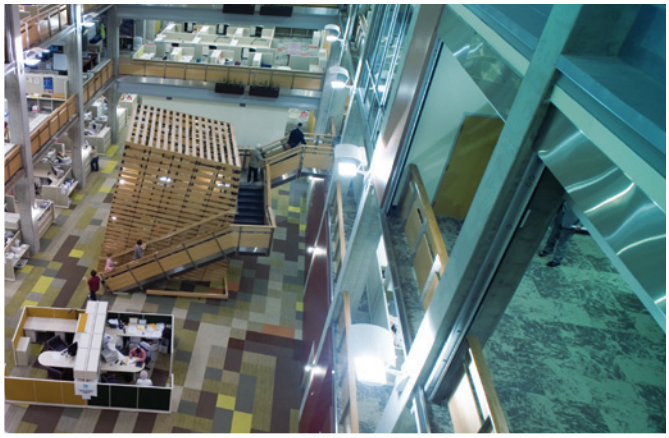

Caltrans Activities to Address Climate Change

Reducing Greenhouse Gas Emissions and Adapting to Impacts

April 2013

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Flex your power!
Be energy efficient!

To the Citizens of California, Governor, and Members of the Legislature:

I am pleased to publish this report detailing the efforts of California Department of Transportation (Caltrans) to both adapt to the growing threat of climate change and mitigate its effects by reducing greenhouse gas emissions.

Climate change poses an immediate and growing threat to California's economy, environment and infrastructure. As of 2009, nearly 2,000 miles of California's roadways were at risk of a 100-year flood event. To prepare for climate change and adapt to its effects, Caltrans is focused on preserving our state's existing transportation infrastructure while continually innovating to find better solutions.

Some steps Caltrans is taking to adapt to climate change include using native plants, mulch, and hardscape in lieu of traditional landscaping plants to reduce the need for irrigation; installing solar panels on approximately 70 Caltrans buildings statewide to generate 3.6 million kilowatt hours of renewable energy annually; and developing a standard for cool pavements that reduce urban heat in the face of global warming.

Caltrans is also working with our other partners to cut greenhouse gas emissions by continually working to reduce traffic congestion, expand active transportation such as walking and biking, and also embrace new technology in construction materials, alternative fuels, efficient lighting and renewable energy. These efforts have reduced greenhouse gas emissions by more than 161,500 tons annually, the equivalent of removing 31,000 passenger cars from California's roads.

Caltrans is responsible for articulating a long-term vision for California's transportation system. As we continue to operate more efficiently, expand alternatives to driving, and encourage smart land use, Caltrans will help California fight global warming and adapt to its effects.

Sincerely,

MALCOLM DOUGHERTY
Director

Caltrans Activities to Address Climate Change

Reducing Greenhouse Gas Emissions and Adapting to Impacts

April 2013

Prepared by:

ICF INTERNATIONAL

For:

Caltrans®

Contents

List of Tables

List of Figures

Acronyms

AASHTO	American Association of State Highway and Transportation Officials
AB	Assembly Bill
ALDOT	Alabama Department of Transportation
ARB	California Air Resources Board
B5	5-percent biodiesel blend
B20	20-percent biodiesel blend
B100	100-percent biodiesel blend
BEV	battery electric vehicle
BTA	Bicycle Transportation Account
Cal-B/C	California Life Cycle Benefits/Costs Model
Caltrans	California Department of Transportation
CBTP	Community-Based Transportation Planning
CIR	cold in-place recycling
CNG	compressed natural gas
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalents
CO-CAT	California Coastal Ocean Climate Action Team
CREBs	Clean Renewable Energy Bonds
CSMP	Corridor System Management Plan
CSS	context sensitive solutions
CTP	California Transportation Plan
DD	Deputy Directive
DGE	diesel gallon equivalent
DOT	Department of Transportation
DP	Director's Policy
DRISI	Division of Research, Innovation, and System Information
E85	85-percent ethanol blend
EJ	Environmental Justice
EO	Executive Order
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act of 1992
FDR	full depth reclamation
FHWA	Federal Highway Administration
GGE	gasoline gallon equivalent
GHG	greenhouse gas(es)
GMAP	Goods Movement Action Plan
Guidance	*Guidance on Incorporating Sea Level Rise*
HDM	*Highway Design Manual*
HEV	hybrid electric vehicle
HMA	hot-mix asphalt
HOT	high-occupancy toll
HOV	high-occupancy vehicle
HVAC	heating, ventilating, and air conditioning
IETMC	Inland Empire Transportation Management Center
kW	kilowatt
LED	light-emitting diode
LEED	Leadership in Energy and Environmental Design
LOS	level of service

MIRIAM	Road Infrastructure Asset Management Systems
MPO	metropolitan planning organization
MTC	Metropolitan Transportation Commission
MV	mercury vapor
MW	megawatt
MWh	megawatt hour
NDOT	Nevada Department of Transportation
NRC	National Research Council
NYSDOT	New York State Department of Transportation
ODOT	Oregon Department of Transportation
PHEV	plug-in hybrid electric vehicle
RAC	rubberized asphalt concrete
RHMA	rubber hot-mix asphalt
RICS	remote irrigation control system
RPC	Rock Products Committee
RTP	regional transportation plan
RTPA	regional transportation planning agency
SB	Senate Bill
SER	*Standard Environmental Reference*
SMUD	Sacramento Municipal Utility District
SR2S	Safe Routes to School
STSP	Statewide Transit Strategic Plan
TMA	Transportation Management Association
TMC	transportation management center
UC Davis	University of California, Davis
UCTC	University of California Transportation Center
UDOT	Utah Department of Transportation
UTC	university transportation center
VMT	vehicle miles traveled
WMA	warm-mix asphalt

Executive Summary

This report provides a comprehensive overview of activities undertaken by the California Department of Transportation (Caltrans) to reduce greenhouse gas (GHG) emissions and adapt the state's transportation system to prepare for the impacts of climate change. It also identifies opportunities for additional reductions in GHG emissions and climate adaptation activities that Caltrans may wish to consider in the future.

The goals of the report are to:

- Help spread information about best practices in GHG mitigation and climate change adaptation among Caltrans staff working in different divisions and districts, as well as among other transportation agencies;
- Aid staff at other state agencies in identifying potential opportunities for collaboration with Caltrans in efforts to meet statewide GHG reduction and energy efficiency targets; and
- Inform the public about the status of Caltrans' initiatives to address climate change.

The report qualitatively discusses activities that are underway across Caltrans divisions and districts, and provides quantitative information on GHG reduction initiatives wherever possible.

Background and Overview

The mission of Caltrans is to improve mobility across California. The agency is responsible for planning, designing, maintaining, and operating more than 50,000 roadway lane-miles that make up the State Highway System, as well as planning for other transportation modes—including public transit, aviation, bicycling, and walking. As public and scientific concern over climate change has grown, California has adopted policies to reduce energy use and GHG emissions, including statewide targets and specific requirements for state agencies. Because on-road vehicles are the largest single producer of GHG emissions by end use in the state,[1] many aspects of California's GHG reduction policies address the transportation sector and therefore involve Caltrans.

This report represents an important step in efforts by Caltrans to identify best practices in GHG mitigation for its operations. It presents quantitative estimates of GHG reductions for emissions sources under the direct control of Caltrans and qualitatively discusses activities related to planning and adaptation.

This report consists of eight chapters. Following the Introduction and Background chapters, the report is organized as follows:

- Planning and Environmental (Chapter 3)
- Materials, Concrete, and Pavement (Chapter 4)
- Maintenance and Operations (Chapter 5)
- Facilities and Administration (Chapter 6)
- GHG Reduction Activities in Caltrans Districts (Chapter 7)
- Adapting to Climate Variability and Change (Chapter 8)

Chapters 3–6 organize the numerous divisions and offices within Caltrans into four broad functional categories, describe the actions that Caltrans is taking to reduce GHG emissions in each category, and identify additional opportunities to reduce GHG emissions. Chapter 7 discusses GHG reduction activities initiated by the individual Caltrans districts that serve different areas of the state. Chapter 8 discusses Caltrans' efforts to adapt to climate change and identifies additional opportunities to strengthen these efforts. Each chapter highlights innovative and high-impact Caltrans projects that have served as examples of best practices for other transportation departments or have influenced other transportation agencies in California as they work to address climate change. Below is a brief summary of each chapter.

Planning and Environmental

Caltrans is responsible for articulating a long-term vision for California's transportation system. This involves planning for future improvements to the State Highway System and intercity rail services, and collaborating with regional transportation agencies across California to create a transportation system that achieves Caltrans' mission. Over the past several decades, Caltrans has shifted from focusing on roadway expansion to managing and maintaining the existing system—by operating the system more efficiently, encouraging smart land use patterns, and providing alternatives to driving. This approach is more cost effective and is crucial to reducing transportation sector GHG emissions. Reducing energy consumption and GHG emissions and encouraging alternatives to driving are the explicit focus of many Caltrans' high-level plans and policies. The Department is now beginning to extend this focus to guidance issued on specific aspects of the planning process. Caltrans also has created funding and technical assistance programs dedicated to helping local and regional governments implement these plans and policies. In addition, Caltrans funds, conducts, and disseminates innovative new research that improves the state of the practice in transportation planning.

Examples of innovative planning activities include:

- Creating a **Complete Streets Implementation Action Plan** that identifies all Caltrans' plans, policies, and guidance documents that need to be amended in order to better accommodate pedestrians, bicyclists, and transit users. This plan spurred a series of comprehensive edits to the *Highway Design Manual* with new or amended guidance on several different aspects of complete streets, including reduced vehicle lane widths, pedestrian refuge islands, adequate bike lane widths, and bus rapid transit and light rail facilities. These changes have the potential to reduce GHG emissions by creating streets that are conducive to all modes of travel, allowing for increased use of alternatives to driving.
- Providing more than $20 million in **Blueprint Planning Grants** to help regional transportation agencies create Blueprint Plans, which are long-term integrated transportation and land use plans. These plans offer a comprehensive look at the environmental and transportation impacts of new growth, and create an opportunity to focus growth in areas with access to transit and other travel alternatives. Blueprint Plans laid the groundwork for Senate

Bill (SB) 375, California's landmark law integrating GHG reduction and regional transportation planning, and this grant program continued to support SB 375 implementation through 2012.

Materials, Concrete, and Pavement

Caltrans oversees construction of the State Highway System and works with regional and local partners to select new projects and manage their delivery. The Department hires and manages construction contractors and sets policies and specifications that guide project delivery. These include design standards for the materials, concrete, and pavement used in transportation infrastructure. Highways are major pieces of infrastructure that require vast amounts of materials to construct, and Caltrans has several initiatives underway that require or allow contractors to use materials that produce fewer life-cycle GHG emissions.

Notable GHG mitigation activities in this category include:

- Amending **concrete specifications** to allow contractors to use greater amounts of less GHG-intensive alternatives to Portland cement, the traditional primary binding agent in concrete, when building roads and bridges. Statewide, Caltrans used more than 130,000 tons of fly ash and more than 56,000 tons of other Portland cement alternatives, including blast furnace slag, on the State Highway System in 2010. These alternatives reduced GHG emissions by more than 47,000 tons, the equivalent of taking more than 9,100 vehicles off the road for a year. These actions also spurred a similar shift among other transportation agencies that reduced additional statewide concrete-related GHG emissions.
- Using **alternative asphalt pavements** that contain recycled rubber, recycled pavements, or binding agents that allow pavement to be mixed and laid at lower temperatures. These changes reduce GHG emissions associated with manufacturing materials and with construction fuel use. In total, Caltrans reduced pavement-related GHG emissions by more than 61,000 tons in 2011, which is roughly equal to the yearly emissions produced by 11,800 passenger vehicles.

Maintenance and Operations

In addition to overseeing the design and construction of the State Highway System, Caltrans is responsible for maintaining and operating the System. Given that the State Highway System encompasses almost 50,000 lane-miles of pavement, this is a labor-intensive undertaking. It involves repairing and resurfacing pavement, removing snow and debris, managing vegetation, operating traffic signals and roadway lighting, and managing traffic. Maintenance and lighting activities directly consume energy and produce GHG emissions, and Caltrans works both to reduce these emissions and find opportunities to generate energy on its property. Traffic management also has the potential to keep the millions of vehicles that use the State Highway System each day operating at efficient speeds.

Projects highlighted in this chapter of the report include:

- Replacing light fixtures along the State Highway System with **energy-efficient lighting**. More than a decade ago, Caltrans began replacing 76,000 incandescent traffic signals with light-emitting diode (LED) fixtures, which reduced the associated energy costs by 80 percent. Caltrans then replaced pedestrian signals, changeable message signs, and a substantial share of sign lighting with more efficient fixtures, and is currently working to replace roadway lighting with LED fixtures. The lighting efficiency efforts undertaken to date reduce GHG emissions by almost 39,000 tons per year. This is roughly equal to the annual emissions produced by 7,500 cars.
- Operating approximately 3,000 **alternative fuel vehicles**, including flex-fuel vehicles that can run on an 85-percent ethanol blend and heavy-duty vehicles that run on a 5-percent biodiesel blend. Caltrans is the largest consumer of biodiesel in California. The Department also operates advanced technology vehicles and equipment

that reduce fuel consumption, such as hybrid electric vehicles and solar-powered changeable message signs and arrow boards.

Facilities and Administration

Several divisions within Caltrans manage offices and facilities around the state. In partnership with the California Department of General Services, this work involves overseeing construction and renovation of Caltrans facilities, managing leases, and administering workplace and employee programs. Caltrans is currently working to reduce GHG emissions from its facilities by requiring that new buildings be energy-efficient, by upgrading equipment and systems in existing buildings, and by encouraging employees to recycle and use alternative transportation to get to work.

Examples of actions in this category include:

- Issuing $20 million in federally backed **Clean Renewable Energy Bonds (CREBs)** to pay for 70 solar photovoltaic projects at Caltrans facilities, which will generate 3.6 million kilowatt (kW) hours per year. CREBs-funded projects built to date reduce GHG emissions by 1,300 tons per year, the equivalent of removing more than 200 vehicles from the road. Caltrans was the only state agency in California that applied to issue CREBs.
- Implementing **employee commute programs** to reduce driving to work. These include reduced-fee monthly bus passes, emergency ride home vouchers, subsidies for vanpools, carpool matching services, secure-access bicycle parking, and a telecommute policy. In 2011, employees using alternative modes to transportation reduced GHG emissions at Caltrans headquarters by more than 1,800 tons (equivalent to taking 350 passenger vehicles off the road). This program, along with similar programs among Caltrans districts, reduced Department-wide emissions by more than 6,500 tons (equivalent to 1,200 passenger vehicles).

Map of Caltrans Districts

Source: Caltrans

GHG Reduction Activities in Caltrans Districts

Caltrans headquarters sets policies and procedures that affect almost every element of the planning, design, construction, operation, and maintenance of the State Highway System. The 12 Caltrans district offices, however, are ultimately responsible for implementing these policies and procedures. To the left is a map of the 12 Caltrans districts.

Each district has its own projects to reduce GHG emissions, which often include building energy efficiency measures, solar photovoltaic facilities, and fleet vehicles powered by alternative fuels.

Highlights of these activities include:

- **District 1** has taken advantage of a renovation to its district offices to install an **upgraded heating, ventilation, and air conditioning (HVAC) system and energy-efficient lighting**. The district upgraded its HVAC system and replaced more than 1,350 light

fixtures with newer fixtures that use 20 percent less energy. In addition, the new fixtures are on timers so that they do not remain on when not in use.

- **District 2** has pioneered the use of a **new recycled product called CRMcrete for weed control**. Workers now take 30 percent fewer trips to remove weeds at sites where CRMcrete is installed and use less fuel for maintenance. CRMcrete, which is a mix of concrete and recycled rubber developed by a District 2 maintenance engineer, also produces fewer embodied GHG emissions (i.e., emissions associated with the production of materials) compared to other hardscaping materials.
- **District 3** runs a successful **employee commute program** that includes subsidies for vanpools and transit costs, emergency ride home vouchers, showers and lockers for bicyclists, and an online system that employees use to find carpool and vanpool matches and to report the amount of miles that they commute via alternative modes. As a result, the number of employees participating in ridesharing programs increased by 75 percent between 2009 and 2011.
- **District 4** has been a pioneer in installing **energy-efficient LED roadway lights**, which use 60 percent less electricity and last five times longer than the existing roadway light fixtures. Although this initiative is just in its infancy, the District saved nearly $150,000 on its electricity bills in 2011 by replacing roadway lights.
- **District 5** has installed new **energy-efficient cool roofs** on two of its buildings. These roofs reduce energy needs for heating and cooling, as well as for maintenance and replacement because they last twice as long as the old roofs.
- **District 6** is constructing a **rest area** in Tulare County that features solar panels, recycled materials, pervious paving, low-flow plumbing, drought-tolerant plants, and an efficient irrigation system. This project is designed to obtain a Leadership in Energy and Environmental Design (LEED) Gold certification. If certified, it will be the first LEED-certified rest area in the state.
- **District 7** has built a **LEED Gold-certified district office building** that features perforated aluminum screens that open and close depending on the weather and sunlight; photovoltaic panels that generate 5 percent of the building's energy; and skip-stop elevators that stop on only four of the building's 13 floors, thus conserving energy and encouraging employees to exercise. The building was originally certified as LEED Silver, but it achieved LEED Gold after commitments to additional changes that included adjusting the thermostat to reduce heating and cooling loads, purchasing recycled products, and adopting more sustainable custodial practices.
- **District 8** has built a **LEED Gold-certified transportation management center**, which is the first essential services facility in the country to achieve this distinction. The center consumes 30 percent less energy than typical essential services facilities, which are buildings with high energy needs designed to function around the clock in emergencies.
- **District 9** is using **locally sourced volcanic cinders to improve traction on snowy and icy roads** instead of imported sand, which reduces the energy needed to transport materials.
- **District 10** has installed **two solar projects that were built by private companies at no initial cost to Caltrans**. These companies operate and maintain the projects, and District 10 purchases the electricity generated at a rate that is guaranteed to be cheaper than what the local utility charges for power from the grid.
- **District 11** has partnered with local planning agencies to **examine GHG and criteria pollutant emissions at crossings along the U.S.-Mexico border**. The resulting studies have identified best practices and performance measures to reduce emissions when planning future changes to border infrastructure.
- **District 12** achieved **LEED Gold certification for its district office building complex,** redesigning it to include energy-efficient features such as daylight sensors that adjust lighting levels according to the amount of ambient

light, automated HVAC control systems, and ENERGY STAR-rated computer systems that shut down automatically when not in use.

Adapting to Climate Variability and Change

Even with successful GHG mitigation strategies underway, GHG emissions are already causing measured changes in the global climate, and these changes will continue into the future. These changes will occur on top of natural variations in local climate and weather. Many transportation agencies, including Caltrans, are considering ways to prepare for challenges caused by natural variability and human-induced changes in climate. This chapter provides an overview of the potential impacts of climate change on California's transportation system, and discusses some of the efforts currently underway to address these impacts.

Some specific examples include:

- Creating **guidance on incorporating sea level rise into the project delivery process** in order to help districts identify potential impacts on future projects. Several districts have already used this guidance to evaluate projects that are planned for roads adjacent to waterways.
- **Mapping "hot spots" along the State Highway System** that are at risk of experiencing flooding or other impacts due to sea level rise.

Summary of Reductions in GHG Emissions

This report quantifies reductions in GHG emissions, including carbon dioxide, methane, nitrous oxide, and other GHGs, from all strategies that affect emissions by Caltrans or its contractors for which sufficient data are available. Collectively, these strategies have reduced GHG emissions by more than 161,500 tons annually, which is the equivalent of removing approximately 31,000 passenger vehicles from the road for a year. The following table summarizes the GHG reductions due to the various strategies quantified in this report.

Summary of Caltrans' Efforts to Reduce GHG Emissions

Strategy	Average Annual GHG Reductions (tons CO_2e)
Materials, concrete, and pavement strategies subtotal	**108,711**
• Alternatives to conventional concrete*	47,236
• Alternatives to conventional asphalt*	61,475
Operations and maintenance strategies subtotal	**41,001**
• Roadway lighting	38,819
• Alternative fuels and vehicles in fleets	2,182
Facilities and administration strategies subtotal	**11,367**
• Renewable energy projects	1,391
• Building energy and water efficiency	3,511
• Workplace commute programs	6,465

**Annual reduction values are based on 2011 data instead of average annual reductions.*

1 Introduction

1.1 Overview

This report provides information on the range of activities undertaken by the California Department of Transportation (Caltrans) to address climate change. Caltrans is a large and diverse organization, and its staff come from a wide array of professions, including engineers, landscape architects, transportation and environmental planners, project managers, maintenance workers, and administrative staff. These individuals support the planning, design, construction, maintenance, and operation of the state transportation system. Although Caltrans addresses climate change at almost every step of its operations, the size and breadth of the organization can make it difficult to track all of these activities.

This report is intended to provide a comprehensive overview of Caltrans' activities to address climate change, both by reducing GHG emissions and by adapting to the impacts of climate change. It also identifies opportunities for additional activities that Caltrans may wish to consider in the future. The report qualitatively discusses activities that are underway across Caltrans divisions and districts, and provides quantitative information on the potential of initiatives to reduce Caltrans' operational GHG emissions wherever possible. The report is not intended to serve as a comprehensive inventory of Caltrans' GHG emissions. Instead, it focuses on the GHG reduction potential of different actions in order to help decision makers assess their effectiveness.

The goals of this report are to:

- Help spread information about best practices in GHG mitigation and climate change adaptation among Caltrans staff working in different headquarters divisions and districts, and among other external transportation partners and agencies focused on transportation and land use;
- Aid staff at other state agencies in identifying potential opportunities for collaboration with Caltrans in efforts to meet statewide GHG reduction and energy efficiency targets; and
- Inform the public about the status of current Caltrans initiatives to address climate change and potential future actions and activities.

1.2 Structure of the Report

This report is organized into eight chapters. Chapters 1 and 2 provide an introduction to the report and background information on the Caltrans mission and responsibilities, its history of environmental activities, and an overview of how state climate policies and projected climate impacts affect Caltrans. Chapters 3 through 6 provide an overview of GHG reduction

activities at Caltrans. These chapters organize the numerous divisions and offices within Caltrans according to four broad functional categories: Planning and Environmental (Chapter 3); Materials, Concrete, and Pavement (Chapter 4); Maintenance and Operations (Chapter 5); and Facilities and Administration (Chapter 6). Chapter 7 discusses specific GHG reduction activities within individual Caltrans districts across the state. Although the focus of Chapters 3 through 7 is on the role of Caltrans in reducing GHG emissions, the Department is also working to adapt to the impacts of climate change, and Chapter 8 describes these adaptation efforts. Appendix A documents the quantification of GHG reductions due to activities by Caltrans.

2 Background

2.1 About Caltrans

As the state's department of transportation (DOT), the mission and vision of Caltrans is to improve mobility across California. Caltrans is responsible for planning, designing, building, maintaining, and operating more than 50,000 roadway lane-miles that make up the State Highway System, and is also involved in planning for other modes, including public transit, aviation, bicycling, and walking.

Caltrans is involved in every phase of transportation projects. It establishes policies and plans that guide future improvements to the state transportation system, creates specifications for the design and construction of roadways and of the roadside environment on the State Highway System, and oversees construction by private companies to build new transportation infrastructure. Once new roads are built on the State Highway System, Caltrans is responsible for operating and maintaining them. This entails managing traffic signals and toll booths to keep vehicles moving, ensuring that roadways are free of snow and debris and are signed and well-lit, responding to incidents and emergencies, and repaving or rehabilitating roadways when necessary. Caltrans also manages many non-roadway facilities, including roadside rest areas, maintenance yards, and administrative buildings, across the state. Operating the largest state transportation system in the United States is a major undertaking, and the 19,200 Caltrans employees work in cooperation with local transportation and land use agencies across the state in order to create plans, deliver projects, and operate the transportation system.

2.2 History of Energy and Resource Efficiency at Caltrans

Keeping California moving requires not only many person-hours and collaboration with local agencies but also large amounts of energy and resources. Long before scientific consensus identified climate change and GHG emissions as a cause for concern, Caltrans was working to conserve energy and natural resources. For example, Caltrans has been conserving fuel and resources in the fleet of vehicles that it uses to maintain roads and travel to worksites since the mid-1980s, by establishing policies and management methods to replace inefficient vehicles with more efficient models; setting specifications for purchasing remanufactured oils, lubricants, antifreezes, and batteries; and changing from steel-belted to radial tires. Because many of the asphalt pavements that are used in road projects are energy-intensive to produce, Caltrans has been working since the 1970s to develop and deploy pavements that include recycled rubber. Recycled rubber reduces both the embodied GHG emissions (emissions associated

with the production of materials) of pavements and the energy required to apply them to roads. In compliance with national and state environmental laws, Caltrans has been analyzing the impact of transportation projects on air quality and other environmental issues since the early 1970s. Caltrans also has been involved in developing renewable energy projects since the mid-1980s. For decades, Caltrans has been funding and leading research on topics related to GHG reduction, including congestion relief, vehicle trip reduction, and air pollution mitigation.

2.3 Policy Context

As public and scientific concern over climate change has grown, California has adopted legislation and issued Executive Orders to reduce statewide energy use and GHG emissions. Assembly Bill (AB) 32[2] and Executive Order (EO) S-3-05[3] together establish statewide targets to reduce GHG emissions to 20 percent below 1990 levels by 2020 and 80 percent below 1990 levels by 2050. Because on-road vehicles are the largest single producer of GHG emissions by end use in the state,[4] many of the state GHG reduction policies address the transportation sector and involve Caltrans. Table 1 summarizes the key state climate and energy policies that affect Caltrans, as well as Caltrans' internal policies that respond to these laws and orders. The focus of this section is on policy; however, it is important to note that Caltrans' response to state climate policies is not limited to the agency-wide internal policies cited in Table 1. It also includes individual policies and working procedures within divisions, as well as guidance and implementation programs that are the focus of the following chapters.

In response to California's climate laws, Caltrans adopted two Director's Policies (DPs) that lay out how Caltrans will address climate change: DP 23-R1 in 2007 and DP 30 in 2012. The former establishes a comprehensive long-term framework for reducing energy use and GHG emissions, both through Caltrans' planning activities and through measures to reduce the impacts of the Department's operations. The latter policy calls for a Department-wide effort to incorporate GHG mitigation and climate adaptation into all of Caltrans' decisions and activities. Both policies contain additional implementation items for different divisions and districts; these items, as well as the Climate Action Program created by Caltrans following DP 23-R1, cover many of the GHG reduction initiatives discussed in this report. Additional state laws and Caltrans policies cover specific GHG reduction activities at Caltrans.

Senate Bill (SB) 391[5] adds new requirements to the state's long-range transportation plan to meet California's climate change goals. SB 391 requires that the California Transportation Plan (CTP) identify the "statewide integrated multimodal transportation system" that is necessary to meet the targets contained in AB 32 and EO S-3-05.

Another important law affecting transportation planning is SB 375.[6] This law establishes targets for GHG reduction from passenger vehicles and light trucks for the metropolitan planning organizations (MPOs) that coordinate regional transportation plans (RTPs) in California's 18 largest metropolitan areas, and the law requires MPOs to create plans to meet these targets. Although MPOs are the lead agencies implementing SB 375, Caltrans is an important partner in the RTP process. Many of the projects that Caltrans is developing on the State Highway System stand to affect regional progress toward meeting GHG targets, and Caltrans can support achieving these targets by working with stakeholders to ensure that the projects do not increase emissions. Caltrans also works to reduce GHG emissions from passenger vehicles by planning to reduce GHG emissions due to interregional travel between metropolitan areas that are outside the jurisdiction of the MPOs responsible for implementing SB 375.

While not explicitly linked to GHG emissions, AB 1358[7] fosters GHG-reducing alternatives to driving by requiring that all local transportation agencies identify how they will accommodate pedestrians, bicyclists, and transit riders in the circulation elements of their general plans. Although the bill does not directly relate to Caltrans, the Department is a key partner in implementing many local transportation projects and has adopted policies that endorse a multimodal approach to planning. Caltrans' Deputy Directive (DD) 64-R1,[8] the Complete Streets policy, directs Caltrans to (1) integrate

consideration of bicyclists, pedestrians, and transit riders into statewide plans; and (2) create performance measures, tools, and guidance on planning for these modes. This policy supplements other Caltrans policies such as DP 22,[9] which adopts a context-sensitive solutions approach to the planning process that encourages thorough stakeholder involvement and consideration of community goals.

Table 1: Key State GHG Reduction Policies That Affect Caltrans

Bill/Order Number	Name	Year Adopted	Requirements	Related Caltrans Director's Policies and Deputy Directives
AB 32	California Global Warming Solutions Act	2006	California Air Resources Board (ARB) to prepare a plan to reduce statewide GHG emissions to 1990 levels by 2020, with participation from other state agencies.	• DP 23-R1: Energy Efficiency and Conservation • DP 30: Climate Change
EO S-3-05	Executive Order S3-05	2005	Reduce statewide GHG emissions to 2000 levels by 2010, to 1990 levels by 2020, and to 80 percent below 1990 levels by 2050.	• DP 23-R1: Energy Efficiency and Conservation • DP 30: Climate Change
SB 391	California Transportation Plan	2009	CTP must identify how the transportation sector will meet the targets in AB 32 and EO S-3-05.	
SB 375	Sustainable Communities and Climate Protection Act	2008	MPOs must create land use and transportation plans that meet regional transportation-sector GHG reduction targets issued by ARB.	
AB 1358	Complete Streets Act	2008	Local transportation agencies must identify how their general plans will accommodate pedestrians, bicyclists, and transit riders.	• DD 64-R1: Complete Streets • DP 22: Context Sensitive Solutions
EO B-18-12	Executive Order B-18-12	2012	State agencies must reduce operational GHG emissions and reduce grid-based energy purchases. New or renovated state buildings larger than 10,000 square feet must achieve LEED Silver certification or higher and include renewable energy generation. New and existing state-owned buildings must achieve zero net energy consumption targets. State agencies must reduce water use. New and existing buildings must incorporate building commissioning.	• DD 96: Unnecessary Idling of Fleet Vehicles and Equipment • DD 13: Water Conservation • DP 23-R1: Energy Efficiency and Conservation • DP 30: Climate Change
AB 75	State Agency Recycling	1999	State agencies must divert at least 50 percent of all solid waste.	
SB 1016	Diversion: Per Capita Disposal Rate	2008	Amends the AB 75 waste diversion target for state agencies so that it is calculated on a per capita basis.	
AB 338	Recycling: Crumb Rubber	2005	Establishes graduated targets for increasing the amount of recycled rubber used in asphalt mixes.	
EO S-13-08	Executive Order S-13-08	2008	Directs state agencies planning construction projects in areas vulnerable to future sea level rise to consider a range of sea level rise scenarios for the years 2050 and 2100.	• DP 30: Climate Change • DD (in development): addressing sea level rise in planning documents

Other GHG and energy reduction policies focus specifically on reducing energy use and GHG emissions due to internal operations among Caltrans and other state agencies. EO S-20-04,[10] issued in 2004, established requirements to reduce energy consumption in all state buildings. In 2012, EO B-18-12[11] superseded EO S-20-04 with strengthened energy reduction targets and added several new requirements for state agencies.

