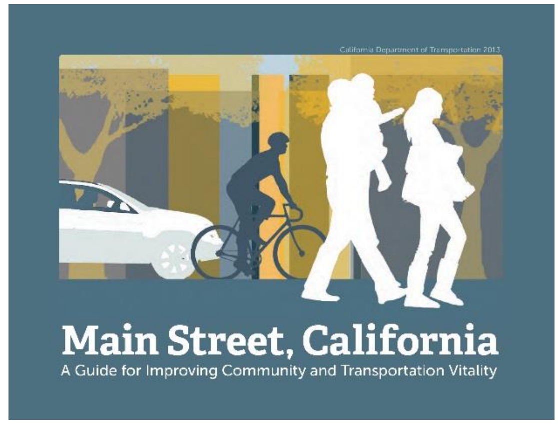
- Design and Construction
- Pavements
- Maintenance
- Vehicle Fleet and Equipment
- Facilities and Administration

Where possible, the report provides estimates of the magnitude of GHG emission reductions associated with recent and on-going activities.

4.1 Design and Construction

Caltrans oversees the design and construction of projects on the State Highway System. The Division of Design develops standards and guidance for highway system improvements, often working closely with other Caltrans divisions. The Division of Construction administers roughly $8 billion worth of construction contracts. A variety of design and construction efforts reduce GHG emissions by supporting multi-modal travel that can reduce VMT, promoting the use of construction materials with lower carbon intensity, and encouraging more energy efficient construction techniques.

Design to Encourage Complete Streets



Caltrans Highway Design Manual (HDM) has been has been updated several times in recent years to facilitate the design of complete streets. The Division of Design also led the creation and update of *Main Street, California: A Guide for Improving Community and Transportation Vitality*. The Main Street guide promotes flexible design of state highways that serve as local main streets. The guide describes planning and design strategies to improve community livability through the creation of a high-quality public realm that supports economic vitality, ecological quality, and community quality of life. *Main Street, California* highlights design options that are compatible with established traffic engineering and design practices, policies, and standards.

Caltrans endorsed the *National Association of City Transportation Officials (NACTO) Urban Street Design Guide* in 2014.[68] In the endorsement, Caltrans stated that the "endorsement of the NACTO guidelines is part of an ongoing effort to integrate a multimodal and flexible approach to transportation planning and design."

Caltrans has recently made some changes to its design exceptions process to more overtly encourage flexible design. For example, recent changes to the HDM included replacing the nomenclature for "mandatory" and "advisory" standards with boldface and underlined standards, respectively. The HDM update also replaced the Design Exception Fact Sheet with a Design Standard Decision Document.

Contracting Methods to Encourage Use of Clean Equipment

Caltrans' Office of Innovative Design and Delivery develops and tests alternative contracting techniques. For instance, contracts could be awarded based on contractors' ability to meet sustainability criteria such as GHG emission reduction.

As one example of this approach, Caltrans initiated a pilot program to promote Tier 4 low emission construction equipment. Tier 4 is the most stringent U.S. EPA emission standard off-road diesel equipment. The standards took full effect in 2015 and require significant reductions in NOx and PM emissions from new off-road equipment engines. However, most construction equipment in use today

[68] Caltrans (April 11, 2014). "Caltrans Backs Innovative Street Design Guides to Promote Biking and Walking."

was manufactured before 2015 and therefore does not meet the Tier 4 standard. Caltrans' pilot program was intended to accelerate deployment and use of Tier 4 equipment.

Under the pilot program, project RFPs were released that asked contractors to respond with one bid that includes Tier 4 equipment and one that does not. This was intended to enable Caltrans to quantify the incremental cost of using Tier 4 equipment. Two projects under this pilot have already been initiated, one in District 6 and one in District 8. The contractors agree to exclusively use Tier 4 equipment on the project, or otherwise pay a penalty of $2,000 per day per piece of non-compliant equipment operated.

Since the Tier 4 emission standard focuses on NOx and PM emissions and does not affect GHG emissions, this current pilot program does not achieve significant GHG reductions. However, the pilot serves as a model that, in theory, could be replicated for GHG reductions. For example, Caltrans could issue construction project RFPs that specify use of alternative fuels (e.g., renewable diesel) or battery electric or hybrid-electric equipment (if available).

Construction Methods and Specifications

Caltrans has advanced several construction methods that improve efficiency and thereby reduce fuel consumption and GHG emissions.

Automated Machine Guidance

Caltrans established requirements for contractors to create three-dimensional models of large construction projects. The contractors then use these models to plan how their equipment will be operated and to program the construction equipment. Using GPS, the construction equipment can execute the project, following the 3-D models, with little human intervention. This approach is called Automated Machine Guidance (AMG). AMG results in faster construction of projects and reduced equipment idling time, which reduces GHG emissions. Prior to using AMG, equipment would idle while survey crews were putting stakes in the ground; this is no longer necessary. The model also enables contractors to more efficiently plan for material movement, rather than stockpiling materials in one spot then moving them out to different locations.

Grader equipped with AMG

Intelligent Compaction

When paving roads, Caltrans has historically had an operator running a compactor for pre-specified number of passes. Caltrans has approved a new procedure called Intelligent Compaction that utilizes a GPS system and temperature sensors attached to the compactor rollers, which can determine precisely how many passes are needed to adequately compact the pavement. The result is more efficient use of the compactor equipment compared to the traditional static rollers. This reduces the time associated with compaction, and also reduces fuel consumption and associated GHG emissions. Another benefit of this strategy that it achieves optimum pavement density to ensure long lasting roadway performance.

In 2014, Caltrans developed two new specifications to allow use of intelligent compaction for construction of hot mix asphalt (HMA) and Cold In Place Recycling (CIR). Since then, dozens of Caltrans projects have used this technique, and it is expected to become standard practice in the near future.

Intelligent Compaction Retrofit Equipment Evaluation- El Dorado Hills, CA 2014

Field Engineer Tablet Pilot Study

Caltrans conducted a pilot project to evaluate the use of mobile devices (tablets) in the construction administration process. Use of tablet computers provides a substitute for hardcopy engineering drawings kept in the project field office, allowing the engineers to spend more time in the field and less time traveling back to an office to retrieve plans, which reduces VMT. For the pilot, tablets were deployed on eight contracts. The goal of the pilot was to evaluate the potential for tablets to improve staff performance, increase transparency, and incorporate sustainability into current construction practices. A report on the pilot estimates that, if tablets were used on all Caltrans construction contracts, the annual GHG savings would total 1,450 tons.[69]

Accelerated Bridge Construction

Accelerated bridge construction (ABC) uses innovative planning, design, materials, and construction methods to reduce the onsite construction time to build new bridges or rehabilitate existing bridges.[70] The benefits of ABC include: reduced mobility impacts to motorists; enhanced safety to motorists and construction personnel; reduced environmental impacts; reduced construction impacts to local communities; and potential improvement to construction quality. ABC can involve a range of methods that can be categorized as follows:

- Prefabricated Bridge Elements and Systems (PBES), which are bridge structural components that are fabricated offsite, or near-site of a bridge, and include features that reduce the onsite construction time and mobility impact time compared to conventional construction methods.[71]
- Geosynthetic Reinforced Soil-Integrated Bridge System (GRS-IBS), which comprises components such as reinforced soil foundation, abutment, and integrated approach, and involves use of alternating layers of compacted granular fill and geosynthetic reinforcement to enable bridge loads that are significantly higher than designed with predictable and reliable performance.[72]
- Structural placement methods, such as self-propelled modular transporters (SPMT) and slide-in bridge construction, to facilitate rapid placement and positioning of the bridge.[73]
- Ultra-High Performance Concrete (UHPC) Connections for PBES. UHPC is defined as steel fiber-reinforced, portland cement-based concrete – an advanced composite material that delivers enhanced performance compared to conventional concrete mixtures. Benefits of using field-cast

[69] Caltrans Division of Construction, "Report on Mobile Device Pilot Project," April 2017.
[70] FHWA. Accelerated Bridge Construction. www.fhwa.dot.gov/bridge/abc/.
[71] FHWA. Prefabricated Bridge Elements and Systems. www.fhwa.dot.gov/bridge/prefab/.
[72] FHWA. Geosynthetic Reinforced Soil-Integrated Bridge System. www.fhwa.dot.gov/innovation/everydaycounts/edc-3/grs-ibs.cfm.
[73] FHWA. Structural Placement Methods. www.fhwa.dot.gov/bridge/abc/structural.cfm.

UHPC to create connections between prefabricated concrete components includes improved speed and simplicity of construction.[74]

Since most of the ABC technologies involve partial or complete fabrication of bridge components off-site in a fabrication facility staging area near the site, they eliminate the need for temporary bridges and additional right of way, as well as deep/pile foundations that are abrasive to the environment and could result in increased GHG emissions due to equipment usage. FHWA estimates indicate that since October 2010, more than 800 bridges have been designed or constructed using PBES, and over 80 bridges using GRS-IBS (eight on the National Highway System and 75 off the National Highway System). In addition, several states have successfully completed bridge installations using slide-in bridge construction.[75]

Caltrans has successfully implemented ABC technologies on several projects. Examples include use of SPMTs on the 2014 Highgrove project in San Bernardino County and use of longitudinal launch to facilitate the emergency replacement of the Pfeiffer Canyon Bridge on Highway 1 in Big Sur (pictured below).

Pfeiffer Canyon Bridge Launch

(Source: Monterey Herald)

Precast Concrete Pavement System

Like PBES, Precast Concrete Pavement System (PCPS) technology involves an off-site fabrication approach that allows for construction of lighter, thinner, or more durable pavement sections through more stringent quality control and the use of design details not feasible for in-place construction. The applications of PCPS include isolated intermittent repairs, intersection and ramp rehabilitation, pavement replacement under overpasses, and construction of longer mainline pavement segments. PCPS technology can aid in faster construction while maintaining pavement quality, and help minimize

[74] FHWA. Ultra-High Performance Concrete Connections for PBES. www.fhwa.dot.gov/innovation/everydaycounts/edc_4/uhpc.cfm.

[75] FHWA. www.fhwa.dot.gov/innovation/everydaycounts/edc-2/pdfs/edc_abc.pdf.

lane closures and traffic disruption, in turn reducing GHG emissions. The advantages of PCPS over traditional cast-in-place methods include: shorter installation time; improved concrete curing conditions; reduced weather restrictions on placement; reduced delay before opening to traffic; elimination of construction-related early-age failures; and longer-life performance compared to traditional cast-in-place methods.[76]

Precast Concrete Pavement Installation
(Source: Kirsten Stahl, Caltrans)

PCPS has been effectively implemented across 25 states, including California; however, the technique is still not widely used. To date Caltrans has developed standard plans and specifications for intermittent repairs, jointed precast pavements (PCP), and prestressed PCP. The Department has implemented PCPS across in several Districts, such as the use of a series of 36-ft prestressed panels placed on a rapid-set lean concrete base and posttensioned to replace long sections of I-680 in District 4, and installation of over 2,300 California Rapid Roadway system panels along Highway 101 in District 7 through downtown Los Angeles.[77]

The GHG benefits of PCPS result primarily from the reduction traffic disruption and delay, and therefore are highly context-specific. There is little research available on the GHG impacts of this strategy.

[76] FHWA. Precast Concrete Pavement Systems. www.fhwa.dot.gov/goshrp2/Solutions/Renewal/R05/Precast_Concrete_Pavement

[77] Tayabji, S., and Brink, W. *Precast Concrete Pavement Implementation by US Highway Agencies*. Report No. FHWA-HIF-16-007). FHWA, Washington DC. 2015.

4.2 Pavements Strategies

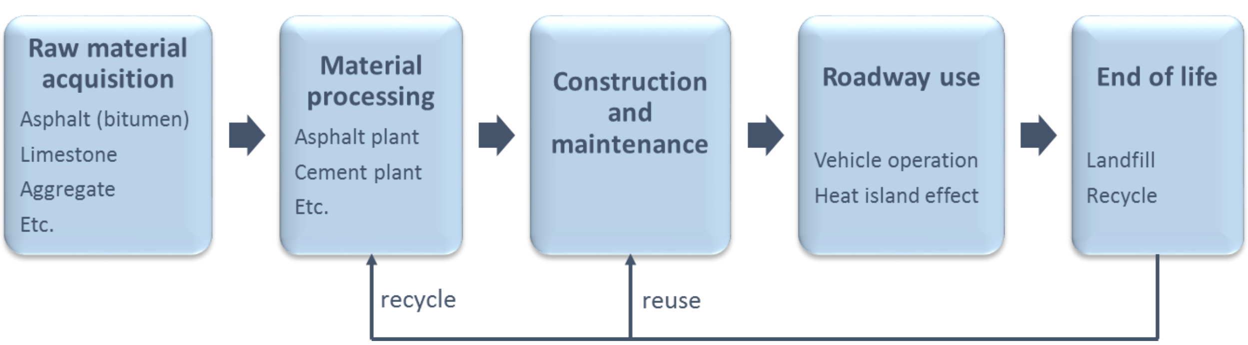
Millions of tons of asphalt and concrete are used in Caltrans roadway and bridge projects every year. As noted in Section 2, the materials used in Caltrans highway construction and maintenance projects account for roughly 2.5 million metric tons of emissions annually, considering raw materials extraction, materials processing, material transport, and construction activities. There are numerous opportunities to reduce the GHG emissions associated with pavements by using alternative materials and modifying construction and maintenance practices. Because of the large volume of pavement materials used by Caltrans, even small changes can result in significant GHG reductions for the state. By virtue of its leadership role in highway design and maintenance, Caltrans also influences the pavement decisions of local transportation agencies, which can lead to additional GHG reductions. This section describes GHG reduction opportunities associated with pavements. Note that some of these opportunities (e.g., alternative concrete mixes) can apply to structures in addition to roadway pavements.