EO B-18-12 requires the following:

- State agencies must reduce their GHG emissions at least 10 percent by 2015 and 20 percent by 2020, compared to a 2010 baseline.
- State agencies must reduce grid-based electricity purchases and other non-building grid-based retail energy purchases 20 percent by 2018, compared to 2003 baseline levels.
- All new state agency buildings and major renovations of existing buildings more than 10,000 square feet must achieve LEED Silver certification or higher, using the applicable version of LEED.
- All new state agency buildings and major renovations of existing buildings more than 10,000 square feet must include renewable energy generation facilities, if economically feasible.
- All state agencies must participate in demand response programs to reduce peak energy use at each state-owned and state-leased facility.
- State agencies must set a target of zero net energy consumption for 50 percent of the square footage of existing state-owned buildings by 2025 and zero net energy consumption from all new or renovated state buildings designed after 2025.
- State agencies must reduce overall water use at facilities 10 percent below 2010 levels by 2015 and 20 percent below 2010 levels by 2020.
- State agencies must incorporate building commissioning (verifying the performance of buildings, particularly for energy efficiency improvements) to facilitate improved and efficient building operations for new and existing buildings.
- State agencies must identify and pursue opportunities to provide electric vehicle charging stations and to accommodate future charging infrastructure demand at employee parking facilities in new and existing buildings.
- State agencies must report on GHG emissions, energy use, and water use to the U.S. Environmental Protection Agency (EPA) and the Climate Registry on an annual basis.

Many existing Caltrans policies designed to reduce operational GHG emissions give Caltrans a head start in meeting the targets in EO B-18-12. DD 96, issued in 2008, forbids unnecessary idling of Caltrans fleet vehicles and equipment; and a follow-up memorandum from 2008 directs Caltrans employees to further conserve fuel by keeping tires inflated and performing preventative maintenance.[12] Another policy memorandum from 2006 advises employees to use alternative fuels in fleet vehicles whenever possible.[13] DD-13, issued in 1993, directs Caltrans staff to minimize water use and implement water conservation measures in transportation facilities.[14] Although DD-13 does not mention GHG emissions, reducing water use can mitigate the GHG emissions associated with treating and transporting water.

In addition to these two orders, AB 75[15] and SB 1016[16] require state agencies to track how much waste they generate and establish a target of recycling or diverting 50 percent of all waste. AB 338[17] establishes requirements for Caltrans to use binding agents containing crumb rubber in all asphalt pavements in order to reduce both embodied emissions and the emissions produced when the pavement is heated so that it can be applied to roads.

The policies discussed above focus on mitigating GHG emissions, but EO S-13-08[18] looks ahead to the need to adapt to the impacts of climate change. The order directs multiple state agencies to analyze potential impacts due to future sea level rise and to consider the vulnerability of projects to sea level rise based on a range of scenarios for the years 2050 and 2100. In addition, the order specifically requires Caltrans to collaborate with other state agencies in assessing the vulnerability of transportation systems to sea level rise and in identifying ways to maintain the State Highway System in vulnerable areas.

2.4 Adapting to Climate Change

In spite of commitments to reducing GHG emissions both in California and around the world, emissions have already reached a level that will trigger irreversible changes to the climate. Although scientists are still working to forecast the localized effects of this global change, many of the resulting impacts stand to affect California's transportation system. For example, rising sea levels could flood or erode coastal highways. The materials that are used in building the State Highway System today may not be designed to withstand increasing temperatures and changing weather conditions, and roads may need to be rehabilitated ahead of schedule. An unstable climate also will lead to more extreme weather events and likely to an increase in weather-related traffic incidents.

Caltrans recognizes that it will need to adjust the way that it designs, operates, and maintains roads and other transportation facilities in order to adapt to these changing conditions. Caltrans is involved in an ongoing process of identifying transportation assets that may be affected by climate change and creating guidance on how best to address these impacts.

2.5 GHG Reduction Efforts

This report represents an important step in efforts by Caltrans to identify best practices in order to reduce GHG emissions. Although the report discusses many activities related to planning and adaptation that are challenging to quantify, the quantitative analysis of various Caltrans strategies to reduce the GHG emissions due to its own operations contained in Appendix A is useful in identifying future GHG reduction initiatives. This report quantifies GHG reductions from all strategies that affect emissions from Caltrans or its contractors for which sufficient data are available. Collectively, these strategies reduce Caltrans' GHG emissions by more than 161,000 tons annually, which is the equivalent of removing approximately 31,000 passenger vehicles from the road for a year. Table 2 summarizes the GHG reductions due to the various Caltrans strategies examined in this report.

Table 2: Summary of Caltrans' Efforts to Reduce GHG Emissions

Strategy	Annual GHG Reductions (tons CO_2e)
Materials, concrete, and pavement strategies subtotal	**108,711**
• Alternatives to conventional concrete*	47,236
• Alternatives to conventional asphalt*	61,475
Operations and maintenance strategies subtotal	**41,001**
• Roadway lighting	38,819
• Alternative fuels and vehicles in fleets	2,182
Facilities and administration strategies subtotal	**11,367**
• Renewable energy projects	1,391
• Building energy and water efficiency	3,511
• Workplace commute programs	6,465

**Annual reduction values are based on 2011 data instead of average annual reductions.*

It is important to note that this table is not a comprehensive list of Caltrans GHG reduction strategies; it is limited to those that can be quantified using the data that are currently available. It is also difficult to gauge the impact of these strategies without a full inventory of Caltrans' operational GHG emissions in all of the sectors covered by this report. Nonetheless, both Table 2 and the following sections of this report are important first steps in cataloging the many efforts to address climate change that are currently underway and in assessing the relative impacts of those strategies for which data are available. Appendix A describes in more depth the calculations behind the GHG reduction figures presented in this report.

The next four chapters discuss Caltrans activities to reduce GHG emissions in more depth. Each chapter focuses on one of the major functional areas within Caltrans:

- Planning and Environmental (Chapter 3)
- Materials, Concrete, and Pavement (Chapter 4)
- Maintenance and Operations (Chapter 5)
- Facilities and Administration (Chapter 6)

Methodology for Quantifying GHG Reductions

When considering the greenhouse gas (GHG) reduction numbers in Table 2 and in similar tables in the following chapters, it is important to keep in mind that this report represents the first step in a greater climate action planning effort by Caltrans. The purpose of the GHG reduction data presented here is to provide a basis for comparing the effectiveness of a wide range of GHG reduction activities that are currently underway at Caltrans. This analysis focuses on strategies to reduce Caltrans' operational GHG emissions for which data are currently available.

Reductions are calculated based on activity data (e.g., the number of tons of alternative pavements used or the number of light-emitting diode [LED] roadway lights installed) submitted by Caltrans headquarters and district offices. These data were collected via surveys distributed to key facility and operations managers within all Caltrans districts and at headquarters, with follow-up interviews and questions to clarify and fill in gaps. Data from different surveys were combined and processed based on the calculation methodology for each strategy. In many cases, quantitative data were available, enabling a precise calculation of GHG benefits. In some cases, however, data were qualitative, leading to more approximate estimates. Generally, strategies that produce a one-time reduction in GHG emissions, such as alternative pavements, were quantified using data from the 2011 calendar year; while annual reduction estimates for strategies that produce ongoing GHG reductions, such as solar installations or energy-efficient lighting, were calculated based on the most current data available. These data were then multiplied by GHG emissions factors that were based on academic literature, reports, and data from public agencies and professional organizations or based on analyses conducted by Caltrans, in order to calculate total GHG reductions. For a complete description of the data sources and methods used in this analysis, see Appendix A.

It is also important to note that, because of the collaborative nature of Caltrans' work, the Department often influences or shares responsibility for GHG reductions in a way that is challenging to quantify. For example, the transportation planning GHG reduction strategies discussed qualitatively in this report contribute to GHG reductions that are commonly attributed to local and regional transportation planning agencies. Likewise, the Department of General Services, which is involved in the design and management of office buildings for state agencies, deserves shared credit for some of the GHG reductions from energy efficiency measures at Caltrans facilities. As a result, some of the GHG reduction activities discussed in this report are directly under Caltrans control, while in other cases, Caltrans shares responsibility with stakeholders, contractors, or other state agencies. The recommendations at the end of each section focus on specific actions that Caltrans could take to further reduce GHG emissions.

Caltrans reports its GHG emissions to the U.S. Environmental Protection Agency and the Climate Registry on an annual basis. This annual reporting, in combination with the information in this report, will enable Caltrans to look more closely at the reduction potential of future efforts to reduce its operational GHG emissions.

3 Planning and Environmental

3.1 Overview of Caltrans' Planning and Environmental Functions

Caltrans is responsible for articulating a long-term vision for California's transportation system. This involves planning for future improvements to the State Highway System and intercity rail services. It also requires Caltrans to collaborate with the many regional and local transportation agencies across California to ensure that the policies and projects implemented by these agencies add up to a transportation system that serves the needs of the State.

Caltrans works to create and realize this vision through a variety of planning processes and implementation programs. Caltrans is responsible for developing long-term, statewide plans, such as the California Transportation Plan and the California Interregional Blueprint, that outline a comprehensive vision for California's transportation system. By necessity, these are large-scale, wide-ranging documents. To provide more specificity on key issues, Caltrans also creates plans that focus on specific modes like rail and transit. Although Caltrans bears responsibility for statewide transportation planning, it is important to note that local and regional transportation agencies typically have the final say over planning decisions in the metropolitan areas that contain the majority of both the state's population and its transportation infrastructure. Caltrans' statewide plans inform the development of local and regional plans. The Department also influences plans and projects through guidelines such as the *Highway Design Manual* (HDM), which dictates how Caltrans districts plan, design, construct, and operate facilities on the State Highway System, and therefore applies to the many key local streets and roads that are part of the system. Caltrans is also responsible for conducting environmental review of projects along the State Highway System. In addition, Caltrans administers several funding and technical assistance programs to help stakeholders create plans and build projects that meet state goals. Caltrans' planning activities are most effective at influencing local and regional transportation plans when these three key components—high-level statewide plans, project-level design guidelines and environmental review, and funding and technical assistance programs—are closely aligned.

Many of Caltrans' planning processes and programs work to reduce GHG emissions. Statewide plans identify policies to meet California's GHG reduction goals, and these policies guide programs that improve alternatives to driving, integrate land use and transportation planning to manage travel demand, and improve the efficiency of the existing system. This chapter divides Caltrans' planning-related activities into two categories: (1) statewide plans that aim to reduce GHG emissions; and (2) funding

and technical assistance programs designed to implement these plans and processes.

The wide geographic reach and long time horizon of Caltrans' planning activities make the GHG impacts of these activities prohibitively difficult to quantify. In addition, it should be noted that many of the plans and policies discussed in this chapter also can reduce the operational GHG emissions associated with building and maintaining roads, which are the focus of the following two chapters and are quantified in the Appendix A.

3.1.1 The Climate Change Branch

The Caltrans Climate Change Branch manages and coordinates the Department's efforts in response to AB 32 and other state policies and initiatives to reduce GHG emissions and to identify and adapt to climate change impacts. The Climate Change Branch provides guidance on issues related to climate change to different divisions and district offices within Caltrans, as well as to other state agencies that work with Caltrans. It also educates Caltrans staff and stakeholders about climate change and related energy, environmental, financial, and economic issues.

The Climate Change Branch has identified liaisons at Caltrans district offices across the state who will facilitate district implementation of guidance and policies related to climate change and participate in future planning efforts. These liaisons will share best practices on reducing operational GHG emission, reducing GHG emissions through transportation planning, and climate adaptation activities.

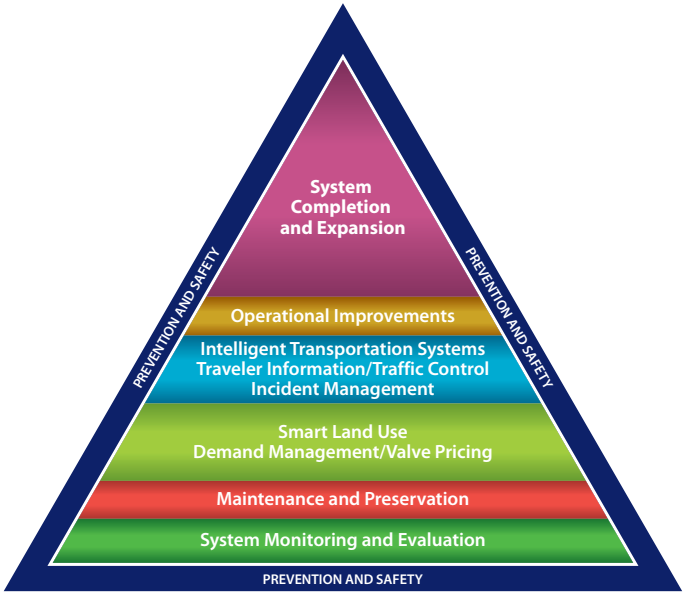
Current projects that the Climate Change Branch is working on, often in collaboration with other Caltrans staff, include:

- **Caltrans Activities to Address Climate Change: Reducing Greenhouse Gas Emissions and Adapting to Impacts:** This document describes activities to reduce GHG emissions and adapt to climate change taking place across Caltrans. It also quantifies the impact of Caltrans' efforts to reduce its operational GHG emissions (e.g., emissions from buildings and facilities, the Caltrans vehicle fleet, highway lighting, and construction materials) and includes a spreadsheet tool that Caltrans staff can use to estimate the emissions reductions, costs, and cost-effectiveness of increasing use of operational GHG reduction strategies.
- **Caltrans Climate Change Strategic Plan:** This plan is a comprehensive effort to formulate and shape Caltrans' policies on how to address climate change and adaptation across the entire Department. The plan will gather data on GHG reduction projects across Caltrans and identify high-priority GHG reduction and climate adaptation measures.
- **Guidance for MPOs/RTPAs on Addressing Climate Change Adaptation in Long-Range Plans:** This guidance will provide MPOs and regional transportation planning agencies (RTPAs) with additional information on how to address climate adaptation in RTPs and other long-range plans.
- **Sea Level Rise Hot Spot Map:** This map identifies locations along the State Highway System that are likely to be vulnerable to sea level rise projections for the year 2100 and will allow for practitioners to begin assessing potential impacts.
- **Guidance on Incorporating Sea Level Rise in Project Initiation Documents:** This document is the first formal guidance provided to Caltrans staff working in coastal areas across the state and describes how to address sea level rise in the early stages of project planning. Caltrans is now working on more detailed guidance related to implementing this document and on similar guidance regarding later phases of the project planning and delivery process.
- **Annual reporting of GHG emissions** to the EPA and the Climate Registry.

3.2 Planning and Environmental Activities to Reduce GHG Emissions

Over the past several decades, Caltrans has shifted from a focus on roadway expansion to managing and maintaining the existing system. This shift is reflected in the Caltrans Mobility Pyramid (Figure 1), originally developed as part of the 2006 California Transportation Plan, which prioritizes activities such as maintenance and preservation, smart land use, and operational improvements as the foundation of the pyramid.

Figure 1: The Caltrans Mobility Pyramid



These high-priority activities are both a more cost-effective way of managing the transportation system and crucial to reducing transportation-sector GHG emissions. Expanding the highway system can foster dispersed land use patterns that lead to more driving and therefore increased GHG emissions. Operational improvements and intelligent transportation systems, which are discussed in more detail in Section 5.2.4, have the potential to make the transportation system operate more efficiently; and smart land use patterns, new multimodal options, and demand management can reduce the amount that Californians drive. This emphasis on reducing energy consumption and GHG emissions is an explicit part of many high-level plans, and Caltrans is beginning to extend this focus to the guidance that it issues on specific aspects of the planning process.

This section describes how Caltrans prioritizes GHG reduction in its plans, processes, and guidance. Table 3 summarizes the documents that are discussed in this section.

Table 3: Caltrans Plans, Processes, and Guidance Documents Related to GHG Reduction

Name	Description	How Document/Plan/Process Addresses GHG Emissions
California Transportation Plan (CTP)	Outlines a 20-year policy vision for the state transportation system.	The CTP identifies how the state will achieve GHG reduction targets in the transportation sector.
California Interregional Blueprint (CIB)	Evaluates the long-term, combined impacts of transportation investments and land use changes.	The CIB establishes an integrated land use and transportation vision for California to meet GHG reduction targets for passenger vehicles.
Regional Transportation Plan Guidelines (RTP Guidelines)	Describes state and federal requirements and recommends procedures for creating regional transportation plans.	The RTP Guidelines include guidance on meeting the statutory requirements related to SB 375 and on analytical methods and for regional agencies to use when analyzing GHG emissions.
Statewide Transit Strategic Plan (STSP)	Outlines policies for Caltrans' support of public transportation through plans, policies, guidance, and projects.	Encouraging a shift from driving to transit ridership is a crucial element of meeting state GHG reduction goals.
California State Rail Plan (CSRP)	Identifies funding for capital projects and operation of California's rail system over a 10-year horizon.	Effective rail service is a less GHG-intensive way to move people and freight, and new technologies can further reduce operational emissions from rail.
Goods Movement Action Plan (GMAP)	Identifies funding for projects that reduce congestion and air pollutants along major freight corridors.	Many pollution-reduction projects have the co-benefits of reducing GHG emissions, and congestion mitigation reduces emissions from passenger vehicles.
Smart Mobility Framework	Introduces an integrated approach to land use and transportation planning that includes economic, social, and environmental performance measures.	Integrating land use and transportation planning is a key step in reducing transportation-sector GHG emissions, and the performance measures include measures related to climate change and energy use.
Context Sensitive Solutions	Involves all stakeholders in the planning process in order to accommodate all travelers and balance mobility with aesthetic, historic, and environmental concerns.	The resulting projects are more likely to enhance the surrounding communities and create facilities and environments that encourage transit, bicycling, and walking in lieu of driving.

Name	Description	How Document/Plan/Process Addresses GHG Emissions
Complete Streets Program	Includes bicycle, pedestrian, and transit modes in all statewide plans and strategies and updates guidance and standards accordingly.	The Complete Streets Program improves alternatives to driving, which can reduce GHG emissions from the transportation system.
Highway *Main Streets Guide*	Outlines design principles for main streets, identifies planning considerations and processes, and highlights design elements that are appropriate for main streets.	Since they function as both multimodal transportation facilities and public places, main streets are important areas of focus for improving alternatives to driving and integrating land use and transportation planning.
Standard Environmental Reference (SER)	Guides agency staff and contractors through the process of preparing, submitting, and analyzing environmental documents for projects on the State Highway System.	The SER directs certain projects to quantify GHG emissions from passenger vehicles and to qualitatively discuss construction impacts, and recommends methods for quantifying emissions and reductions.

These transportation plans guide project selection on the sections of the state transportation system that are under Caltrans' direct control and establish policies for Caltrans' collaboration with local and regional transportation agencies. Local and regional agencies are collectively responsible for the majority of the state transportation system, particularly in urban areas where most of California's population lives; through these plans and policies, Caltrans can help these agencies meet California's GHG reduction goals.

3.2.1 California Transportation Plan

The CTP is a long-range plan that outlines a 20-year vision for California's future transportation system and defines goals, policies, and strategies to guide transportation investments and decisions toward achieving this vision. Caltrans is responsible for updating the plan every 5 years. Under SB 391, the CTP is required to chart a path toward meeting the GHG reduction goals in AB 32 and EO S-3-05, which respectively commit California to reducing total emissions to 1990 levels by 2020 and 80 percent below 1990 levels by 2050. The GHG reduction policies identified in the CTP help guide MPOs across the state as they work to implement SB 375 and meet regional targets. Through the CTP, Caltrans also identifies interregional transportation improvements to ensure that the many different local and regional transportation plans add up to achieve the state's long-term GHG reduction goals. The 2040 CTP will compare transportation scenarios, using tools such as the California Statewide Travel Demand Model to evaluate how different strategies and policies affect transportation GHG emissions.

3.2.2 California Interregional Blueprint

The California Interregional Blueprint (CIB) combines statewide transportation goals with regional transportation and land use plans to produce a unified multimodal transportation strategy. The CIB assesses proposed changes to the state transportation system, including interregional highways, transit, intercity rail, high-speed rail, freight movement, and aviation, using a common analytics framework that accounts for GHG emissions and other impacts. This analytical framework will allow Caltrans to respond to the SB 391 requirement that the next CTP identify the statewide integrated multimodal transportation system needed to achieve GHG reduction goals established by AB 32 and EO S-3-5.

3.2.3 Regional Transportation Plan Guidelines

Caltrans works closely with the California Transportation Commission to create the Regional Transportation Plan Guidelines (RTP Guidelines), which establish a framework for regional agencies to meet federal and state requirements while promoting multimodal planning, maintaining environmental quality, and engaging stakeholders through the RTP process. Following the passage of SB 375, the RTP Guidelines were updated to describe the law's statutory requirements and to outline the steps that MPOs should take to integrate land use and transportation planning and address GHG emissions through the RTP process. Caltrans continues to play a role in recommending appropriate analytical techniques for MPOs to use when analyzing GHG reductions in the RTP process.

Amtrak Capitol Corridor intercity rail service, funded by Caltrans.

A long-haul truck.

3.2.4 Statewide Transit Strategic Plan

Recognizing that meeting the GHG reduction goals outlined in AB 32 and SB 375 will require a substantial increase in transit use, Caltrans recently completed California's first Statewide Transit Strategic Plan (STSP) through coordination with the California Transit Association and other stakeholders. This involved compiling a statewide inventory of transit assets and ridership and working with stakeholders to identify common priorities and best practices. The STSP establishes a new direction for Caltrans' support of public transportation and identifies cost-effective actions by Caltrans that can encourage transit use through plans, policies, guidance, and projects in order to support the long-term vision outlined in the CIB. These actions are intended not only to encourage a shift from driving to transit, which is a less GHG-intensive mode of transportation, but also to use transit investments to foster walkable, mixed-use communities that enable more widespread reductions in driving.

3.2.5 California State Rail Plan

The California State Rail Plan is a comprehensive plan that identifies funding to build new capital projects and operate California's freight and intercity passenger rail systems over a 10-year horizon. Caltrans is responsible for updating the plan every 2 years. The plan works to reduce GHG emissions in two ways. First, by improving the capacity and efficiency of the state's rail system, Caltrans can help encourage more passenger and freight movement by rail, which is typically less GHG-intensive than highway travel for long-distance trips. Second, the plan encourages technological improvements such as emissions-control technologies for locomotive engines and new energy-efficient switchers that can reduce the operating GHG emissions of the rail system.

3.2.6 Goods Movement Action Plan

The Goods Movement Action Plan (GMAP), which was developed by Caltrans in cooperation with the California Environmental Protection Agency (Cal EPA) and other state agencies between 2005 and 2007, focuses on identifying projects to reduce congestion and criteria pollutants along four key freight corridors.[19] The GMAP helped guide project selection for the allocation of $2 billion in funding from the Proposition 1B Trade Corridors Improvement Fund Program. Although the GMAP does not focus explicitly on GHG emissions, it identifies many congestion and pollution mitigation projects with a co-benefit of reducing GHG emissions from freight transportation. Freight transportation is a significant source of statewide GHG emissions and, in the case of road freight, a cause of congestion for passenger vehicles.

3.2.7 Smart Mobility Framework

In 2010, Caltrans adopted a new framework for transportation planning, the Smart Mobility Framework.[20] Among other goals, this framework seeks to address climate change and reduce vehicle miles traveled (VMT) by integrating transportation and land use planning and

by creating transportation systems that accommodate all modes. The Smart Mobility Framework introduces a set of place types designed as tools for planning and programming to achieve smart mobility outcomes. The framework also identifies 17 Smart Mobility performance measures, including measures related to climate and energy conservation, to help ensure that broader economic, social, and environmental considerations are addressed at all stages of planning and project development. Caltrans is now piloting implementation of Smart Mobility with partner agencies at both the corridor and regional levels.

3.2.8 Context Sensitive Solutions

Context sensitive solutions (CSS) is an approach to transportation planning developed by the Federal Highway Administration (FHWA) in collaboration with professional transportation planning and engineering organizations. Whereas the transportation planning process in the past often focused more narrowly on creating roadways that were capable of moving the required number of automobiles, CSS is a collaborative, interdisciplinary approach that involves all stakeholders in order to maintain safety and mobility for all travelers while preserving scenic, aesthetic, historic, and environmental resources.[21] The resulting projects and plans are more likely to enhance the surrounding communities and create facilities and environments that encourage transit, bicycling, and walking, thus supporting the GHG reduction goals of the statewide plans discussed above. Caltrans adopted CSS as a transportation planning approach in 2001, and created an implementation plan intended to institutionalize CSS in all Caltrans activities through outreach to stakeholders, staff training, and revisions to planning documents and processes.

3.2.9 Complete Streets Program

The Complete Streets Act (AB 1358, 2008) directs local transportation agencies across California to plan facilities that meet the needs of all users, including bicyclists, pedestrians, and transit riders. DD 64-R1 directs Caltrans to include bicycle, pedestrian, and transit modes in statewide plans and strategies; develop tools and processes to identify and address the needs of these users; and update guidance and standards accordingly. Caltrans developed a Complete Streets Implementation Action Plan identifying the other plans, policies, and guidance documents that need to be revised, beginning with the HDM, which has since been updated to reflect this new emphasis on multimodal planning. Successful long-term implementation of this program is intended to result in improved alternatives to driving and a corresponding reduction in GHG emissions.

Implementing Complete Streets Statewide

Caltrans' Complete Streets Program provides an example of how the Department can successfully translate policy into guidance that dictates how districts plan, design, and build roads. The Complete Streets Implementation Action Plan provides a comprehensive list of Caltrans actions that are needed in order to accommodate pedestrians, bicyclists, and transit users. One key task identified in the Implementation Action Plan was a *Highway Design Manual* (HDM) update. In 2012, a series of comprehensive edits to the HDM incorporated new or amended guidance on several different aspects of complete streets, including right-of-way utilization, reduced vehicle lane widths, pedestrian refuge islands, traffic controls for bicyclists, adequate bike lane widths, curb bulb-outs for transit stops, and bus rapid transit and light rail facilities. The HDM is a comprehensive, wide-ranging document; the *Main Streets Guide* combines the key sections of the HDM related to complete streets in an easy-to-use resource for practitioners.

3.2.10 *Main Streets Guide*

Many sections of the State Highway System also function as main streets through communities. In addition to serving as transportation corridors, main streets are important public places and need to be designed to accommodate both of these purposes. Caltrans is updating this comprehensive guide, which outlines design principles for main streets, identifies both important project planning considerations and opportunities to incorporate main streets into long-term planning processes, and highlights design elements from the HDM and other resources that are appropriate for main

streets. The guide is part of efforts by Caltrans to help local governments create complete streets and to create mixed-use neighborhood centers that will help achieve the GHG reduction targets laid out in SB 375.

3.2.11 Standard Environmental Reference

Before construction begins, all transportation projects in California must undergo environmental review. Through these reviews, lead agencies identify potential impacts on air quality; water, plant, and animal species; and other aspects of the environment, in addition to ways to mitigate significant impacts. Environmental review can be a complicated process, and Caltrans maintains the *Standard Environmental Reference* (SER)[22] to guide agency staff and contractors through the process of preparing, submitting, and analyzing environmental documents. The SER currently directs all capacity-increasing or congestion-relief projects to quantify operational GHG emissions from vehicles on the roads using the California Air Resources Board (ARB) Emissions Factors model and to qualitatively discuss construction impacts. The SER also discusses various GHG reduction activities and provides guidance on quantifying some of them.

3.3 Funding and Technical Assistance Programs to Reduce GHG Emissions

The actions described in the previous section align California's long-term transportation plans and policies, as well as much of the funding that is allocated through these plans and policies, toward reducing GHG emissions. In addition, Caltrans has developed several funding and technical assistance programs that directly assist local and regional transportation agencies with creating plans and building projects that reduce GHG emissions. This section discusses programs administered by Caltrans with the goal of reducing GHG emissions or supporting transportation modes that serve as alternatives to driving. Table 4 summarizes these programs, the type of assistance that they offer, and the type of projects that are eligible to receive assistance from each program.

Table 4: Caltrans Funding and Technical Assistance Programs with GHG Emission Reduction Benefits

Program	Funding/Assistance Offered	Efforts Considered for Funding
Regional Blueprint Planning Program	More than $20 million in grants from 2005 to 2012	Creation and implementation of long-term regional plans that identify transportation investments and land use changes that achieve GHG reductions and meet other community goals.
Community-Based Transportation Planning (CBTP)/ Environmental Justice (EJ) Grant Programs	$62.5 million in grants since 2000	Transportation and land use planning projects that include community and key stakeholder input, collaboration, and consensus building through an active public engagement process; in the case of EJ grants, projects that address the interests of low-income, minority, Native American, and other under-represented communities.
Corridor System Management Plans (CSMPs)	Technical assistance funding through Proposition 1B	Multi-jurisdictional plans and projects to improve transportation options in the state's most heavily congested transportation corridors by increasing sustainable transportation options and by reducing congestion so that vehicles operate more efficiently.
Bicycle Transportation Program	Technical assistance, $7 million per year in grants	Projects that encourage bicycling as an alternative to driving for commute trips, including bikeways, bicycle lockers, and bicycle plans.
Safe Routes to School (SR2S)	$110 million in grants every 2 years	Projects designed to increase the number of children walking and bicycling to school through new infrastructure and educational programs, including traffic calming; bicycle safety programs; and sidewalk, crosswalk, and traffic signal installations and improvements.
Transportation Enhancement (TE) Funds	$75 million per year in transportation funding	Projects that either directly support bicycling and walking through new infrastructure and safety programs or create aesthetically pleasing communities that are more conducive to biking and walking.
Partnership Planning Grants	$1.2 million in grants awarded annually	Multi-agency partnerships to improve mobility and reduce congestion and related traffic emissions.
Transit Planning Grants	$1.5 million in grants awarded annually	Projects that improve transit services and facilitate congestion relief by offering alternatives to driving.

3.3.1 California Regional Blueprint Planning Program

Since 2005, Caltrans has provided more than $20 million to regional transportation agencies to fund the creation of Regional Blueprint Plans, which are long-term integrated transportation and land use scenarios that inform plans to guide a region's growth over the course of several decades. Integrating land use and transportation planning is a key step in reducing GHG emissions, because it allows regions to plan for growth in areas where residents drive less, including neighborhoods with access to transit and other travel modes, thereby reducing vehicle trips. These Blueprint Plans served as an antecedent to SB 375, California's law requiring regional transportation agencies to create integrated land use and transportation plans that meet GHG reduction targets. The Blueprint Grant Program continued to fund key GHG reduction projects and programs that support the implementation of SB 375 and other transportation programs intended to reduce GHG emissions through 2012.

The Blueprint Planning Program and Senate Bill 375

The text of Senate Bill (SB) 375, California's groundbreaking law integrating transportation and land use planning, makes it clear that the Blueprint Plans funded by Caltrans played an important role in preparing MPOs to implement the law: "Some regions have engaged in a regional 'blueprint' process to prepare the land use allocation [of their regional transportation plans]... The Legislature intends, by this act, to build upon that successful process." Even before SB 375 established regional greenhouse gas (GHG) reduction targets, many of the adopted Blueprint Plans identified opportunities for long-term reductions in VMT and GHG emissions. The type of regional land use planning contained in these blueprints has historically been difficult in California because of laws that give local governments sole authority over land use decisions. The funding provided by Caltrans enabled regional agencies to conduct the extensive outreach and scenario planning that was critical to gaining local support for Blueprint Plans. Blueprint Grants continue to support a host of SB 375 implementation activities, including technical assistance programs through which regional agencies give local governments the tools that they need to plan for smart growth.