Overview of Pavement GHG Reduction Strategies

A life cycle assessment (LCA) approach is needed to understand the full GHG impacts of pavements. As discussed in Section 2, a LCA for GHG emissions (sometimes called a “carbon footprint”) accounts for all materials, activities, and GHG emissions that result from a pavement decision. The activities can be grouped into the following five phases, illustrated in the figure below:[78]

- **Raw material acquisition** – includes mining or extraction of bitumen, aggregate, and limestone.
- **Material processing** – includes the production of cement, asphalt, steel, and other materials
- **Construction and maintenance** – includes equipment used at the site and transport of material to the site
- **Roadway use** – includes the emissions from vehicles operating on the roadway, which are affected by pavement smoothness
- **End of life** – includes the disposal of pavement at the end of its life, including recycling and reuse

Figure 9. Phases in Pavement LCA



[78] Harvey, John, Alissa Kendall, and Arash Saboori, “The Role of Life Cycle Assessment in Reducing Greenhouse Gas Emissions from Road Construction and Maintenance,” National Center for Sustainable Transportation, July 2015. https://ncst.ucdavis.edu/white-paper/ucd-dot-wp1-2/

Pavement LCA is a complex and active field of research. Until recently, decisions regarding sustainable pavements often focused only on the raw material acquisition, material processing, and construction phases. But the roadway use phase can have major implications for the total GHG impacts, particularly for high-volume roadways. For this reason, a more holistic LCA approach is needed. The UC Davis Pavement Research Center supports Caltrans efforts to better understand pavement sustainability issues and improve pavement decisions.

Federal, state, and local transportation agencies spend millions of dollars annually to reduce or eliminate highway pavement distresses (both functional and structural), and have maintenance strategies and programs in place to ensure highway pavement networks operate at higher smoothness levels. Smoother pavements not only ensure safer highway networks, they also help reduce pavement-vehicle tire friction, and thereby reduce overall fuel consumption and resulting GHG emissions. Effective pavement maintenance and rehabilitation strategies (e.g., overlay, recycling, grinding, sealing) and timely interventions can enable Caltrans to achieve desired pavement smoothness thresholds.

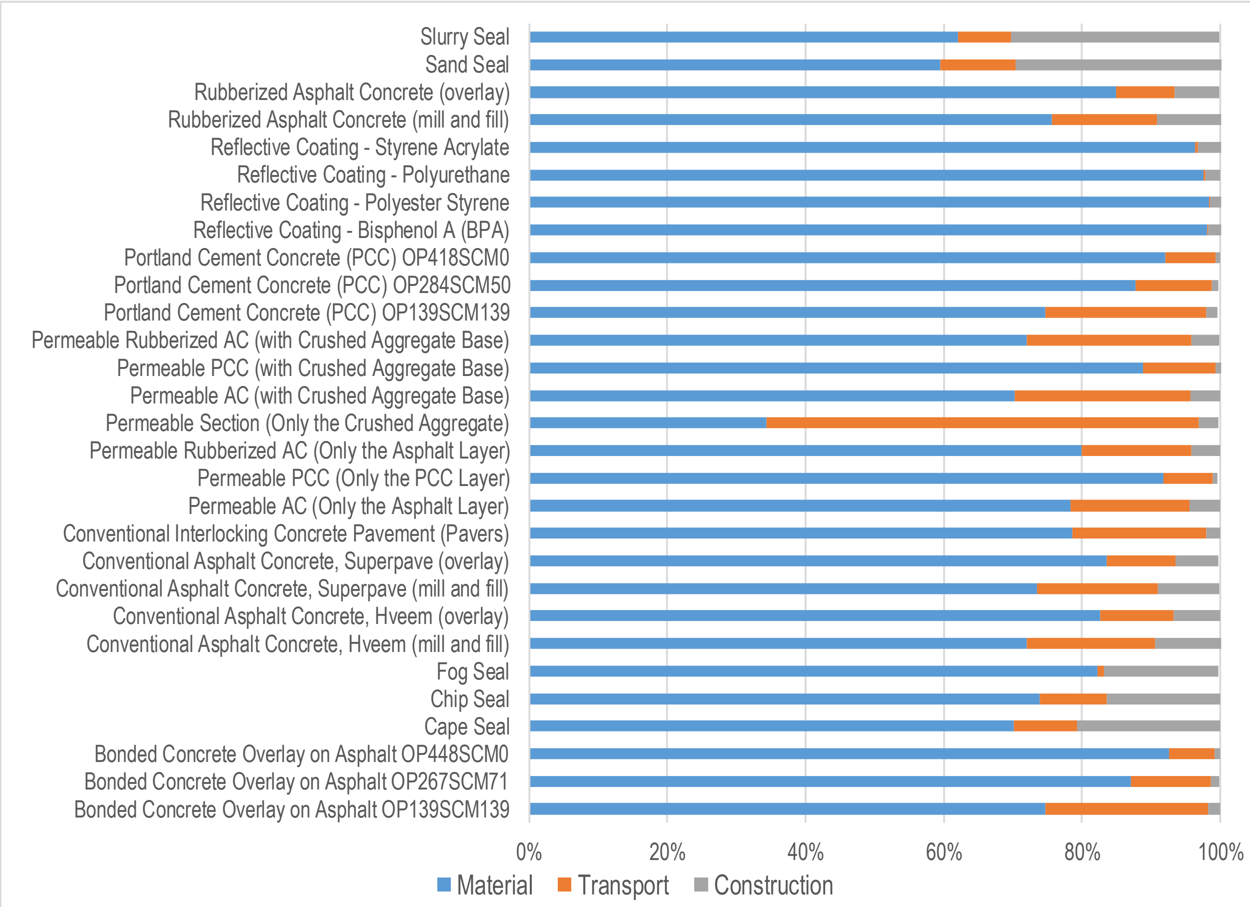
The GHG benefits of pavement smoothness can be substantial. One research study, funded by Caltrans, suggests that Caltrans could achieve an annual GHG reduction of 0.57 to 0.82 million metric tons across the entire State Highway System simply through the strategic application of maintenance and rehabilitation treatments that minimize roughness. This study used a life-cycle analysis approach that considered material acquisition, processing, and construction phases, as well as vehicle use.[79]

Alternative pavement materials and techniques have been shown to yield substantial energy and GHG reduction. The most promising additional GHG reduction opportunity for Caltrans for asphalt pavements appears to be greater use of reclaimed asphalt pavement (RAP). For concrete pavements, the greatest additional GHG reduction opportunities appear to be greater use of supplemental cementitious materials (SCMs). However, the net effect of different pavement options is complex and often dependent on the project context. For example, RAP may not be advantageous if the recycled material is not locally sourced.

Pavement options differ substantially in terms of the contribution of the different lifecycle phases to the total GHG impact, as illustrated in the figure below. Considering just the materials acquisition and processing, materials transport, and construction phases, this figure shows, for a variety of pavement treatments, the portion of lifecycle GHG emissions resulting from each of these three phases. For example, more than 90 percent of GHG emissions for Portland cement concrete comes from the materials phase, while for treatments like chip or slurry seal, only 60 to 70 percent of emissions are associated with materials.

[79] Wang, T., Harvey, J. and Kendall, A., "Reducing greenhouse gas emissions through strategic management of highway pavement roughness," Environmental Research Letters, 9(3), p.034007. 2014. https://iopscience.iop.org/article/10.1088/1748-9326/9/3/034007/pdf

Figure 10. Relative Contribution to Global Warming Potential of Pavement Materials, Transport, and Construction Phases



Source: Levinson, R., Gilbert, H., Ling J., Mandel, B., Millstein, D., Rosado, P., Harvey, J., Kendall, A., Li, H., Saboori, A., Lea, J., Ban-Weiss, G., Mohegh, A., and Santero, N. "Life-Cycle Assessment and Co-Benefits of Cool Pavements," Prepared for the California Air Resources Board and the California Environmental Protection Agency. Contract # 12-314. 2017.

Asphalt Pavements

Asphalt is the most common paving material in the state. Laying asphalt requires a binder—typically bitumen, a petroleum product. It also generally requires heating the asphalt, which requires energy and results in GHG emissions. A variety of alternative asphalt pavement techniques can result in lower GHG emissions.

Warm-Mix Asphalt

Warm Mix Asphalt (WMA) is a group of asphalt concrete mixture technologies that allow for retention of properties and performance of traditional hot mix asphalt (HMA) at reduced production, placement, and compaction temperatures. While production temperatures of traditional HMA range from 280 ˚F to 320 ˚F, production temperatures of WMA are typically between 212 ˚F and 280 ˚F. WMA technologies could comprise organic additives/waxes, chemical additives/surfactants, and foaming processes that use water. Reduction in production temperatures using WMA technologies allows for benefits such as energy savings, reduced fuel consumption, reduced GHG emissions, reduced worker exposure, enhanced compactability and durability, improved temperature uniformity, longer hauling distances, and cold weather paving ability. Introduced in Europe in the late 1990s, WMA has since found extensive use across U.S. and Europe, primarily with an intent to reduce energy and provide workers with a safer work environment.[80]

Asphalt Mixtures by Temperature Range

(Source: Fleming, M.H., Introduction to Warm-Mix Asphalt, PennDOT)

Per FHWA estimates, WMA is currently used in more than 40 states.[81] In California, WMA technologies are used for various applications that include field test sections, accelerated pavement testing, and associated laboratory testing. Generally, however, the volume of WMA on Caltrans projects is very small compared to the volume of HMA (less than 5 percent). Caltrans approved WMA technologies include additive and water injection/foamed technologies, which can be used for Type A HMA, RHMA-G (rubberized hot mix asphalt), and OGFC (open graded friction course). Caltrans' inspection process requires that WMA surface temperatures and roller passes be documented and reported to ensure that compaction operations conform to method specification requirements.

As mentioned, one of the significant benefits associated with use of WMA is GHG emissions reduction. Estimates indicate that WMA production results in 25 to 50 percent energy savings, and that 20 to 35 percent energy savings in WMA production translates to a reduction of 4.1-5.5 kg of CO_2 equivalent per

[80] Bonaquist, R.F. *Mix Design Practices for Warm Mix Asphalt*. NCHRP Report 691. Transportation Research Board, 2011. www.trb.org/Publications/Blurbs/165013.aspx

[81] Williams, B.A., Copeland, A., and Ross, C.T. Asphalt Pavement Industry Survey on Recycled Materials and Warm-Mix Asphalt Usage: 2017, Informational Series 138 (8th edition). FHWA, 2017.

ton of WMA.[82] [83] [84] A reduction of HMA production temperature by 68˚F (i.e., production temperature of WMA) could potentially reduce combined CO_2 emissions resulting from fuel and asphalt binder use by about 44 percent.[85]

Reclaimed Asphalt Pavement

Reclaimed asphalt pavement (RAP) refers to recycled or reprocessed pavement material components (asphalt binder and aggregates) that are used to partially replace virgin materials within asphalt concrete mixtures. FHWA estimates indicate that in 2017, more than 76 million tons of RAP was used in asphalt mixtures, which translates to over 3.8 million tons (21.5 million barrels) of asphalt binder conserved, and more than 72 million tons of virgin aggregate replaced.[86] Aggregative savings through use of RAP provides benefits such as conservation of natural resources, lower material and transportation costs, reduced waste disposal, reduced haul distances, reduced energy consumption, and reduced GHG emissions.

In 2009, Caltrans started to allow up to 15 percent RAP in HMA (by aggregate weight), which was increased to 25 percent by aggregate weight in 2013, along with a maximum binder replacement of 25 percent for the surface course (upper 0.2 foot of HMA, exclusive of the open-graded friction course) and 40 percent for lower courses. Caltrans currently allows for use of up to 100 percent RAP in pavement base layers (asphalt treated bases), and is evaluating options to allow 30-40 percent RAP usage to replace HMA in pavement surface layers.

Estimates indicate that use of 15 percent or higher RAP in traditional HMA reduces asphalt binder requirement by about 12 percent and virgin aggregate by about 15 percent, thus resulting in GHG emission reduction at a rate of 5 pounds GHG per ton of RAP used in HMA.[87] Use of RAP, particularly in WMA (since WMA allows for increased use of RAP compared to traditional HMA), is found to yield significant GHG emission reduction benefits. Adding 15 percent RAP for a 2-inch surface course of WMA and 25 percent RAP for a 4-inch base course layer of WMA can result in significant energy savings related to reduced fuel usage (approximately a quarter gallon of diesel fuel per square meter of pavement), which translates to a GHG reduction of 2.4 kg CO_2 per square meter of pavement.[88] [89] It is

---

[82] European Asphalt Pavement Association (EAPA) (2010) EAPA Position Paper on the Use of Warm Mix Asphalt. www.eapa.org/usr_img/position_paper/the_use_of_warm_mix_asphalt_january_2010.pdf

[83] Croteau, J.-M. and Tessier, B. (2008) Warm Mix Asphalt Paving Technologies: A Road Builder's Perspective. www.colascanada.ca/uploads/colascanada/File/expertise/WarmMixAsphaltPavingTechnologies.pdf

[84] Tutu, K.A. and Tuffour, Y.A. Warm-mix asphalt and pavement sustainability: a review. *Open Journal of Civil Engineering*, *6*(02), p.84. 2016.

[85] Keches, C. and LeBlanc, A., Reducing Greenhouse Gas Emissions from Asphalt Materials. BSc. Thesis, Worcester Polytechnic Institute, Worcester, 2007.

[86] Williams, B.A., Copeland, A., and Ross, C.T. Asphalt Pavement Industry Survey on Recycled Materials and Warm-Mix Asphalt Usage: 2017, Informational Series 138 (8th edition). FHWA, 2017.

[87] Pavement Management Report 2015. County of Riverside Transportation Department

[88] Croteau, J.-M. and Tessier, B. (2008) Warm Mix Asphalt Paving Technologies: A Road Builder's Perspective. http://www.colascanada.ca/uploads/colascanada/File/expertise/WarmMixAsphaltPavingTechnologies.pdf

[89] Tutu, K.A. and Tuffour, Y.A. Warm-mix asphalt and pavement sustainability: a review. *Open Journal of Civil Engineering*, *6*(02), p.84. 2016.

estimated that a use of 25 percent RAP in WMA could result in lifecycle GHG emissions reduction of around 15-20 percent.[90]

Rubberized Asphalt Pavement

Terminal Blending Process for Rubberized Asphalt

Since 1960s, recycled tire rubber has been used in asphalt paving. Rubberized asphalt pavement includes use of recycled tire rubber as a modifier for asphalt binders and as an additive for asphalt concrete mixtures. The rubberized asphalt production process is carried out at higher mixing temperatures, but use of WMA technology along with rubberized asphalt can help reduce mixing temperatures and improving mixture compaction and workability, resulting in approximately 20–25 percent of fuel savings. In addition, energy consumption for rubberized asphalt is typically lower than the traditional HMA during maintenance phase. Benefits of using rubberized asphalt pavement include reduced pavement noise levels, cold temperature paving, safer worker environment, reduced waste disposal, energy savings, and reduced GHG emissions. GHG emissions from the production and construction of rubberized asphalt mixtures are akin to HMA.[91] [92] According to staff in the Caltrans pavement program and UC Davis researchers, the net lifecycle GHG impact of using rubberized asphalt in Caltrans projects is unclear and requires further research.

Caltrans has been using rubberized hot mix asphalt (RHMA) to resurface roadways since the 1970s, and state policy has turned best practices into requirements. AB 338 requires Caltrans to use at least 15 percent crumb rubber in 35 percent of asphalt pavements, as illustrated in the figure below. Caltrans works to implement AB 338 in partnership with CalRecycle, which works to keep tires out of the waste stream.[93] Per Public Resource Code section 42703(a)(3) requirements, Caltrans is required, on average, to annually use no less than 11.58 pounds of crumb rubber modifier (CRM) per metric ton of the total amount of asphalt paving materials used.[94]

[90] National Asphalt Paving Association (NAPA) (2009) Black and Green: Sustainable Asphalt, Now and Tomorrow. Special Report Number 200. National Asphalt Paving Association, Lanham. http://www.hotmix.org/images/stories/sustainability_report_2009.pdf

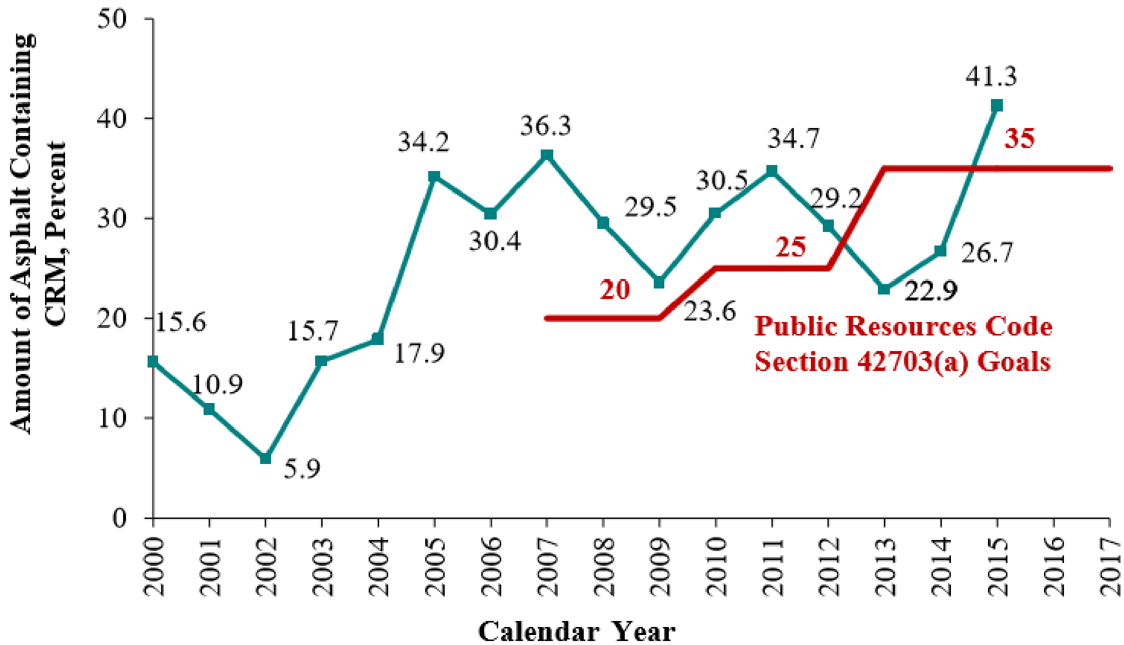
[91] FHWA. The Use of Recycled Tire Rubber to Modify Asphalt Binder and Mixtures. Technical Brief. FHWA-HIF-14-015. FHWA, Washington DC. 2014.

[92] Wang, T., Xiao, F., Zhu, X., Huang, B., Wang, J. and Amirkhanian, S. Energy consumption and environmental impact of rubberized asphalt pavement. Journal of Cleaner Production, 180, pp.139-158. 2018.

[93] California Legislative Information, AB 338 – Recycling: crumb rubber. http://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=200320040AB338

[94] 2015 Crumb Rubber Report. Public Resources Code Section 42703. California Department of Transportation.

Figure 11. Caltrans Annual Use of Asphalt Containing Crumb Rubber Modifier

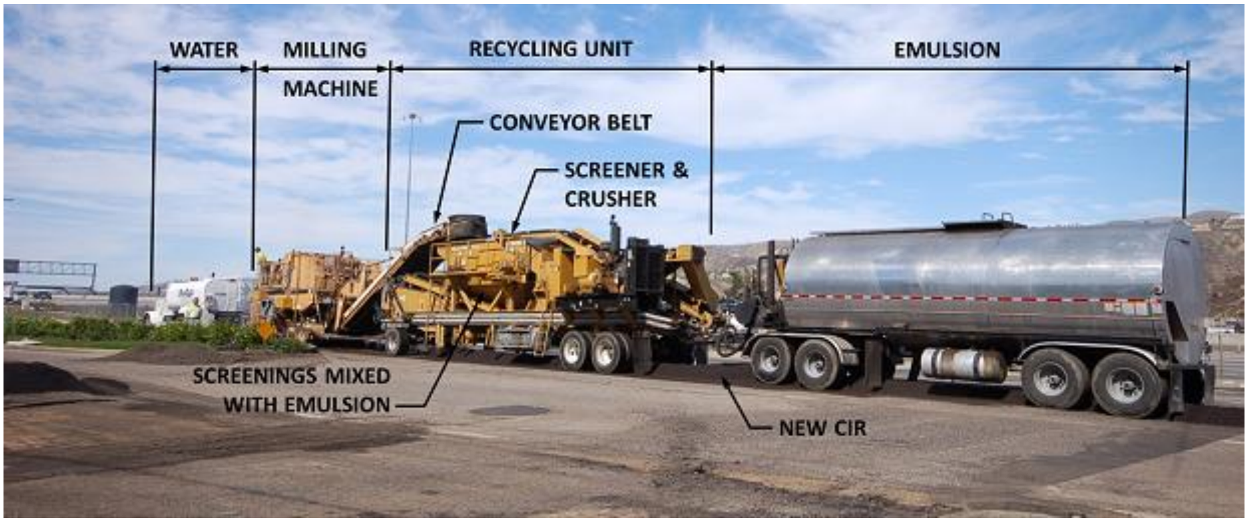


Cold In-Place Recycling

Cold in-place recycling (CIR) involves partial depth removal of pavement surface, including pulverization of a portion of the asphalt pavement layers, mixing with a recycling agent (e.g., foamed asphalt emulsion), and compacting and in-place repaving. CIR utilizes 100 percent of the RAP generated during the process, and involves typical treatment depths of around 3 to 4 inches. Typically suited for low to moderate volume roadways, CIR involves recycling of existing pavement, resulting in material and energy savings, and reduction in GHG emissions.

Estimates indicate that CIR process emits an equivalent of 5 to 20 kg of CO_2 per ton of material laid, as compared to 45 to 50 kg of CO_2 with traditional HMA (even when recycled asphalt is utilized).[95] Using the UC Berkeley PaLATE model, CIR was found to reduce CO_2 emissions by 52 percent compared to a traditional rehabilitation procedure with 6 inches of HMA laid across a 1 km of pavement section at a width of 7.5 meters.[96]

[95] Dorchies, P. T. The Environmental Road of the Future: Analysis of Energy Consumption and Greenhouse Gas Emissions. The 2008 Annual Conference of the Transportation Association of Canada. Toronto, Ontario. 2008.
[96] Alkins, A., Lane, B. and Kazmierowski, T. Sustainable pavements: environmental, economic, and social benefits of in situ pavement recycling. *Transportation Research Record: Journal of the Transportation Research Board*, (2084), pp.100-103. 2008.



CIR Process

(Source: Los Angeles Public Works Department)

Concrete Pavements

Concrete is commonly used as pavement for Caltrans roadways, particularly in urban areas where highways experience high traffic volumes. Concrete is typically composed of four materials: aggregates such as sand or gravel, cement to bind the aggregate together, water, and admixtures that help give the concrete specific properties. The most common cement is Portland cement, produced by heating crushed limestone to high temperatures in a kiln. Producing Portland cement is highly GHG intensive, so alternative mixes that reduce the use of Portland cement yield GHG reductions. Other approaches to reducing GHG emissions from concrete pavements involve reduction in virgin aggregate or other materials.

Supplementary Cementitious Materials

Supplementary cementitious materials (SCMs) are inorganic materials or mineral admixtures that enhance concrete mixture properties and reduce the use of Portland cement. Examples of SCMs include fly ash, slag cement (ground, granulated blast-furnace slag), silica fume, rice husk ash, and natural pozzolans (e.g., calcined clay/shale, volcanic ash). Use of SCMs typically improve concrete performance through improved mixture workability, durability, and strength. As SCMs aid in reduced consumption of Portland cement per unit volume of concrete, they help with reduced material consumption and waste disposal, along with energy savings and GHG emission reduction.[97]

Increased use of SCM or ground limestone is estimated to reduce 0.918 tons of CO_2 emitted on average per ton of AASHTO M 85 Portland cement manufactured.[98] Ground granulated blast furnace slag

[97] FHWA. Supplementary Cementitious Materials Best Practices for Concrete Pavements. Technical Brief. FHWA-HIF-16-001, 2016.

[98] Dam, V.T., "Supplementary cementitious materials and blended cements to improve sustainability of concrete pavements. Tech Brief," National Concrete Pavement Technology Center, Iowa State University Institute for Transportation, 2016.

(GGBFS), an SCM, could reduce approximately 0.5 tons of CO_2 at a 50 percent replacement rate per ton of Portland cement.[99] By another estimate, at a worldwide level, a 15 percent replacement of Portland cement in concrete by SCMs could potentially reduce CO_2 emissions by 250 million tons annually, while a 50 percent replacement could reduce CO_2 emissions by 800 million tons.[100] [101]

Amendments to Caltrans Standard Specifications in 2010 removed a requirement that at least 75 percent of the cement used in concrete be Portland cement. The change in specifications also offered contractors more options for alternatives to Portland cement by removing limits on the amount of fly ash and allowing up to three materials to be used in cement mixes. Caltrans now requires use of at least 25 percent SCMs, and allows up to 50 percent. Based on a review of pavement mix design samples, it appears that concrete producers for Caltrans projects are typically using only minimum 25 percent fly ash. In line with ASTM C977 standards, Caltrans also allows up to 5 percent limestone (high calcium quicklime or dolomite quicklime) in Portland cement concrete, although Caltrans estimates that 3 percent limestone is typical for Caltrans projects. Thus, there are opportunities to substantially increase SCM use on Caltrans projects and achieve larger GHG reductions.

Subgrade Enhancement (Subgrade Stabilization)

Subgrade, per Caltrans Standard Specifications, refers to the "roadbed portion on which pavement, surfacing, base, subbase, or a layer of any other material is placed". For increased foundation support and strength, subgrade soils can be stabilized by improving the subgrade properties either mechanically, chemically, or both. Subgrade stabilizations can serve as alternatives to thicker pavements, which can yield material (aggregate) cost savings, increased pavement strength, extended pavement service life, energy savings, and reduced GHG emissions. The stabilization methods include: [102]

- Mechanical stabilization, which is achieved by interlocking of soil particles using compaction, blending, and/or geosynthetics (geogrids/geotextiles).
- Cementitious stabilization, which involves treating subgrade soils using cementitious stabilizers such as soil cement, lime, fly ash, cement kiln dust, lime kiln dust, or ground-granulated blast furnace slag.
- Asphalt stabilization, using asphalt emulsion, foamed asphalt, cutback/liquid asphalt, and coal tar.
- Additive stabilization, using materials such as petroleum resins or sulfonated oils.

---

[99] Owaid, H.M., Hamid, R.B., and Taha, M.R. A review of sustainable supplementary cementitious materials as an alternative to all-Portland cement mortar and concrete. *Australian Journal of Basic and Applied Sciences*, *6*(9), pp.287-303. 2012.
[100] Malhotra, V.M. 2004. Role of supplementary cementing materials and superplasticizers in reducing greenhouse gas emissions. In Fiber composites, high-performance concrete, and smart materials; Proc. ICFRC intern. conf., Chennai, India, January 2004: 489 - 499.
[101] Naik, T.R. and Moriconi, G. Environmental-friendly durable concrete made with recycled materials for sustainable concrete construction. In *International Symposium on Sustainable Development of Cement, Concrete and Concrete Structures, Toronto, Ontario, October* (pp. 5-7). 2005.
[102] Jones, D., Rahim, A., Saadeh, S., and Harvey, J.T. Guidelines for the stabilization of subgrade soils in California. No. UCPRC-GL-2010-01. California Department of Transportation. 2010.