3.3.2 Community-Based Transportation Planning/ Environmental Justice Grant Programs

The Community-Based Transportation Planning (CBTP) and Environmental Justice (EJ) grant programs share the Blueprint Planning Program's goal of integrating land use and transportation planning through the public engagement process. These programs are intended to advance a community's effort to reduce greenhouse gases, create sustainable communities, encourage alternatives to driving, promote economic opportunity, and advance a community's effort to address the impacts of climate change and sea level rise. Eligible applicants for CBTP and EJ grants include regional transportation agencies, local governments, transit agencies, and Native American tribes. Over the past decade, these two grant programs have provided more than 400 grants totaling $62.5 million. Although reducing GHG emissions is not an explicit goal of these grant programs, in practice, the grant work supported by these programs may help to mitigate emissions by improving the jobs-housing balance in order to shorten commutes, creating plans for areas served by transit that are designed to increase ridership, and developing new transportation services in communities where there are few options other than driving.

3.3.3 Corridor System Management Plans

Caltrans is working with stakeholders to implement and expand multimodal, multijurisdictional Corridor System Management Plans (CSMPs) for the state's most heavily congested transportation corridors. CSMPs have the potential to reduce long-term GHG emissions if they focus on managing congestion without adding roadway capacity, through such strategies as increasing

sustainable transportation options, active system management, operational improvements such as ramp metering and auxiliary lanes, and improved incident response. Caltrans provides stakeholders with guidance that focuses on operational improvements over system expansion and tools, such as the California Life Cycle Benefits/Costs Model (Cal-B/C), that help to quantify the GHG impacts of CMSPs. Caltrans uses the tools and guidance that it promotes through the CSMP process to help the responsible agencies analyze and identify strategies to reduce GHG emissions.

3.3.4 Bicycle Transportation Program

Caltrans bicyclists on Bike to Work Day.

Through the Bicycle Transportation Program, Caltrans provides technical expertise on bicycle transportation in state, regional, and local planning processes. Caltrans also administers the Bicycle Transportation Account (BTA), which provides approximately $7 million in grants each year for projects that improve safety and convenience for bicycle commuters. Projects that are eligible to receive BTA funds include new bikeways, bicycle lockers, and bicycle plans. These projects encourage bicycling as an alternative to driving for trips to work. To increase funding available for bicycle projects and to make the program more effective, the Administration proposed the creation of the Active Transportation Program as part of the January 2013 Governor's Budget.

3.3.5 Safe Routes to School

Safe Routes to School (SR2S) is a program designed to increase the number of children walking and bicycling to school through new infrastructure and educational, enforcement, and encouragement programs. Caltrans administers both the state and federal SR2S programs, allocating approximately $110 million in grant funds every 2 years for projects such as traffic calming; bicycle safety programs; and sidewalk, crosswalk, and traffic signal installations and improvements. The majority of students who live within 2 miles of school currently are driven by their parents. Over the short term, therefore, successful SR2S projects reduce the GHG emissions associated with car trips to school. Over the long term, these projects encourage the next generation of Californians to use active transportation instead of driving. To increase funding available for safe routes to schools projects and to make the program more effective, the Administration proposed the creation of the Active Transportation Program as part of the January 2013 Governor's Budget.

3.3.6 Transportation Enhancement Program

Transportation Enhancement (TE) funds are allocated by the federal government to state DOTs for activities including pedestrian and bicycle infrastructure and safety programs, scenic and historic highway programs, landscaping and scenic beautification, and historic preservation.[23] Caltrans receives approximately $75 million per year in TE funds, which it allocates to projects through state and regional transportation plans. The TE program is a key source of funding for projects that accommodate bicycling and walking, which are the modes of transportation that emit the fewest GHGs.

Landscaping in roadway median.

3.3.7 Partnership Planning and Transit Planning Grants

Caltrans is responsible for distributing federal funds for Partnership Planning and Transit Planning. The former are funded by the FHWA and support projects that strengthen multi-agency partnerships while improving mobility and reducing congestion and related traffic emissions. Transit Planning grants are funded by the Federal Transit Administration and support projects that improve transit services and facilitate congestion relief by offering alternatives to driving. In the most recent funding cycle, Caltrans awarded $1.2 million in Partnership Planning grants and $2.5 million in Transit Planning grants.

3.4 Research and Innovation Projects

In addition to integrating current best practices in reducing GHG emissions into the planning process, Caltrans works to develop and disseminate innovative new research that improves the state of the practice in transportation planning. Caltrans is a key funder of several university transportation centers (UTCs) across California that pursue projects on a wide range of topics related to reducing transportation-sector GHG emissions. These include analyzing market demand for high-speed rail, modeling the impact of land use variables on travel behavior, identifying barriers to walking and bicycling among different segments of the population, implementing innovative new alternatives to driving such as bus rapid transit and bike sharing, and leveraging transit investments to produce mixed-use community centers. Caltrans then works to field-test and deploy ideas developed by the UTCs. For example, Caltrans is currently working with stakeholders to deploy dynamic management of parking prices at transit station parking lots in the Bay Area and to test Transit Signal Priority systems that speed up travel times for bus rapid transit. Caltrans also hosts monthly webinars that disseminate research ideas to professionals in the field on topics such as collecting transportation data and better integrating transit into the planning process.

3.5 Planning and Environmental GHG Mitigation—Suggestions for Additional Activities

Caltrans has made significant progress in integrating GHG reductions into its high-level plans and policies and, in some cases, in translating these policies into guidance and implementing them through funding programs. For decades, however, transportation planning has focused primarily on accommodating automobiles, which has contributed to progressively higher GHG emissions from the transportation sector. Consequently, there are many opportunities for Caltrans to better align its guidance and standards with its GHG reduction policies, and to strategically fund projects and programs that reduce emissions. This section discusses several such opportunities.

Implement a program to incorporate high-level plans and policies such as the Smart Mobility Framework and the other GHG reduction policies into Caltrans guidance and standards, and district staff training.

Efforts to date by Caltrans to reduce GHG emissions through its planning activities represent a crucial step to reverse a decades-long trend of planning to accommodate steadily increasing levels of vehicle use. These efforts are only an initial step. The next phase is to ensure that guidance and standards, such as the HDM, are consistent with high-level plans and policies because these guidance and standards ultimately dictate Caltrans' response to individual transportation planning decisions. In some cases, the existing guidance still focuses primarily on accommodating vehicles rather than on promoting multimodal travel and reducing GHG emissions. Consequently, local transportation agencies may find that progressive efforts to encourage transit use, bicycling, and walking conflict with existing Caltrans guidance

DD-64 requires Caltrans to integrate a Complete Streets approach into all guidance and standards and led the Department to amend the HDM to better accommodate transit users, bicyclists, and pedestrians. This is one example of Caltrans successfully incorporating high-level policies into its existing guidance. Caltrans should (1) extend this approach to the other GHG reduction policies discussed in this chapter, such as the Smart

Mobility Framework; and (2) expand these implementation efforts to include additional training in order to familiarize staff with these changes. Because Caltrans standards apply to the whole state by necessity, they do not always account for local conditions—particularly in the urban environments that are most conducive to transit and other low-GHG travel. This training therefore should include context-sensitive approaches to implementing new standards and guidance.

Marked bicycle lane.

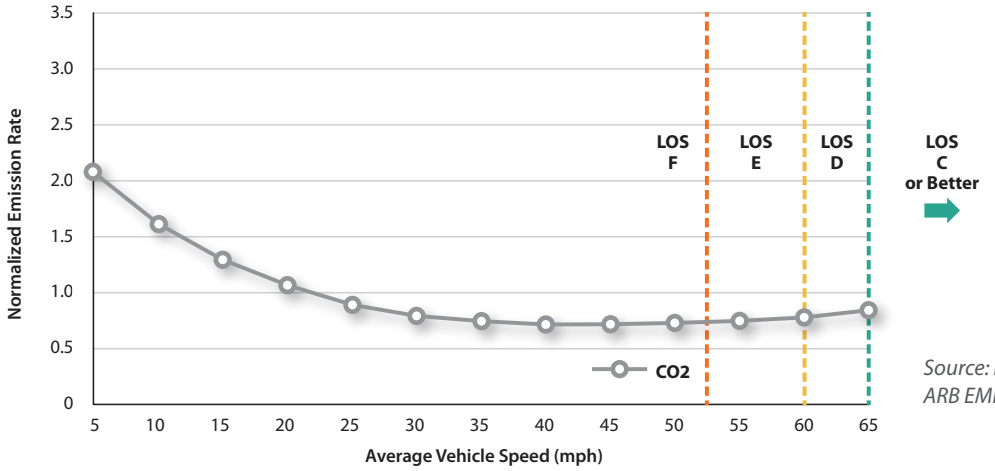
Revise the LOS thresholds in Caltrans guidance documents.

Level of service (LOS) thresholds provide a specific example of an area in which Caltrans' guidance may not be aligned with high-level plans and policies to reduce GHG emissions. LOS is a commonly used metric in transportation planning that assigns a letter grade to a roadway based on the amount of delay that vehicle drivers experience, with LOS A representing free-flowing traffic with no delays. Engineers and planners use LOS to assess current traffic operations and to examine future impacts on the transportation system. A number of Caltrans guidance documents refer to LOS targets or thresholds, including the *Guide for the Preparation of Traffic Impact Studies* (TIS Guide), and plans such as CSMPs and Transportation Concept Reports often establish LOS thresholds for transportation corridors

In spite of the efforts described earlier in this chapter to reduce GHG emissions in Caltrans plans and documents, LOS guidance largely reflects past policy aimed exclusively at improving traffic safety and reducing traffic congestion, and therefore may not always be consistent with GHG reduction efforts. For example, the HDM emphasizes accommodating future demand by stating that "Freeways should be designed to accommodate the design year peak hour traffic volumes and to operate at a LOS determined by District Planning and/or Traffic Operations," and the TIS Guide establishes the borderline between LOS C/D as a desired threshold for the State Highway System. For a typical freeway, the LOS C threshold is associated with speeds at 65 miles per hour (mph) or higher (see Figure 2). At these speeds, vehicles burn more fuel than at lower speeds such as 55 mph. Breakdown LOS F conditions are also not typically desired because excessive idling and stop-and-go travel waste fuel.

Over the long term, LOS standards that focus exclusively on accommodating anticipated levels of vehicle traffic can result in decisions to widen roads, which can create induced demand by making driving a more appealing alternative to other forms of transportation, or by leading homes and businesses to relocate closer to new road facilities.[24] Higher vehicle speeds and throughput also make a facility less attractive to pedestrians and bicyclists.

Figure 2: Relationship between Freeway LOS, Speed, and GHG Emissions



Source: Fehr and Peers, adapted from ARB EMFAC model

In general, more effort is needed to understand how to address conflicts that can arise between objectives related to mobility and those related to GHG reduction, and to make explicit the state's position when it comes to trade-offs. When reducing GHG emissions is an objective, Caltrans has the ability to manage traffic flow for desired speeds that would reduce fuel consumption and emissions, not only by adjusting LOS thresholds, but also through lowering the design speeds of new roadways or ramp metering strategies, and doing so would align guidance documents with the priorities in the Mobility Pyramid. The key challenge in this example is that previous efforts to lower speeds limits have not been publicly supported. Targeted use of the strategies discussed above may be more acceptable, or Caltrans may require additional legislative or political direction to manage speeds in order to reduce GHG emissions.

Allocate additional resources for developing tools and assistance programs to help local, regional, and state agencies plan to reduce GHG emissions.

Caltrans has shown leadership in providing information, tools, and technical assistance to help regional and local agencies analyze the GHG impacts of transportation planning decisions, such as the recently completed project "Improved Data and Tools for Integrated Land Use-Transportation Planning in California."[25] However, Caltrans could not accommodate the many requests from transportation agencies for locally calibrated versions of the tools and assistance with the available funding. Caltrans could continue to develop advanced methods to model regional GHG emissions, assess GHG emissions generated by new projects, and evaluate operational GHG emissions under different levels of congestion. This would entail not only creating analytical tools but also making it easier for other agencies to access data from the California Statewide Travel Survey and other sources for research, modeling, and planning. For example, Caltrans could work with the California ARB to improve tools such as URBEMIS (urban emissions) and California Emissions Estimator Model (CalEEMod). These models contain estimation methods for VMT that do not represent the best available data from household travel surveys or regional/local travel demand models, such as trip lengths and trip generation rates.

Caltrans also could continue to partner with other state agencies to develop and improve the framework for analyzing statewide transportation decisions. This would include (1) improving tools such as the California Statewide Travel Model and Urban Footprint, an interactive scenario planning tool for evaluating the effects of alternative land use and transportation policies on VMT, energy use, GHG emissions, and other impacts; and (2) identifying opportunities to integrate these tools into decision-making processes.

Use state transportation funds to support SB 375 implementation.

SB 375 requires that MPOs allocate transportation funding to projects that support regional sustainable communities strategies, which are planning documents designed to meet regional GHG reduction targets. Caltrans can support MPOs in this effort by coordinating with them to allocate resources from the State Transportation Improvement Program and other Caltrans-controlled transportation funding sources toward projects that achieve GHG reductions. For example, Caltrans and the FHWA recently selected an alternative for proposed improvements to Interstate 5 in San Diego that reduced the number of new travel lanes, which freed up an extra $800 million in RTP funds for that region, most of which went toward improving transit access and offering incentives to local governments to support smart growth. Although this decision was made independent of the SB 375 planning process, it illustrates the potential of Caltrans' decisions to support local and regional projects that reduce GHG emissions. In order to further support SB 375 implementation, Caltrans could work to allocate more state transportation funding from the share of the Interregional Transportation Improvement Program to alternatives to driving and smart growth land use programs. This funding could go toward GHG reduction projects on the State Highway System in metropolitan areas that are affected by SB 375 or could support projects to reduce interregional GHG emissions identified in the CTP.

Conduct a strategic planning assessment of measures to reduce freight-generated GHG emissions.

The GMAP and the freight transportation plans that preceded it established a framework for coordinating statewide planning for freight transportation. These plans did not explicitly focus on GHG reductions, however, and Caltrans could build upon this framework to create a plan to mitigate freight-related GHG emissions. The Oregon Department of Transportation (ODOT) is currently conducting a statewide evaluation of goods movement systems and operations that could serve as an example. ODOT is focusing on establishing short- and long-range funding, incentives, and system modifications to reduce GHG emissions per ton-mile of goods moved within and to/from Oregon. The study is quantifying the GHG benefit, feasibility, and costs associated with various packages of strategies, including but not limited to, bottleneck removal on highways, freight-related intelligent transportation systems (ITS), integrated land use and freight infrastructure planning, freight mode shifts, eco-driving, alternative fuels, and improvements to vehicle technology. Caltrans is coordinating with ARB in developing an update to the GMAP that will specifically address GHG reductions. Caltrans will also coordinate with ARB to significantly reduce freight-related emissions in the coming decades.

Create a marketing and communications plan for Caltrans' efforts to address climate change.

The size and breadth of Caltrans can make it difficult for employees to keep track of the Department's many efforts to address climate change and to understand how these initiatives relate to their day-to-day job responsibilities. As Caltrans expands its initiatives to reduce GHG emissions and adapt to climate change impacts, it is important to create a marketing and communications plan to promote internal awareness and identify best practices and synergies between activities spearheaded by different divisions or districts. Creating a central source of information for Caltrans' climate initiatives would also make it easier to identify opportunities for collaboration and coordination with local and regional transportation agencies within California, DOTs in other states, and federal transportation agencies working on complementary efforts.

Promoting Sustainability Department-Wide: NYSDOT's GreenLITES Program

The New York State Department of Transportation (NYSDOT) GreenLITES Program has helped NYSDOT communicate its sustainability efforts to staff and track the implementation of different strategies. GreenLITES is a self-certification rating system that helps staff and stakeholders examine the extent to which projects, operational strategies, and planning efforts incorporate sustainable choices. The system includes spreadsheet tools in which users enter the information on different sustainability strategies in a project and are assigned a certification level based on the strategies that they incorporate. The strategies recognized by GreenLITES include many of the energy use and greenhouse gas emission reduction strategies that are discussed in this report, such as light-emitting diode (LED) lighting, warm-mix asphalt, and corridor management planning. The system serves as a way for NYSDOT to communicate its sustainability efforts to staff, recognize best practices, and track implementation of different strategies. It also helps NYSDOT promote its sustainability efforts both internally and to the public, and the Department holds annual award ceremonies recognizing high-achieving projects.[26]

Amend design standards to reduce lane widths under appropriate circumstances.

As discussed in Chapter 3, there is an opportunity for Caltrans to better align guidance on designing transportation facilities with plans and policies to reduce GHG emissions. In particular, the HDM currently requires minimum vehicle lane widths of 12 feet in most cases. Although Caltrans has procedure and guidance on the use of traffic lanes of less than a 12-foot width, Caltrans has generally not viewed narrower lanes from the perspective of minimizing GHG emissions. If GHG reduction is a goal in transportation decision making, Caltrans could amend the HDM to include more exceptions where 10- or 11-foot lanes would be allowed. Research has demonstrated that narrower vehicle lanes do not

cause traffic operations or safety problems under many circumstances,[27] and reducing minimum lane widths would reduce GHG emissions associated with the additional materials and construction activity required for wider lanes. It would also support efforts to reduce GHG emissions by encouraging a shift away from travel by single-occupant vehicles. Many efforts to reduce vehicle lane widths, such as "road diets," reallocate vehicle space to bicyclists, pedestrians, or high-occupancy vehicles, with the intent of increasing the use of active transportation modes or increasing network efficiency through greater vehicle occupancy.

4 Materials, Concrete, and Pavement

4.1 Overview of Caltrans' Materials, Concrete, and Pavement Functions

Caltrans oversees the design and construction of the State Highway System, and works alongside regional and local agencies to select new projects and manage their delivery. Caltrans oversees construction contractors that it hires, and sets policies and specifications that guide project delivery. These include design standards for the materials, concrete, and pavement used on the State Highway System. Highways are major pieces of infrastructure that require vast amounts of materials to construct, and Caltrans has several initiatives underway to reduce life-cycle GHG emissions associated with materials and construction activities and improve overall sustainability. These include changes to specifications that allow or mandate the use of construction materials and processes that use less energy and produce more sustainable products.

Closure and rehabilitation of I-5 near downtown Sacramento in 2008.

4.2 Materials, Concrete, and Pavement GHG Reduction Initiatives

4.2.1 Concrete

Caltrans specifies requirements for all construction materials that can be used in highway projects through its *Standard Specifications*.[28] Caltrans amended the 2010 version of the *Standard Specifications* for concrete to allow contractors to use less energy-intensive concrete mixes. These amendments have significant GHG reduction potential because the production of concrete, and specifically the cement that binds the mixture together, is very GHG intensive to produce.

Concrete is composed of four ingredients: aggregates such as gravel and sand, which strengthen the mixture; cement, which binds the aggregate together; water,

which enables the mixture to be shaped and poured before hardening; and admixtures, which aid in giving the concrete specific properties, such as faster curing time or improved strength. Cement accounts for the bulk of concrete's life-cycle emissions.

The most common type of cement used in concrete is Portland cement, which is produced by quarrying and crushing limestone and feeding it into a kiln, where it is heated to temperatures approaching 2700˚ F. This creates a chemical reaction that turns the limestone into lime, which emerges from the kiln in pebbles called *clinkers*. Clinkers must be further ground to produce the fine cement that is used in concrete mixtures. Producing 1 pound of cement emits approximately 1 pound of GHG emissions, which come both from the carbon dioxide that is a natural byproduct of the chemical reaction that converts limestone to lime and from the energy required to heat the kilns and grind the cement. The embodied GHG emissions in two truckloads of conventional concrete are approximately equivalent to the emissions that the average passenger vehicle generates in a year.

Manufacturers can produce less GHG-intensive concrete by substituting other binding materials for Portland cement, as long as these materials are sourced locally so that GHG emissions due to materials transportation do not increase. These alternatives include fly ash, blast furnace slag, silica fume, and rice hull ash. They are much less energy-intensive than Portland cement to produce because they are byproducts of other industrial processes, typically coal combustion, steel production, and computer manufacturing. Natural clay and volcanic ashes also can be used as binding agents in concrete. Some of these materials also increase the strength and durability of concrete, which in turn reduces GHG emissions associated with maintenance.

The 2010 *Standard Specifications* removed a requirement that at least 75 percent of the cement used in concrete be Portland cement. It also offered contractors more options for alternatives to Portland cement by removing limits on the amount of fly ash and allowing for up to three materials to be used in cement mixes. Table 5 shows the GHG reductions in 2011 due to the use of alternatives to Portland cement, including cases where individual districts use less GHG-intensive cement mixes than the mixes generally used on the State Highway System.

In total, Caltrans estimates that the shift toward alternatives to Portland cement reduced GHG emissions by more than 47,000 tons in 2011, which is equivalent to the reductions produced by approximately 9,100 passenger vehicles in a year. Because most alternatives to Portland cement are cheaper than cement, using these substitutes can be a cost-effective way to reduce GHG emissions provided that alternative materials are available to contractors.

Table 5: Caltrans' Use of Alternatives to Portland Cement and the Resulting GHG Reductions (2011)

Portland Cement Alternative	Total Annual Cement Use (tons)	Average Proportion of Alternative in Cement Mix	GHG Reductions per Ton (tons CO_2e/ tons used)	Annual GHG Reductions (tons CO_2e)
Limestone	374,066	2%	0.012	4,501
Fly ash/furnace blast slag		25%	0.111	41,345
District-specific mixes		varies	varies	1,389
Total				**47,235**

The Far-Reaching Impact of Caltrans' Concrete Specifications

The changes to Caltrans' concrete specifications are one of the single most effective greenhouse gas (GHG) mitigation initiatives undertaken by the Department to reduce its own emissions, and they also have reduced the emissions produced by other agencies. These changes helped to spur a greater shift in concrete production that led to increased use of alternatives to Portland cement in transportation projects across the state, including those administered by local and regional transportation agencies. The amendments to the 2010 *Standard Specifications* helped Caltrans win first place for Innovation in the U.S. Environmental Protection Agency's Coal Combustion Products Partnership Awards, which recognize organizations that find new uses for byproducts like fly ash. Many other departments of transportation have since adopted Caltrans' concrete specifications. While this bodes well for GHG reductions outside of California, it also has increased competition for fly ash and other substitutes for Portland cement, which has made these materials more difficult for Caltrans' contractors to procure.

Caltrans is also looking into other ways to reduce GHG emissions associated with concrete. Caltrans works with industry through the Rock Products Committee (RPC) to improve construction methods, material specifications, and test methods. The RPC was established to provide a forum for materials suppliers, contractors, and industry to interact directly with Caltrans in development and modification of Caltrans' specifications, with a focus on sustainability.

In collaboration with the RPC, Caltrans is investigating the following techniques to achieve longer lasting materials and designs that can decrease the amount of virgin concrete used in road projects, as well as the associated GHG emissions:

- Use of a greater variety of types of recycled concrete
- Use of reinforced concrete pavement, which reduces thickness needed for concrete, lasts longer, lowers maintenance costs, and uses recycled steel for reinforcement
- Use of precast pavement
- Improved materials and designs that last longer than traditional concrete

Caltrans and RPC are also researching:

- Increased use of roller-compacted concrete, which requires less cement as a binding agent
- Use of recycled aggregates in concrete to reduce life-cycle emissions
- The GHG impacts of transporting materials to and from job sites in order to better account for the effect of materials supply on emissions

4.2.2 Asphalt

The most commonly used paving material in the State Highway System along with concrete is asphalt. Asphalt is typically used in the top several layers of flexible pavements, so called because they flex to distribute weight evenly as vehicles pass over them. Like concrete, asphalt consists of aggregates such as stone, sand, and gravel mixed with a binding agent. The binding agent in asphalt is typically a by-product of distilling crude oil. Asphalt binder is naturally thick and viscous, so it must be heated in order to be mixed with the aggregates, and aggregates must also be heated in order to reduce moisture. After it is mixed, asphalt must be kept warm as it is transported to project sites and then compacted in order to compress it into a dense, durable pavement. This means that traditional hot-mix asphalt (HMA) is energy intensive, not only to produce but also to apply to roadway surfaces. Caltrans has multiple initiatives to reduce the carbon content of asphalt and the energy required to lay it. Table 6 shows Caltrans' annual usage of three GHG-reducing alternatives to HMA and the resulting annual reductions in GHG emissions.

Table 6: Caltrans' Use of Asphalt Alternatives and the Resulting GHG Reductions

Strategy	Annual Usage	Unit	GHG Reductions per Unit Used (lbs. CO_2e/unit)	Annual GHG Reductions (CO_2e)
Cold-in-place recycling	1,630,442	Cubic yards	0.007	12,043
Rubberized hot-mix asphalt	2,610,071	Tons	0.019	49,056
Rubberized warm-mix asphalt	67,696	Tons	0.006	376
Total				**61,475**

Caltrans' use of alternatives to HMA has reduced its operational GHG emissions by more than 61,000 tons per year—more than any other GHG reduction initiative quantified in this report. This is equivalent to the annual emissions produced by approximately 11,800 passenger vehicles.

Rubber hot-mix asphalt (RHMA) (also known as rubber asphalt concrete, or RAC) is created by adding crumb rubber from recycled tires to asphalt, either by mixing the rubber in with the cement prior to adding the aggregate or by adding rubber to the cement-aggregate mix. The rubber acts as a binding agent, expanding to fill gaps between the pieces of aggregate and requiring less asphalt cement in the final mix. Caltrans has been using RHMA to resurface roadways since the 1970s, and recent state policies have turned best practices into requirements. AB 338[30] requires Caltrans to use at least 15 percent crumb rubber in 35 percent of asphalt pavements. Caltrans works to implement AB 338 in partnership with CalRecycle, which works to keep tires out of the waste stream. There is no shortage of used tires. Producers also convert recycled rubber to fuel to use as a substitute for fossil fuels in cement kilns, to make weed abatement mats, and to manufacture sealant for cracks in roads. Caltrans also uses shredded waste tires as a lightweight fill material in engineering projects.

The Benefits of Rubber Hot-Mix Asphalt

Caltrans is required to prepare annual reports on waste tire usage. According to the most recent report, from 2007 to 2011, Caltrans used almost 25 million recycled tires.[29] Most of the total was for rubber hot-mix asphalt (RHMA). In 2010, waste tires accounted for 30.8 percent of all flexible pavements by weight, and Caltrans estimates that, on average over the past decade, the rubber content of asphalt increased by almost 50 percent. Not only does all of this recycling help to keep tires out of landfills, it also reduces greenhouse gas (GHG) emissions associated with the production of petroleum-based kiln fuels and asphalt cement. On average, manufacturing and laying a ton of RHMA produces 13 percent fewer GHG emissions than a ton of hot-mix asphalt (HMA). In 2011, Caltrans used 2.6 million tons of RHMA in place of conventional HMA—the equivalent of 6.7 million tires—reducing GHG emissions by 49,000 tons.

Above: Caltrans workers laying down rubberized hot-mix asphalt. Right: Closeup of shredded recycled tires used in RHMA.

Cold-in-place recycling train.

Caltrans is also using alternatives to conventional hot mix asphalt that reduce the energy needed to mix and lay asphalt pavement. In 2012, Caltrans adopted specifications to use warm-mix asphalt (WMA). This process uses less viscous binding materials that allow the asphalt to be mixed at lower temperatures. Compared to HMA, WMA can reduce production temperatures by 35–100 degrees F, potentially yielding 25–35 percent fuel savings and an 18-percent reduction in the overall GHG emissions produced in manufacturing, mixing, and laying the asphalt. Using WMA instead of HMA reduces air pollutant emissions and can increase opportunities to use rubberized asphalts because RHMA is challenging to lay in cold climates.

Cold-in-place recycling (CIR) and full depth reclamation (FDR) are techniques that involve breaking down existing asphalt and using it as aggregate in a new layer of pavement or base after adding new binding agents, such as foamed asphalt, cement, or emulsions. CIR involves recycling only the existing asphalt surface, while FDR mixes both the existing asphalt surface and base into a new stronger base. FDR is typically used when the depths of repairs needed exceeds what can be accomplished with CIR. Although a cap of new asphalt pavement is placed on top of the CIR/FDR layer to provide a durable surface, on the whole, the process uses less HMA than repaving with new asphalt. On average, replacing HMA with CIR or FDR reduces emissions by 93 percent. CIR can be much more cost-effective in reducing GHG emissions than other asphalt alternatives because it streamlines the construction process and recycles materials onsite. This reduces the need to transport material on- and off-site or acquire virgin material. Caltrans has dedicated funds to construction of CIR strategies to preserve and maintain its roadways. Many districts have approved the use of CIR in pilot projects, and Caltrans' specifications now allow asphalt aggregates to be 100 percent recycled. Some of these projects have been successful; however, others have found that not all of the old asphalt can be reused due to weather or road conditions. In addition to using CIR/FDR, some projects also use recycled asphalt as aggregate in the road base.

In collaboration with the RPC, Caltrans is investigating the following techniques to improve the sustainability of asphalt pavement and reduce the associated GHG emissions:

- Use of a greater variety of types of recycled asphalt. Current specification are allowing up to 25 percent, with potential to go higher
- Use of new multi-layered asphalt design, which reduces pavement cracking and helps pavement last longer
- Improved binders, which perform longer than traditional asphalt binder.

4.2.3 Sustainable Pavements

Pavement surfaces, whether for highways, streets, parking lots, erosion control, or pedestrian walkways, are one of the most widely found man-made features.

Caltrans has been a leader in developing pavement strategies to reduce GHG impacts and improve sustainability. In addition to the aforementioned items under concrete and asphalt, Caltrans is developing and implementing the following:

- **Porous Pavement.** Pavement that is porous allows rainwater to pass down to the soil. In high temperatures, the process reverses as the heat draws water up to the surface. The resulting evaporation, as well as the lighter color of pervious concrete, reduces surface temperatures and mitigates the urban heat island effect, which in turn has the potential to reduce the energy required to cool urban areas in summer.
- **Smoothness.** Studies across the country and internationally have shown that smoother pavements reduce rolling resistance and increase fuel economy, which reduces GHG emissions from vehicles. To improve smoothness, Caltrans strengthened the smoothness requirement for new pavement and overlays by 15%, and also introduced additional requirements to smooth pavements prior to placing overlays.
- **Long Life Pavement.** Increasing the longevity of pavements not only reduces the demand for new materials, but also decreases the need for maintenance and rehabilitation, which reduces GHG emissions from maintenance and construction activities and from motorists delayed by construction. Since 2007, Caltrans has increased its minimum design requirements for rehabilitation projects from 10 to 20 years, and increasingly is using 40-year strategies. New roadway construction projects, which used to be designed to last 20 years, are now being designed to 40 years or more. Caltrans uses life cycle cost analysis to determine the optimum life of a pavement based on current and future costs and impacts. To extend lives even further, Caltrans is investigating and introducing new materials and mixes. In 2009, Caltrans adopted continuously reinforced concrete pavement for high volume goods movement corridors; 14 projects are now using this pavement, with more than 200 lane miles in or near construction.
- **Pavement Preservation.** Pavement preservation is the process of protecting existing pavements from cracking or getting rough through proactive maintenance treatments. Pavement preservation has been shown to extend the life of existing pavements using strategies that are less expensive and intrusive than rehabilitation (some studies show costs at one-sixth that of rehabilitation). This reduces the need for acquiring and transporting new materials, use of construction equipment, and delaying motorists in traffic from construction work, all of which create additional GHG emissions.
- **Quiet Pavement.** Although not directly related to GHG emissions, noise is a quality of life issue faced by California residents who rely on roads to transport them via automobiles or transit to their destinations. A sizable part of road noise comes from interaction between vehicle tires and the paved surface. To minimize noise generated from this interaction, Caltrans, along with industry and the University of California, have been developing and testing quieter surfaces and making improvements to the specifications.