Similar to Portland cement concrete, Caltrans allows up to 5 percent limestone (high calcium quicklime or dolomite quicklime) for soil stabilization purposes, in line with ASTM C977 standards. Caltrans estimates that 3 percent limestone is typical for Caltrans projects. It is unclear why contractors are not going to 5 percent limestone; possible reasons include limited supply of limestone and increased costs of transporting limestone from manufacturing plants to project locations.

Recycled Concrete Aggregate

Recycled concrete aggregate (RCA) is the granular aggregate material generated through recycling of used concrete. FHWA estimates indicate that over 140 million tons of concrete is annually recycled within the U.S., and 44 states use RCA for various applications, including on concrete pavement mixtures, pavement base and subbase layers, and embankments and shoulders. Like RAP, RCA helps offset the need for quarry virgin aggregates, thus leading to reduced material and hauling/transportation costs, landfill, energy consumption, waste disposal, and GHG emissions.[103]

Concrete Recycling Process

(Source: Van Dam et al., Towards Sustainable Pavement Systems: A Reference Document, FHWA, 2015)

[103] FHWA. Accelerated Implementation and Deployment of Pavement Technologies. Annual Report. 2016-2017.

Aggregate production involves several processes such as quarrying, hauling, crushing, and screening, with its GHG emissions ranging from 2.5 to 10 kg of CO_2 per ton of aggregate.[104] Because recycling allows for reduced use of virgin aggregates, thus lowering aggregate production levels, GHG emissions can be considerably reduced. In addition, on-site recycling can help reduce hauling and material transportation activity, thus further lowering GHG emission levels. One project that documented the environmental impacts of RCA is the Beltline Highway project in Madison, Wisconsin, where a life-cycle assessment indicated 13 percent reduction in CO_2 emissions and 9 percent reduction in hazardous waste materials.[105] [106]

Returned Plastic Concrete

Returned plastic concrete (RPC) refers to underutilized or excess concrete, which is in unhardened/plastic state and suitable for recycling and reuse. Since RPC reduces the need for production of new batches of fresh concrete, its potential benefits include reduction in energy consumption, landfill areas and disposal costs, depletion of coarse and fine aggregates, construction, hauling, and transportation costs, and GHG emissions.

Caltrans' Revised Standard Specifications Section 90-9, "Returned Plastic Concrete," allows for the addition of up to 15 percent returned plastic concrete to fresh concrete, with RPC not to exceed 100 ˚F at any time. Typically, RPC is used for minor jobs and not roadway pavement, so the overall GHG benefits of RPC are limited compared to other pavement strategies.

Applying Pavement Research to Reduce GHG Emissions

The research and examples described above make clear that there are numerous opportunities to reduce GHG emissions through pavement strategies. And as described in Section 2, the large volume of material used on Caltrans roadway projects means that implementation of these strategies can yield significant benefits statewide. Caltrans projects in 2017 used more than 1 million cubic yards of concrete, which involved approximately 325,000 tons of Portland cement, more than 4 million tons of hot mix asphalt, and 1 million cubic yard of aggregate.

The main challenge is that decisions to promote specific pavement materials and methods in the name of GHG reduction must be supported by careful analysis that considers not only the materials, transport, and construction phases, but also any effects on vehicle fuel economy (use phase) and durability and lifetime of the pavement. This challenge can be address by working closely with the UC Davis Pavement Research Center and other experts to improve understanding of pavement lifecycle GHG impacts, and then incorporating the research and understanding into Caltrans pavement decision support tools.

[104] Chehovits, J. and Galehouse, L. Energy usage and greenhouse gas emissions of pavement preservation processes for asphalt concrete pavements. In *Proceedings on the 1st International Conference of Pavement Preservation* (pp. 27-42). 2010.
[105] Snyder, M.B., Cavalline, T.L., Fick, G., Taylor, P., and Gross, J. Recycling Concrete Pavement Materials: A Practitioner's Reference Guide. FHWA, 2018.
[106] Bloom, E. F., G. J. Horstmeier, A. P. Ahlman, T. B. Edil, and G. Whited. 2016a. Assessing the Life-Cycle Benefits of Recycled Material in Road Construction. Paper presented at Geo-Chicago 2016: Sustainability, Energy, and the Geoenvironment, August 14–18, Chicago, IL.

Because of the complexity of pavement LCA research, some degree of uncertainty about the magnitude of these impacts is likely to remain for some time. However, the urgency to reduce GHG emissions calls for taking steps quickly to put into practice more pavement strategies for which at least the directionality of GHG benefit is clear.

Caltrans also needs better procedures to track the use of GHG-reducing pavement strategies. Currently Caltrans has data only for the annual use of standard materials such as hot-mix asphalt and concrete. Caltrans also tracks use of rubberized HMA because this is a state requirement. However, no centralized records exist to monitor the use of other alternative asphalt or concrete mixes that can reduce GHG emissions. As a result, Caltrans does not have good estimates of the current use of pavement strategies such as WMA, CIR, and SCMs, nor does Caltrans have reliable information to indicate trends in use of these strategies.

4.3 Maintenance

In addition to pavement repair and resurfacing, described above, Caltrans performs a wide variety of other activities to maintain the State Highway System including vegetation management and maintenance of roadside lighting and signage. These activities offer numerous opportunities to reduce GHG emissions through use of alternative materials and more efficient practices.

Material Recycling and Re-use

AB 74 and SB 1016 require that state agencies track how much waste they generate, and establish a target for recycling or diverting waste. Use of recycled materials typically reduces GHG emissions by minimizing the production of new materials, which can be GHG-intensive. Caltrans employs a variety of approaches to recycle and reduce the use of materials during the construction and maintenance of highway facilities.

- In landscape architecture and highway maintenance, Caltrans uses urban green waste as a compost. This not only diverts waste, but also enhances soil structure and increases water conservation.
- Caltrans recently created a standard that allows the use of recycled mats to control weeds that grow under and obscure guard rails and posts. Historically, Caltrans paved the ground under guard rails and around posts with concrete.
- Caltrans requires the use of recycled paint to abate graffiti. Specifically, unused paint is mixed together to create a grey or brown color, which is painted over graffiti.
- Caltrans uses recycled motor oil and lubricants, recapped tires, and recycled solvents. Steel posts and metal guard rail used along highways are also recycled.
- A pilot project is recycling lead acid batteries (discussed in Section 4.4).

Standard specifications require that contractors submit data on their waste stream each year. Generally, Caltrans has recycled roughly 50 percent of construction materials, and 75 percent if pursuing LEED certification.[107] While contracts do not typically require this, construction material recycling is a CalGreen and a LEED requirement, and is only slightly more costly for the contractor.

Lighting Energy Efficiency

Caltrans has undertaken energy efficiency improvements for a variety of lighting used in the highway system and associated maintenance facilities.

Signal Lighting

Historically, traffic signals were one of the largest uses of electricity for Caltrans. Incandescent lights were originally used for the roughly 76,000 traffic signals along the State Highway System. Starting in 1999, Caltrans began converting traffic signals from incandescent lights, which use 85-155 watts of electricity, to light-emitting diode (LED) lights, which use only 22 watts on average. Caltrans has now converted nearly all signal lighting, and requires LEDs in all new traffic signals. Caltrans' early adoption of the technology helped lead to the nationwide standardization of LEDs for traffic signals.

Highway Lighting

In addition to reducing highway lighting to points of conflict (e.g., ramps, lane merges), Caltrans has been improving the energy efficiency of the lighting by retrofitting roughly 80 percent of its overhead "cobra head" highway lights with LEDs. In an earlier pilot phase, District 11 found that LEDs for highway lighting consume up to 66 percent less energy than the traditional high-pressure sodium (HPS) lights. In addition to the improved energy efficiency, LEDs last 15 to 20 years, four to five times longer than HPS lights, thus reducing the need for maintenance.

Changeable Message Signs

Caltrans operates more than 700 changeable message signs (CMS) along the State Highway System to inform travelers about road conditions and provide other information. Initially, Caltrans replaced the traditional incandescent light bulbs in these signs with xenon bulbs, which consume 72 percent less energy than incandescent bulbs. However, updated Caltrans' specifications require that all new signs use LEDs, which use 71 percent less energy than xenon fixtures (and 92 percent less than incandescent). Caltrans has now converted approximately 90 percent of its CMS to LEDs. However, Caltrans has also increased its inventory of CMS, so the energy savings from LEDs may be partially offset by the increased number of signs.

[107] U.S. Green Building Council, Construction and demolition waste management, https://www.usgbc.org/credits/reqmrc21r1-0; https://www.usgbc.org/credits/reqmrc22r1-3?view=language

Roadway Signage Lighting

Caltrans has more than 600,000 signs for the highways it manages, many of which require lighting for nighttime visibility. In 2003, Caltrans implemented energy savings guidelines that required the use of more energy efficient magnetic induction light fixtures for highway signs in place of more conventional mercury vapor (MV) fixtures to reduce the energy demand of sign lighting. Subsequently, Caltrans has been replacing 85-watt induction lamps with 60-watt LED lamps.

Retroreflective Sheeting on Signs

In addition to replacing fixtures for highway signs with more energy efficient lighting, Caltrans has been eliminating the need for lighting altogether by replacing lit roadway signs with retroreflective signs. Retroreflective sheeting materials feature a prismatic background that makes them highly visible under vehicle headlights. In addition to saving energy, these signs improve safety for Caltrans staff engaged in sign maintenance, and they decrease vandalism and copper-wire theft because they do not require maintenance catwalks. Caltrans specifications now require that all new green-background (directional) and yellow-background (warning) signs have this retroreflective sheeting, and existing signs are being replaced. Eventually, Caltrans plans to eliminate 70 to 85 percent of sign lighting, although the ultimate number depends on engineering requirements. For instance, lighting may be required in areas that are very foggy or where road curvature reduces sign reflectivity. In the future, Caltrans could reduce the amount of time that the signs are lit, or only turn the sign lighting on when fog is present or when traffic volumes are high.

Yard Lighting

Lighting has accounted for 70 percent of energy consumed at Caltrans maintenance yards, which require lighting for regular maintenance work that occurs at night. The maintenance yards and buildings previously used high-pressure sodium (HPS) and fluorescent lights. Caltrans is targeting to change these lighting systems to LED by the end of 2018. In addition to improved energy efficiency, LEDs do not need to warm up as compared to HPS lights, enabling a more refined control system to turn off lights when they are not in use, which can help reduce lighting energy consumption.

Summary of Roadway Lighting GHG Reductions

The table below shows a 2017 inventory of Caltrans highway system lighting by type. The vast majority of lights have been converted to LED.

Table 12. Caltrans Highway Lighting by Type, 2017

Lighting Type	Number
Traffic light fixture LED - Intersections	72,799
Traffic light fixture LED - Ramp Meters	5,147
Flasher LED	2,207
Ped Signal LED	37,736
Changeable Message Sign Xenon	183
Changeable Message Sign LED	545
Roadway LED	63,846
Roadway HPS	8,144
Roadway MV	1,419
Induction Sign Lighting (85W)	~15,000

Source: Caltrans

The table below shows the estimated GHG reductions that result from Caltrans lighting energy efficiency efforts.

Table 13. Annual CO_2 Emission Reductions Associated with Lighting Efficiency Strategies, 2017

Lighting Type	Fixtures Replaced	GHG Reduced (tons CO_2 per year)
Roadway		
Signals	117,889	12,065
Highway	63,846	13,246
CMS	728	2,745
Signage	~15,000	~2,000
Facilities		
Office	12,356	595
Yard and maintenance bay	13,778	1,536
Total (approximate)	**224,000**	**32,000**

Source: ICF calculations using lighting inventory provided by Caltrans.

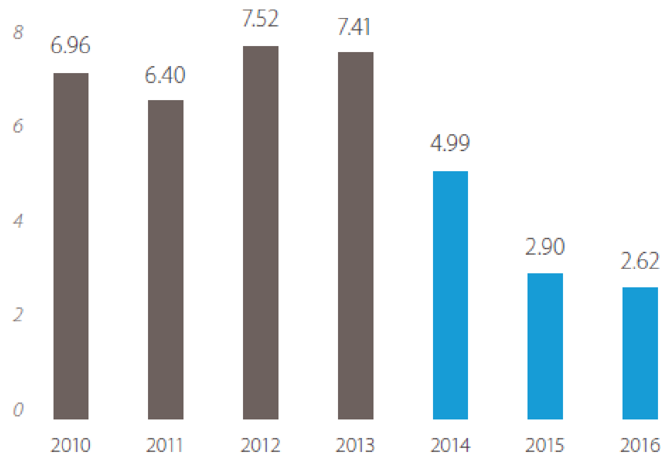
Water Conservation

Caltrans conserves water in roadside irrigation, at rest areas, and elsewhere. A reduction in the use of water means less energy devoted to pumping and treating water, which contributes to a reduction in GHG emissions.

Water Conservation in Irrigation

In response to the severe 2011-2015 drought, Caltrans adopted a goal of a 50 percent reduction in water use based on a 2013 baseline. Because Caltrans is responsible for 33,000 acres of landscaping, targeting this irrigation for reduction makes a substantial contribution to overall statewide water conservation efforts. Caltrans exceeded its water conservation goal; water use in 2016 was 65 percent below 2013 levels.

Figure 12. Caltrans Statewide Water Use (billions of gallons)



Source: Caltrans, MileMarker, September 2017

Water use reductions have been achieved through several strategies. Caltrans has invested in increased installation of "smart controllers" for roadside irrigation systems around the State. These smart controllers sense soil moisture levels and adjust water irrigation accordingly; they also receive weather reports via satellite. If the irrigation system is broken or faulty, the smart controllers quickly notify Caltrans maintenance staff, and shut off water flow if a line breaks.

Caltrans has also increased its use of recycled water for activities like cleaning vehicles and irrigation. Between 2014 and June 2017, Caltrans increased recycled water use statewide from 14 to 23 percent by converting 48 irrigation water sources to recycled water. Deputy Directive 013 requires that Caltrans irrigate landscapes exclusively with recycled water by 2036.

Caltrans has also taken steps to limit water use in its buildings. Several Caltrans district offices have installed low-flow water fixtures to reduce water use. Some districts have modified the watering of landscaping around their offices and have committed to washing vehicles only when they become too dirty to operate. District 8, as an example, cut water usage by 58 percent over roughly four years by implementing such strategies.

Water Conservation at Rest Areas

Caltrans operates 86 Safety Roadside Rest Areas across the state, most of which are in rural areas that are not part of municipal water and wastewater systems. Irrigation accounts for the majority of water use at these locations, particularly during summer months. Some rest areas use recycled water to flush toilets, reducing their discharges, which are regulated and must be treated. For example, Dunnigan rest area, located on Interstate 5 in Yolo County, recycles toilet water for non-potable uses. Caltrans is also exploring treatment options that can handle the volume and quality of the remaining rest area wastewater. At the Sunbeam Rest Area, located in Imperial County on Interstate 8, Caltrans has installed a system that treats wastewater from toilets and sinks. The treated water is suitable for use in the drip irrigation lines used for grass lawns at the rest area. At the Ereca rest area on Interstate 5 near Fresno, Caltrans is building a water recycling system to recycle toilet water.

Sunbeam Rest Area on Interstate 8

4.4 Vehicle Fleet and Equipment

Caltrans reduces GHG emissions from its vehicle fleet through alternative fuels, advanced technologies, and efficient vehicle operation.

Alternative Fuels for Caltrans Light-duty Vehicles

Caltrans supports State initiatives to reduce GHG emissions by expanding use of alternative fuels in the light-duty vehicle (LDV) fleet, which includes automobiles and pickup trucks. The focus of its alternative fuel efforts is on replacing gasoline and diesel LDVs with zero emission vehicles (ZEVs), which consist of electric vehicles (EVs) and fuel cell vehicles (FCVs). Executive Order B-16-12 created a target of 1.5 million ZEVs in California by 2025, and required that the State vehicle fleet increase its number of ZEVs so that at least 10 percent of LDV purchases are ZEV by 2015, and at least 25 percent of fleet LDV purchases are ZEV by 2020. The State adopted a ZEV Plan in 2016, which outlines a path for achieving this goal. Executive Order B-48-18 created a target of 5 million ZEVs in California by 2030, and 250,000 electric vehicle charging stations and 200 hydrogen fueling stations in California by 2025. The DGS Management Memo "Zero-Emission Vehicle Purchasing and Electric Vehicle Service Equipment Infrastructure Requirements" directs agencies to purchase ZEV charging equipment to further Executive Order B-16-12.

Caltrans has implemented a ZEV Action Plan, which created a generalized schedule for light-duty vehicle ZEV purchases as a part of overall fleet replacement. Each year's actual ZEV purchasing is based on vehicle condition and scheduled turnover; therefore, if none of the LDVs in the fleet require replacement, no ZEVs will be purchased that year.

Caltrans has exceeded the EO B-16-12 ZEV fleet requirement, as ZEVs accounted for approximately 20 percent of LDV purchasing in FY 2017-18. Because some state departments can accommodate ZEVs more easily than others, compliance with EO B-16-12 will eventually be on a State basis rather than a Departmental basis, and Caltrans may be required to increase their ZEV LDV fleet beyond the executive order requirements to help the statewide goal. However, one challenge that Caltrans faces is that nearly half of its LDV fleet is composed of pickup trucks, and currently there are no ZEV pickups available from original equipment manufacturers.

Electric Vehicles

There are two main categories of electric vehicles. Battery electric vehicles (BEVs) have no internal combustion engine and run on electricity supplied by the onboard battery alone; current BEVs typically have a range of approximately 60 to 250 miles, with most models limited to less than 150 miles. Plug-in hybrid electric vehicles (PHEVs) have both an internal combustion engine and a battery that can be charged via plug; PHEVs run on the battery's electricity for the first 10 to 50 miles and then switch to using the gasoline-powered engine after the battery is depleted, allowing PHEVs to travel distances comparable to conventional gasoline-fueled cars.

To date, Caltrans has largely met and exceeded its ZEV fleet requirements by replacing conventional and hybrid LDVs with battery electric and plug-in hybrid electric vehicles. In 2017, the Department operated 80 BEVs and 136 PHEVs.

Electric Vehicle Charging Equipment

In addition to purchasing electric vehicles, Caltrans has been actively installing EV charging equipment. State agencies are mandated to provide EV charging at five percent of their workplace parking spaces, with the intent that State employees will use the EV charging for their commute vehicles during the day, and the agency's fleet will use the EV charging at night. Caltrans is in the process of meeting this goal. Currently, Caltrans has 142 electric vehicle charges, 128 of which are dual-port. Fifteen of these are solar electric charging stations.

Solar powered EV charging station at Caltrans Headquarters

Caltrans will contribute funding to DGS for the installation of EV charging infrastructure. Significant funding will be required. While EV charging equipment is relatively inexpensive, preparing and installing equipment at charging locations can be much more expensive, as it can require trenching, installing conduit and wiring, upgrading electrical panels, and acquiring a fire marshal's permit.

Fuel Cell Vehicles

While Caltrans has largely replaced its older LDV fleet with EVs, the Department is also interested in procuring hydrogen fuel cell vehicles, as they hold a number of advantages over electric vehicles. Hydrogen FCVs have a longer range than typical EVs and can be fueled more quickly. Furthermore, hydrogen fueling is more resilient in a disaster as it does not depend on the electrical grid and backup generators can be used to produce additional hydrogen fuel if necessary. To date, Caltrans has purchased 50 Toyota Mirai FCVs. Because Caltrans does not yet have its own hydrogen fueling infrastructure, these vehicles refuel at public fueling stations located in Districts 3, 4, and 7.

Toyota Mirai Fuel Cell Vehicles at Caltrans District 7

The GHG benefits of the fuel cell vehicles can vary widely depending on the production and transportation processes of the hydrogen used to fuel the FCVs. Larger GHG reductions can be achieved if the hydrogen is liquefied for transport of the fuel; GHG reductions can be ten times larger if the hydrogen is produced locally using a renewable energy source such as solar or wind.

Summary of Light Duty Vehicle Emissions Benefits

The table below shows the number of Caltrans hybrid, electric, and fuel cell vehicles in operation in 2017, the total mileage of these vehicles, and the resulting annual GHG reductions. In total, Caltrans alternative fuel light duty vehicles generated approximately 200 tons of GHG reduction in 2017. This reduction has subsequently increased as Caltrans has added more of these vehicles to its fleet.

Table 14. Number of Hybrid, Electric, and Fuel Cell Vehicles and Total Mileage, 2017

Vehicle Type	GHG Reduction per Vehicle	Number of Fleet Vehicles (2017)	Total Mileage (2017)	Total Annual Fleet GHG Emission Benefits (tons)
Hybrid Electric Vehicle	18%	91	831,467	56
Plug-In Hybrid Electric Vehicle	38%	136	500,116	73
Battery Electric Vehicle	67%	80	197,385	50
Fuel Cell Vehicle	38%	37	181,953	26
Total		**344**	**1,710,920**	**204**

Source: ICF calculation using vehicle mileage data from Caltrans. All vehicles compared to a conventional gasoline vehicle, assumed to be a Chevrolet Cruze. PHEVs assumed to operate 40% in electric mode (EMFAC). Fuel cell vehicles assumed to use compressed gaseous hydrogen from central reforming of fossil natural gas.

Additional Light Duty Vehicle GHG Mitigation Opportunities

Caltrans has aggressively added EVs and FCVs to its light duty vehicle fleet, as described above, and will continue to integrate more as part of regular fleet turnover. Opportunities to use EVs and FCVs for Caltrans' light truck (e.g., pickup) fleet vehicle fleet are currently limited by commercial availability. If viable battery electric or fuel cell options become available for light-duty trucks, Caltrans expects to consider adding these vehicles to its fleet. Otherwise, there are limited opportunities for Caltrans to further reduce fleet GHG emissions through vehicle electrification beyond the planned vehicle replacements.

Alternative Fuels for Caltrans Heavy-duty Vehicles and Off-road Equipment

State agencies have also started to explore opportunities to use alternative fuels in heavy-duty vehicles, which include construction, maintenance, and utility trucks. Caltrans has used alternative fuels for many decades, but applications were limited because of the operational and power requirements for these large vehicles. However, alternative fuels and newer technologies are increasingly available for heavy-duty applications. Options that reduce GHG emissions include:

- Biodiesel fuel
- Renewable diesel
- Compressed natural gas (conventional and renewable)
- Hybrid electric and full electric vehicles
- Hydrogen fuel cell vehicles

Through 2015, Caltrans was widely using biodiesel blended with conventional diesel in nearly all HDVs. As a fuel made from animal and vegetable fats, biodiesel has a lower GHG emission rate on a life-cycle basis compared to conventional diesel. However, to meet the petroleum reduction goals set by Executive Order B-30-15, the Department of General Services (DGS) released Management Memo 15-07

"Diesel, Biodiesel, and Renewable Hydrocarbon Diesel Bulk Fuel Purchases," which instructs state agencies to purchase renewable diesel in lieu of bulk conventional diesel and biodiesel. Renewable diesel is a product of fats or vegetable oils refined by a hydro treating process, which results in a fuel that meets the same standards as conventional diesel and thus, unlike biodiesel, does not need to be blended with conventional diesel. Renewable diesel can therefore be a "drop-in" fuel that generates 50 to 60 percent less GHG emissions than conventional diesel. The adoption of renewable diesel has become a more feasible alternative to other forms of diesel in recent years because of the improved cost competitiveness that have resulted from credits generated under the federal Renewable Fuel Standard and state Low Carbon Fuel Standard (LCFS).

Caltrans also employs compressed natural gas (CNG) engines for some heavy-duty vehicles, such as sweepers and refuse trucks. Because CNG also has significantly lower ozone precursor emissions than diesel, many of these vehicles are deployed in the South Coast Air Basin (Districts 7, 8, and 12) where ozone pollution is most severe. The GHG emissions associated with natural gas vehicles partly depend on the source of the gas; natural gas can be produced from renewable sources, which have lower life-cycle GHG emissions than conventional natural gas from fossil fuel sources. For example, natural gas from landfills has a carbon intensity that is roughly half that of natural gas from conventional fossil sources.

CNG Fueling Infrastructure at Caltrans Foothill Maintenance Station, District 7

Assembly Bill 739 (2018) requires that, by 2025, at least 15 percent of newly purchased vehicles with a gross vehicle weight rating (GVWR) of 19,000 lbs. or more be zero emission vehicles (ZEVs), and that by 2030, at least 30 percent of these vehicles be ZEVs. However, because available electric trucks have limited ranges and long charge times, electric trucks cannot currently meet Caltrans' operational requirements for most construction and maintenance activities, particularly emergency maintenance response.

While electric vehicle options to replace Caltrans heavy-duty vehicle are limited, fuel cell vehicles offer the range and rapid fueling that match conventional diesel powered counterparts. As a result, Caltrans is examining fuel cell vehicle options for various heavy-duty applications. Fuel cells have been used in forklifts and heavy-duty trucks at ports, where the range requirement is lower. In 2018, Caltrans funded the development and deployment of the world's first fuel cell freeway sweeper in District 7 as a demonstration project. Caltrans is also purchasing a gasoline-electric hybrid and a diesel-electric hybrid sweeper. These vehicles use an average of 45 percent less fuel than a conventional diesel sweeper. The University of California, Riverside is currently evaluating the performance of these advanced technology sweepers and will assess the feasibility of expanding the use of these vehicles. If the vehicles perform adequately, Caltrans intends to place hydrogen sweepers in the South Coast Air Basin and other locations where hydrogen fueling infrastructure exists, and place the hybrid-electric sweepers elsewhere.

Caltrans fuel cell sweeper

The table below shows the use of heavy-duty vehicle alternative fuels by Caltrans in 2017 and the resulting GHG reductions, as compared to conventional diesel fuel. Renewable diesel can come from different sources (pathways) which vary in their carbon intensity. Because the source of Caltrans renewable diesel was not known at the time of this analysis, the GHG reduction calculation conservative assumes a relatively high carbon intensity pathway. Thus, the actual GHG reduction from renewable diesel could be greater than shown here.