Caltrans also will be developing a specification for "cool pavements" that can help to minimize urban heat island effect. The term "heat island" refers to warmer urban air and surface temperatures that result when natural landscape is replaced with hardscape surfaces such as pavement, buildings, and other infrastructure. Recent California legislation, AB 296 (Skinner, 2012), directs the California Environmental Protection Agency to develop a definition for the urban heat island effect, including an urban heat island effect index for California cities such that cities can have a quantifiable goal for heat reduction. As part of this legislation and upon completion of a definition for an urban heat island effect index, Caltrans will develop a standard specification for sustainable or cool pavements that can be used to reduce the urban heat. Sustainable or cool communities strategies have potential for reducing the Urban Heat Island Index. The result is a city that is more livable, and its residents reduce their GHG emissions, mainly through less use of air conditioning.

Caltrans, along with the University of California, are integral participants in the FHWA sponsored National Sustainable Pavements Technical Working Group. The efforts of this group are to:

- Develop tools for measuring environmental benefits of pavement decisions (life cycle assessment). This will aid in measuring GHG benefits of different alternatives.

- Identifying the best practices and procedures for sustainable pavements, which will give cities, counties, and agencies both within California and nationally, the best practices for reducing environmental impacts, including GHG emissions.
- Coordinate research efforts nationally to make sure needed questions are getting answers and that research dollars are being used efficiently as possible.

This group met in Davis, California on April 25th and 26th, 2012.

4.2.4 Other Recycled or Reused Construction Materials

Caltrans also has explored using recycled materials that can reduce life-cycle GHG emissions in other aspects of the road system. For example, the 2010 *Standard Specifications* allow for the use of plastic instead of metal in storm drain pipes, provided that pipes meet requirements for strength and durability. This creates an opportunity for contractors to use recycled plastic, which Caltrans encourages. Caltrans also has initiated pilot projects that examine the potential to use rubber in storm drain pipes, which would create further opportunities for recycling. In addition, Caltrans advocates for conservation by encouraging contractors to rehabilitate pipes in place rather than digging up and replacing entire sections of pipe.

Caltrans also sees opportunities to reduce GHG emissions due to materials production by reusing construction debris from highway projects. AB 75[31] and SB 1016[32] require state agencies to track how much waste they generate and establish a target of recycling or diverting 50 percent of all waste. Although Caltrans cannot force contractors to recycle or reuse construction waste, the Department requires contractors to report whether debris is taken into landfills, and currently more than 80 percent of construction waste gets diverted. Contractors are allowed to keep any waste from construction projects and use it as they see fit.

The Design and Maintenance Divisions have tested and now allow the use of green waste from agricultural operations as mulch along the roadside. In districts where agricultural lands are located, this strategy reduces GHG emissions associated with transporting mulch to project sites.

4.2.5 Research and Innovation Projects

Through its research program, Caltrans works to identify opportunities to further develop many of the GHG reduction initiatives associated with the project development and construction processes discussed above. It spearheads programs dedicated to identifying, testing, and recommending appropriate uses for less energy-intensive paving materials and procedures, including CIR and WMA, as well as longer-lasting pavements that reduce emissions associated with maintenance and materials for repaving.

Because each strategy employed can have different or sometimes competing benefits and consequences, Caltrans has been working since 2007 with researchers at the University of California to develop a holistic approach to measuring the GHG impacts of project alternatives. Known as life cycle assessment, this process can ultimately provide decision makers with the tools to determine which strategies and designs will result in the lowest GHG emissions for construction, materials, maintenance, and operation of paved facilities.

Caltrans is working not only to reduce the embodied GHG emissions in pavement but also to develop innovative new pavement materials with lower rolling resistance, which have the potential to improve fuel efficiency for the millions of vehicles that use California's roads every day. The Department participates in the Models for rolling resistance In Road Infrastructure Asset Management Systems (MIRIAM) project, a collaborative effort between researchers and transportation agencies in the United States and Europe to explore new paving materials that reduce both life-cycle GHG emissions and emissions due to vehicle usage.

4.3 Materials, Concrete, and Pavement GHG Mitigation—Suggestions for Additional Activities

Caltrans efforts to reduce the embodied emissions associated with concrete and asphalt are some of the most successful GHG mitigation activities that the Department has engaged in. This section discusses additional opportunities to further these successes, as well as new ways in which Caltrans could act to reduce emissions.

Update the *Standard Specifications* to encourage greater use of alternatives to conventional concrete and HMA.

The GHG emissions that are embodied in concrete and asphalt contribute a large share of Caltrans' overall emissions, and the activities that Caltrans has taken so far to mitigate these emissions account for some of the largest GHG reductions quantified in this report. Caltrans should continue to seek opportunities to further these successes. Although there are several recycled or low-GHG substitutes for the bitumen, cement, and aggregates that make up concrete and asphalt, Caltrans is limited in the extent to which it can require that contractors use minimum amounts of these substitutes in road projects. Caltrans' first priorities in building road projects are to ensure safety and conserve taxpayer dollars, and requiring minimums of low-GHG substitutes may reduce the durability of materials or drive up costs—particularly in areas of the state where these materials are not readily available. Furthermore, mandating recycled materials may increase GHG emissions from the transportation of these materials to and from project sites in areas where recycled materials are not readily available. However, one approach to further reduce GHG emissions is to amend the *Standard Specifications* to incorporate performance based specifications.

Caltrans could adopt specifications that require contractors to use materials that meet minimum tests for strength, durability, and other criteria rather than simply specifying the allowable proportions of different ingredients in each material. This would allow contractors the flexibility to conserve fuel and energy through alternative materials such as WMA and use a greater proportion of recycled materials without compromising quality. Since high-performance concrete typically contains lower amounts of GHG-intensive Portland cement and higher amounts of recycled industrial byproducts such as silica fume and fly ash, performance-based specifications would likely reduce the GHG emissions associated with concrete. These specifications also could lead to more durable pavements and structures, which would reduce GHG emissions associated with maintenance and with manufacturing replacement materials.

Where federal and state law allow, Caltrans could even offer alternative incentives to contractors that meet the requirements in the specifications while using lower proportions of GHG-intensive materials such as Portland cement and bitumen. This approach also may induce the construction industry to examine new locally sourced substitutes for cement and asphalt binder.

Encourage use of CIR/FDR where appropriate and continue to research methods to apply CIR/FDR to a wider variety of projects.

CIR/FDR has been widely tested, and local transportation departments have found that CIR pilot projects reduce costs and GHG emissions without sacrificing quality for certain project types. Although several districts have used CIR/FDR in some projects, CIR/FDR currently accounts for less than 4 percent of pavements used in Caltrans' projects. CIR/FDR requires a relatively warm climate; and some guidance does not recommend CIR/FDR for high-volume roads, due to concerns about its ability to withstand high traffic volumes and the potential for the CIR/FDR process to disrupt traffic more than paving with conventional HMA. However, new CIR/FDR processes that add cement to the asphalt mix increase the strength of the pavement. Districts may lack information about the benefits of CIR/FDR and about projects for which it is appropriate. Caltrans has the opportunity to encourage greater use of CIR/FDR by creating specifications for the process, particularly CIR pavements and processes that can be used on higher-volume roadways, and by producing guidance for the districts on the circumstances under which CIR/FDR is

appropriate. Over the long term, Caltrans can continue to research new recycling processes that can further increase the opportunities to apply CIR/FDR.

Pushing the Limits of CIR at the Nevada Department of Transportation

Many transportation agencies limit the use of cold in-place recycling (CIR) to low-volume roadways that do not carry freight traffic, but the Nevada Department of Transportation (NDOT) has used CIR on multiple high-volume roads, including a 20-mile stretch of Interstate 80 that carries more than 5,000 vehicles per day.[33] Expanded use of CIR by NDOT is the result of a combination of research, planning, design, and communication. The Department has conducted rigorous testing of CIR in order to determine its limits and improve upon CIR mixes. For example, NDOT found that the addition of lime slurry improves the performance of CIR mixes. Pavement preservation planning tools created by NDOT that rank treatments based on life-cycle rather than initial costs have created a rationale for using CIR in a greater number of projects. Performance-based specifications and field testing ensure quality while allowing contractors the flexibility to keep costs down, and NDOT continuously monitors the performance of CIR projects and keeps a central database of all projects. Finally, the Department has created a 2-hour required workshop for all staff involved in CIR projects to ensure that they are educated about the unique aspects of the CIR process. As a result of all these efforts, NDOT has used CIR to resurface 770 centerline miles, or 11 percent of its state highway system, since 1997.[34]

Develop Life Cycle Assessment Tool

A life cycle assessment tool will provide decision makers with the information needed to predict the GHG emissions impacts from various material and pavement strategies from construction, maintenance, and operation. Such a tool will allow decision makers to take into account characteristics of their local area such as available material alternatives, recyclable materials, climate (urban heat island effect), transportation costs, vehicle delays from construction and maintenance activities, and other impacts in choosing the strategies that will best reduce GHG emissions.

5 Maintenance and Operations

5.1 Overview of Caltrans' Maintenance and Operations Functions

In addition to overseeing design and construction of the state's highways, Caltrans is directly responsible for maintaining and operating the system. Given that the State Highway System encompasses more than 50,000 lane-miles of pavement, this is a labor-intensive undertaking. Caltrans keeps roadways in a state of good repair by repairing and resurfacing pavement, sealing cracks, painting and striping lanes and markings, maintaining drainage systems, and restoring shoulders and guardrails. Caltrans keeps roads clear by removing snow and debris, controlling avalanches and landslides, and trimming back vegetation. Caltrans also ensures that traffic runs smoothly and safely by operating traffic signals and roadway lighting, overseeing signage, investigating accidents, managing leases and permits for use of roadside space, and running Traffic Management Centers in metropolitan areas.

Caltrans has long-standing initiatives to reduce the energy required to run its fleet of maintenance vehicles and to power roadway lighting. Recently, more aggressive shifts to new technologies such as flex-fuel vehicles and LED lighting have reduced GHG emissions substantially. Furthermore, one of Caltrans' goals is to maximize the performance of the highway system, which means reducing congestion and delay. Because the millions of passenger vehicles that use the State Highway System each day operate less efficiently in congested conditions, finding innovative ways to avoid traffic delays can substantially affect GHG emissions.

5.2 Maintenance and Operations GHG Reduction Initiatives

5.2.1 Solar Energy Production in the Highway Right-of-Way

As discussed in Section 6.2.1, solar photovoltaics on Caltrans facilities have substantial energy generation potential. However, it pales in comparison to the possible energy generation and GHG reductions from solar panels in Caltrans' airspace. Airspace is Caltrans-owned property that is within the right-of-way of an existing roadway or at a Caltrans facility that is neither available for sale, used for transportation purposes, nor part of the operational highway. Currently, Caltrans generates additional revenue by leasing airspace to uses such as parking garages located under elevated highways, or licenses use of the space to wireless communications providers for towers and antennae.

In 2009, the FHWA issued new guidance that allowed renewable energy facilities to be located in the highway right-of-way. A high-level study of the potential for solar energy generation in the right-of-way that was conducted by Caltrans in 2010 found huge energy generation potential for such projects. The study estimated that such projects could generate a minimum of 1 megawatt (MW) of energy per project, compared to a 2.4-MW total potential for all 70 CREBs-funded projects (see Section 6.2.1). Nevertheless, Caltrans has remaining safety concerns about widespread placement of such installations in proximity to live traffic and the associated risks to errant drivers—as well as the potential for glare from roadside solar arrays to blind drivers. Caltrans is conducting follow-up studies on these issues, in addition to working to develop standards for discretionary installation of solar panels in the right-of-way.

A natural gas-powered sweeper in District 7.

In the meantime, individual Caltrans districts have been working on pilot projects to install solar panels in the right-of-way. For example, District 4 has completed environmental review for a project that would lease property to a private developer. The developer would install solar panels at seven interchanges along US-101 in Santa Clara County, generating an estimated 15 MW of electricity, and would sell the electricity to utilities.

5.2.2 Alternative Fuels and Equipment

Caltrans owns a fleet of more than 12,000 pieces of mobile fleet equipment, used primarily to maintain the State Highway System. Caltrans has been using alternative fuels since the 1970s and working to conserve fleet fuel use since the mid-1980s by developing more efficient ways to manage the fleet. More recent efforts focus on using alternative fuels and more efficient vehicles and equipment, such as:

- Biodiesel fuel
- Ethanol fuel
- Liquefied petroleum gas (propane)
- Solar-powered changeable message signs
- Compressed natural gas (CNG)
- Hybrid electric vehicles
- Solar-powered arrowboards

As of 2009, the Caltrans fleet included approximately 3,000 alternative fuel vehicles. Caltrans encourages staff to use bulk fueling stations for vehicles and equipment at its maintenance facilities, where some alternative fuel stations are available, and has developed a mobile phone application to help its staff locate stations that carry alternative fuels.

As Table 7 shows, the GHG impacts of alternative fuels vary widely. Some fuels have minimal GHG emissions benefits compared to gasoline or diesel, while others produce substantial reductions. Even for a given alternative fuel, GHG reductions can vary widely depending on how the fuel is produced. Although some alternative fuels may not substantially reduce GHG emissions, there may be other benefits to using these fuels, such as reduced criteria pollutant emissions and reduced dependency on petroleum. Overall, Caltrans' use of alternative fuels reduces GHG emissions by more than 1,900 tons per year, equivalent to removing almost 400 passenger vehicles from the road.

Table 7: Caltrans' Alternative Fuel Usage and the Resulting GHG Reductions

Fuel	Annual Usage in Gallons	Used as a Substitute for:	Annual Usage in GGE or DGE*	GHG Reduction per GGE or DGE (lbs. CO_2e)	Annual GHG Reductions (tons CO_2e)
E85 Ethanol (from corn)	164,083	Gasoline	119,429	0.05	3
B5 biodiesel (70% waste oil, 30% soy)	2,959,146	Diesel	2,949,001	0.87	1,290
Liquefied petroleum gas (propane)	28,568	Gasoline	21,002	5.65	57
Compressed natural gas (CNG)	N/A	Diesel	136,482	8.53	582
Total			**3,225,914**		**1,932**

** GGE = gasoline gallon equivalent; DGE = diesel gallon equivalent*

Biodiesel is an alternative fuel made by reacting animal or vegetable fats with alcohol. It is typically sold in a blend with conventional diesel and can generally be used in conventional diesel engines without requiring any modifications. Using biodiesel instead of conventional diesel can reduce GHG emissions. Although burning biodiesel produces approximately the same amount of GHG emissions per unit of energy produced as burning conventional diesel, switching to biodiesel reduces the total GHG emissions on a life-cycle (or "well-to-wheels") basis that accounts for fuel production and distribution. The GHG emissions benefits depend on the source of the fuel. Biodiesel from waste oils has much larger GHG benefits than biodiesel made from soybeans. Currently, approximately 70 percent of California's biodiesel comes from waste oil.

Most of the equipment that Caltrans uses for highway maintenance runs on diesel fuel, and the Department operates approximately 220 maintenance stations across the state that supply diesel. Beginning in 2009, approximately 180 of these stations began using biodiesel fuel, currently at a 5-percent biodiesel blend (B5). Caltrans has used a 20-percent biodiesel blend (B20) in prior years. Caltrans remains the largest consumer of biodiesel in California, using almost 3 million gallons of B5 per year.

A flex-fuel vehicle filling up on E85 fuel.

Many of the light-duty vehicles in the Caltrans fleet are flex-fuel vehicles, meaning they can operate on gasoline, an 85-percent ethanol blend (E85), or any combination of the two. Ethanol is a pure alcohol that is typically blended with gasoline to produce a cleaner-burning fuel. As with biodiesel, the overall life-cycle impacts of switching to ethanol depend greatly on the feedstock that is used to produce the ethanol. According to ARB estimates, ethanol made from corn has minimal GHG benefits compared to gasoline.[35] Ethanol from sugarcane has more GHG benefits, and ethanol produced from non-food crops like switchgrass or from agricultural waste has very low net GHG emissions. The Caltrans fleet consumes more than 150,000 gallons of E85 per year, and several districts have installed E85 pumps to ensure that alternative fuel is available for their vehicles.

Other Caltrans vehicles can operate on CNG or liquefied petroleum gas (propane). Some of these are bi-fuel vehicles, meaning they are capable of operating on two different fuels. CNG and propane have lower GHG emissions compared to conventional gasoline or diesel. In total, approximately 2,500 of the light-duty vehicles in the Caltrans fleet—primarily sedans and pickup trucks—are flex-fuel or bi-fuel vehicles. Green Technology, a nonprofit initiative to aid sustainability efforts in government agencies, honored Caltrans for its alternative fuel programs with a 2009 Green California Leadership Award.

In addition to vehicles that run on alternative fuels, Caltrans has purchased 172 hybrid electric vehicles (HEVs) that are powered both by gasoline and a battery that recharges as the vehicle brakes. A new HEV passenger car is typically 20–45 percent more fuel efficient than an equivalent gasoline-powered vehicle. By using HEVs, Caltrans reduces its fleet GHG emissions by an additional 315 tons each year. Heavy-duty truck applications of HEVs are currently limited, but Caltrans operates two diesel hybrid electric personnel hoist trucks. Caltrans will additionally be pursuing the purchase of zero-emission vehicles (ZEVs), consistent with Governor Brown's Executive Order directing state government to help accelerate the market for ZEVs in California

Caltrans also has taken steps to reduce particulate matter emissions from its diesel fleet. More than 1,700 heavy trucks manufactured before 2007 and more than 100 pieces of off-road construction equipment have been retrofitted with diesel particulate filters, which significantly limit tailpipe emissions that contribute to adverse public health impacts. Reducing black carbon particle emissions is also thought to help curb climate change effects, although there is uncertainty about the magnitude of these benefits.

5.2.3 Efficient Operation of Vehicles and Equipment

In addition to investing in vehicles that use alternative fuels, Caltrans works to identify other techniques and technologies that reduce GHG emissions by increasing the operating efficiency of vehicles and equipment. Many of these are simple, low-cost solutions. One of the most important ways to increase efficiency is to avoid engine idling, which burns fuel unnecessarily. DD 96 requires that all vehicles not be left idling, except when in traffic, during vehicle maintenance, while providing power to equipment, and when idling is necessary to prevent emergency situations. Finally, Caltrans uses recycled water and solvents to clean vehicles and parts.

Caltrans also reduces energy consumption and GHG emissions by making innovative equipment and maintenance purchases. These include recapped tires, which are lightly used tires that have been resurfaced with fresh rubber, and re-refined oil and lubricants, which require less energy to produce than virgin lubricants. To help employees avoid the idling that is needed to operate warning lights, Caltrans has installed additional batteries in some vehicles and is transitioning to low-power, LED warning lights in newly purchased vehicles. New mobile equipment enables Caltrans to conserve fuel by connecting the equipment to a vehicle engine rather than needing to run a separate generator. Lastly, Caltrans has installed double-walled, sensor-equipped fuel tanks at maintenance yards to prevent fuel leaks, which produce GHG emissions.

5.2.4 Energy-Efficient Lighting

Above: LED roadway lighting on a bridge. Right: An LED traffic signal.

Operating the highway system requires a substantial amount of electricity to power light fixtures—from traffic signals to roadway lighting, message boards, and lighting for signs. Over the past several years, Caltrans has begun to require that most of these systems use LED light fixtures, which are some of the most energy-efficient fixtures currently available, or other alternatives when LED fixtures are not feasible. Not only do energy-efficient lights cut energy costs and reduce GHG emissions associated with electricity, but they also last longer; this means that Caltrans conserves fuel and reduces workers' exposure to accidents by maintaining lights less frequently.

Table 8 summarizes the GHG reductions from the various lighting strategies used by Caltrans. In total, these strategies reduce emissions by almost 39,000 tons per year,

which is equivalent to taking almost 7,500 passenger vehicles off the road.

Caltrans is now working to install more energy-efficient freeway sign lighting. New specifications issued in 2003 called for using magnetic induction light fixtures, which produce the same amount of light using less than half the energy of the existing mercury vapor (MV) fixtures. The transition to new freeway sign lighting has been slower than the transition to LED traffic lights because the lights are more difficult to replace, but a substantial share of all freeway signs now have energy-efficient induction lights, and Caltrans replaces approximately 1,000 lighting fixtures per year. In the future, retroreflective signs, which are highly visible under vehicle headlights alone, could completely eliminate the need to light some signs. Caltrans' specifications currently require that all new signs have retroreflective sheeting, although some of the new signs continue to require lighting, depending on conditions.

Caltrans operates more than 700 changeable message signs along the State Highway System that inform travelers about road conditions and provide other information. Caltrans has upgraded the bulbs in these signs from incandescent to energy-efficient xenon bulbs, which consume 70 percent less energy than incandescents, or to LED lighting fixtures, which use 70 percent less energy than xenon fixtures and 90 percent less than incandescents. New changes to Caltrans' specifications require that all new signs use LEDs.

Early Successes with LED Traffic Signals

Efforts by Caltrans to increase the use of energy-efficient lighting began with the 76,000 traffic signals along the state highway system. Although each signal uses a relatively small amount of energy, these signals collectively are one of the largest end uses of electricity for Caltrans. In 1999, Caltrans started replacing traditional incandescent traffic lights with light-emitting diodes (LEDs) because the incandescent lights were overloading electrical networks, causing short circuits. It began by replacing red traffic signals, which were the first fixtures for which an LED alternative was available. Two years later, when green and yellow LED fixtures became available, Caltrans began switching out these lights as well; and the energy crisis of the early 2000s played a key role in speeding a statewide conversion to all-LED traffic signals. Today, Caltrans uses LEDs not only in its traffic signals but also in pedestrian signals—as is now required by the California Energy Code. The result is a dramatic decrease in energy consumption. Whereas an incandescent traffic signal light uses 85–155 watts of electricity, the average LED lighting module consumes only 22 watts. Replacing all of the signals reduced Caltrans' statewide energy costs for traffic lights by 80 percent.

Table 8: Caltrans' Use of Energy-Efficient Lighting and the Resulting GHG Reductions

Strategy	Type of Fixture Replaced	Number of Fixtures Replaced To Date	Wattage of New Fixture	Wattage of Old Fixture	Annual GHG Reductions per Fixture Replaced (tons CO_2e)	Annual GHG Reductions (tons CO_2e)
LED traffic signals	Incandescent	72,799	22	120	0.31	22,621
LED ramp metering lights	Incandescent	5,147	22	120	0.31	183
LED pedestrian signals	Incandescent	37,736	15	85	0.22	8,377
LED flashers	Incandescent	2,207	25	155	0.21	455
Xenon message signs	Incandescent	183	4,200	15,000	4.28	783
LED message signs	Incandescent	545	1,200	15,000	5.47	2,981
LED roadway lighting	High-pressure sodium	1,426	100–200	230–450	0.40	565
Induction sign lighting	Mercury-vapor	15,000	85	205	0.19	2,854
Total		**135,043**				**38,819**

Caltrans is also in the process of adopting specifications for LED lighting in the roadway lights that provide nighttime visibility along the State Highway System. The change to LEDs has huge potential because there are so many roadway lights—approximately 70,000—and they stay lit on average for half of the day. LED roadway lights are typically 35–60 percent more efficient than the high-pressure sodium (HPS) lamps that they are replacing; each HPS lamp uses between 230 and 450 W of power. They also last 15–20 years, whereas sodium lamps last only 4 years. In addition to LED traffic lights, LED roadway lights are one of the most cost-effective ways to reduce GHG emissions through new lighting technologies. Based on successful pilot tests of LED lights along several bridges to ensure that LEDs did not reduce visibility, Caltrans is purchasing 50,000 LED fixtures to replace HPS lights. Caltrans anticipates having a sufficient supply to install the LED fixtures ahead of the normal replacement schedule for the HPS lights in order to reduce costs and energy use as quickly as possible.

In addition to all of the lighting in and along roadways, Caltrans lights its maintenance yards in order to keep projects moving at night, when less traffic is on the roads. Currently, lighting accounts for 70 percent of the energy consumed at maintenance yards, and Caltrans plans to convert fixtures at these yards to more efficient lighting. Caltrans is purchasing 5,600 LED fixtures, which typically consume 35–50 percent less energy than the current HPS fixtures and last 15 years instead of 2 years. Unlike other types of lighting, LED lights do not have a warm-up period and are at full brightness when they are turned on. This will enable Caltrans to install control systems that turn the lights off when they are not in use, which may yield substantial additional energy savings and GHG reductions. Caltrans estimates that LED lighting could reduce the average amount of time that maintenance yard lights are on by more than 90 percent, from 4,100 hours per year to 400 hours. The combined transition to LED lights and new control systems could reduce the overall energy consumption for lighting at maintenance yards by 60–80 percent.

Installation of an overhead changeable message sign along State Route 99.

Finally, Caltrans now requires that facilities that lease space in the right-of-way (e.g., parking facilities located under freeway overpasses) use LED lighting.

5.2.5 Maintenance Waste Management

Used guard rails for recycling.

Caltrans is exploring opportunities to reduce GHG emissions associated with materials manufacturing by recycling or using long-lasting substitutes for the materials that it uses and replaces in maintenance, including guardrail metal, signs and posts, sand and salt, and paint. For example, thermoplastic road paints last two to three times as long as traditional waterborne paints and reduce the amount of fuel needed to re-stripe lanes. Some districts also use recycled paint to cover graffiti.

5.2.6 Traffic Operations

Caltrans improves traffic operations by managing traffic incidents quickly and efficiently, mitigating delay due to construction projects, and providing information to help travelers avoid congested areas and traffic incidents. All of these activities keep traffic moving at efficient speeds, which reduces GHG emissions caused by traffic congestion.

Bay Bridge I-80 westbound traffic with a CMS indicating extended bridge closure for construction.

Over the past decade, Caltrans has deployed several new traffic management strategies with the potential to further smooth traffic and reduce GHG emissions. These include new high-occupancy vehicle (HOV) lanes that allow cars with at least two (or in some cases, three) occupants to bypass congestion, as well as high-occupancy toll (HOT) lanes that are open to carpools or to single-occupant vehicles that pay a fee. These lanes have the potential to reduce GHG emissions not only by encouraging drivers to carpool but also by reducing overall congestion. Caltrans works in partnership with many local and regional transportation agencies to create and administer new HOV/HOT facilities.

Caltrans and its local and regional partners also operate metering lights at many freeway onramps; these lights are designed to reduce delays as vehicles merge. Studies conducted by Caltrans have found that ramp metering during peak hours results in a 30–40 percent reduction in freeway congestion, which reduces GHG emissions.[36] Caltrans has been working to streamline management of ramp meters by developing a software package called Universal Ramp Metering Software that will allow coordination of ramp metering across different jurisdictions. Ramp metering has proven effective at increasing traffic speeds on freeways. Consequently, Caltrans is now working to create new methods to evaluate the impact of meters on traffic on adjacent local arterial streets in order to reduce congestion where these streets feed into onramps.

Caltrans also works to optimize traffic flow through traffic light synchronization. According to studies conducted by Caltrans, projects funded under the Proposition 1B Traffic Light Synchronization Program have achieved 45-percent reductions in travel time delays along the corridors where these projects are in place.[37]

Caltrans identifies and prioritizes effective traffic management strategies and implementation actions through plans such as the Traffic Management Systems Master Plan and the Ramp Metering Development Plan. The Connected Corridors pilot project, currently underway, aims to reduce congestion by unifying policies and operational strategies across jurisdictions. One of the goals of the project is to develop and implement strategies that aid the State in meeting its transportation-related GHG reduction targets.

Caltrans also works to evaluate the impacts of new strategies to manage delay during repairs. In certain cases, Caltrans has shifted from spreading maintenance and improvements on major freeway facilities over long periods, which results in long stretches of delay as lanes are closed one at a time for improvements, to concentrating projects in a brief period during which facilities are closed completely. Caltrans closed a stretch of Interstate 405 in Los Angeles for a single weekend in July 2011 in order to replace the east span of the Mulholland Bridge. This approach minimizes overall delay, especially if Caltrans keeps travelers well-informed about closure impacts and travel options, but may result in an increase in GHG emissions depending on demand management and the availability of alternative routes.[38] Caltrans regularly assesses the benefits of several of these strategies and works with stakeholders to implement them locally as it updates its Traffic Management System Master Plan.

In addition to managing traffic through special lanes and signals, Caltrans has several systems in place that provide travelers with information to help them avoid congested routes and incidents. The Traffic Operations System network (TOSnet) is a Caltrans communication network that provides real-time traffic data from multiple sources, including roadway cameras, metering lights, emergency responders, freeway offices, and traffic signals. This information helps transportation management centers (TMCs) located in each district to quickly select appropriate incident response strategies and keep travelers informed about routes to avoid. The new Caltrans Satellite Communication (CT SAT COM) system provides voice, video, and data communications services to emergency sites across the state in order to ensure that travelers and other agencies are fully informed of changing conditions. Freeway Service Patrols, which Caltrans operates in conjunction with the California Highway Patrol and local agency partners, consist of tow trucks that travel congested urban freeways during peak travel hours in order to clear incidents and reduce congestion.

Caltrans also has several initiatives to reduce the energy use associated with its traffic management activities. These include solar- and wind-powered ramp signals, radio repeaters, and traffic counting devices. The CT SAT COM system also reduces the need for Caltrans staff to travel to and from emergency sites.

5.2.7 Landscaping

Because Caltrans sets standards and provides guidance for maintenance of vegetation in the area surrounding roadways, a number of opportunities to reduce GHG emissions are associated with roadside maintenance and watering. Caltrans encourages the use of native plants, mulch, and hardscape or other non-vegetative cover in lieu of traditional landscaping plants and grasses within the right-of-way, which limits the need for irrigation. Reducing water use can yield substantial reductions in GHG emissions, especially in more arid parts of the state where water supplies are energy-intensive to source and distribute. Non-vegetative cover does not require mowing and control of weeds, thereby reducing the GHG emissions due to fuel use in maintenance vehicles.

In order to assist with selecting appropriate plant cover, Caltrans has collaborated with UC Davis to create the California native plant database, which identifies appropriate plant species based on the county, route post mile, local rainfall, elevation, and plant community. This database is used not only by Caltrans staff but also by government agencies and contractors across the state. Caltrans requires that all green material used on the roadside be locally sourced, which reduces the emissions associated with transporting materials.

Caltrans has made extensive use of remote irrigation control systems (RICSs). These systems include sensors to ensure efficient operation and can remotely identify malfunctions. In addition to conserving water use, RICSs conserve fuel by limiting field trips by maintenance crews. In a few locations, Caltrans has installed solar-powered irrigation systems. Direct burial techniques, rather than PVC pipes, are now used for the wiring for landscaping systems, which reduces material consumption and associated GHG emissions. Looking ahead, Caltrans is considering the use of irrigation systems controlled by cell phone, which can further cut down on travel by maintenance staff.