Table 15. Heavy Duty Vehicle Alternative Fuel Use and GHG Reductions, 2017

	Annual fuel use, 2017 (gallons or dge)	Annual GHG reduction, 2017 (tons)
CNG	145,022	456
Renewable diesel	3,772,536	23,637
Total	**3,917,558**	**24,093**

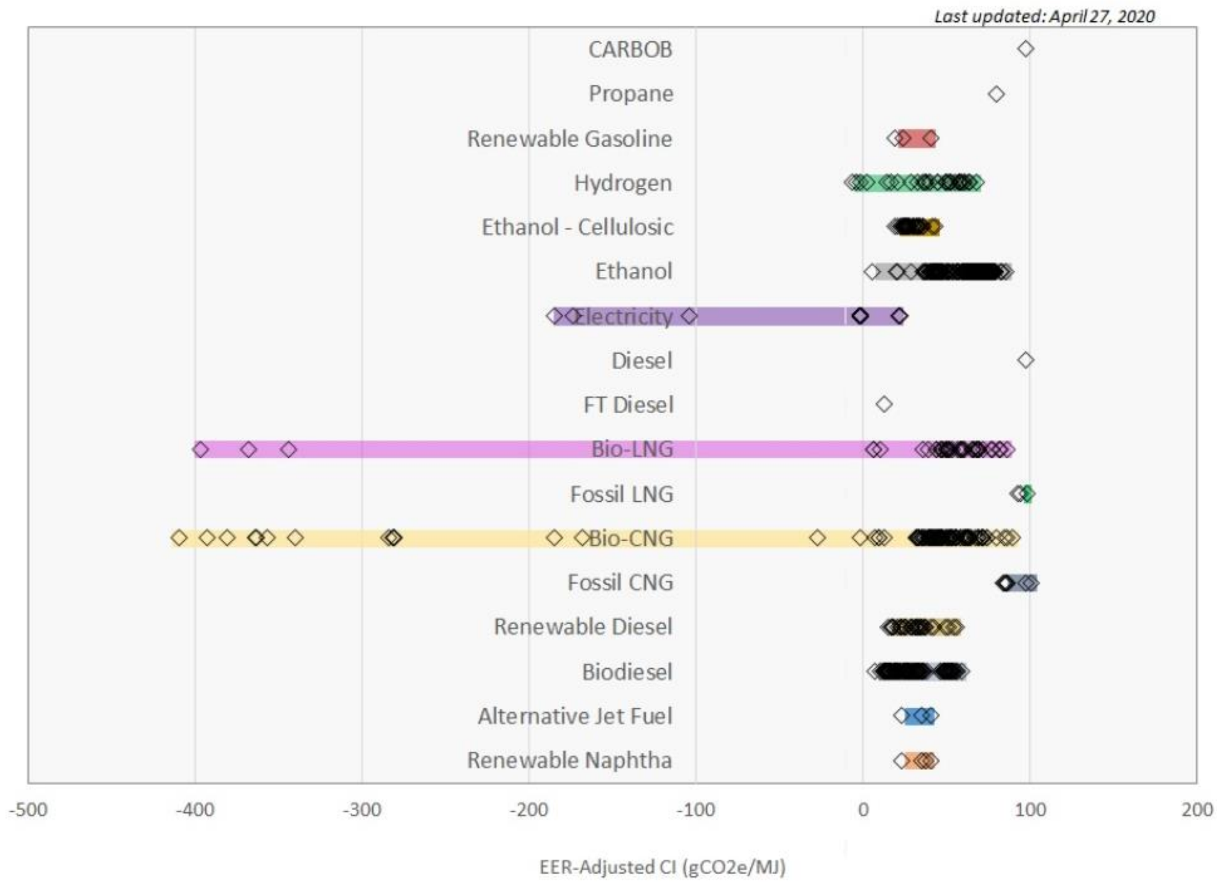
Source: ICF calculation using fuel use data from Caltrans. Emission factors from CARB LCFS pathways.

Additional Heavy-Duty Vehicle GHG Mitigation Opportunities

Similar to light duty trucks, the ability to reduce GHG emissions by using electric or fuel cell technology for heavy-duty vehicles is currently limited by the commercial availability these vehicles. In the future, when electric or fuel cell options become more widely available, Caltrans can likely achieve additional GHG reductions through these technologies.

Presently, low carbon fuels other than electricity offer more immediate potential for additional GHG reductions in Caltrans heavy duty fleet. California's LCFS mandates a 10 percent reduction in the carbon intensity of California's transportation fuels and is helping to drive the introduction of many low carbon fuel options. The figure below shows the carbon intensity (CI) for fuel pathways that have been certified under the LCFS program. Conventional gasoline (CARBOB) and diesel have carbon intensities of approximately 100 grams of CO_2-equivalent per megajoule (MJ). Renewable diesel, already used by Caltrans, is available with CI values of 20-55 g CO_2e/MJ, or 45 to 80 percent lower than conventional diesel. Even lower carbon intensities are available for some forms of renewable natural gas (Bio-CNG). Caltrans can achieve larger fleet GHG reduction by purchasing these low carbon fuels where they are available.

Figure 13. Carbon Intensity Values of Certified LCFS Pathways (2020)



Source: California Air Resources Board

Efficient Operation of Caltrans Vehicles

In addition to replacing gasoline and diesel with alternative fuels, Caltrans has implemented a wide range of strategies to reduce the consumption of fuels in general.

Idling consumes fuel for other purposes besides propulsion. Caltrans Deputy Directive 096 “Unnecessary Idling of the Department’s Fleet Vehicles and Equipment” supports efforts to reduce unnecessary energy consumption from vehicle idling. However, some idling can serve important functions that support Caltrans work. For example, drivers sometimes run their engines to keep their cabs heated. In four yard trucks purchased recently, Caltrans added heaters that draw a smaller amount of fuel than running the vehicle engine to keep the cab warm; however, Caltrans has found that drivers are not always using this heater in place of idling.

In some cases, Caltrans has deployed more energy efficient vehicles and equipment. Caltrans maintenance vehicles operate amber warning lights for driver and worker safety. While older vehicles must run the engine to shine warning lights, newer vehicles use LED warning lights which require very little power, reducing the load on the vehicle engine. To reduce vehicle air conditioning needs and evaporative emissions, DGS Management Memo 12-03 mandates that all State agency LDVs be white, silver metallic, or gold metallic, which are solar reflective colors that reduce the amount of vehicle cabin heating.

Caltrans also has improved vehicle and equipment efficiency by implementing GPS-based tools to assist the operators. Caltrans has added GPS to all vehicles but offload trailers. In addition to helping recover stolen vehicles, GPS devices track driving speeds; speeding reports are sent to administrative deputies and District discipline services, who follow up with drivers to encourage slower, more fuel efficient driving speeds. GPS also eliminates the need for drivers to manually log their vehicle data, thereby increasing organizational efficiency. Caltrans has also installed automated vehicle locators (AVLs) on their snow plows, which help operators improve overall efficiency by indicating when plows are down and tracking the amount of material (sand, salt, etc.) that has been deployed.

Recycled Vehicle Batteries

In California, 160,000 tons of lead acid batteries must be recycled per month. Currently, many of these batteries go to the Exide plant in the City of Industry, California. This creates a toxic hazard for the community, as lead has been found in the community's ground and water and in residents' blood tests. These batteries are also often sent abroad where the waste is managed poorly. Assembly Bill 2832 calls for creation of an advisory group to develop recommendations to ensure sustainable recycling of vehicle batteries.

To help reduce lead waste, Caltrans has engaged in a pilot partnership with a private company called AquaMetals. AquaMetals extracts lead from batteries to produce 99.9 percent pure lead ingots, which it can then resell. This lead is not only higher quality, but it is also lighter, stronger, and holds a charge for longer than using lead that is typically available.

4.5 Facilities and Administration

Caltrans reduces GHG emissions through its programs for purchasing supplies, procuring renewable energy and improving the efficiency of its workplace offices for employees, and supporting employee commute travel.

Purchasing and Contracting

Caltrans is currently pursuing several methods to purchase products and create projects that are less GHG-intensive. This includes analyzing the lifecycle emissions of purchases, and using sustainable purchasing, environmentally preferred purchasing, and environmental product declarations, and alternative contracting methods.

Sustainable Purchasing

Caltrans Division of Procurement and Contracts is currently establishing a Sustainable Purchasing Program. The Division will identify opportunities to incorporate sustainability, including both environmental and social components, into products carried in Caltrans supply warehouses, such as wood posts, sign posts, and related equipment. Notably, this does not include purchasing related to construction, facilities, or the vehicle fleet, which are handled by other divisions.

As part of the development of this program, Caltrans plans to conduct an economic input-output lifecycle analysis to quantify the GHG emissions embedded in all of Caltrans' purchases. This analysis will provide a baseline of GHG emissions and help identify areas where Caltrans could improve. For instance, the analysis will provide the zip codes of suppliers and purchasers, associated transportation emissions, and whether those emission could be reduced by using a local supplier or at least a supplier that is closer to the purchaser.

Environmentally Preferred Purchasing

Caltrans indirectly incorporates environmentally preferred purchasing (EPP) under Department of General Services (DGS) procurements. While Caltrans lacks the authority to incorporate EPP when selecting a contractor, Executive Order B-18-12 requires that state agencies conduct environmentally preferred purchasing, including DGS. Therefore, when Caltrans uses a DGS-developed procurement agreement, the agreement considers EPP. For instance, many state departments and entities use tires; DGS has contracted with numerous vendors to provide tires, and the contract tire specifications include EPP. As a result, when Caltrans purchases tires through this contract, they indirectly incorporate EPP into the tire purchase.

While Caltrans provides input into DGS specifications, the Department does not lead the development of the specifications.

Environmental Product Declarations

In 2016, Caltrans began pursuing the use of environmental product declarations (EPDs). An EPD is an internationally recognized environmental impact label, similar to a nutrition label on food. EPDs are developed in accordance with specific standardized methods for quantifying the environmental impacts of manufacturing a particular product on a lifecycle (cradle to grave) basis. Caltrans has contracted with the University of California, Davis Pavement Research Center helped to assemble a roadmap for Caltrans use of EPDs.

In 2017, the Buy Clean California Act (AB 262) was passed. AB 262 directs the Department of General Services (DGS) establish and publish standardized methods for calculating the lifecycle GHG emissions (called global warming potential) of four commonly purchased products: carbon steel rebar, flat glass, mineral wool board insulation, and structural steel. Potential suppliers of these materials to the state will then be required to report the global warming potential of their products using an EPD. DGS will also establish and publish in the State Contracting Manual a maximum acceptable global warming potential for each category of product. Caltrans purchases these products will results in lower GHG emissions once the program requirements take effect July 1, 2019.

Purchase of Recycled Material

Caltrans purchases a variety of products containing recycled content. Caltrans reports annually regarding progress toward the State Agency Buy Recycled Campaign (SABRC), which is a joint effort between CalRecycle and DGS to implement state law requiring state agencies to purchase recycled-content products and track those purchases. The table below shows Caltrans reporting for fiscal year

2016-17 in 11 categories of materials.[108] Caltrans generally meets the SABRC targets unless suppliers of suitable recycled-content products are not available.

Table 16. Caltrans Purchases of Recycled Content, 2016-17

Product Category	Total Purchases	SABRC Compliance Purchases	Percent Compliant	Minimum Post-Consumer Recycled Content
Antifreeze	$190,412	$101,661	53%	70%
Compost, Co-Compost, Mulch	$2,484,684	$2,484,684	100%	80%
Glass Products	$342,424	$342,089	100%	10%
Lubricating Oils	$1,086,722	$906,338	83%	70%
Paint	$1,918,341	$980,834	51%	50%
Paper Products	$237,847	$131,119	55%	30%
Plastic Products	$3,209,642	$824,044	26%	10%
Printing & Writing Paper	$490,816	$240,431	49%	30%
Metal Products	$42,758,715	$38,483,777	90%	10%
Tire-Derived Products	$21,008	$5,087	24%	50%
Tires	$4,050,226	$725,956	18%	Retread/Recapped

Source: Caltrans

One challenge in requiring the use of recycled or sustainable materials is that when using federal funds, Caltrans cannot necessarily create material restrictions as this can restrict trade with other states.

Renewable Energy

Electricity produced by renewable sources such as solar power displaces electricity used from the grid, which is comes from more GHG-intensive sources. To date, Caltrans' primarily renewable energy projects have been conducted under the Clean Renewable Energy Bonds solar program. As discussed below, Caltrans has opportunities for achieving additional GHG reductions by pursuing solar power projects in the highway right-of-way (ROW).

Clean Renewable Energy Bonds Solar Program

Caltrans has participated in the Clean Renewable Energy Bonds (CREBs) program to finance the installation of photovoltaic (PV) energy systems. The CREBs program was created by the Federal government in 1995 as a way to finance renewable energy projects. Caltrans initially received approval for CREBs projects in 2006. Caltrans was the only state agency to participate significantly in the CREBs program. Caltrans has completed installation of 70 PV projects financed through CREBs. The projects are located at a variety of Caltrans facilities, as summarized in the table below.

[108] Memorandum, To Angela Shell, Chief, Division of Procurement and Contracts, "State Agency Buy Recycle Annual Report Fiscal Year 2016-17," October 25, 2017.

Table 17. Caltrans CREBS Solar Projects by Facility Type

Facility Type	Number of Projects
Maintenance Facilities	46
Equipment Shops	9
Safety Roadside Rest Areas	3
Office Buildings	4
Materials Laboratories	2
Transportation Management Centers	2
Toll Bridge Facilities	2
Truck Inspection Facilities	2
Total	**70**

Source: Caltrans

In total, these projects generate 2.38 MW of renewable energy, enough to power 500 homes, which is more than the 2.1 MW used by Caltrans' 344 maintenance stations. Caltrans has noted that in some cases, energy production performance of PV installations could be improved. In some locations, the PV panels and inverters have needed repair; others do not receive frequent cleaning, which can degrade their performance.

To improve tracking of performance and issues in real-time, Caltrans uses telematics (remote tracking) to monitor most of the CREBs installations (61 out of 70). The remaining 9 locations lack internet capabilities or have equipment incompatibility issues, but Caltrans is identifying potential tools to track energy production and display information on a user-friendly dashboard for all 70 sites.

Other Solar Projects at Caltrans Facilities

In addition to the CREBs projects, Caltrans has been developing several other solar projects. In District 8, Caltrans installed a 1 MW solar facility – Caltrans' largest solar installation – at its Southern Regional Lab and traffic management center in Fontana. Other projects include:

- District 3 – A solar canopy in the Marysville office parking lot (in progress)
- District 4 – Solar facilities at the San Francisco-Oakland Bay Bridge Maintenance, Warehouse, and Training Complex
- District 5 – Mobile EV chargers with solar panels at three locations
- District 6 – Solar panels at the northbound and southbound Philip Raine Rest Areas on SR99
- District 7 – A solar pavement pilot project at a district office building, working with a company from the Netherlands on the technology
- District 12 – Mobile EV chargers with solar panels (installed); and solar canopies/EV charging stations at Park and Ride lots

Solar panels at the Caltrans Traffic Management Center in Fontana, District 8

Summary of GHG Reductions from Renewable Energy

The table below shows the estimated GHG reductions in 2017 that result from Caltrans renewable energy efforts.

Table 18. Annual CO_2 Emission Reductions Associated with Solar Projects, 2017

Solar Project Type	Estimated Electricity Produced (kWh)	GHG Reduced (tons CO_2 per year)
Clean Renewable Energy Bonds (CREBs)	3,617,400	955
Other projects	3,282,000	866
Total	**6,899,400**	**1,821**

Source: ICF calculation using electricity production data provided by Caltrans

Although nearly all of Caltrans' solar projects were previously developed through the CREBs program, other projects are now estimated to produce nearly as much electricity as the CREBs solar installations. Actual electricity production – and associated GHG reductions – at each site may vary considerably, depending on system design, weather, and other factors that impact solar generation.

Solar PV Arrays in Highway ROW

While Caltrans has achieved energy savings and reduction in GHG emissions using through successful installation of PV energy systems on various Caltrans facilities (e.g., maintenance facilities, equipment shops, etc.), the Department can further reduce GHG emissions by targeting other types of underutilized spaces for renewable energy technologies such as solar PV. Many transportation agencies have been exploring installation options for decentralized renewable energy technologies on spaces that are not conventionally considered for energy generation, including use of the highway ROW.[109] The highway ROW and other land areas used by transportation agencies are often in proximity to electrical infrastructure, which can make these locations ideal for renewable energy applications.[110] California's aggressive renewable portfolio standard, expanded in 2015 as part of SB 350, requires all utilities in the state to source half of their electricity sales from renewable sources by 2030, so the demand for renewable energy is growing rapidly.

Renewable energy generation in the ROW can come from solar, wind, and other technologies. Solar PV is the most promising immediate option for the highway ROW. California has some of the best conditions for solar power in the U.S. PV arrays are formed by modules of connected individual PV cells that typically produce 1 to 2 watts (W) of solar power. They can utilize two types of PV systems: traditional flat-plate PV systems (which use conventional solar cells) or concentrating photovoltaic systems (in which solar power is captured in more expensive high-efficiency solar cells, using lenses/mirrors, which reduces required cell area and increases the cell efficiency).

Countries such as Canada, Austria, France, Germany, the Netherlands, Switzerland, and the United Kingdom have implemented solar cell applications (including PV noise barriers) along highways and railways within existing ROW. State DOTs in the U.S. are increasingly exploring solar-related initiatives and technologies for highway ROW. Oregon DOT piloted the first highway ROW solar PV installation in 2008 at the interchange of I-5 and I-205 near Portland. Recent examples are shown in the figure and table below.[111]

Caltrans is currently researching the potential of using highway ROW for solar energy, with a goal of developing a ROW pilot solar project in 2019 and the potential to expand to other Caltrans sites after that.

---

[109] FHWA, Renewable Energy in Highway Right-of-Way, www.fhwa.dot.gov/real_estate/right-of-way/corridor_management/alternative_uses.cfm

[110] Poe, C. and Filosa, G., 2012. Alternative uses of highway rights-of-way: accommodating renewable energy technologies. *Transportation Research Record: Journal of the Transportation Research Board*, (2270), pp.23-30.

[111] FHWA. Renewable Energy Generation in the Highway Right-of-Way Briefing. FHWA-HEP-16-052. January 2018. www.fhwa.dot.gov/environment/sustainability/energy/publications/row/fhwahep16052.pdf

Figure 14. Examples of Solar PV in Highway ROW or other State DOT Property

MassDOT-installed solar panels in the ROW at Exit 13 North on I-90 in Framingham, MA

Oregon DOT-installed 1.75 MW solar array at the French Prairie Rest Area on I-5

Oregon DOT-installed solar array at the interchange of I-5 and I-205 near Portland

Solar panels along Northwest Parkway near Denver, Colorado

Sources: Oregon DOT; Massachusetts DOT; Northwest Parkway LLC, www.northwestparkway.org/road-info.html#Sustainability

Table 19. Use of ROW by State DOTs to Accommodate Solar Energy Technologies

Project	Purpose	Size
Arizona: I-10, Riverpoint Solar Research Park (in progress)	Generate energy through compression air storage underground	
Colorado: Northwest Parkway Solar (I-25/U.S. 36/State Highway 128) (2008)	Electric power from PV arrays (20-year ROW lease)	26 PV arrays
Oregon: I-5/I-205 Interchange Solar Demonstration Project (2008)	Illuminate adjacent interchange	594 panels, 104 kW, 0.2-acre footprint
Ohio: I-280 Veterans Glass City Skyway Bridge (2010)	Test flexible and rigid solar panels' abilities to offset demand and operating costs of LED bridge structure.	115.6 kW
Oregon: Baldock Safety Rest Area (2012)	Generate/retain Renewable Energy Certificates	6,994 panels, 1.75 MW, 7-acre footprint
Massachusetts: State Route 44 (2012)	Power nearby water treatment facility	99 kW, 1.26-acre footprint
Massachusetts: Solar PV Program	Purchase electricity generated through low, 20-year rate schedule	Minimum 6 MW (from multiple locations)
Various States (e.g., FL, HI, MI, MO, NY, WY)	Solar at rest areas and other highway facilities	

Source: FHWA. Renewable Energy Generation in the Highway Right-of-Way Briefing. FHWA-HEP-16-052. January 2018. www.fhwa.dot.gov/environment/sustainability/energy/publications/row/fhwahep16052.pdf

Green Buildings

Caltrans is pursuing various green building initiatives, including LEED certification, Zero Net Energy buildings, energy efficient lighting, and others.

LEED Certification

Three district offices and a Caltrans Transportation Management Center are certified to Leadership in Energy and Environmental Design (LEED) Gold standards, and two other district offices are LEED Silver. In compliance with Executive Order B-18-12, Caltrans is pursuing LEED-EB (Leadership in Energy and

Environmental Design for Existing Buildings) certification for its office buildings that exceed 10,000 square feet. Seven of Caltrans' buildings meet this criterion, including:

- Three buildings that have submitted their application to the U.S. Green Building Council
- Two buildings that are in the application process
- One building that is working to improve its Energy Star rating before applying
- One building that is in the process of installing submetering to qualify before applying

District 3 Headquarters, Marysville, CA

Additionally, Caltrans requires that buildings at rest areas be LEED certified. Recently, the Phillip Raine Safety Roadside Rest Area along SR99 near Tipton was built and certified as LEED Platinum.

Zero Net Energy Buildings

Executive Order B-18-12 also requires new or existing State buildings to achieve zero net energy, offsetting any energy consumed with renewable energy production. Buildings can achieve zero net energy both by implementing energy efficiency measures and by installing renewable energy sources. The order requires that half of all new facilities beginning after 2020 be zero net energy, and that all new State buildings and major renovations beginning after 2025 be zero net energy. Additionally, half of State agencies' building square footage must be zero net energy by 2025.

In response, Caltrans has begun assessing their buildings to determine how to achieve these goals. Caltrans plans to assess which buildings can most feasibly become zero net energy. It may not be possible to convert some buildings to zero net energy due to limitations. For instance, District 4 facilities in Oakland lacks enough physical space for solar panels; therefore, they may look into installing panels elsewhere.

To meet the energy performance targets, Caltrans has made a concerted effort to replace office lighting in all administrative buildings with more energy efficient options. In 2015, the Department upgraded 9,000 bulbs in the headquarters building, replacing T12 fluorescent lights with T8 lights, which use 20 percent less energy. For each District's office buildings, Caltrans purchased LED light fixtures, which use significantly less energy than traditional fluorescent lights. Some Districts have completed the replacements while others are still working to finish replacing their fixtures; one District has been unable to replace the bulbs because the LEDs were not compatible with the light fixtures.

Employee EV Charging

Executive Order B-18-12 requires state agencies to identify and pursue opportunities to provide electric vehicle charging stations at employee parking facilities in new and existing buildings. The state's 2016

ZEV Action Plan calls on each state agency to develop a workplace charging plan that will result in EV charging availability at a minimum of 5% of workplace parking spaces at state-owned facilities. In response, Caltrans is developing a new Policy regarding the provision of EV charging infrastructure for use by Caltrans employees. Caltrans currently has 413 EV charging ports for employee vehicles, with a goal of 1,000 EV charging ports within three years.

Employee Commute Options

Commute travel by Caltrans employees generates approximately 50,000 tons of GHG emissions annually. While this figure is small in relation to the emissions from all roadway system users, Caltrans recognizes its role as the state's leader in transportation to reduce the GHG emissions from employee commuting to set an example for other state agencies and the traveling public. While Caltrans has a number of programs in place to encourage less carbon intensive commuting, there are opportunities to increase the effectiveness of these efforts.

Caltrans offers or supports a number of programs to encourage Caltrans employees to utilize alternative transportation modes and reduce the amount of solo driving trips to and from work. To improve employee alternative transportation options, Caltrans provides bicycle parking and lockers for some Caltrans buildings, subsidizes transit passes, and supports vanpool programs.

With more than 4,000 employees in the Sacramento area, which offers a number of transportation options, Caltrans Headquarters has a distinct opportunity to influence travel and GHG emissions from employee commuters. Data was collected from Caltrans administration and self-reported information submitted through the Commuter Club portal of the Sacramento Transportation Management Association. More than 1,300 employees at Headquarters take a transit subsidy or payroll deduction to pay for transit. Another 50 Headquarters employees receive reimbursements for participating in the vanpool program. Additionally, 141 employees report biking to work.

Headquarters and each District administered a survey of employees about their commute patterns. The Districts that collected and shared data showed a large variance in the share of employees commuting by different modes. The adoption of alternative modes is largely a reflection of the mode options available and the land use patterns around each office.

Caltrans District 9 Employees Celebrate Bike to Work Month

The table below shows the estimated GHG reductions that result from employee commute programs administered or supported by Caltrans.

Table 20. Annual CO_2 Emission Reductions Associated with Employee Commute Programs, 2017

Mode	Number of Participants	GHG Reduced (tons CO_2)
Transit	2,570	3,754
Carpool	1,041	1,829
Vanpool	455	1,207
Bicycle	277	255
Total	**4,342**	**7,175**

Source: Calculations by ICF using employee commute data gathered from Districts. GHG reduction calculations follow the methods described in Caltrans Activities to Reduce GHG emissions, 2013, with updated emission factors.

Even though robust transit options for commuters are largely limited to large urban areas (i.e., Headquarters, District 4, and District 7), transit makes up the largest share of alternative commute trips and associated GHG reductions. The reductions associated with carpool and vanpool are roughly half that of transit. A small portion of employees bike to work, with about half of the reported bicyclists commuting to Headquarters. Note that District 11 did not report commute data, which could represent significant additional reductions given the variety of transportation options in the San Diego area and the proximity of the District 11 office to a light rail stop.

Additional programs and incentives could further increase transit use, ridesharing, and bicycling among Caltrans employees. For example, in some Districts, the Department could consider offering subsidized or free bikeshare memberships to encourage bicycling. The District of Columbia Department of Transportation and some federal agencies in Washington D.C. offer this benefit to employees.[112]

Guaranteed Ride Home programs encourage non-vehicle commute by providing a safety net for employees who may be concerned about getting home quickly in case of an emergency, late at night, or when transit may not be running. While some Caltrans offices offer this service through partnerships with transportation management associations (TMAs), such programs could be expanded Department-wide. The Washington State DOT administers a Guaranteed Ride Home program for WSDOT employees, offering up to eight taxi rides for employees from work to home per year. WSDOT contracts with taxi companies and manages a hotline to coordinate rides.[113]

Location Efficiency

Location efficiency refers a combination of land use and transportation system characteristics that provide efficient access to destinations via a multimodal transportation system. Areas with high location efficiency typically are adjacent to bicycle and pedestrian infrastructure and are accessible by frequent transit service. In addition, neighborhood characteristics, such as density, mixed land uses, and equitable access among income groups are also important features that encourage non-vehicle travel.

Caltrans can help to GHG emissions associated with employee commuting by ensuring that any new office facilities are located in areas with high location efficiency. In 2016, the California Strategic Growth Council adopted the *Resolution on Location Efficiency in Strategic Growth Council Agency Leased Facilities*.[114] Under this resolution, the Council set a goal to increase the average location efficiency score of new leased facilities for infill-compatible uses among Strategic Growth Council agencies. Location efficiency scores come from the US General Services Administration's Smart Location Calculator, which uses a scale of 0-100 based on a number of accessibility factors.[115] Factors include accessibility via transit, walking and bicycling, land use mix, regional mode share, retail, residential, and office density, intersection density and street design, and vehicle ownership, among others. Locations with high location efficiency scores are likely to exhibit less vehicle travel and emissions. Each score is relative to its own metro region. This means that high scoring locations in metropolitan areas with lower overall accessibility may generate more VMT than lower scoring locations in metropolitan areas with higher overall accessibility.

For example, the Caltrans District 4 office has a location efficiency score of 81. This office has a relatively high numbers of transit and bicycle commutes, likely in part due to transit access and bicycle infrastructure, and also a high number of carpoolers. District 1 has fewer transit options but has a

[112] DC Government Department of Human Resources website. https://dchr.dc.gov/page/capital-bikeshare-membership-discount

[113] Washington State Agencies Commute Trip Reduction website. www.ctr.wa.gov/employees/saferide.htm

[114] State of California Green Buildings website. Retrieved from: https://green.ca.gov/buildings/resources/les/

[115] Smart Location Calculator. Retrieved from: https://www.slc.gsa.gov/slc/#

location efficiency score of 89, higher than District 4, because the score compares characteristics of the office location to other locations in the Eureka metropolitan area. Again, these scores cannot be compared across regions; they represent the location efficiency relative to their own metropolitan region. The table below shows the location efficiency score of each Caltrans District headquarters office.