5.2.8 Research and Innovation Projects

Caltrans has several research efforts underway to evaluate how it can better accommodate electric and alternative-fuel vehicles as they become more prevalent on state highways. For example, Caltrans is partnering with public agencies and private entities on the Sustainable Transportation Energy Pathways (STEPS) sponsorship program through UC Davis, which supports research on all major alternative fuel types. It is also working with UC Davis to develop and field test generators and lighting rigs that use hydrogen fuel cells instead of diesel fuel, and with Humboldt State University to develop improved fueling stations for hydrogen fuel cell vehicles. The latter project will lead to improvements in fueling infrastructure that can double the range of these vehicles. Caltrans is examining best practices among other state DOTs in providing facilities for electric vehicles and is assessing the feasibility of installing electric vehicle charging stations along with alternative fueling stations along major highways in California. This would extend the range of all electric vehicles, which currently

can travel approximately 70 miles on a single charge. These projects have the potential not only to continue to increase fuel efficiency in the Caltrans fleet but also to develop technologies that will facilitate broader use of energy-efficient vehicles.

Operations at a Caltrans Traffic Management Center.

Other research projects at Caltrans are examining ways to improve traffic data collection in order to provide travelers with better information on how to avoid congested areas. These include efforts to develop better traffic detection devices and to sync them with video monitors in order to verify vehicle counts and improve data collection in complex situations. This will enable Caltrans to respond to incidents more effectively and improve the data that are available to Caltrans when planning new facilities. Caltrans also has developed a mobile TMC that can coordinate incident response from the field in the event of an emergency or serve as a backup in case a district TMC becomes disabled.

The Caltrans Landscape Architecture Program has overseen a variety of research projects related to climate change or water conservation. One recent project reviewed the economic and environmental value of carbon sequestering provided by trees and other vegetation in the highway right-of-way, and identified strategies that will increase the amount of carbon sequestered. Another research project developed methods to grow native grass sod, which can be used to protect bare soil and requires less water. As a result of this research, native grass sod is now commercially available in California.

5.3 Maintenance and Operations GHG Mitigation—Suggestions for Additional Activities

Some of Caltrans' most long-standing efforts to reduce energy use and GHG emissions have focused on using alternative fuels in its fleet and installing energy-efficient lighting. Since Caltrans initiated these activities, new technologies have become available, resulting in new opportunities to reduce GHG emissions. This section discusses these opportunities and identifies additional opportunities for Caltrans to further reduce GHG emissions due to congestion.

Continue to evaluate the potential for alternative energy in the right-of-way.

In recent studies, Caltrans has found that solar installations in the right-of-way have huge potential, and other DOTs have successfully implemented solar photovoltaic projects along highways. For example, the Oregon Department of Transportation (ODOT) partnered with a local utility to initiate the Oregon Solar Highways Project, which has so far installed two solar arrays—one at a freeway interchange and another on DOT land adjacent to a rest area, with a total generation capacity of 1.9 MW. ODOT also conducted an in-depth analysis to develop an inventory of other potential sites for solar installations in the right-of-way and is now analyzing options for financing an additional 3.2 MW of generation capacity at the two highest-priority sites.[39]

Two districts have initiated pilot projects for solar installations in the right-of-way. A collaborative effort by Caltrans and the Sacramento Municipal Utility District (SMUD) to install solar in the right-of-way along US 50 outside of Sacramento was abandoned when contractors submitted only one bid for the project that was well outside the budget. District 4 is currently working with a private developer to install solar panels at interchanges along US-101 in Santa Clara County. Caltrans can use the lessons learned from these two projects to identify critical success factors and opportunities to further streamline future projects to install solar photovoltaics in the right-of-way. This effort also could benefit from an in-depth examination of lessons learned from ODOT's Solar Highways Project.

Future studies of alternative energy in the right-of-way need not focus exclusively on solar energy. For example, opportunities may exist to generate wind power along the right-of-way in passes, along bridges, and in other windy locations.

Create an implementation plan for solar installations at park-and-ride lots.

DD-104 encourages Caltrans to install solar photovoltaics at park-and-ride lots, maintenance stations, and other facilities where solar energy systems can be safely and cost-effectively implemented along the State Highway System. Unlike solar installations in the right-of-way, which are still relatively rare in the United States, solar panels at parking lots are widespread, and District 6 has installed one at its headquarters building. There may be further opportunities for Caltrans to install solar at locations where panels can be relatively high-capacity without producing other negative impacts as a result.

Increase the use of B20 and other low-carbon fuels.

As discussed above, the GHG benefits of alternative fuels can vary widely. Caltrans can achieve greater GHG reductions by increasing use of those fuels with a low carbon content, as measured on a life-cycle basis. Because Caltrans operates its own fueling stations in many districts, it has the option of purchasing alternative fuels for these stations where alternatives are available. A first step would be to shift from B5 to B20, which Caltrans has used in the past. Because Caltrans has already made the transition to biodiesel blends, any maintenance impacts of using B20 would be minimal. In the past, B20 was significantly more expensive than B5, but the price is now comparable. Per unit of energy, the B20 typically available in California has 12 percent lower GHG emissions than conventional diesel. Over time, it may be possible to use biodiesel blends higher than B20, including B100 (100-percent biodiesel blend), if the fuels industry establishes a standard for B100 and manufacturers offer warranties on equipment that cover these fuels.

Another longer-term opportunity would be to purchase E85 with lower carbon content, which contains ethanol made from sugar cane, non-food crops such as switchgrass, or plant waste. E85 from corn feedstock does not significantly reduce GHG emissions compared to conventional gasoline, according to ARB estimates.[40] Currently, however, there is very limited supply of non-corn based ethanol in California.

Table 9 summarizes GHG reductions from various alternative vehicle fuels. Note that these values normalize GHG reductions by units of energy rather than by gallons of fuel in order to account for the differences in fuel energy intensity.

Table 9: GHG Reductions from Alternative Vehicle Fuels

Fuel Type	Reduction in GHG Emissions per Megajoule (MJ) Compared to Conventional Fuel
Gasoline alternatives	
• E85 (Corn ethanol)	0.2%
• Propane	19.7%
Diesel alternatives	
• B5 (Soybean biodiesel)	0.6%
• B20 (Soybean biodiesel)	2.3%
• B100 (Soybean biodiesel)	12.1%
• B5 (Waste oil biodiesel)	3.9%
• B20 (Waste oil biodiesel)	15.7%
• B100 (Waste oil biodiesel)	83.3%
• B5 California Average (70% waste oil/30% soybean)	2.9%
• B20 California Average (70% waste oil/30% soybean)	11.7%
• B100 California Average (70% waste oil/30% soybean)	61.9%
• Compressed natural gas (CNG)	28.2%

To maximize the effectiveness of alternative fuel strategies, Caltrans also can continue to encourage employees to fill up fleet vehicles at the Department's fueling stations where E85 and biodiesel are dispensed.

Purchase hybrid electric vehicles where feasible.

The Caltrans fleet is one of its biggest energy consumers. Additional fuel savings and GHG reductions can be achieved by purchasing more HEVs when possible. HEVs are now widely available as a substitute for sedans and light trucks, and many offer fuel economy gains of 20–45 percent. To date, Caltrans has favored flex-fuel vehicles over HEVs, in part to comply with the Energy Policy Act of 1992 (EPAct), which

requires government fleets to acquire alternative-fuel vehicles in order to reduce dependence on foreign oil.[41] HEVs do not count toward these requirements.

HEVs cost more than comparable gasoline vehicles, due mostly to the cost of the batteries, but reduce fueling costs. The payback period can range from 5 to 10 years, depending on the annual mileage of the vehicle. In order to maximize GHG reductions, Caltrans should consider purchasing HEV versions of light-duty vehicles where the opportunity exists without increasing long-term costs or violating EPAct requirements. Furthermore, the EPAct does offer an alternative compliance pathway that would allow for HEVs, as well as some of the other efficiency strategies discussed in this chapter, to count toward the EPAct requirements.[42] An application for this alternative compliance pathway would need to be led by the California Department of General Services, not by Caltrans.

Electric vehicles charging at a parking lot facility.

Looking ahead, other options for advanced technology vehicles using electric drive systems are becoming available. These include plug-in hybrid electric vehicles (PHEVs), which can run on either conventional gasoline or electricity, and battery electric vehicles (BEVs), which run exclusively on electricity. These vehicles offer the potential of much larger fuel savings and GHG reductions. To take advantage of these technologies, Caltrans may need to invest in the infrastructure to charge electric vehicles. Many PHEVs and BEVs currently on the market can complete a charge overnight using conventional electrical outlets, but more extensive infrastructure will be necessary to manage electricity consumption from larger numbers of charging vehicles. BEVs and some PHEVs count toward EPAct requirements; therefore, installing charging infrastructure can support opportunities to simultaneously reduce GHG emissions and meet EPAct requirements.

Expand anti-idling measures through training or monitoring.

So far, Caltrans' efforts to eliminate unnecessary idling have been limited to directives instructing employees not to idle. While this policy is a good first step, Caltrans has the opportunity to be more proactive. Other DOTs have taken more aggressive measures to encourage drivers to operate vehicles more efficiently, such as using computer systems to monitor the amount of time that vehicles spend idling and by instituting "eco-driving" programs that instruct employees in a number of techniques to conserve fuel when driving, including turning off a vehicle instead of letting it idle. Caltrans should consider these approaches; the reduced fuel consumption over time would likely pay for the upfront costs.

Require rental vehicles and equipment to be hybrid or alternative fuel where options are available.

Because a greater number of road projects are scheduled for periods when weather conditions are favorable, Caltrans often needs to rent additional equipment in summer. In addition, the need to rent additional vehicles and equipment likely will increase as Caltrans reduces its fleet size under a recent mandate from the Governor.[43] Caltrans could ensure that rental equipment contributes to efforts to reduce GHG emissions by instituting a policy requiring that all rental equipment use alternative fuels or hybrid electric engines where the technology and rental options are available. Light-duty hybrid vehicles are widely available, and diesel hybrid versions of several types of heavy equipment are currently available or anticipated to become available in the near future. If fuel blends that use a high portion of biodiesel become more widely available, rental equipment that can run on these fuels may also become available. Caltrans could also compile information on sources of green rental equipment across the state in order to provide districts with the necessary information to implement this policy.

Accelerate deployment of LED lighting and target the least-efficient fixtures for conversion first.

Switching the 76,000 traffic lights on the State Highway System from incandescent fixtures to LEDs produced substantial GHG reductions and saved Caltrans money because LEDs consume so much less electricity. There is an opportunity for Caltrans to achieve even greater GHG reduction by mounting a similarly comprehensive effort to replace the 80,000 roadway lights operated by the Department to LEDs. LEDs consume 2–4 times less energy than the HPS light fixtures that Caltrans uses for most of its roadway lighting. District 4 has done extensive testing of LED roadway lighting on bridges and in tunnels, and found that LED lights do not negative affect visibility. LEDs also can be used in changeable message signs, where they reduce energy consumption by more than 90 percent.

Caltrans intends to purchase 40,000 LED fixtures over the next 7 years to replace HPS roadway lights that are near the end of their life spans and has replaced more than 500 changeable message signs with LEDs. Additional opportunities may exist to increase the deployment of LEDs through better guidance and innovative financing. For example, adopting specifications for LED lighting or creating a standard list of accepted LED fixtures that includes information on cost benefits may encourage districts to use LEDs even when funding is not available from headquarters. Caltrans has partnered with utilities to pay for energy efficiency projects in its headquarters building through on-bill financing, under which utilities loan money to finance energy efficiency upgrades and Caltrans repays these loans through their monthly energy bills, using the savings from these upgrades. Caltrans should investigate the feasibility of using on-bill financing, bonding, or other innovative approaches to cover the upfront costs of LED roadway lighting. These measures also could be applied to other energy-efficient lighting strategies, including replacing the remaining 50 percent of roadway sign lights that are MV fixtures with induction fixtures, which use half the energy.

When Caltrans replaces roadway lighting, it should target the least-efficient fixtures for conversion first. Although Caltrans uses HPS lights on most roadways, District 7 still has more than 1,400 MV fixtures. These fixtures consume the same amount of energy as HPS fixtures but produce much less light. An LED roadway fixture consumes 91 percent less energy than an MV fixture that produces a comparable amount of light, and 78 percent less energy than the equivalent HPS fixture.

Efficiency Innovations in Fleet Management

Several state departments of transportation have implemented fleet management software or hardware to limit idling. For example, the Alabama Department of Transportation (ALDOT) has placed GPS tracking systems on two-thirds of the equipment and vehicles in its fleet; it uses these systems to monitor idle time and equipment usage. In addition to helping ALDOT enforce its anti-idling policy, these systems allow ALDOT to compare the operating costs of equipment to industry standards and to identify opportunities for cost savings. The GPS systems are part of a package of green fleet initiatives that save ALDOT $6.6 million per year.[44] The Utah Department of Transportation (UDOT) also has installed software to monitor idling. In 2011, this program reduced the UDOT fleet's collective idling by 3.5 percent.[45] Other DOTs, including Oregon (ODOT) and Kansas, have installed hardware on vehicles and equipment that limits idling time. As of 2010, ODOT had placed anti-idling hardware on 81 of the 3,000-plus vehicles in its fleet. ODOT installs this hardware on all new all new three-quarter ton, one-ton, five-yard, and ten-yard trucks and has a policy of installing anti-idling hardware on all vehicles whenever feasible.[46]

Maximize the benefits of ramp metering through cooperation with local agencies and joint operation of freeway ramps and local streets.

Ramp metering is a key strategy for managing congestion and reducing GHG emissions associated with vehicle operations. Ramp meter operations in most Caltrans districts follow HDM guidelines, which suggest that ramp meter queuing be contained within available ramp storage instead of spilling over onto adjacent streets. While this minimizes local traffic impacts, it can also limit the effectiveness of ramp metering in reducing congestion, and more aggressive ramp metering operations could further reduce GHG emissions due to congestion in some situations. Caltrans is pursuing joint operations between ramp meters and local traffic signals, so that the available queue storage could be utilized in a balanced and coordinated manner. These opportunities should be further explored. When implementing ramp metering, Caltrans, in partnership with local agencies, should consider the trade-offs between congestion on local streets and congestion on highways in order to select the scenario that best reduces overall congestion and GHG emissions.

Freeway ramp meter indicator.

Track the traffic and GHG impacts of total roadway closures for maintenance and rehabilitation.

Caltrans has begun to use a new method of completely closing roadways and concentrating repairs in a short period instead of an extended period of working on one lane at a time while keeping the rest of the roadway open. This approach could reduce or increase GHG emissions. It could reduce vehicle trips during road closures, reduce congestion associated with road projects, and reduce the amount of fuel used by maintenance vehicles, or it could increase emissions in the absence of demand management to mitigate congestion on alternative routes. Drawing conclusions is difficult, however, without more data on how these closures affect travel behavior and fuel usage. Monitoring the impacts of these closures would not only help Caltrans quantify the GHG benefits of total closures but also potentially help to mitigate public opposition to closures, justify adopting this approach for a greater number of projects through the *Standard Specifications*, and encourage other transportation departments to adopt total closures.

Improve communication for the results of DRISI projects.

Caltrans' Division of Research, Innovation, and System Information (DRISI) has conducted or funded research related to a wide range of GHG reduction strategies, including many of the opportunities discussed elsewhere in this report. However, Caltrans is a large organization, and findings from this research can be slow to develop into best practices without effective communication between DRISI and the districts that are ultimately responsible for implementing projects. DRISI conducts ongoing work to determine how best to utilize technology transfer opportunities to disseminate research results. DRISI currently maintains a website, issues research briefs, and hosts monthly webinars that bring together practitioners and researchers to discuss emerging topics in transportation.

Much of the research funding allocated by DRISI goes to the University of California Transportation Centers (UCTCs), and the DRISI website provides links to the different centers. The division could help practitioners who want to delve into a given topic in more depth by organizing UCTC research by category and providing direct links to research papers. However, engineers and decision makers often need more reassurance that a new approach will work for a specific project type. DRISI could encourage the adoption of new practices by compiling information and specifications

on projects that have successfully used innovative techniques and making this information available on its website. DRISI could also collaborate with other divisions to provide training for Caltrans engineers that summarizes best practices in sustainability and GHG reductions. The training could cover a broad range of research and practitioner experience. Additionally, deployment planning, which is the systematic process of distributing an innovation for use within an organization, should be included in the research process from beginning to end. DRISI's Deployment Support Branch and Communication Team can notify and inform both Caltrans staff and partners at other agencies of the potential benefits of new processes or products in order to provide an easier and more effective transition from initial concept to implementation.

6 Facilities and Administration

6.1 Overview of Caltrans' Facilities and Administration Functions

Several divisions within Caltrans work to provide and manage facilities for Department offices around the state. This work involves overseeing construction of new Caltrans offices and improvements of existing facilities, managing leases, and administering workplace and employee programs. Caltrans is currently working to reduce GHG emissions from its facilities by requiring that new buildings are energy-efficient, by upgrading equipment and systems in existing buildings, and by encouraging employees to recycle and use alternative transportation to get to work. Many Caltrans districts have initiated programs to make their buildings more energy efficient or to promote commute alternatives, and these programs are discussed in more depth in the sections on individual districts below.

EO B-18-12 directs all state agencies, including Caltrans, to take steps to make state buildings more sustainable, reduce GHG emissions, and improve energy efficiency. State agencies are to reduce the amount of grid-based energy purchases and non-building grid-based retail energy purchases by 20 percent below 2003 levels by 2018.[47] This EO also strengthens the energy efficiency requirements for state agencies previously established in EO S-20-04.[48]

The EO mandates that:

- All state buildings constructed or the design renovated after 2025 achieve zero net energy consumption;
- All new buildings and major renovations more than 10,000 square feet achieve LEED Silver certification or higher and include renewable energy generation facilities, if economically feasible;
- State agencies must reduce their GHG emissions by at least 10 percent below 2010 levels by 2015 and 20 percent below 2010 levels by 2020;
- State agencies must incorporate building commissioning to facilitate improved and efficient building operations for new and existing buildings;
- State agencies must identify and pursue opportunities to provide electric vehicle charging stations and accommodate future charging infrastructure demand at employee parking facilities in new and existing buildings;
- State agencies must reduce overall water use by 10 percent below 2010 levels by 2015 and 20 percent below 2010 levels by 2020; and
- All state buildings participate in demand response programs to reduce peak energy use.[49]

Many of the lighting activities described in Chapter 5 have set Caltrans on a path to meet this target, but Caltrans is looking for other opportunities to further reduce energy consumption and GHG emissions in its buildings. Even prior to EO B-18-12, Caltrans strived for new facilities and major rehabilitation projects to be designed to meet or exceed LEED Silver standards.

One component of Caltrans' strategy to reduce GHG emissions from its facilities is to construct new solar photovoltaic projects at buildings. Many of these projects are funded through federally backed CREBs, and Caltrans is the only state agency to receive this funding. Caltrans also continues to work with the California Department of General Services to achieve energy efficiency improvements and to implement water and resource conservation systems in existing buildings. The information collected while monitoring and reviewing existing energy usage enables Caltrans to target the most cost-effective ways to make its facilities more energy-efficient. Table 10 summarizes the impacts of several of the most widely deployed strategies to reduce GHG emissions at Caltrans administrative facilities. In total, these strategies reduce Caltrans' annual GHG emissions by almost 4,800 tons per year, which is equivalent to removing approximately 400 passenger cars from the road.

Table 10: Caltrans Strategies to Generate Clean Energy and Increase Efficiency in Facilities and the Resulting GHG Reductions

Strategy	Annual GHG Reductions (tons CO_2e)
LEED certification	769
Data center upgrades	85
Overall building upgrades	1,517
Computer energy reduction	505
Energy-efficient facility lighting	630
Low-flow toilets and water fixtures	4
Total	**3,511**

The remainder of this chapter discusses strategies to reduce building energy use in more depth.

6.2 Facilities and Administration GHG Reduction Initiatives

6.2.1 Renewable Energy Installations at Caltrans Facilities

In 2009, the State announced the sale of $20 million in CREBs to pay for solar photovoltaic projects on 70 Caltrans facilities. The CREBs program is administered by the United States Internal Revenue Service. The federal government pays interest on CREBs in the form of tax credits, and the proceeds from the bonds go toward renewable energy installations. Due to the intensive process and short deadlines, Caltrans was the only state agency in California that applied to issue CREBs. All 70 CREBs-funded projects are complete and generating energy. The majority of these projects are at Caltrans maintenance facilities and equipment shops; the remainder are at rest areas, office buildings, laboratories, and toll/management facilities.[50] Although several

CREBs Projects Reduce GHG Emissions While Saving Taxpayer Dollars

The 70 projects funded by Clean Renewable Energy Bonds (CREBs) that have been constructed as of January 2012 account for 2.4 megawatts (MW) of solar generation capacity.[51] It is anticipated that these projects will generate approximately 3.6 million kilowatt hours annually, keeping almost 1,400 tons of greenhouse gas (GHG) emissions out of the atmosphere each year, which is equivalent to removing 270 passenger vehicles from the road. Caltrans estimates that the photovoltaic installations will save the agency—and hence taxpayers—approximately $650,000 per year in energy costs. After accounting for the cost of paying off bond debt and maintaining the facilities, this translates into $5.6 million in savings over the anticipated 25-year life of the solar panels. In other words, each ton of GHG emissions reduced by CREBs-funded projects saves taxpayers $159.

districts had solar projects in place, the CREBs program dramatically increased Caltrans' overall solar generation capacity. The CREBs-funded projects will help to meet the goals established under EO B-18-12, issued in 2012, which sets a target for state agencies to reduce their consumption of grid-based energy by 20 percent below 2003 levels by 2018.

Solar panels at a maintenance facility in District 7.

6.2.2 Energy Efficiency Projects

Many of the innovative measures that Caltrans promotes to reduce GHG emissions in its facilities and workplaces around the state have been developed in the Caltrans Sacramento headquarters. For instance, Caltrans staff have partnered with SMUD to develop a modernized energy management system to collect real-time data on the energy consumption of different components of the HVAC system in the Caltrans headquarters building in Sacramento. Caltrans is now expanding this monitoring system to buildings in several district headquarters in order to identify cost-effective measures to reduce energy use and energy-efficient options for replacing old equipment. Caltrans also has been working with SMUD to explore new ways of financing energy-efficient repairs and retrofits for HVAC systems and lighting systems.

Caltrans recently installed energy-efficient lighting fixtures at its Royal Oaks warehouse in Sacramento through an American Recovery Act-funded program offered by SMUD. Caltrans replaced approximately 130 less efficient 400-watt high-intensity discharge lighting fixtures with T-5 fluorescent lighting fixtures with high-output ballasts. These new fixtures produce the same light as the old fixtures while using approximately 40 percent less electricity; they also have a longer life span. Caltrans projects over $20,000 in savings per year due to this project, which was implemented at no cost to the Department.

Computers account for an increasing proportion of building energy consumptions, and in 2010, Caltrans began monitoring real-time energy use in desktop and laptop computers in use in facilities statewide. The Computer Energy Reduction and Documentation (CERD) system tracks computer usage and average energy used by each district. It manages, measures, and reduces energy consumption on personal computer networks, reducing GHG emissions in the process.

Many Caltrans district offices also have taken steps to reduce building energy use; these are discussed in Chapter 7.

6.2.3 Water Conservation

Many Caltrans buildings include water conservation features such as low-flow faucets and toilets. While conserving water is an important environmental goal in and of itself, it can also be an important GHG reduction strategy. Water can be energy-intensive to treat and transport, particularly in areas of the state that are located farther from major water sources. Caltrans district offices continue to replace fixtures and toilets as needed with newer models that use half the water. In addition, many Caltrans maintenance facilities recycle the water that they use to wash vehicles, as discussed in Chapter 4. EO B12-18 requires that Caltrans, along with all other state agencies, reduce water use by 10 percent by 2015 and by 20 percent by 2020, in comparison to 2010 levels.

6.2.4 Office Waste Management

Like all state agencies, Caltrans is required to track how much waste is taken to landfills and to meet a target of recycling or diverting 50 percent of all waste.[52] Caltrans has exceeded this target in recent years. In order to reduce waste, Caltrans provides recycling bins for paper, plastic, and batteries in its headquarters building and district offices. Recycling these materials reduces GHG emissions associated with transporting waste to landfills and manufacturing virgin materials.

Recycling bins at a District office.

6.2.5 Using Recycled/Sustainable Materials

Caltrans works to reduce the life-cycle GHG emissions from its workplaces by using recycled or sustainable materials in its office buildings wherever possible. Caltrans purchases recycled paper for printers and copiers statewide. Furthermore, Caltrans prohibits acquisition of new office furniture when existing surplus furniture is available as an alternative. Caltrans also has purchased energy-efficient new equipment for printing major graphics, signs, and publications.

6.2.6 Employee Travel and Communications

In order to reduce vehicle emissions associated with travel to and from work meetings, Caltrans encourages its employees to take transit for work trips where feasible and provides information to help employees plan transit trips. Caltrans provides transit passes for business travel and makes increasing use of virtual meeting tools such as videoconferencing and webinars, which eliminate the need to travel to meetings.

6.2.7 Employee Commute Options

Caltrans takes an active role in encouraging its employees to commute to work by transit, carpool, vanpool, walking, or bicycling instead of driving alone. Caltrans also has a telecommute policy that allows employees to work from home or alternative worksites in order to reduce congestion and emissions when work conditions warrant telecommuting.

Employee Commute Programs at Caltrans Headquarters

Caltrans has a wide set of programs to encourage employees at its Sacramento headquarters to get to work without driving alone. For employees who take transit, Caltrans provides monthly bus passes, offers subsidies to reimburse workers for their transit costs, and allows employees to deduct the cost of transit passes from their payroll on a pre-tax basis. The office is also a member of the Sacramento Transportation Management Association (TMA), which offers prizes and incentives for workers who take transit or other alternative transportation modes to work. The TMA offers emergency ride home vouchers to transit riders, which cover the costs of taxis or other transportation in case of an emergency.

Caltrans also offers a subsidy to help workers pay for vanpools instead of driving to work. Employees are responsible for organizing vanpools and paying the upfront costs of leasing carpool vans on a long-term basis. Caltrans reimburses their costs and offers priority parking for vanpools at its headquarters building. The Sacramento TMA runs a "match list" to help drivers find other workers with whom to carpool. As a result of these programs, almost 150 employees at Caltrans headquarters carpool or take a vanpool to work, which reduces annual greenhouse gas emissions by more than 300 tons annually.

In order to make it easier and safer for employees to commute by bicycle, Caltrans headquarters offers secure access bicycle parking for employees and bicycle racks for visitors. Caltrans has sponsored Bike to Work Days in Sacramento and encourages employees to participate by offering T-shirts and other prizes. Caltrans headquarters won the Sacramento region's Bike Month challenge for large employers in 2012, when its workers logged 57,647 miles, the most miles ridden of any workplace with more than 500 employees.

Both headquarters and individual district offices offer employee commute programs designed to reduce GHG emissions by encouraging alternatives to solo driving. Table 11 summarizes the GHG reductions due to Caltrans employees who use alternatives to driving alone to get to work. Alternative commutes reduce emissions by almost 6,500 tons per year, which is approximately equivalent to taking more than 1,200 passenger cars off of the road.

Top: Caltrans staff commuting by vanpool.
Bottom: Caltrans staff commuting by transit.

Table 11: Statewide Participation in Caltrans Employee Commute Programs and the Resulting GHG Reductions

Mode	Number of Participants	Annual GHG Reductions (tons CO_2e)
Bicycle	666	493
Vanpool	312	721
Carpool	695	1,449
Transit	1,645	3,802
Total	**3,318**	**6,465**

6.3 Facilities and Administration GHG Mitigation—Suggestions for Additional Activities

Many Caltrans districts and Caltrans headquarters have successfully initiated innovative programs to reduce energy use at their respective buildings and facilities. However, additional opportunities exist for Caltrans to implement throughout the Department some of the best practices developed by individual districts.

Focus on energy efficiency when constructing or renovating buildings.

Caltrans has taken a commendable lead in implementing solar photovoltaics through the CREBs program. However, solar projects are costly to build and yield relatively few GHG emission reductions because most building sites are not able to accommodate a solar installation with a large generation capacity. In contrast, Caltrans' efforts to make its buildings more energy efficient through strategies such as modernization of HVAC systems, lighting upgrades, LEED certification, and building retrofits have produced a greater amount of GHG reductions and typically have lower upfront costs and a shorter payback period. The wide variety of energy efficiency measures implemented in Caltrans buildings also gives the Department an ample reserve of experience to draw upon when designing new facilities. In the future, Caltrans should seek to maximize energy efficiency when constructing new buildings or renovating existing ones before considering solar panels or other renewable energy facilities if limited budgets force tradeoffs between different GHG reduction measures.

Enhance the recycling program.

Caltrans could further promote innovative recycling programs that have been developed within district offices (e.g., District 3's use of recycled light fixtures in its new offices) across the rest of the organization and could initiate new programs, such as recycling electronic waste. Caltrans also could coordinate with CalRecycle to incorporate best practices from other state agencies. Enhancing the Recycling Program statewide would help to reduce GHG emissions embodied in disposed waste and would yield the many other environmental benefits associated with higher recycling rates, such as keeping toxics out of landfills.

Conduct energy audits for Caltrans buildings and facilities.

Energy audits are a key step in identifying cost-effective energy improvements. They can help to identify potential improvements in old buildings and check whether new buildings are performing as anticipated. Caltrans has made widespread investments in energy-efficient buildings, and EO B-18-12 has established more ambitious targets to reduce operational GHG emissions and energy use. Conducting energy audits is a crucial step in ensuring that Caltrans' investments in energy efficiency are putting it on a path to meet established goals, objectives, and targets.

Establish a revolving fund to cover the upfront costs of energy-efficient renovations and equipment.

Although energy efficiency measures can save money over time, they often involve higher upfront costs that act as a barrier to purchase. To overcome this barrier, Caltrans could establish a revolving fund dedicated to energy-efficient equipment and building renovations. Individual divisions and districts could borrow money from this fund to cover the capital costs of these items and then reimburse the fund with the savings from reduced fuel and electricity consumption.

7 GHG Reduction Activities in Caltrans Districts

7.1 Overview of Caltrans Districts

The 12 Caltrans district offices are ultimately responsible for implementing the policies and procedures established by headquarters. Each district selects, designs, and manages the construction of highway projects within its jurisdiction, in addition to maintaining and operating all sections of the State Highway System that lie within its bounds. Figure 3 is a map of the 12 Caltrans districts.

Lifting of a segment of the new Bay Bridge as seen from the new Bay Bridge tower.

Figure 3: Map of Caltrans Districts

Source: Caltrans

Although all of the activities described in the previous chapters contribute to Caltrans' collective efforts to shrink its carbon footprint, each district has its own projects to reduce GHG emissions. This section highlights some of the innovative GHG reduction projects within the individual districts. Many of these projects can serve as best practices throughout the Department:

- **District 1** has taken advantage of a renovation to its district offices to install an **upgraded HVAC system and energy-efficient lighting**. The District upgraded its HVAC system and replaced more than 1,350 light fixtures with newer fixtures that use 20 percent less energy. In addition, the new fixtures are on timers so that they do not remain on when not in use.
- **District 2** has pioneered the use of a **new recycled product called CRMcrete for weed control**. Workers now take 30 percent fewer trips to remove weeds at sites where CRMcrete is installed and use less fuel for maintenance. CRMcrete, which is a mix of concrete and recycled rubber developed by a District 2 maintenance engineer, also produces fewer embodied GHG emissions (i.e., emissions associated with the production of materials) compared to other hardscaping materials.
- **District 3** runs a successful **employee commute program** that includes subsidies for vanpools and transit costs, emergency ride home vouchers, showers and lockers for bicyclists, and an online system that employees use to find carpool and vanpool matches and to report the amount of miles that they commute via alternative modes. As a result, the number of employees participating in ridesharing programs increased by 75 percent between 2009 and 2011.
- **District 4** has been a pioneer in installing **energy-efficient LED roadway lights**, which use 60 percent less electricity and last five times longer than the existing roadway light fixtures. Although this initiative is just in its infancy, the District saved nearly $150,000 on its electricity bills in 2011 by replacing roadway lights.
- **District 5** has installed new **energy-efficient cool roofs** on two of its buildings. These roofs reduce energy needs for heating and cooling, as well as for maintenance and replacement because they last twice as long as the old roofs.
- **District 6** is constructing a **rest area** in Tulare County that features solar panels, recycled materials, pervious paving, low-flow plumbing, drought-tolerant plants, and an efficient irrigation system. This project was designed and is being built to obtain a LEED Gold certification. If certified, it will be the first LEED-certified rest area in the state.
- **District 7** has built a **LEED Gold-certified main building** that features perforated aluminum screens that open and close depending on the weather and sunlight; photovoltaic panels that generate 5 percent of the building's energy; and skip-stop elevators that stop on only four of the building's 13 floors, thus conserving energy and encouraging employees to exercise. The building was originally certified as LEED Silver, but it achieved LEED Gold after commitments to additional changes that included adjusting the thermostat to reduce heating and cooling loads, purchasing recycled products, and adopting more sustainable custodial practices.
- **District 8** has built a **LEED Gold-certified transportation management center**, which is the first essential services facility in the country to achieve this distinction. The center consumes 30 percent less energy than typical essential services facilities, which are buildings with high energy needs designed to function around the clock in emergencies.
- **District 9** is using **locally sourced volcanic cinders to improve traction on snowy and icy roads** instead of imported sand, which reduces the energy needed to transport materials.
- **District 10** has installed **two solar projects that were built by private companies at no initial cost to Caltrans**. These companies operate and maintain the projects, and District 10 purchases the electricity generated at a rate that is guaranteed to be cheaper than what the local utility charges for power from the grid.
- **District 11** has partnered with local planning agencies to **examine GHG and criteria pollutant emissions at crossings along the U.S.-Mexico border**. The resulting studies have identified best

practices and performance measures to reduce emissions when planning future changes to border infrastructure.

- **District 12** achieved **LEED Gold certification for its main offices**, redesigning them to include energy-efficient features such as daylight sensors that adjust lighting levels according to the amount of ambient light, automated HVAC control systems, and ENERGY STAR-rated computer systems that shut down automatically when not in use.

7.2 District 1

Caltrans District 1 covers four counties along or near California's northern coast: Del Norte, Humboldt, Mendocino, and Lake. Over the past several years, District 1 has been working on a $10 million renovation to its district offices in Eureka. The original goal of the renovations was to bring the building into compliance with local fire codes, and the District took the opportunity to upgrade the building's lighting and HVAC systems to make them more energy-efficient. It replaced more than 1,350 older T12 fluorescent lighting fixtures with T8 lights that use 20 percent less energy. In addition, these lights are on timers so that they do not stay on when they are not needed. District 1 also is working to install appliances that are more energy efficient in the cafeteria.

The District has installed CREBs-funded solar arrays at five locations: the main office building, equipment shop, and two maintenance facilities in Eureka and the maintenance station in Ukiah. Together, these five projects have a capacity of 210 kilowatts, and account for almost 10 percent of the total capacity of CREBs-funded projects. Each year, they generate more than 300 megawatt hours (MWh) of electricity and keep more than 110 tons of GHG emissions out of the atmosphere. District 1's Green Team was instrumental in getting these projects up and running, and worked within the District to identify opportunities and advocate for solar facilities.

District 1 also recycles a high proportion of construction materials, including all signs and guard rails and asphalt grindings. Although the grindings of roads cannot be reused in conventional asphalt in District 1 due to climate and weather conditions, inland districts can use these recycled materials in their pavements. District 1 is exploring use of WMA on a pilot project basis, which would allow the District to use recycled asphalt locally.

7.3 District 2

Caltrans District 2 covers seven counties in the northeastern corner of California: Siskiyou, Modoc, Trinity, Shasta, Lassen, Tehama, and Plumas, as well as portions of Butte and Sierra Counties. It is one of the most rural Caltrans districts, with an average population density of only 6 percent of the statewide mean.

District 2 has pioneered the use of new recycled materials for weed control. A District 2 maintenance engineer developed a new product called CRMcrete, which is composed of concrete mixed with recycled tire rubber. Instead of using asphalt concrete, herbicides, or maintenance equipment to control weeds beneath metal guardrails along the side of roads, District 2 began to lay CRMcrete around guardrails after crash-testing to ensure that it met safety standards. Since CRMcrete uses recycled rubber, it produces fewer embodied GHG emissions than asphalt concrete. At the same time, CRMcrete is low-maintenance, and workers in District 2 now take 30 percent fewer trips to remove weeds at sites where CRMcrete is installed, in addition to less use of maintenance equipment and herbicides.

District 2 makes shared bicycles available for employees to use for work trips instead of driving. The District has purchased two shared bicycles that employees can use for trips to different district facilities or to project sites. Some facilities also have lockable bicycle cages or bicycle racks to make parking easier for cyclists. The District encourages its employees to ride to work through events and activities such as Bike-to-Work Days, and 20 District 2 employees now commute by bicycle on a regular basis.

Top: A bike cage at the District 2 office.
Bottom: A cubicle at District 2 with daylighting from adjacent windows.

7.4 District 3

Caltrans District 3 covers the northern Central Valley and Sierra Nevada, including Butte, Colusa, El Dorado, Glenn, Nevada, Placer, Sacramento, Sierra, Sutter, Yolo, and Yuba Counties. The District 3 headquarters, which is located in Marysville, also serves as the Caltrans North Region office and coordinates inter-regional projects in Districts 1, 2, and 3. In January 2009, District 3 moved its offices into a state-of-the-art, LEED Silver-certified building that is designed to use 27 percent less energy than required by state energy efficiency standards. The building, which houses more than 750 Caltrans employees, boasts a state-of-the-art HVAC system and is designed to use daylight instead of artificial light wherever possible. Furthermore, many of the electric lights that the building does use were recycled from other sites and are controlled by sensors so that they turn on only when needed. In 2010, the Precast Concrete Institute gave District 3 headquarters its award for the best public/institutional building.

District 3 is also working to retrofit old facilities with more efficient lighting and heating systems. For example, the District has a pilot project to convert under-truck lighting to LEDs at the Donner Pass truck weight station. District 3 also has replaced halogen light fixtures with more efficient fluorescents at its maintenance station in Chico. Retrofits at other District 3 maintenance facilities have focused on improving insulation in order to conserve energy used for heating.

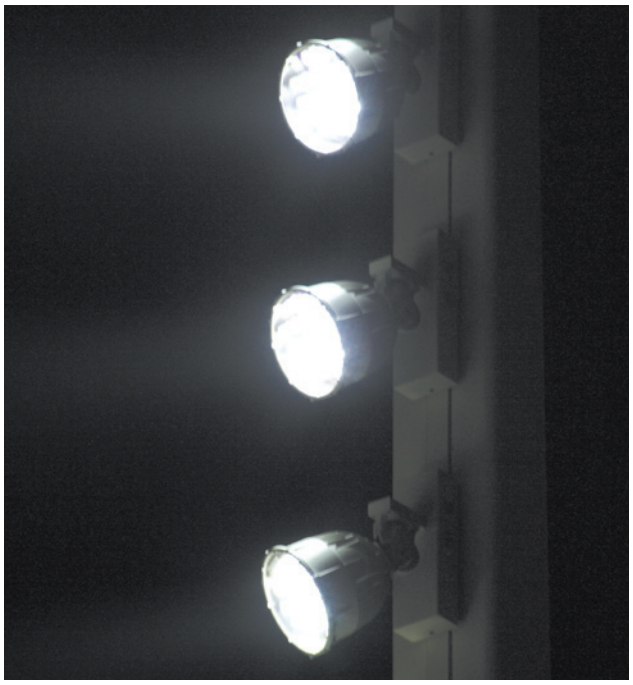
District 3 runs a successful employee commute program that provides its workers with sustainable options to get to work. The District operates an online system in collaboration with the local air district, transit agency, and TMA that employees can use to find carpool matches, assemble vanpools, and report the miles that they commute by different modes. While Caltrans does not own vans, the District subsidizes fuel purchases for vanpool participants, and also offers a subsidy to employees who take transit to cover fare costs. District 3 is a member of the Yuba-Sutter TMA, which runs an Emergency Ride Home program that covers the cost of taxis or car rentals for employees who carpool or vanpool when they need to get home quickly in an emergency. Between 2009 and 2011, the number of District 3 employees participating in this program increased by 75 percent, due in part to the consolidation of district offices to a new building in Marysville. District employees also make up a strong majority of the total participants in the TMA's ride-sharing program. The District also allows employees to telecommute and provides showers and lockers for employees who bicycle to work.

District 3 works to reduce the GHG emissions produced not only by employee commutes but also by work trips to job sites and meetings. The District maintains a fleet of 35 vehicles and an online system that employees can use to sign up for vehicles and arrange carpools for

work trips. The fleet includes three hybrids and many vehicles that can run on ethanol; therefore employees have several options to use more efficient vehicles. The District also allows employees who will attend an off-site meeting on the following morning to take these vehicles home overnight, enabling employees to travel directly to meetings instead of needing to stop at the District office to pick up vehicles. As a result of all these programs, the number of single-occupant vehicle trips at District 3 has been steadily declining, and the District has been able to drop leases on some of its parking lots.

7.5 District 4

Caltrans District 4 serves the state's second largest metropolitan area, covering the nine San Francisco Bay Area counties of Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma. District 4 has been a pioneer in installing energy-efficient LED roadway lights, which are 60 percent more efficient and last five times longer than the HPS lights that are conventionally used to light freeways. Using LED roadway lights reduces GHG emissions not only from electricity consumption but also from fewer maintenance trips to replace lights.



New LED bridge lighting on the "Skyway" portion of the new Bay Bridge.

In 2008, District 4 began installing LED lights on bridges, beginning with pilot projects on the Richmond-San Rafael and Carquinez bridges. Through these pilot projects, District 4 determined that LED lights did not affect visibility and were durable enough to withstand weather and vibrations. The District has since moved ahead with installing LED lighting on other Bay Area bridges, at major interchanges and intersections, and in tunnels. This project has the potential to substantially reduce GHG emissions because there are more than 14,000 roadway lights in the District. In 2011, District 4 saved nearly $150,000 on its electricity bills by replacing roadway lights.

District 4 works to use vehicles, equipment, and fuels that produce fewer GHG emissions. Of the 112 vehicles in the District's vehicle pool, 39 are hybrid electric vehicles—the most of any Caltrans district. District 4 is also the largest consumer among Caltrans districts of E85 ethanol and biodiesel. The district owns many flex-fuel vehicles, and many of its 1,300 pieces of maintenance equipment (which are mostly heavy equipment such as trucks, lifts, and sweepers) run on alternative fuels. The District works to procure equipment that runs on alternative fuels whenever possible and to ensure that fuels for these vehicles are readily available. District 4 operates an E85 fuel pump that supplies fuel for its vehicle pool and for privately owned vehicles, works to buy biodiesel from local filling stations when there is not enough available through Caltrans' bulk purchasing agreements, and monitors all usage of alternative fuels.

District 4 also is working to replace the pumps that are used to drain runoff from highways with more energy-efficient models. Although this initiative is relatively new, it has huge potential to reduce GHG emissions. The many below-grade highways in the District, combined with the high water table in the Bay Area, require that runoff is constantly drained off the highways. District 4 operates more than 70 pumps for this purpose.

7.6 District 5

Caltrans District 5 spans five counties along California's scenic Central Coast: Monterey, San Benito, San Luis Obispo, Santa Barbara, and Santa Cruz. Some of District 5's most innovative GHG reduction initiatives have been focused on the remote Willow Springs Maintenance

Station, which is located along US-1 in Big Sur. In 2010, District 5 installed two solar panels at the station that partially meet the station's electricity needs. These panels are particularly important because Willow Springs is off the grid and historically has used diesel generators to supply its electricity. Electricity for the Willow Springs Station therefore is more GHG-intensive than electricity from the grid, which comes from a mix made up mostly of natural gas, hydroelectric power, nuclear power, and renewables. The solar panels on Willow Springs offset a proportionately greater number of GHG emissions than the six other CREBs-funded solar projects in District 5.

District 5 also has installed new energy-efficient cool roofs on two of its buildings. The district replaced hot tar-and-gravel roofs on the main District offices in San Luis Obispo and on one of the lab buildings with high-density foam roofs with a white elastometric coating. The new roofs reduce heating and cooling loads. The high-density foam has a higher insulating value than the old tar-and-gravel roof, while the white coating reflects sunlight instead of absorbing it. Indoor temperatures in these buildings are now naturally more consistent and therefore require less energy to manage. Furthermore, the new roofs will last 40 years, as opposed to 20 years for the old roofs, and therefore will require less energy to maintain and replace.

A view of the cool roof on a District 5 building in San Luis Obispo.

District 5 has installed more energy-efficient lighting in many of its facilities. The District has replaced 345 of the old T12 fluorescent tubes in many of its facilities with T8 fixtures that contain only two bulbs instead of four and use almost half the energy. Because the new fixtures provide better light, District 5 has been able to reduce the total number of fixtures in some facilities. The District also has replaced the 200 W metal halide or HPS outdoor lighting at its District offices with 14 W compact fluorescents, reducing energy consumption in these fixtures by 93 percent. In addition, the District installed temperature and motion sensors so that lights are on only when needed. These combined lighting measures keep 24 tons of GHG emissions from entering the atmosphere each year.

7.7 District 6

Caltrans District 6 covers the southern half of California's Central Valley, serving Madera, Fresno, Tulare, Kings, and Kern Counties. The District includes the Phillip S. Raine Rest Area, which is located on Highway 99 near Tipton in Tulare County. This is the only rest area in the state designed to achieve LEED Gold certification, and it features solar panels and low-flow toilets. In order to solicit innovative design ideas for the rest stop, Caltrans partnered with the Great Valley Center and the American Institute of Architects to sponsor an international competition that asked entrants to design an off-the-grid rest area using techniques that could then be duplicated in other rest areas around the state. The improvements at the Phillip S. Raine Rest Area not only reduce on-site GHG emissions but also serve as a template for energy-efficient retrofits at other rest areas across California.

District 6 has made extensive energy efficiency improvements to its district offices in Fresno. In 2009, the District converted all indoor lighting in the office from T12 fluorescents to energy-efficient T5 fixtures, upgraded outdoor lights from metal halide lamps to LEDs fixtures, and upgraded the HVAC system. When possible, the offices use daylight from the building's large front-facing windows instead of overhead lights. The District also installed a 91.9 kilowatt (kW) solar array on a carport in the parking lot for the main

office. This is one of eight CREBs-funded solar projects in District 6, including projects on maintenance facilities, office buildings, and the solar carport at the district offices. Collectively, these facilities generate approximately 415 MWh of electricity and keep more than 150 tons of GHG emissions out of the atmosphere each year.

7.8 District 7

Caltrans District 7 operates the State Highway System in Los Angeles and Ventura Counties, which are located in the heart of California's largest metro area. The District 7 office building in downtown Los Angeles is one of the most striking examples of innovative, energy-efficient design in Caltrans' building stock. The building, which was constructed in 2004, is home to 1,850 Caltrans employees and 500 staff from the Los Angeles DOT. The façade on the east and west sides of the building is covered with perforated aluminum screens that open and close depending on the weather and sunlight. This reduces the energy needed to heat and cool the building, because the offices are shaded during hours when the sun is at its peak and open to daylight in the mornings and evenings. The entire south façade is covered in photovoltaic panels that generate 5 percent of the building's energy and provide additional shade during the hottest hours of the day. A central atrium provides additional daylight, reducing the need for overhead lighting; and the building's skip-stop elevators, which stop on only 4 of the building's 13 floors, conserve energy and encourage employees to exercise. The building was originally certified as LEED Silver, but it achieved LEED Gold in 2011 after a series of additional changes, which included adjusting the thermostat to further reduce heating and cooling loads, committing to purchase recycled products, and adopting more sustainable custodial practices. LEED Gold buildings generally use 39 percent less energy than conventional buildings.

The LEED Gold-certified District 7 main office in Los Angeles.

District 7 continues to work to reduce energy consumption in its offices. It recently installed LED lighting fixtures using a rebate from the Los Angeles Department of Water and Power. Approximately 850 LED fixtures replaced conventional lighting fixtures in the stairwells and parking structure. The new fixtures include occupancy sensors and bi-level lighting and can conserve energy by dimming or turning off when full lighting is not needed. District 7 also replaced 100 halide light fixtures in the auto shop and loading dock with LED fixtures. Caltrans identified the District 7 Los Angeles Data Center for a U.S. Department of Energy-compliant Data Center Dynamic Cooling demonstration project. This project installed a Datacenter Automation Hardware and Software (DASH) system, which dynamically controls fan speeds to reduce energy use while maintaining required temperatures. This project has reduced the annual electricity consumption of the data center from 815 to 579 MWh per year, almost a 30-percent gain in efficiency, at no additional cost to Caltrans.

District 7 has been working to convert many of its heavy vehicles to run on CNG, which produces nearly 28 percent fewer GHG emissions per unit of energy than gasoline. Most of the District's 40 street sweepers run on CNG instead of gasoline or diesel, as does one of its cargo trucks. The conversion has not been without issues; CNG-powered sweepers have less range than their gasoline- or diesel-powered counterparts and can be more difficult to repair. However, District 7 is

working to overcome these issues in order to continue to reduce GHG emissions. The District consumes more than 84,000 gallons of CNG each year, the most of any Caltrans district, and using this fuel instead of diesel reduces its GHG emissions by almost 360 tons annually.

7.9 District 8

Caltrans District 8, which serves the Inland Empire counties of San Bernardino and Riverside and is headquartered in the city of San Bernardino, covers the largest land area of any Caltrans District; more than 27,000 square miles. The District has been working to limit the amount of water used for landscaping. Reduced water usage can substantially affect GHG emissions because of the arid climate and the large amount of energy required to transport water to the area. The District uses mulch to control weeds in roadside areas, which retains water and reduces irrigation needs. It has also been using more native plants for landscaping, which require almost no water once they are mature.

District 8 recently completed construction on the LEED Gold-certified Inland Empire Transportation Management Center (IETMC), which is the first essential services facility in the nation to achieve this certification. Essential services facilities are designed to continue functioning in case of emergencies, which means that they have high energy demands. The IETMC is the nerve center from which District 8 staff continuously monitor road conditions and coordinate the District's response to emergencies. It is built to withstand a 7.5-magnitude earthquake and function around the clock in the event of an emergency. Although these constraints can make it difficult to incorporate sustainable design, many of the IETMC's energy efficiency features (e.g., solar tubes that bring daylight into interior spaces, energy-efficient lights that dim automatically, and shades over windows) both reduce GHG emissions and contribute to the building's resilience by allowing it to function longer with less electricity. These features reduce energy use for heating, cooling, and lighting at the IETMC by 30 percent; and the building also uses 50 percent less water than typical buildings of its kind. District 8 plans to further reduce the IETMC's GHG emissions by building a solar array on adjacent land and is investigating the possibility of constructing wind turbines nearby.

District 8 uses ethanol and biodiesel instead of gasoline and diesel in many of its fleet vehicles. One of the District's maintenance facilities has tanks for both E85 ethanol and B5 biodiesel so that fleet vehicles have easy access to alternative fuels. District 8's location can make it challenging to use B5, which tends to gel in higher altitudes, but the District remains committed to using B5 for trips along the valley floor. Each year, the District uses 120,000 gallons of B5 and more than 5,000 gallons of E85, which reduce GHG emissions by more than 50 tons per year. In addition to using alternative fuels in order to make employee travel more efficient, District 8 is working to replace business trips with video conferencing, webinars, and conference calls whenever possible. Many District 8 employees used to travel to Caltrans headquarters in Sacramento 2–3 times per year but now make the trip only once a year.

7.10 District 9

Caltrans District 9 serves Mono and Inyo Counties in the eastern Sierra Nevada. To reduce energy costs and GHG emissions, the District has replaced the water boiler in its equipment shop with a more energy-efficient model. Because the new boiler is more efficient than the old model, the district was able to downsize the fuel tank that supplies the boiler. This change is particularly important in reducing GHG emissions in the district. Because natural gas is not available in District 9, boilers must run on diesel fuel, which produces more GHG emissions per unit of energy than natural gas.

Vantage Hydronic boiler for the District 9 office.

Due to its mountainous location, District 9 expends a lot of time and energy working to keep roads open during winter and has several projects to reduce the associated GHG emissions. These include using locally sourced volcanic cinders instead of imported sand to improve traction on snowy and icy roads, which reduces the energy needed to transport materials. District 9 also began using salt brine to pretreat winter roads in 2011 and has installed several snow fences that prevent roadside snowbanks from spilling over onto the roadway. These measures reduce the number of trips that snowplows must take to clear roads and therefore the amount of diesel fuel that the District burns.

District 9 has used CIR or full-depth reclamation (which recycles a deeper section of the road in place) on several road rehabilitation projects over the past several years, including State Routes 120 and 270 and U.S. 395. These strategies have reduced GHG emissions in addition to saving the District money by requiring purchase of fewer virgin materials. In 2011, District 9 reduced GHG emissions by almost 2,000 tons through its use of CIR alone.

District 9 has installed CREBs-funded solar panels on its main office and at the Bishop and Shoshone Maintenance Stations. Together, these projects generate more than 210 MWh of electricity and keep almost 80 tons of GHG emissions from entering the atmosphere each year. The District also uses solar panels to power many of its flashing signs and traffic count stations.

7.11 District 10

Caltrans District 10 spans eight counties: San Joaquin, Stanislaus, and Merced, in the Central Valley; and Amador, Alpine, Calaveras, Tuolumne, and Mariposa in the Western Sierra Nevada. The District was a leader in installing solar panels on its facilities even before CREBs funding became available. In 2007, District 10 unveiled two solar projects, one at its equipment shop and one at its main offices in Stockton. These projects were built, operated, and maintained by private companies, at no initial cost to Caltrans. District 10 purchases the electricity generated by these projects from the companies that operate them at a discounted rate that is guaranteed to be cheaper than what the local utility charges for power from the grid. The operating agreement also gives the District the option to purchase the solar panels outright. District 10 is also home to three CREBs-funded solar projects: two at rest areas in Merced and Stanislaus Counties and one at a maintenance station in Stockton. Together, these projects generate 118 MWh and keep 40 tons of GHG emissions out of the atmosphere each year.

Solar panels on roof of District 10 equipment shop.

District 10 has a pilot project to reduce GHG emissions due to electricity use by replacing older T12 fluorescent bulbs with new T8 fixtures, which typically use 25–40 percent less energy. So far, the District has replaced the lights in its main offices and is seeking additional funds to offset the higher initial costs of T8 lights. These upgrades are the latest in a series of energy efficiency upgrades that have reduced annual electricity consumption in District 10's main offices by 31 percent, reducing GHG emissions by nearly 100 tons per year.

District 10's vehicle pool includes 60 flex-fuel vehicles that can use conventional gasoline or E85 ethanol. The District encourages all of its employees to use ethanol, which is easy to find in the lowland areas of the District thanks to Caltrans' efforts to install ethanol fueling stations throughout the Central Valley.

7.12 District 11

Caltrans District 11 serves San Diego and Imperial Counties, a geographically diverse region that stretches from the coast to the desert and includes California's third largest metropolitan area. In 2011, the District's main offices, which are housed in a five-building campus located in downtown San Diego, were certified as LEED Gold for existing buildings. To achieve this certification, District 11 upgraded many aspects of the building to be more energy-efficient, beginning in 2006, when a 19.5 kW solar panel in the campus' central courtyard was installed. Later retrofits included upgrading the fluorescent light bulbs from T12s to energy-efficient T5s and replacing halogen spot lights with LEDs. District 11 also installed sensors on many of the lights in the building so that they turn off or operate at partial capacity when they are not needed, and all computer monitors in the offices are programmed to turn off automatically after 5 minutes with no use. A new variable speed drive on the building's HVAC system reduced electricity and natural gas usage by allowing the system to operate at lower capacity when heating and cooling loads are not as high. In addition to these technological upgrades, the District instituted programmatic changes designed to conserve energy and reduce GHG emissions. The offices contain kitchens on each floor so that employees do not bring in their own individual food appliances. Even after achieving LEED Gold certification, District 11 continues to look for opportunities to reduce energy consumption and GHG emissions in its main offices. In 2011, the District began a major modification of its HVAC system, replacing the central chiller unit with a compressor system, which it estimates will reduce energy use by an additional 30–40 percent.

District 11 uses RAC to pave the shoulders of roads in almost every resurfacing project. RAC produces fewer embodied GHG emissions than conventional asphalt because it contains recycled rubber instead of asphalt cement derived from petroleum production. It also has a longer service life, so it takes less energy and materials to maintain. District 11 also is testing LED highway lighting, which has a huge potential to reduce GHG emissions associated with electricity consumption and maintenance because there are so many roadway lights—almost 2,400—in the District. District 11 has installed four fixtures in a test area in Imperial County to determine whether these lights provide sufficient visibility and are sufficiently durable to withstand weather conditions in the desert. In general, LED lights consume 60 percent less energy and last four to five times as long as the HPS lights that currently light most of California's highways, and District 11 staff have found even greater gains in efficiency of up to 66 percent.

District 11's GHG reduction efforts are not limited to operational emissions. The District has partnered with the San Diego Association of Governments to examine the impacts of congestion and delays at crossings along the U.S.-Mexico border on vehicle emissions, including carbon dioxide. The resulting studies have identified best practices and performance measures to reduce emissions when planning future changes to border infrastructure. District 11 is also working with San Diego Gas and Electric to install a solar array that powers electric vehicle charging stations in the parking lot at a state-owned park-and-ride lot. The project will include batteries that store excess energy generated by the solar panels when no vehicles are charging, which means that drivers may be able to charge their vehicles using solar energy even after dark. The goal of the project is to establish an approach for installing similar facilities at other state-owned park-and-ride lots across the state.

7.13 District 12

Caltrans District 12, the only single-county Caltrans District, serves Orange County in Southern California. District 12's main offices were dispersed among several buildings within a larger building complex in Irvine. In 2009, the District consolidated these offices into a single structure within the complex and took an active role in designing the new space to include many energy-efficient features. These included daylight sensors that adjust lighting levels according to the amount of ambient light, automated HVAC control systems, and ENERGY STAR-rated computer systems that shut down automatically when not in use. These efforts helped the new district building office complex achieve LEED Gold certification.

A large portion of District 12's vehicle fleet runs on alternative fuels. The District runs its entire diesel fleet using B5 biodiesel, which can produce fewer emissions than biodiesel depending on the source of the biofuel, and uses 80,000 gallons of B5 per year. All of District 12's street sweepers run on CNG, and more than 80 of its sedans and construction trucks are flex-fuel vehicles that can run on gasoline or E85 ethanol, which is available at two of the four maintenance yards in the District. The District's fleet also includes 20 hybrid electric passenger sedans. Collectively, District 12 has reduced annual GHG emissions by nearly 150 tons per year by greening its vehicle fleet.

District 12 is home to four CREBs-funded solar projects that are located at maintenance facilities in the cities of Orange and Costa Mesa. These projects generate more than 270 MWh of electricity and keep nearly 100 tons of GHG emissions out of the atmosphere each year.

8 Adapting to Climate Variability and Change

Even with successful GHG mitigation strategies underway, GHG emissions are already causing measured changes in the global climate, and those changes will continue into the future. The changes will occur on top of natural variations in local climate and weather. Many transportation agencies, including Caltrans, are therefore considering ways to prepare for challenges caused by natural variability and human-induced changes in climate. Efforts to evaluate and prepare for changes in climate do not preclude efforts to simultaneously minimize the degree to which climate change may occur; rather, both mitigation and adaptation are essential parts of a comprehensive climate change strategy.

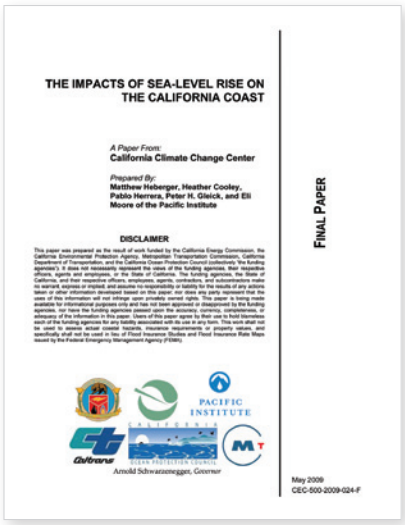
This chapter provides an overview of the potential impacts of climate change on Caltrans' transportation system and operations, and then discusses some of the efforts currently underway to adapt to climate change through planning, project delivery, and maintenance and operations.

8.1 Climate Variability and Change—Impacts on Transportation in California

Climate in California is already changing, and further changes are anticipated throughout the 21st century. Climate change will cause the sea level to rise, temperatures to warm, and precipitation patterns to change—all of which have important implications on transportation assets and services.

8.1.1 Sea Level Rise

Sea level along the California coast has risen during the 20th century by approximately 7 inches.[53] During the 21st century, sea level rise is expected to accelerate. The net effect depends in part on location, because land subsidence will magnify sea level rise while land uplift will offset sea level rise. The section of the California coast south of Cape Mendocino, where Highway 1 is the primary coastal route, faces land subsidence. Here, the National Research Council (NRC) of the National Academy of Sciences projects that sea level will rise 2–12 inches by 2030, 5–24 inches by 2050, and 17–66 inches by 2100.[54] Along the coast north of Cape Mendocino, where Highway 101 is the primary coastal route and where land is experiencing uplift, sea level is projected to change between -2 inches (sea level fall) and +9 inches by 2030, -1 inch to +19 inches by 2050, and from 4 to 56 inches by 2100. The ranges of projected sea level rise reflect the relatively large range in projections for warming as well as uncertainty in how quickly glaciers and ice sheets will melt.[55]


THE IMPACTS OF SEA-LEVEL RISE ON THE CALIFORNIA COAST

A Paper From:
California Climate Change Center

Prepared By:
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Arnold Schwarzenegger, Governor

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Sea level rise has several implications for roadways in California. First, sea level rise is likely to exacerbate the existing vulnerability of California's transportation network to flooding. As of 2009, approximately 1,900 miles of California's roadways were at risk of a 100-year flood event; projected sea level rise of 55 inches would increase the roadway at risk to approximately 3,500 miles.[56] Sea level rise is also likely to amplify the impacts of storm surge on coastal infrastructure. Low-lying coastal areas are likely to experience more frequent and more intense flooding, as well as intensified erosion. On longer time horizons, low-lying areas are at risk of becoming permanently inundated. As sea level rises, habitats and the character of the land surface may change (e.g., wetlands may migrate). The shifts in the types of land cover that exist could have implications for the current transportation infrastructure, as the need to protect or preserve some of these migrating habitats could conflict with operation and maintenance of roadways and railways. Similarly, changes in the types of land cover could affect the planning of future infrastructure (e.g., wetland migration could require planners to protect areas that may be converted to wetlands as local sea level rises).