Table 21. Location Efficiency Score of Caltrans District Offices

District	Address	Location Efficiency Score
HQ	1120 N Street, Sacramento CA	98
1	1656 Union Street, Eureka CA	89
2	1657 Riverside Drive, Redding CA	75
3	703 B Street, Marysville CA	79
4	111 Grand Avenue, Oakland CA	81
5	50 Higuera Street , San Luis Obispo CA	75
6	1352 W. Olive Avenue, Fresno CA	81
6	2015 E Shields, Fresno CA	89
6	855 M Street, Fresno CA	94
7	100 S. Main Street, Los Angeles CA	88
8	464 West 4th Street, San Bernardino CA	73
9	500 South Main Street, Bishop CA	89
10	1976 Dr. M.L.K. Jr Blvd, Stockton, CA	65
11	4050 Taylor Street, San Diego CA	64
12 (former location)	3347 Michelson Drive, Irvine CA	57
12	1750 E 4th St, Santa Ana, CA	69

Source: ICF calculation using US General Services Administration's Smart Location Calculator

While Caltrans has not leased any new properties since the time the directive was issued through the Strategic Growth Council's initial reporting period, Caltrans can encourage employee travel by modes with low carbon intensity by ensuring that any new facilities (owned or leased) be located in areas with high location efficiency.

5 Summary

This report documents the numerous ways that Caltrans is helping to reduce GHG emissions through its planning, programming, design, construction, maintenance, traffic operations, and administrative activities, and also identifies opportunities for Caltrans to further contribute to GHG reduction efforts.

By far the greatest opportunities for Caltrans to reduce GHG emissions relate to influencing vehicle travel on the State Highway System. Vehicle travel on the State Highway System produces roughly 89 million metric tons of GHG emissions annually, or 21 percent of California's total GHG inventory. The primary opportunities for Caltrans to reduce these emissions are:

- **Limit demand for travel by SOVs.** Caltrans can limit the demand for SOV travel that accounts for the bulk of transportation GHG emission in the state by avoiding highway capacity expansion projects that induce new vehicle travel. Adding highway capacity in urbanized areas, including HOV and express lanes, often will induce new vehicle travel, limiting long-term congestion reduction benefits and leading to increased VMT and potentially higher GHG emissions. As an alternative to capacity expansion, roadway pricing provides a mechanism for reducing the demand for SOV travel and improving network performance, although Federal law currently prohibits Caltrans from imposing tolls on Interstate highway general purpose lanes.
- **Support transportation system improvements that to provide alternatives to SOV travel.** Caltrans can lead the development of new facilities for bicyclists, pedestrians, and carpoolers. For example, Caltrans develops bicycle lanes on state highways and constructs park-and-ride lots that encourage ridesharing. Caltrans can also support demand management strategies that are implemented by other organizations. For example, Caltrans supports public transit service by enabling bus operations on the highway shoulder where possible and facilitates exceptions to highway design standards that support local complete streets efforts. By promoting mode shift, these activities have been demonstrated to reduce GHG emissions, although the magnitude of GHG impacts is typically small as compared to those from vehicles on the highway system.

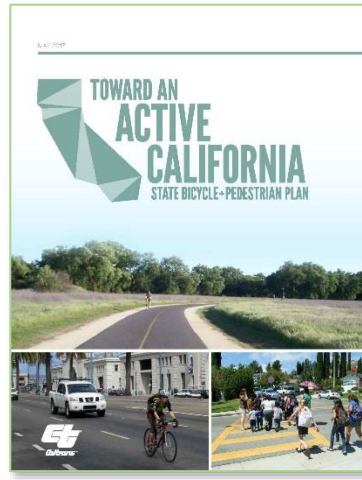
Caltrans highway construction and maintenance projects result in substantial GHG emissions, particularly when considering the emissions associated with the extraction, processing, and transport of materials such as concrete, asphalt, and aggregates. A variety of strategies are available to reduce emissions from paving and other highway construction and maintenance projects, including use of reclaimed asphalt pavement and use of supplemental cementious materials (such as fly ash) in concrete. Because of the large volume of roadway construction materials used on Caltrans projects, and Caltrans influence among partner agencies and the pavement and road construction industry, the Department can achieve significant GHG reductions through its design and construction process specifications. However, the impact of pavement choices on GHG emissions is complex, and any decisions to promote pavement or other materials strategies for GHG reduction should be informed by experts in the field of LCA research.

Caltrans is directly responsible for approximately 120,000 tons of CO_2-equivalent emissions per year due to its own internal operations, which is about 0.03 percent of California's total statewide GHG emission inventory. Sources of these emissions include the fuel used to power Caltrans vehicle fleet, energy used for lighting on the State Highway System, and energy used in Caltrans buildings. The internal operations emissions under direct Caltrans control have declined 45 percent since 2010, and are expected to continue to decline as more energy efficiency measures are implemented, low carbon vehicle fuels gain market share, and California's grid electricity becomes cleaner. Opportunities to further reduce Caltrans internal operations emissions include increasing renewable energy generation by installing solar power projects in the highway right-of-way, purchasing fuels with lower carbon intensities for Caltrans fleet such as renewable natural gas, and expanding programs and incentives to increase transit use, ridesharing, and bicycling for Caltrans employee commuting.

Appendix A

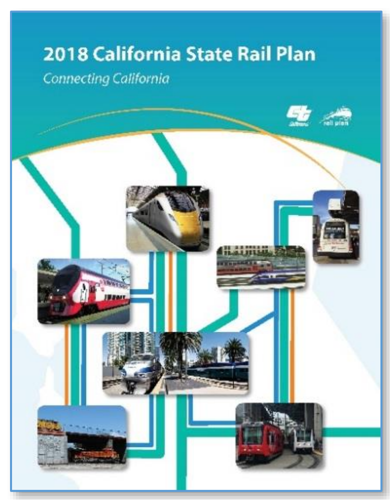
Caltrans Modal Plans

Toward an Active California: State Bicycle + Pedestrian Plan



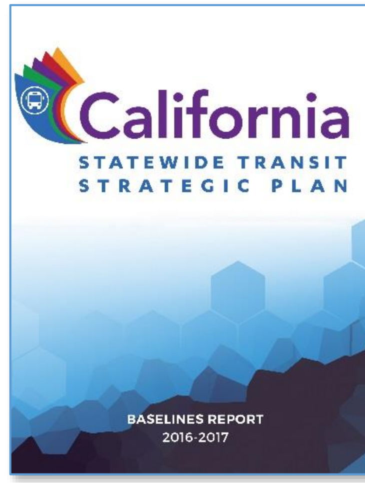
In 2017 Caltrans released *Toward and Active California: State Bicycle + Pedestrian Plan*, which describes Caltrans' overall approach for non-motorized transportation facilities. The plan describes statewide transportation system goals that can be supported by the development of bicycle and pedestrian facilities, such as improved mobility and social equity, and strategies for achieving those goals. To the extent they shift travel from motorized modes, measures that encourage bicycling and walking have clear GHG benefits, as these modes have no direct GHG emissions. An appendix to the plan provides an estimate the environmental benefits, including CO_2 emissions reduced, of achieving the active transportation mode share targets established in the Strategic Management Plan. The study estimates 2.2 million more bicycling trips and 11.4 million more walk trips; some factor of these would replace motorized trips, resulting in a reduction of 1.2 million tons of CO_2 per year. This equates to roughly 1 percent of the state's current annual CO_2 emissions from passenger vehicles.

California State Rail Plan: Connecting California



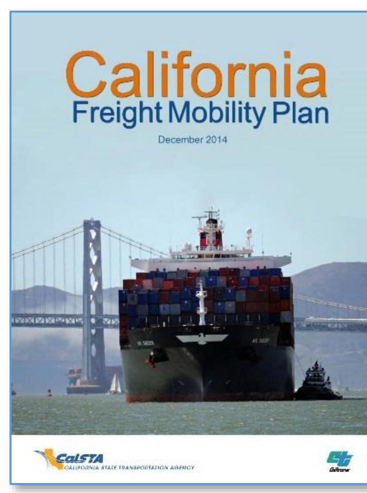
The *California State Rail Plan* was released in September 2018. The plan includes an expansive overview of rail system in California, including the State's goals for the rail system, policies driving rail service, and funding and financing. Rail investments can impact both passengers and freight movement. The plan envisions faster service and improved connectivity across the entire transportation network as a result of the rail plan elements. Improvements in rail can result in GHG emission reductions by shifting both passenger travel and freight shipping from on-road vehicles and from improvements in rail locomotives, including the electrification of rail lines. According to the plan documentation, there are currently 115,000 intercity rail passenger trips per day; in 2040, the plan forecasts 151,000 daily trips without the projects outlined in the plan to improve capacity and operations and over 1.3 million daily passenger trips if the 2040 plan is fully implemented as envisioned. While improvements in freight rail and grade crossings can encourage shifting of freight shipments from on-road trucks to rail and reduce congestion for all vehicles on shared roadways, the plan does not include these potential shifts in its emission benefit estimates. The emissions analysis instead focuses on the shift from personal vehicles to passenger rail. If the elements of the rail plan are not implemented, the plan estimates that on-road vehicles and locomotives will emit over 416,000 tons of CO_2 per day in 2040; with the plan fully implemented, CO_2 emissions will be reduced by 12,778 tons per day.

California Statewide Transit Strategic Plan



The *Statewide Transit Strategic Plan* consists of three separate reports from 2012: an assessment of baseline transit conditions and trends; a summary of outcomes from stakeholder engagement activities; and recommendations for Caltrans Division of Mass Transportation. Caltrans is in the process of updating the transit plan, with new baseline and stakeholder engagement reports released in 2017 and a new set of recommendations scheduled to be released in 2018. Unlike newer modal plans (and the new recommendations report not yet released) which discuss efforts and strategies for all relevant state and local government agencies, the 2012 transit plan focuses narrowly on efforts that Caltrans Division of Mass Transportation could implement. These recommendations include: sponsoring vanpools; supporting station vans to provide last-mile trips; supporting bus-only lanes; allowing buses on shoulders of controlled access highways; and supporting local efforts to implement congestion pricing mechanisms. Statewide strategies and investments in public transportation systems have the potential to reduce VMT by encouraging travelers to replace private vehicle trips with transit trips, especially when considering transit systems have a key role in network connectivity which can improve travel across the broader multimodal transportation system. The 2012 transit plan does not include estimates of VMT or GHG emission reductions related to its recommendations.

California Freight Mobility Plan



The 2014 *California Freight Mobility Plan* describes the state's long-range plan for a sustainable freight transportation system. The plan recognizes the threat that GHG emissions impose and includes objectives for environmental stewardship and congestion relief and describes general strategies to achieve those goals. The plan describes the many local (port) and state programs that are in action to reduce emissions related to maritime, rail, on-road trucking, and air freight movement, and the associated reductions in criteria pollutant emissions. The plan describes the many local (port) and state programs that are in action to reduce emissions related to maritime, rail, on-road trucking, and air freight movement, and the associated reductions in criteria pollutant emissions. The Freight Mobility Plan does not include an estimate of the GHG impacts of the plan. However, the plan includes a list of potential projects, both financially constrained and unconstrained, in an appendix.

Planning Grants

Sustainable Communities Grants

Sustainable Communities Grants are intended to help local and regional agencies achieve or improve GHG reductions through their multimodal transportation and land use planning efforts. SB1 provides $250 over ten years, or $25 million per year, for this grant program, with half being allocated to competitive grants and the other half through formula grants. For fiscal year 2017-2018, Caltrans received 127 applications requesting a total of $34.1 million in the for competitive grant program. Caltrans awarded 43 grants, totaling $12.4 million, and work has started on those projects. Under the formula program, 13 MPOs were awarded a share of the grant funding as they met minimum program requirements, which include having a Regional Transportation Plan Sustainable Communities Strategy (RTP-SCS) in place and meeting environmental justice standards. As of May 2018, Caltrans had awarded $12.8 million for 47 competitive grants and $12.5 million for 17 MPOs.

Adaptation Planning Grants

Adaptation Planning Grants are awarded to agencies to support local and regional planning to prepare for and reduce the impacts associated with climate change. This is a competitive grant program that is funded for $20 million split over three years (FY 2017/2018 through FY 2019/2020). Grant projects should identify climate risks to multimodal transportation infrastructure, vulnerabilities, and actions to mitigate vulnerabilities, in addition to developing potential designs, cost estimates, and cost analyses. Furthermore, these grant projects must involve partnerships across sectors and jurisdictions and identify co-benefits associated with adaptation efforts (e.g., air quality, public health, natural environment, economic, and equity improvements). Caltrans awarded 21 grants worth $7 million in fiscal year 2017-2018 and 22 grants for $7 million in fiscal year 2018-2019.

Strategic Partnerships Grants

Strategic Partnerships Grants are awarded to MPOs and Regional Transportation Planning Agencies (RTPAs) to encourage engagement of local and regional planning agencies with Caltrans to ultimately improve the State Highway System. Projects have included studies of corridors and multimodal or intermodal facilities; state-level research and modeling; and sustainable freight planning. The grant funding is provided by FHWA (FHWA State Planning and Research, Part I) and administered by Caltrans. In fiscal year 2017-2018, $1.5 million was available for the program; $4.3 million is available for fiscal year 2018-2019, with awards ranging from $100,000 to $500,000. Also in FY 2018/2019, the program newly directs funding for transit planning projects to address multimodal transportation gaps.