8.1.2 Temperature

Most of California already experienced warming during the 20th century.[57] Projections for mid-21st century climate show average temperature increases of several degrees (1.8°F to 5.4°F), averaged across the state.[58] The end-of-century projections for warming span a greater range of temperatures (3.6°F to 9°F).[59] The warming is expected to occur across all parts of the state and across all seasons. California's interior will likely warm more than the coastal areas.

As part of the increase in long-term averages of temperature, heat waves are expected to increase in their frequency, intensity, and duration. By the end of the 21st century, some projections suggest that long heat waves (lasting 5 days or longer) could be experienced as much as 20 times more frequently than heat waves occurring during the end of the 20th century.[60]

Impacts on transportation infrastructure[61] from warming include softening or buckling of road pavement, which could compromise the pavement's integrity during heat waves or reduce its useful lifetime. Similarly, bridge joints can expand during periods of extreme heat, inhibiting bridge operation and requiring maintenance. Heat waves and overall higher temperatures are likely to pose problems for vehicle fleets, increasing the frequency of breakdowns or reducing service lifetimes. Higher temperatures also can lead to rail buckling and forced speed reductions for trains. More frequent or intense heat waves also may contribute to increased incidents of poor air quality, which could affect traffic management or siting of new roadways. Heat waves could require limitations on construction activities, as high temperatures could pose a risk to workers' health. Also, warming likely will cause streamflow to peak earlier in the calendar year, changing the timing in which high flows, and the potential for flooding, typically occur. Meanwhile, some areas may experience benefits from increased temperatures. Reductions in the length of the snow and frost seasons could reduce the need for removing snow and ice from roadways, or for repairing infrastructure damaged by snow, ice, or freeze-thaw cycles.[62]

8.1.3 Precipitation

Precipitation in California varies considerably from year to year and from decade to decade—that is, some years and decades are significantly wetter than others. This variability, which underlies the occurrence of flooding and droughts, is likely to continue in the future.[63] Any

changes in overall annual precipitation for the future are highly uncertain. Most computer models suggest that California will become drier (especially in the southern portion of the state), but some projections suggest that the future may be wetter overall.[64]

Projections do tend to agree on one result: regardless of whether the future is wetter or drier on average, there are likely to be more dry days.[65] This change could make dry spells last longer, when they do occur.

Although the direction and magnitude of future precipitation changes is uncertain, periodic heavy rainfall events and droughts will remain a feature of California's climate. Heavy rainfall events are likely to cause periodic flooding of roadways and railways, and in some cases, erosion or mudslides. In areas of California where dry spells become longer, risks of forest fires may grow. Increases in the frequency or intensity of forest fires could cause closures of roads and rail and damage the underlying infrastructure.[66]

A flooded call box location after a heavy rain.

8.1.4 Effects of a Changing Climate on Transportation Demand Patterns

In addition to posing challenges to transportation infrastructure and operations, Caltrans may need to accommodate changes to transportation demand patterns caused by climate change. For example, earlier thaws may increase the timing, accessibility, and use of seasonal mountain passes. This could have implications for schedules and allocation of resources for maintenance and repair. Similarly, changes in the viability of coastal infrastructure or shifts in seasonal cycle (e.g., shorter winters, more intense summers) may result in population, commercial, or tourism shifts that increase the demand for travel to some destinations, while reducing demands for other destinations. These potential changes in demand may affect the validity of assumptions used in long-range planning.

8.2 Caltrans Activities to Assess and Adapt to a Changing Climate

Driven by statewide directives, agency strategic efforts, and local-level observation of recent climate conditions, Caltrans has already begun implementing measures to prepare for a changing climate. These efforts have thus far focused primarily on sea level rise, although impacts from changes in temperatures and precipitation patterns are beginning to be addressed as well. While some adaptation efforts within Caltrans are specifically driven by efforts to adapt to climate change, many of them are driven by efforts to improve the system more generally but have the added benefit of leaving the transportation system better prepared for a changing climate. Activities to increase resilience to climate change are occurring across nearly all Caltrans functional areas, including planning, project delivery, operations, and maintenance at the headquarter and district levels.

8.2.1 Caltrans Adaptation Activities—Contribution to Statewide Efforts

In November 2008, Governor Schwarzenegger signed EO S-13-08, directing Caltrans and other state agencies to address California's vulnerability to sea level rise. Since then, Caltrans has been actively working with the California Natural Resources Agency and other stakeholders to develop an updated California Climate Readiness Strategy, to be released later in 2013. The original document, the *California Climate Adaptation Strategy*, was released in 2009.[67] The California Climate Readiness Strategy is anticipated to build on the 2009 document and summarize the science on climate change impacts in California; assess the state's vulnerability; and provide recommendations on how state

agencies can adapt across seven sectors, including transportation infrastructure.

Under EO S-13-08, the Natural Resources Agency, in cooperation with Caltrans and other agencies, was directed to commission the NRC to prepare a sea level rise assessment report to better understand sea level rise estimates along the West Coast. *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future* was released in June 2012.[68] Caltrans worked with the California Coastal Ocean Climate Action Team (CO-CAT) to develop the *State of California Sea-Level Rise Interim Guidance Document* featuring interim sea level rise scenarios before the NRC report was released in mid-2012.

8.2.2 Caltrans Adaptation Activities—Planning and Environmental

Caltrans is beginning to incorporate adaptation activities into the long-term planning of new transportation infrastructure. Currently, the emphasis of climate change adaptation activities is on sea level rise, due in large part to EO S-13-08, which directs state agencies planning construction projects in areas potentially exposed to sea level rise to consider a range of sea level rise scenarios for the years 2050 and 2100. In addition, the California Coastal Commission now requires that sea level rise is evaluated for all projects requiring a coastal permit. Efforts are underway to provide guidance for general climate change impacts, including temperature and precipitation changes. Within Caltrans, efforts to bring climate change into the planning realm have focused on development of agency-wide guidance documents that aim to provide a consistent set of guidelines to the district offices, as well as more general guidance for preparing permitting and CEQA documents. These efforts are discussed below.

In May 2011, the Caltrans Climate Change Workgroup and the headquarters Divisions of Transportation Planning, Design, and Environmental Analysis released the *Guidance on Incorporating Sea Level Rise* (the Sea Level Rise Guidance) to help assess vulnerability of projects in the planning phase and determine whether to incorporate adaptation measures into the projects. The Sea Level Rise Guidance document draws from the CO-CAT *State of California Sea-Level Rise Interim Guidance Document* to provide transportation-specific guidance for considering timeframe, risk tolerance, and adaptive capacity. In early 2012, the Caltrans Office of Land Surveys released *Estimating Sea Level for Project Initiation Documents: Converting Tidal Datums to Project Elevations and Predicting Future Sea Levels*, which serves as a technical supplement to the Sea Level Rise Guidance for engineers in the initial project planning process. Caltrans is considering expanding the scope of the Sea Level Rise Guidance to facilitate consideration of sea level rise at all phases of project delivery, such as design and construction.

According to the Sea Level Rise Guidance, the Project Development Team should screen a project based on the proposed location and design life to determine whether it will be affected by sea level rise. The second step is to balance the potential impacts with the level of risk and potential consequences, to determine whether adaptation measures should be incorporated into the project. The findings of the project analysis are to be recorded in the Project Initiation Document (PID). The Sea Level Rise Guidance and technical supplement will be updated to reflect sea level rise projections from the recently released NRC sea level rise assessment report.[69]

The Sea Level Rise Guidance is still relatively new, and therefore has been considered for only a handful of projects so far. When considered, sea level rise is reflected in project documentation; however, consideration of sea level rise does not necessarily cause modifications to siting or design of projects. For example, District 5 looked at sea level rise for a current project related to HOV lanes outside of Santa Barbara but recognized that the project lifetime of new bridges along Highway 101 is only 50–75 years and therefore the 2100 sea level rise projections would not affect the project. Also in District 5, a realignment project for Highway 101 considered sea level rise, but determined that the existing plans for relocation of the road were sufficient.

Caltrans is developing guidance for California MPOs and RTPAs to address climate change adaptation in their RTPs, which MPOs and RTPAs in California must prepare every 4–5 years. The adaptation assessment

manual will assist California MPOs and RTPAs with incorporating climate change impacts such as temperature, precipitation, sea level rise, wild fires, flooding, and landslides into planning, design, engineering, and operational decisions related to transportation infrastructure. The manual will contain tools and resources, including climate change information specific to each geographic region.

One important resource arising out of this work is a matrix of the potential impacts of climate change on California's transportation system, as well as potential planning, design, and operations or maintenance responses to those impacts. This resource covers not only sea level rise but also changes in precipitation and temperature. This matrix is shown in Table 12.

Table 12: Potential Climate Change Impacts on California Surface Transportation Infrastructure and Associated Adaptation Strategies

Potential Impact		Possible Strategies to Mitigate Impacts		
Infrastructure	**Operations**	**Planning**	**Design**	**Operations/Maintenance**
Sea Level Rise				
• Coastal erosion	• Roadway washout • Damage to roadway substructure • Route closures • Travel delays	• Identify segments of roadway vulnerable to erosion • Address vulnerability in transportation plans	• Strengthen, heighten, and construct new seawalls and dikes • Use a combination of hard engineering (human-made structures) and soft engineering measures (implementing ecological principles and practices) to protect coastal infrastructure • Relocate highly affected or vulnerable infrastructure	• Repair damage as needed by emergency contract or permanent restoration project • Increase monitoring of infrastructure and conditions in coastal areas vulnerable to erosion • Repair/replace/restore affected infrastructure as needed • Increase erosion control • Prepare for weather-related delays and traffic disruptions • Prepare to provide alternative route information
• Coastal and inland tidal zone road flooding	• Flooding of roadways • Roadway damage • Road closures • Travel delays • Disruption of transit services	• Identify segments of roadway vulnerable to storm surge and sea level rise • Address vulnerability in transportation plans • Support land use policies that discourage development on shoreline • Plan and design more redundancy into the system	• Increase base elevation of infrastructure • Change to more resilient building materials • Build larger or additional drainage canals near coastal routes • Relocate sections of road • Strengthen, heighten, and construct new seawalls and dikes • Use a combination of hard engineering (human-made structures) and soft engineering measures (implementing ecological principles) to protect coastal infrastructure	• Repair damage as needed by emergency contract or permanent restoration project • Increase monitoring of infrastructure conditions during high tide and storm events • Ensure that drainage systems are adequate to accommodate flood conditions • Ensure that bridge openings/culverts are clear for appropriate flood management • During extreme precipitation events, continually monitor drainage systems • Prepare for weather-related delays and traffic disruptions • Prepare to provide alternative route information • Implement emergency operations response procedures
• Bridge scour	• Compromised integrity of bridge structures • Bridge failure resulting in closure • Reduced bridge capacity	• Identify locations of bridges in areas vulnerable to sea level rise and bridge scour • Address vulnerabilities in transportation plans	• Protect bridge piers and abutments with riprap • Retrofit/replace/relocate existing bridges for new scour conditions	• Repair damage as needed by emergency contract or permanent restoration project • Increase monitoring for bridge pier and abutment scour

Potential Impact		Possible Strategies to Mitigate Impacts		
Infrastructure	**Operations**	**Planning**	**Design**	**Operations/Maintenance**
• Railway flooding	• Rail and railway roadbed damage • Disruption of rail traffic (e.g., closure or delay)	• Identify segments of railway vulnerable to sea level rise • Address vulnerability in rail plans	• Increase base elevation of infrastructure • Strengthen, heighten, and construct new seawalls and dikes • Use a combination of hard engineering (human-made structures) and soft engineering measures (implementing ecological principles and practices) to protect coastal infrastructure • Relocate sections of track	• Increase monitoring of infrastructure conditions • Ensure that drainage systems are adequate to accommodate flood conditions • Ensure that bridge openings/culverts are clear for appropriate flood management
Increase in Intense Precipitation Events				
• Flooding of roadways	• Route closures • Travel delays • Increased safety risks • Increased need for emergency response services • Rapid deterioration of infrastructure	• Identify roadway segments affected by past intense precipitation events • Address vulnerabilities in transportation plans • Integrate improved flood protection into transportation plans • Identify alternatives to vulnerable routes • Restrict development in floodplains • Perform increased risk assessment for new roads	• Protect critical evacuation routes • Upgrade bridge deck and road drainage systems (increase the standard drainage capacity for new infrastructure) • Increase culvert capacity • Increase/provide new water retention/detention storage systems • Use new asphalt/concrete mixtures able to withstand flood conditions	• Repair damage as needed by emergency contract or permanent restoration project • Increase monitoring of infrastructure conditions • Use pavement grooving and sloping • Prepare for service delays • Ensure that bridge openings/culverts are clear for appropriate flood management • During extreme precipitation events, continually monitor drainage systems • Increase capacity and maintenance at pump plant facilities • Minimize repair backlogs • Prepare to provide alternative route information • Implement emergency operations response procedures
• Landslides • Road washouts	• Route closures • Travel delays • Increased safety risks	• Identify roadway segments affected by past intense precipitation events • Address vulnerabilities in transportation plans • Identify alternatives to vulnerable routes • Perform increased risk assessment for new roads	• Protect critical evacuation routes • Incorporate landslide mitigation measures for projects in vulnerable areas • Ensure adequate drainage on roadbed surfaces and shoulders • Incorporate rock fall protection measures	• Repair damage as needed by emergency contract or permanent restoration project • Increase monitoring of infrastructure conditions • Ensure that the roadway is clear of rocks, debris, and downed vegetation • During extreme precipitation events, continually monitor drainage systems • Minimize repair backlogs • Prepare to provide alternative route information • Integrate emergency evacuation procedures into operations
• Bridge scour	• Compromised integrity of bridge structures • Bridge failure resulting in closure • Reduced bridge capacity	• Identify bridges in locations vulnerable to sea level rise and bridge scour • Address vulnerabilities in transportation plans	• Protect bridge piers and abutments with riprap	• Increase monitoring for bridge pier and abutment scour

Potential Impact		Possible Strategies to Mitigate Impacts		
Infrastructure	**Operations**	**Planning**	**Design**	**Operations/Maintenance**
• Railway flooding	• Disruption of rail traffic (e.g., closure or delay) • Rail and railway roadbed damage • Malfunctions of track or signal sensors	• Identify segments of railway vulnerable to sea level rise • Address vulnerability in rail plans	• Increase base elevation of rail beds • Upgrade rail drainage systems • Increase warning and advisory systems for dispatch centers and crews	• Increase monitoring of infrastructure conditions • Ensure drainage systems are adequate to accommodate flood conditions • Ensure bridge openings/culverts are clear for appropriate flood management
Increase in Temperature and Extreme Heat Events				
• Highway asphalt rutting • Highway asphalt buckling • Concrete deterioration • Limits on periods of construction activity	• Route closures • Travel delays • Limits on construction periods during summer	• Identify roadway segments affected by past extreme heat events • Address vulnerabilities in transportation plans	• Develop new heat-resistant asphalt/ concrete mixtures • Overlay with new rut-resistant asphalt	• Increase monitoring of infrastructure during extreme heat events • Overlay with more rut-resistant asphalt • Increase maintenance to prevent impacts of extreme heat • Shift to evening construction schedule
• Rail buckling	• Potential for train derailment • Malfunction of track and signal sensors • Disruption of rail traffic (e.g., closure or delay)	• Identify segments of railway located in areas most vulnerable to extreme heat events • Address vulnerability in rail plans	• Design for higher maximum temperatures in replacement or new rail infrastructure	• Improve monitoring of rail temperatures, tracks, track sensors, and signals during extreme heat events • Increase track maintenance • Use lower speeds and shorter trains to lessen braking distance when necessary • Lighten loads to reduce track stress when necessary
• Increased thermal expansion of bridges	• Bridge damage • Bridge closures	• Identify bridges affected by past extreme heat events • Address vulnerabilities in transportation plan	• Ensure that bridge joints can accommodate anticipated thermal expansion • Design for higher maximum temperatures in replacement or new construction	• Improve monitoring of bridge joints • Increase ongoing bridge maintenance
• Changes to vegetation/ biodiversity	• Increased drought conditions • Additional watering requirements for landscaped right-of-ways • Altered natural biodiversity	• Work with local municipalities to use reclaimed water for irrigation	• Increase consideration of drought-tolerant vegetation • Convert to new "smart" irrigation systems that water only when necessary • Design alternatives to water-reliant plants such as decorative hardscape • Use native drought-resistant plants • Increase use of inert materials as ground-cover to minimize exposure and need for plantings	• Increase vegetation management
• Increase in wild fires and mudslides	• Route closures and detours • Damaged infrastructure such as guardrails and signs		• Use heat-resistant infrastructure • Incorporate mudslide mitigation measures for projects in vulnerable (e.g., burned-out) areas	• Increase monitoring of slope stability in vulnerable areas • Repair damage as needed by emergency contract or permanent restoration project

In addition, Caltrans is working to provide guidance to projects in the preliminary planning phase on assessing sea level rise through development of a sea level rise hot spot map. Caltrans GIS Engineering Services is leading a GIS-based assessment of transportation infrastructure vulnerabilities to population, travel, or climate effects, with the goal of identifying critical vulnerability hot spots. The map focuses on vulnerabilities along coasts and can potentially incorporate other climate variables as data become available. The project also will develop a climate vulnerability plan that will assess the level and type of transportation infrastructure vulnerability, the adaptation options and strategies, and a framework for prioritizing implementation efforts. The assessment uses available data and studies, and will be updated with the recently released NRC report, *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*.[70]

Incorporating Sea Level Rise into Corridor Planning

The University of California, Davis, in partnership with District 4, conducted the State Route 37 (SR 37) Stewardship Study to pilot test the use of more stewardship-based transportation corridor planning. SR 37 passes through the environmentally sensitive San Francisco Bay marshlands and is vulnerable to sea level rise. The study, funded by the Transportation Research Board, was a first step in collaborative transportation and environmental planning and involved corridor stakeholders and resource agencies. The stakeholder group used the Sea Level Rise Guidance, among other tools and outreach strategies, to gather input on potential sea level rise impacts and explore a range of scenarios for adapting SR 37 to sea level rise. The results of the study will help shape the long-range planning of SR 37 by informing the updates of the Transportation Concept Report. District 4 also will use this study as the foundation for future decision making in potential follow-up studies, including a hydraulic study and a transit opportunities assessment.

Caltrans provides guidance in discussing climate change adaptation strategies in environmental compliance documents for projects. Caltrans maintains the Standard Environmental Reference (SER), which serves as a resource to guide agency staff and contractors through the process of preparing, submitting, and analyzing multiple environmental documents for projects on the state highway system (see Section 3.2.11 for more information on the SER). Among other resources, the current SER provides annotated template outlines of environmental documents. The climate change portion of the annotated outlines contains boilerplate text that provides a general overview of Caltrans' adaptation activities at the headquarters level.

The Metropolitan Transportation Commission (MTC) of the San Francisco Bay Area has conducted vulnerability assessments of transportation infrastructure to projected sea level rise along the Alameda County shoreline in the San Francisco Bay. The project was conducted in partnership with Caltrans District 4 and the San Francisco Bay Conservation and Development Commission, with support from federal and regional agencies and funding from FHWA. The pilot project used a conceptual risk assessment model developed by the FHWA to inventory transportation assets, gather climate information, and assess the risks to climate change. Caltrans and MTC led the identification and assessment of transportation assets.[71] The project resulted in a technical report that documented the asset inventory, climate impacts, and vulnerability and risk assessment. The lessons learned from this project will not only inform District 4 on its climate-related vulnerabilities but also will provide important lessons learned for other districts and transportation agencies interested in conducting similar assessments.

8.2.3 Caltrans Adaptation Activities—Project Delivery

Currently, there are no national or statewide climate change design and construction specifications. While it is not Caltrans' responsibility to update these specifications, the Department is able to address climate change in project design as it deems appropriate.

The design of transportation assets is driven in part by expected local climate conditions. Caltrans will design

and construct based on presently known or expected hydrologic, temperature, and other climate conditions. Caltrans is not actively engaged in developing projections about how local conditions may change, which largely is the responsibility of other state and national organizations. Rather, Caltrans views its responsibility as designing and constructing based on the best information available. Any efforts by other state and national agencies to account for climate change will ripple through to Caltrans' design and construction activities. For example, the Sea Level Rise Guidance is based on sea level rise projections from CO-CAT and will be updated with the estimates from the NRC's *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*.[72] Similarly, Caltrans is not adjusting assumptions in federal flood plain maps, but instead will wait for the Federal Emergency Management Agency to do so. Caltrans could use locally adopted values for sea level rise if a local agency updated the Flood Insurance Rate Maps.

Adapting to Climate Change Impacts Unintentionally

Some existing Caltrans efforts will contribute to climate change adaptation. Coastal roadways already experience challenges due to erosion, landfalls, and flooding—problems that could be exacerbated under climate change. Efforts to address these current problems will have the ancillary benefit of making the system more prepared for future climate conditions. For example, Route 1 in the Devil's Slide region of San Mateo County has frequently faced closure and repair due to rockslides and land slippage from adjacent steep slopes District 4 is currently working to relocate a section of the highway to a safer location by constructing two tunnels beneath San Pedro Mountain. This relocation will help that stretch of highway avoid increased erosion or landslides that could be caused by climate change.

Design of assets is driven by the *Highway Design Manual* (HDM) and by nationally accepted engineering design standards. The Department's Division of Design is responsible for managing the contents of the HDM, which establishes uniform policies and procedures for design of the state highway system. Caltrans adopts most American Association of State Highway and Transportation Officials (AASHTO) standards to ensure consistency in transportation facilities across the country. Caltrans' responsibility does not include updating these engineering guidelines, but efforts by AASHTO to account for changes in climate would affect the design and construction of Caltrans transportation assets.

Addressing Sea Level Rise on Highway 101

A project along Highway 101 is testing approaches for incorporating sea level rise into the transportation decision-making processes.

As part of the South Coast 101 High Occupancy Vehicle (HOV) Lane Project, District 5 is adding one HOV lane in each direction. In its draft environmental impact report for the project, District 5 considered sea level rise. District 5 determined that three locations within the project limits could be exposed to a 55-inch sea level rise. However, the design life of bridges considered in this project is such that the design life would be exceeded by 2100, the timeframe associated with the 55-inch rise in sea level. Therefore, no adjustments to the project design were deemed necessary at this point. The project also examined impacts from a 16-inch sea level rise by 2050, but determined that changes in the project design were not necessary. In the future, addressing impacts from sea level rise will require close coordination with local agencies, as local agencies often have jurisdiction over maintaining certain roadway assets or building protective structures like dunes.

That said, Caltrans has flexibility in how guidelines are actually implemented, allowing for local, professional judgment to drive the ultimate design of assets. Caltrans engineers can therefore incorporate local, site-specific conditions, drawing on past experiences with projects in the area. Caltrans headquarters provides general design guidance to districts in order to ensure consistency in transportation facilities across the state. Districts largely follow the guidance, but they can veer from

this guidance when warranted by local situations. In these situations, the district must document and justify why they are veering from the guidance provided by headquarters.

In some cases, California's permitting procedures can help to facilitate Caltrans' consideration of climate change impacts at the project level. For example, before obtaining a permit for the Piedras Blancas Realignment Project, Caltrans District 5 was asked to analyze the impacts of sea level rise on the project. Given that planning relies on professional judgment, the district used a qualitative approach to explain how sea level rise will be incorporated into the project. The project team determined that the siting and design of the project did not need to be adjusted due to sea level rise considerations.

8.2.4 Caltrans Adaptation Activities—Maintenance and Operations

In addition to making changes in planning, design, and construction to adapt to climate change, Caltrans is undertaking activities within the maintenance and operations divisions to increase resiliency to climate impacts.

Districts have dealt with erosion and landslide conditions through landscaping. Erosion control grasses that have been planted, particularly along slopes, help prevent soil from being displaced onto the roads. These efforts reduce the maintenance required after large flooding, wind, or precipitation events.

As temperatures increase and rainfall patterns change, landscaping can be affected. In some districts, Caltrans has made efforts to use drought-resistant plants to reduce maintenance costs, and these efforts will become more important in the future. Using hardscapes instead of plants is also an option being considered in areas where water may be scarce.

A number of communications and traffic management activities already are underway within Caltrans. While these efforts have not been implemented for the purposes of climate change adaptation, they will increase the ability of the transportation system to better deal with the consequences of climate change.

Addressing Landslides and Flooding in District 1

The process of dealing with landslides and flooding along the highways in District 1 is a constant challenge that involves many Caltrans functional units. Climate change may bring an increase in these natural phenomena, and if so, adaptation will be necessary. During the wet season, District 1 is often forced to close highways for periods ranging from a few hours to a few days in order to clear debris and repair roadway damage from landslides. Efforts to mitigate large impacts from landslides include such strategies as the installation of subsurface drainage facilities; rock buttress construction; and soil nailing, which involves inserting reinforcement bars to stabilize steep slopes. At times, the installation of structures such as retaining walls, viaducts, and bridges are used to rebuild, restore, and protect highways from further landslide threat. For example, two bridges were built along Highway 101 at Confusion Hill in Mendocino County to bypass a notorious landslide area and prevent future highway loss and major travel impacts.

The District also has closed highways due to flooding caused by heavy rainfall and high tides and high river levels. Tide gates along parts of the highway help to reduce flooding of private properties and local streets. To help avoid older culverts from failing during big storm events, District 1 ensures that the culverts are properly maintained, and sometimes upgraded.

Caltrans' communications efforts are one example. Caltrans realizes the role of rapidly advancing technology in its adaptive capacity to climate change. Districts have been using changeable message signs and portable signs along roads to indicate road closures due to extreme events, including landslides, snowstorms, and flooding. Other methods to communicate closures or detours include text messages; email alerts; and updates to QuickMap, an online map

of current traffic conditions. The Division of Traffic Operations is working on further integrating technology into its methods of real-time communication to commuters.

Traffic on a flooded freeway.

In addition, each district has prepared Transportation Management System Plans featuring detour plans to be implemented under an array of events. As more information on climate change impacts becomes available and impacts become more severe, the detour plans will incorporate events under climate change. The Division of Traffic Operations is considering developing "play books," guidance operations manuals to indicate traffic operation procedures under extreme weather events.

As Caltrans continues to incorporate newer technology into its operations and adapt its traffic management plans to climate change, it will be better prepared to notify travelers of road conditions and detours, minimizing the impacts of road closures on overall system performance.

8.3 Adapting to Climate Variability and Change—Suggestions for Additional Activities

Caltrans has shown proactive leadership in implementing climate change adaptation measures. During conversations with Caltrans district and headquarters offices, a few areas were identified that represent opportunities for additional adaptation activities.

Provide guidance on addressing climate change impacts beyond sea level rise as new information becomes available.

Caltrans' guidance for climate change currently focuses primarily on sea level rise impacts. As new data on other impacts of climate change become available, Caltrans can consider future temperature changes and especially changes in precipitation patterns, which could also significantly affect the transportation system. Extreme heat has been known to cause expansion of rails, and extreme temperature variations may affect the expansion and contraction of roadway pavement materials. Extreme precipitation may cause more landslides and flooding. Meanwhile, new hydrologic dynamics from increased storm surge and spring runoff may necessitate changes to the design of bridges and road drainage systems.

As regional and local climate data on various projected climate conditions and impacts become available, Caltrans headquarters can examine the feasibility of providing guidance on adaptation to temperature and precipitation changes, similar to the agency's Sea Level Rise Guidance. Caltrans can examine the feasibility of incorporating the climate information into planning, design, construction, operations, and maintenance activities. For example, districts have expressed interest in guidance on the best materials to use during construction of roads to adapt to extreme heat and cold. It may be informative to investigate the validity of assumptions about precipitation patterns that influence computation of return periods (e.g., that the characteristics of a 20-year or 50-year storm developed from past data may not correspond to current or future climate conditions). Hydrologic analysis conducted by state agencies and academic institutions can inform such an investigation. Districts may also benefit from headquarter-issued guidance on how to incorporate projected spring runoff and flooding into new infrastructure projects, such as design standards for larger drainage systems to accommodate higher flows.

Consider the effects of projected temperature change on the demarcation of pavement climate regions.

Caltrans has categorized the state highway system into "pavement climate regions" that are based on historical temperatures. These categorizations inform engineers on what types of specifications may be appropriate given the local climate. The pavement climate regions may need to be reevaluated as temperatures change. Because these climate regions are dictated by past temperatures over a period of years, there may be a lag in accounting for changing temperatures, as more recent temperatures will be partly tempered by historical temperatures in the calculations. Therefore, Caltrans may wish to consider reevaluating these regions as temperatures change.

Further clarify the use and purpose of *Guidance on Incorporating Sea Level Rise*.

Several districts have noted that the recent Sea Level Rise Guidance lacks specificity in exactly how projects should be adjusted to account for sea level rise. Given the role that professional judgment plays in design and planning, the more generalized approach of the Sea Level Rise Guidance is likely appropriate. That is, it is more important that districts are *thinking* about these levels of sea rise, so that potential issues could be identified early on, and it may not be necessary (or desirable) to dictate that specific design or planning changes are made to coastal projects due to sea level rise. More careful articulation of this purpose may help districts better understand the intended use of the document.

Continue Caltrans' significant stakeholder role in regional planning, and engage in statewide activities that build resilience.

Greater impacts will require greater reliance on system element redundancy planning, roadside and direct-to-vehicle event messaging, traffic and mode rerouting, evacuation planning, and disaster recovery. As climate conditions change, Caltrans will need to work with other state and local agencies to ensure that these activities are adjusted accordingly. For example, Caltrans districts may wish to further engage with local transportation agencies and emergency coordinators to ensure that messaging systems and rerouting plans are continually updated to reflect changing needs.

Aerial view of the south portal and roadway of the Devil's Slide Tunnel.

Appendix A: Methodology for Calculating GHG Emission Reductions and Cost Impacts

This appendix documents the quantitative analysis of various Caltrans strategies to reduce GHG emissions due to its own operations. The appendix describes the methodology used in this report and in the associated spreadsheet-based tool to calculate GHG reductions and cost impacts related to alternative pavement and concrete, alternative vehicle fuels, alternative vehicles, employee commuting alternatives, water conservation, solar installations, roadway lighting, facility energy efficiency, and facility lighting. For each of these topics, information is presented concerning the data collected, assumptions used in the analysis, GHG emission and cost factors, and calculation methods.

Pavement

The pavement analysis quantified the GHG emissions and cost impacts of substituting three alternative materials and processes for conventional hot-mix asphalt (HMA):

- Cold-in-place recycled (CIR) pavement.
- Warm-mix asphalt (WMA).
- Rubberized hot-mix asphalt (RHMA).

Data Collected

The following data were collected for the pavement analysis:

- From Caltrans district offices, the amount of CIR and WMA used in calendar year (CY) 2011 by each district.
- From Caltrans headquarters, the amount of RHMA, WMA and HMA used in CY 2011 by each district.
- When data for the amount of WMA used by a given district were available from both Caltrans headquarters and the district office, the data from headquarters were used in the analysis.

GHG Emissions and Cost Factors

In addition to information on materials costs from Caltrans headquarters, the following information was used in the pavement analysis:

- The GHG emissions for the HMA, RHMA, and WMA processes were obtained from the draft Pavement Life-Cycle Assessment Tool for Environmental and Economic Effects (PaLATE) model developed by the University of California, Berkeley.[73]
- The GHG emissions for the CIR process were obtained from an analysis of CIR projects conducted by Sonoma County.[74]
- CIR data were converted from lane miles and tons to square yards, and WMA data were converted from lane miles to tons using conversion factors from the CIR project data provided by the City of Napa.[75]
- Information on the energy reduced by the WMA process was obtained from a study conducted by FHWA.[76]
- Cost data for HMA and RHMA were taken from a 2012 Transportation Research Board (TRB) report,[77] and cost data for HMA and CIR were taken from the Sonoma County analysis.[78]

Assumptions

- According to research, the cost premiums associated with using WMA in lieu of HMA vary from a savings of $1 per ton to an increased cost of $3–5 per ton, depending on both the WMA mix used and the method used to analyze costs.[79] Given this range of values, a price premium of $4 per ton was assumed for the analysis to avoid underestimating the costs associated with using WMA. The cost of WMA is expected to decrease in a few years as contractors complete retrofits and purchase new equipment and technology.

Calculation Methods

To calculate annual GHG reductions, the amount of alternative pavement materials or processes used was multiplied by the difference in GHG emissions per ton between HMA and the respective alternative.

To calculate the cost impacts of CIR, RHMA, and WMA, the amount of the material or process used was multiplied by the per-unit cost difference between HMA and the respective alternative. In some cases, the cost difference was negative, indicating that the process or material resulted in savings for Caltrans.

To calculate the cost effectiveness of GHG emission reductions from CIR, RHMA, and WMA, the total costs were divided by the total GHG emission reductions for each material or process.

Concrete

The concrete analysis quantified the GHG emissions and cost impacts of substituting three alternative materials for conventional Portland cement concrete (PCC):

- Concrete with higher limestone content.
- Concrete with a minimum of 25 percent fly ash in cement blends, as is currently required by Caltrans statewide.
- Alternative concrete mixtures in districts that use additional supplemental cementitious materials (SCMs), such as blast slag and silica fume.

Data Collected

The following data were collected for the concrete analysis:

- The Caltrans Cost Data Book provided CY 2010 data on the amount of concrete used in each district.
- Several Caltrans districts provided CY 2011 data on the average composition of concrete mixtures used locally (in pounds per cubic yard of concrete).
- Additional Caltrans reports provided information on the percent of concrete used by Caltrans that comes from within California[80] and on the proportion of limestone used in cement statewide.[81]
- The Caltrans Division of Construction provided supplemental data on concrete mixtures, including the percentage of cement in concrete by volume and density of cement.

GHG Emissions and Cost Factors

- Caltrans headquarters provided the following GHG emissions for the concrete analysis:[82]
  - Materials GHG emissions for fly ash and blast furnace slag in pounds of CO_2e per pound of material.
  - Transportation GHG emissions for SCMs in pounds of CO_2 per ton-mile by mode, based on average transportation distances for SCMs and cement used in California.
  - GHG emissions for limestone.[83]
- Materials and transportation GHG emissions for PCC and limestone were derived from a 2006 report by the Athena Institute.[84]
- Data on the cost of PCC were obtained from Cheng and Hicks 2012.[85]
- Data on the cost of limestone were obtained from *ecoseed.org*.[86]
- The Caltrans Division of Construction provided data on the cost of fly ash.
- Data on the cost of blast slag were obtained from a 2009 report written for the California Energy Commission (CEC).[87]
- Data on the cost of silica fume were obtained from an FHWA report.[88]

Assumptions

- It was assumed that the Caltrans minimum standard for fly ash in cement is implemented uniformly statewide, and that the average limestone content of cement does not vary between districts.
- The benefits of these concrete alternatives were applied to all districts based on the proportion of concrete used.

Calculation Methods

To quantify the GHG benefits of concrete alternatives, GHG emission factors were calculated for four different concrete mixes:

- Conventional PCC.
- Concrete with high limestone content.
- Concrete with 25 percent fly ash content.
- District-specific GHG emission factors were calculated for districts using district-specific concrete mixes.

To calculate the GHG benefits of using concrete with high limestone content and concrete with 25 percent fly ash content, the tons used of the respective alternative were multiplied by the difference between the GHG emission factor for that concrete alternative and the GHG emission factor for conventional PCC. When the GHG emissions for a district-specific concrete mix were lower than the GHG emission factor for the Caltrans-wide standard 25 percent fly ash mix, the district-specific emission factor was used to calculate the additional GHG reductions from using district-specific concrete mixes instead of the Caltrans-wide standard mix.

To calculate the cost impacts of concrete alternatives, an overall cost per ton was calculated for each alternative concrete mixture based on the proportion and cost per ton of SCMs and concrete used in the mixture. The difference between the cost of the respective alternative mixture and the cost of PCC then was multiplied by the total amount of respective alternative concrete used in each district.

To calculate the cost effectiveness of GHG emission reductions from using alternative concrete mixes, the total cost of the alternative concrete was divided by the total GHG emission reductions for the respective alternate mix.

Alternative Vehicle Fuels

The analysis of alternative vehicle fuels quantified the GHG emissions and cost impacts for five alternative vehicle fuels:

- Replacing gasoline with E85 (an ethanol fuel blend of up to 85 percent denatured ethanol fuel and gasoline or other hydrocarbon by volume).
- Replacing diesel with B5 (a blend of 5 percent biodiesel and 95 percent petroleum diesel).
- Replacing diesel with B20 (a blend of 20 percent biodiesel and 80 percent petroleum diesel).
- Replacing gasoline with liquefied petroleum gas (LPG or propane).
- Replacing diesel with compressed natural gas (CNG).

Data Collected

The following data were collected for the analysis of alternative vehicle fuels:

- Caltrans headquarters provided vehicle fuel usage by fuel type and district.
- Caltrans headquarters provided cost data for conventional and alternative vehicle fuels.

GHG Emissions and Cost Factors

- Data on the energy content of different fuels (in megajoules [MJ]/gallon) were obtained from the U.S. Department of Energy.[89]
- Data on GHG emissions per unit of energy by fuel type (in grams of CO_2 equivalent [g CO_2e]/MJ) were obtained from the California Air Resources Board low-carbon fuel standard lookup tables.[90] These standards often contain multiple manufacturing pathways for a given fuel type. When this was the case, the following pathways were used in the analysis:
  - Waste oil biodiesel: conversion of used cooking oil to biodiesel where "cooking" is required.
  - Soy-based biodiesel: conversion of Midwest soybeans to biodiesel.
  - Ethanol from corn: California average ethanol fuel stock with 80 percent Midwest corn and 20 percent

California corn; dry milled and processed using natural gas.

  - CNG: North American natural gas delivered via pipeline, compressed in California.[91]

- Data on the carbon and energy content of cellulosic ethanol were obtained from the CEC.[92]

Assumptions

The following assumptions were incorporated into the analysis of alternative fuels:

- B20 carries a 20 cent premium over B5.
- The cost of gasoline was assumed at $3.12 based on 2011 data provided by Caltrans headquarters. Higher prices could significantly change the cost impacts of alternative fuels.
- The E85 consumed by the Caltrans fleet comes from corn ethanol.
- Of the B5 and B20 consumed by the Caltrans fleet, 70 percent comes from waste oil-based biodiesel and 30 percent from soy-based biodiesel.

Calculation Methods

GHG emissions and cost impacts of alternative fuels were calculated per unit of energy rather than per gallon. Because many alternative fuels are not as energy-dense as conventional gasoline or diesel, vehicles using these fuels must burn a greater number of gallons to travel the same distance. Calculating impacts per unit of energy accounts for this difference.

The first step in the analysis was to convert all fuel usage data from gallons to MJ of energy. Next, the GHG emissions for different blends of alternative fuels (such as B5 and E85) were calculated based on the composition of these blends and the emission factors for the different fuel types contained therein. The GHG emissions used in the analysis take into account both direct GHG emissions from fuel combustion and indirect (or "well-to-pump") emissions, because accounting for both types of emissions is key to understanding the overall GHG benefits of alternative fuels. For other strategies that reduce fuel usage (such as alternative vehicle fleets and employee commuting alternatives), reductions were quantified only for direct GHG emissions.

To determine the GHG emissions of each alternative fuel listed above, the GHG emission factor for the alternative fuel used was subtracted from the GHG emission factor for the baseline fuel (either gasoline or diesel). The difference was then multiplied by the MJ of energy consumed through use of the alternative fuel.

To find the cost of each alternative fuel, the difference in cost between the alternative fuel and the baseline fuel was calculated. That amount was multiplied by the total gallons of alternative fuel consumed, correcting for differing energy intensities of the fuel (MJ/gal).

To calculate the cost effectiveness of GHG emission reductions from use of alternative fuels, the total cost of each alternative fuel was divided by the total GHG emission reductions for the respective alternative fuel.

Alternative Vehicles

Caltrans achieves GHG benefits from the use of hybrid electric vehicles (HEVs) and other alternative vehicles in both its headquarters and district fleets. This analysis focused on the GHG emissions and cost impacts of HEVs because no data were available on the number of plug-in hybrid electric vehicles (PHEVs) or battery electric vehicles (BEVs) in the Caltrans fleet. However, calculations were set up to be able to incorporate the GHG emissions and cost impacts of these vehicles in the future as these data become available.

Data Collected

The following data were collected for the analysis of alternative vehicles:

- Caltrans headquarters provided 2011 data on the number of HEV vehicles and the average vehicle miles traveled (VMT) per vehicle.

GHG Emissions and Cost Factors

- Fuel economy information was obtained from the U.S. Department of Transportation's Bureau of Transportation Statistics.[93] Fuel economy data are

generally provided through government or industry sources for the most popular vehicles on the road.

- Data on fuel economy for HEVs were obtained from the U.S. Department of Energy.[94]
- Information on vehicle costs in 2012 was obtained from ViNCENTRiC.[95]
- The fuel carbon content (in g CO_2e per gallon) for gasoline was obtained from the U.S. Environmental Protection Agency's (EPA's) GHG inventory, Table A-33.[96]
- The carbon intensity of electricity (in g CO_2 per kilowatt hour [kWh]) for the California-Mexico region was obtained from EPA's eGrid database.[97]

Assumptions

- Upfront costs of vehicles were annualized based on an assumed lifetime of 10 years.
- The cost of gasoline was assumed at $3.12 based on 2011 data. Higher prices could significantly change the cost impacts of alternative vehicles.

Calculation Methods

The GHG emissions of alternative vehicles were calculated on a per-mile basis. First, the average fuel consumed per mile by a conventional vehicle was calculated. This amount was compared to the average fuel consumed per mile by HEVs, PHEVs, and BEVs, based on averages for 2013 models. The average fuel consumption per mile was obtained for the Toyota Prius, Toyota Prius PHEV, and Nissan Leaf as well as for conventional vehicles comparable to each: the Toyota Corolla and Nissan Versa. To calculate annual gasoline savings, the difference in fuel consumption per mile between alternative vehicles and conventional vehicles was multiplied by the number of alternative vehicles and their average annual VMT for each district. Finally, annual gasoline savings were converted into annual GHG emission reductions. For PHEVs and BEVs, GHG emissions were estimated for the electricity consumed by these vehicles on a per-mile basis; these emissions were subtracted from the annual GHG emission reductions due to reduced gasoline use.

The analysis of the cost impacts of alternative vehicles took into account two factors:

- The cost premium associated with purchasing an alternative vehicle instead of a comparable conventional vehicle.
- The annual savings due to reduced gasoline consumption.

To calculate the upfront cost premium, the price premiums for a typical alternative vehicle (HEV, PHEV, and BEV) were calculated by comparison to a similar conventional vehicle. The impact of available tax credits was included. These costs then were annualized over the assumed average vehicle life of 10 years. Annual gasoline savings were calculated as discussed above, and the average cost of gasoline was used to estimate the cost savings. For PHEVs and BEVs, the additional cost of the electricity consumed by these vehicles was estimated on a per-mile basis and subtracted from the annual savings due to reduced gasoline use.

To calculate the cost effectiveness of GHG emission reductions from use of alternative vehicles, the total cost was divided by the total GHG emission reduction for each alternative vehicle considered in the analysis.

Employee Commuting Alternatives

Caltrans provides a number of incentives to its employees to encourage them to use alternatives to single-occupancy vehicles (SOVs) to get to work. These alternatives include:

- Carpooling
- Vanpooling
- Bicycling
- Taking transit

The GHG emissions and cost impacts of each of these alternatives were estimated.

Data Collected

The following data were collected for the analysis of commuting alternatives:

- Caltrans district offices provided annual data from CY 2011 or CY 2012 on bicycle, carpool, and vanpool participation among employees. Data were not available for each commuting mode for all districts because of the limited alternative commuting options in use or because data had not been collected.
- Participation in transit subsidy programs from fiscal year 2011–12 was calculated from Transit Reimbursement Data provided by the Caltrans Travel Policy Section.
- Caltrans headquarters provided data on transit subsidy costs.
- Staff from District 3 provided CY 2010 data on VMT displaced by bicycle, transit, vanpool, and carpool ridership within the district.
- Data on the distribution of transit riders across different transit modes (bus, heavy rail, light rail, and demand response) were obtained from the National Transit Database[98] except for District 7, where LA Metro provided transit mode share data for the Los Angeles metropolitan area.
- Data on the average trip distance for each bicycle and car trip were collected from the National Transportation Household Survey.[99]
- Average gas mileage for passenger vehicles was obtained from 2010 FHWA Highway Statistics, Table VM-1.

GHG Emissions and Cost Impacts

- The fuel carbon content (in g CO_2e per gallon) for gasoline was obtained from EPA's GHG inventory, Table A-33[100] and was used to calculate displaced SOV emissions from carpooling, vanpooling, transit, and bicycling, as well as direct emissions from carpooling and vanpooling.
- The Federal Transit Administration (FTA) estimates of pounds of CO_2 emissions per rail passenger-mile and bus passenger-mile were used to calculate transit GHG benefits.[101]
- Vanpool fuel efficiency was obtained from the U.S. Department of Energy.[102]
- For all districts except District 7, transit GHG emissions (in pounds of CO_2 emissions per passenger-mile) from the FTA were used.[103] The FTA provided region-specific transit GHG emissions for the Sacramento and San Diego metropolitan areas (Districts 3 and 11), and the national average was used for other areas. For District 7, transit GHG emissions were taken from the LA Metro *2012 Sustainability Report*.[104]

Assumptions

- Two trips per day were assumed for all commuters.
- The average number of passengers was assumed at three per carpool and seven per vanpool, except for District 8, where four passengers per vanpool were assumed.
- A total of 250 work days per year were assumed, to account for weekends and holidays.
- If not commuting by vanpool, carpool, transit, biking, or walking, it was assumed that employees would use gasoline-powered SOVs. No diesel-powered SOVs were accounted for in the analysis of commute alternatives.
- It was assumed that use of all alternatives to SOVs at Caltrans was a result of the Department's alternative commute programs. In reality, some employees likely would have used alternatives to get to work regardless of the programs offered by Caltrans.
- It was assumed that each bicycle trip displaced 3.6 VMT and that each carpool, vanpool, and transit trip displaced 13.9 VMT (the average length of a car trip) based on figures from the National Transportation Household Survey.[105] This is likely a conservative estimate for vanpooling because vanpoolers tend to travel longer commute distances.
- Participation rates for the reported number of carpool and vanpool riders were assumed to be 100 percent, except for the exceptions noted below:
  - Because District 1 had five regular participants and five occasional participants, an overall participation level of 75 percent was assumed.
  - Because District 4 employees' participation in commuting alternatives varied based on weather

conditions, their level of participation was assumed to be 82 percent, based on the number of days with precipitation per year in Oakland.[106]

- District 8 provided information on the number and occupancy of commute vehicles. For this district, a commute vehicle with two to five participants represented a carpool, and a commute vehicle with six or more participants represented a vanpool.

Calculation Methods

The annual SOV VMT displaced by alternative commute modes were calculated by multiplying the number of participants in each alternative commute program by the number of trips per day, the number of commute days per year, and the length of the SOV trip displaced by each commute mode. Displaced VMT were converted to displaced GHG emissions based on the average gas mileage for passenger vehicles and the GHG content of gasoline.

Carpool, vanpool, and transit vehicles also produce GHG emissions; therefore, net GHG reductions were calculated by subtracting the direct GHG emissions from these vehicles from the GHG reductions associated with displaced SOV travel. Direct emissions from carpools, vanpools, and transit vehicles were calculated as follows. For carpools and vanpools, the number of participants in each program was divided by the average occupancy of carpool/vanpool vehicles in order to estimate the number of carpool/vanpool trips, which were then converted to annual GHG emissions based on the average gas mileage for passenger vehicles and the GHG content of gasoline. For transit vehicles, total transit passenger miles by were calculated by multiplying the number of Caltrans employees who received transit subsidies by the number of trips per day, the number of commute days per year, and the average length of transit trips. Total transit passenger miles were then allocated to different transit modes (bus, light rail, and heavy rail) based on either (1) the average transit mode share within the metropolitan area in which a district's headquarters was located; or (2) the average statewide transit mode share if metropolitan area data were not available. Modal transit passenger miles were then multiplied by modal GHG emission factors and summed to calculate direct emissions from transit.

The costs of these strategies were based on the dollar amount of subsidies provided by Caltrans for transit and vanpools. Neither the costs of conducting additional outreach to travelers using alternative commutes nor commuter transportation costs were included in the analysis. The cost effectiveness of each alternative commute strategy was determined by dividing the total cost of each strategy by the amount of GHG emissions that were displaced.

Water Conservation

The GHG emissions and cost impacts were calculated for three water conservation strategies that are commonly used in Caltrans offices:

- Low-flow toilets.
- Low-flow urinals.
- Low-flow fixtures.

Data Collected

The analysis of water conservation measures uses data from Caltrans districts on:

- The number and types of low-flow fixtures installed to date, from 2006 to the present.
- The water usage rates (in gallons per minute or per flush) of conventional and low-flow fixtures.

GHG Emission and Cost Factors

- The analysis uses data on the energy intensity of water for northern California and southern California from the California Air Pollution Control Officers Association (CAPCOA) *Quantifying Greenhouse Gas Mitigation Measures Handbook*.[107]
- In cases in which fixture-specific flow rates were not available from district offices, default fixture flow rates were taken from the CAPCOA handbook.[108]
- The carbon intensity of electricity (in g CO_2 per kWh) for the California-Mexico region was obtained from EPA's eGrid database.[109]

- Installation and purchase costs for fixtures were obtained from the homewyse™ website.[110] Estimates for faucet costs include the cost of both low-flow and sensor technology.[111]
- The average number of flushes per day (30) comes from the U.S. Department of Energy.[112]
- The minutes of restroom faucet use per flush (0.11 minute per flush) comes from the Pacific Institute.[113]
- The estimated average cost of water per gallon in California was based on various water district rates from the cities where district main offices are located. This estimate does not account for monthly service charges based on meter size.

Assumptions

- Upfront costs of low-flow fixtures were annualized based on an assumed lifetime of 15 years.
- A total of 250 work days per year were assumed, to account for weekends and holidays.

Calculation Methods

The annual water savings due to low-flow fixtures were calculated by multiplying the difference between the flow rates of water-saving and conventional fixtures by the average usage rates of different fixtures (in flushes per day and, if applicable, average minutes of fixture use per flush) and by the average number of work days per year. This figure was converted to annual electricity savings using the energy intensity of water (in kWh per 1,000 gallons), and to GHG reductions using the GHG intensity of electricity.

The analysis of costs accounted for the upfront costs of fixtures, annualized over the assumed fixture lifetime of 15 years, minus annual savings from reduced water usage, which were calculated based on the average cost per gallon of water. The cost effectiveness of each strategy was determined by dividing the total cost of the strategy by the amount of GHG emissions that were displaced by use of the strategy.

Solar Installations

The analysis calculated GHG reductions from Caltrans' solar installations—both those funded by Clean Renewable Energy Bonds (CREBs) and by other sources.

Data Collected

Data on the cost and generation capacity of Caltrans' solar installation projects were collected from two sources:

- Information on CREBs-funded projects was obtained from Caltrans' report to the legislature on the CREBs program.[114]
- Caltrans headquarters provided data on the non-CREBs-funded solar installations.

GHG Emission and Cost Factors

- The factor for the GHG intensity of electricity (in g CO_2 per kWh) for the California-Mexico region was obtained from EPA's eGrid database.[115]
- Data on the cost of electricity were obtained from Southern California Edison.[116]

Assumptions

- Solar installations from each project were assumed to generate electricity for 1,500 hours per year, an average of slightly more than 4 hours per day.
- The analysis assumes a lifetime of 25 years for solar installations, based on a review of literature regarding solar projects.[117]

Calculation Methods

To calculate the annual GHG reductions for solar projects, the installation capacity was multiplied by the productive hours of solar generation per year to estimate total electricity savings, which were then converted to GHG emissions using the GHG emissions coefficient of electricity. To calculate the net costs of each installation, the upfront costs of solar projects were annualized based on an assumed lifetime of 25 years, and the annual savings from reduced electricity usage were subtracted from this amount. The cost

effectiveness of GHG reductions from solar projects was calculated by dividing the total GHG emission reductions from Caltrans' solar projects by the total cost of these installations.

Roadway Lighting

The GHG emissions and cost impacts associated with roadway lighting were calculated for several strategies to reduce energy consumption by replacing older, less efficient fixtures with newer, more efficient fixtures. These include:

- Replacing incandescent intersection traffic lights with light-emitting diodes (LED) fixtures.
- Replacing incandescent ramp meter traffic lights with LED fixtures.
- Replacing incandescent pedestrian signals with LED fixtures.
- Replacing incandescent flashers with LED fixtures.
- Replacing incandescent changeable message signs (CMSs) with xenon fixtures.
- Replacing incandescent CMSs with LED fixtures.
- Replacing high-pressure sodium (HPS) roadway lighting with LED fixtures.
- Replacing mercury vapor (MV) sign lighting with induction fixtures.

Data Collected

The following data were collected for the analysis of roadway lighting:

- Caltrans headquarters provided data on the total number of lighting fixtures that had been replaced with energy-efficient fixtures as of October 2012, by district. In addition, Caltrans headquarters provided data on the wattage of the original and replacement fixtures; the upfront costs of energy-efficient lighting fixtures; and the average proportion of time that green, yellow, and red lights are illuminated on the typical traffic signal, with the following exceptions:
  - For District 4, data were available only for roadway LED fixtures that were installed in 2011–2012; data on projects from previous years were not available.
  - No installation costs were available for replacement of MV lighting with induction lighting for roadway signs.
  - The amount of time that CMSs spend illuminated was determined from the GreenDOT tool.[118]

GHG Emission and Cost Factors

- The factor for the GHG intensity of electricity (in g CO_2 per kWh) for the California-Mexico region was obtained from EPA's eGrid database.[119]
- The cost of electricity is based on information from Southern California Edison.[120]

Assumptions

- Based on recent lighting replacement practices, the analysis assumes that Caltrans is replacing lighting fixtures ahead of the normal replacement schedule. Therefore, the full upfront costs of energy-efficient light fixtures, rather than the marginal costs, were used in the cost calculations.
- The analysis assumes that ramp meter traffic lights operate 4 hours per day and only on weekdays.
- The analysis assumes that flashers operate 50 percent of the time, all year long.
- The analysis assumes that half of the CMSs are big signs (60-pixel matrix modules [PMMs]), and half are small signs (30 PMMs).
- The upfront costs of ramp meter lights were assumed to be equivalent to the upfront costs of intersection lights.

Calculation Methods

First, the difference in kWh consumed per year per fixture installed for each lighting strategy was calculated by multiplying the difference between the average wattage of conventional fixtures and energy-efficient fixtures by the anticipated yearly hours of operation of each fixture type. Next, GHG reductions were calculated for each strategy by multiplying kWh reductions by the GHG intensity of electricity and the total number of energy-efficient fixtures installed. To calculate the yearly costs of each strategy, the value

of the annual energy savings was subtracted from the annualized upfront costs of the new fixture. The result was multiplied by the total number of energy-efficient fixtures installed. The cost effectiveness of each strategy was determined by dividing the total cost of the strategy by the amount of GHG emissions that were displaced.

Facility Lighting

The analysis addresses the GHG emissions and cost impacts of several strategies to reduce energy consumption by replacing older, less efficient facility lighting fixtures with newer, more efficient fixtures—both for indoor and outdoor light fixtures. Indoor light efficiency projects include upgrading office lights and replacing less efficient bulbs with higher efficiency bulbs; outdoor projects primarily consist of upgrading outdoor lights to more efficient technology.

Data Collected

The following data were collected for the analysis of facility lighting:

- Caltrans headquarters and districts provided the number of fixtures replaced and the wattage of new and old fixtures for various facility lighting projects undertaken as of 2011. Projects that lacked sufficient data were excluded from the analysis but were kept as placeholders in the spreadsheet in the event that data become available on these projects.
- Data on the cost and lifetime of different lighting fixtures were obtained from Caltrans districts and headquarters, and from the following sources:
  - A report from the U.S. Department of Energy.[121]
  - Various lighting manufacturer websites.
- Caltrans headquarters provided data on the cost of labor to install lighting fixtures.

Assumptions

- In the absence of data from the sources described above on the lifetime of lighting fixtures, the operating lifetime was assumed to be 15 years.
- The analysis assumes that office lighting was in use for 10 hours per day, 250 days per year, for a total of 2,500 hours per year.
- The analysis assumes that hallway and outdoor lighting was in use for 10 hours per day year-round, for a total of 3,650 hours per year.
- It was assumed that lights in parking structures are always on, and are in use for 8,760 hours per year.
- The cost of labor to install energy-efficient lighting fixtures was assumed to be the same as the cost of labor to install conventional lighting fixtures.

GHG Emission and Cost Factors

- The factor for the GHG intensity of electricity (in g CO_2 per kWh) for the California-Mexico region was obtained from EPA's eGrid database.[122]
- Data on the cost of electricity were based on information from Southern California Edison.[123]

Calculation Methods

First, the difference in kWh consumed per year per fixture installed for each lighting strategy was calculated by multiplying the difference between the average wattage of conventional fixtures and energy-efficient fixtures by the anticipated yearly hours of operation of each fixture type. Next, GHG emission reductions for each strategy were calculated by multiplying kWh reductions by the GHG intensity of electricity and the total number of energy-efficient fixtures installed. To calculate the yearly costs of each strategy, the energy savings were subtracted from the difference in annualized upfront costs between new and old fixtures; the result was multiplied by the total number of energy-efficient fixtures installed. To determine the cost effectiveness of each strategy, the total cost of the strategy was divided by the amount of GHG emissions that were displaced.

Facility Energy Efficiency

The GHG emissions and cost impacts of the following strategies to improve the energy efficiency of Caltrans facilities were calculated:

- Retrofitting building systems such as heating, ventilation, and air conditioning equipment and data centers.
- Retrofitting buildings to achieve Leadership in Energy and Environmental Design (LEED) certification.
- Caltrans' computer energy reduction and documentation (CERD) system.

This category of strategies is diverse, and complete information was not consistently available. The analysis therefore is limited to projects for which complete data were available.

Data Collected

The following data were collected for the analysis of facility energy efficiency:

- Information on total building energy consumption and on energy reductions due to various strategies to reduce facilities energy use was provided by facilities managers at Caltrans headquarters and districts.
- Caltrans's 2012 *Facilities Infrastructure Plan*[124] provided data on energy savings related to the CERD system.

GHG Emission and Cost Factors

- Information on the average energy savings in LEED buildings was obtained from a study conducted by the National Research Council of Canada.[125]
- Information on the capital price premium associated with newly constructed LEED-certified buildings was found at EVstudio.[126]
- Information on the cost of upgrading existing buildings to LEED standards was taken from the *Business Review*.[127]

Calculation Methods

First, the annual electricity savings in kWh due to facility energy efficiency strategies was calculated. Electricity savings for many strategies were taken directly from Caltrans records. For LEED-certified buildings, electricity savings were calculated by multiplying the percentage reduction in energy use due to LEED certification by the annual building electricity consumption prior to implementation of energy efficiency strategies. Next, GHG reductions for each strategy were calculated by multiplying kWh reductions by the GHG intensity of electricity.

Neither cost impacts nor cost effectiveness was calculated for facility energy efficiency strategies because data were not available for the upfront costs of most strategies.

Table 13: Summary of Greenhouse Gas Emission Reductions

	HQ	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	All Caltrans
Pavement Strategies, Annual GHG Reduction (tons)														
Replace HMA with CIP	-	-	-	5,207	-	-	-	-	1,174	1,996	1,391	-	2,275	12,043
Replace HMA with RHMA	-	2,071	2,454	8,200	5,434	1,135	5,081	10,715	3,429	1,208	4,261	2,965	2,102	49,056
Replace HMA with WMA	-	36	9	40	-	-	2	-	-	-	-	-	288	376
Concrete Strategies, Annual GHG Reduction (tons)														
Use limestone in cement	-	112	35	955	699	57	290	1,106	91	1	211	204	742	4,501
Use 25% FA "Caltrans Minimum"	-	1,028	317	8,771	6,421	520	2,664	10,159	835	10	1,934	1,871	6,815	41,345
Use "green" cement mix, district mix	-	-	266	922	78	103	-	19	-	-	-	-	-	1,389
Alt Fuel Strategies, Annual GHG Reduction (tons)														
Replace gasoline with E85	0.0	-	-	0.4	0.7	-	0.3	0.4	0.1	-	0.3	0.2	0.4	2.7
Replace diesel with B5	6.2	-	198.9	455.9	210.4	-	149.2	95.0	52.1	2.6	10.7	74.6	34.5	1,290.2
Replace diesel with B20	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Replace diesel with propane	3.4	1.8	2.7	6.4	7.4	5.9	3.3	7.3	3.4	0.7	6.6	3.4	4.9	57.2
Replace diesel with CNG	1.0	-	-	-	-	-	-	358.5	120.4	-	-	0.2	101.8	581.9
Fleet Strategies, Annual GHG Reduction (tons)														
Replace conventional passenger car with HEV	20	31	17	6	68	40	4	34	6	1	4	10	7	249
Replace conventional passenger car with PHEV	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Replace conventional passenger car with BEV	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Commuting Strategies, Annual GHG Reduction (tons)														
Bicycle commute	350	6	16	42	13	18	10	21	-	12	2	-	2	493
Vanpool	125	17	-	48	31	134	8	194	101	-	48	-	15	721
Carpool	195	-	-	548	331	57	9	-	221	-	6	-	82	1,449
Transit	1,171	1	-	10	2,568	11	4	2	4	-	3	1	27	3,802
Water Strategies, Annual GHG Reduction (tons)														
Low-flow toilets	-	-	0.50	0.26	-	1.94	-	-	-	-	-	-	-	2.71
Low-flow urinals	-	-	0.09	0.18	-	0.94	-	-	-	-	-	-	-	1.22
Low-flow fixtures	-	-	0.05	0.05	0.12	0.01	-	-	-	-	-	-	-	0.23
Solar Strategies, Annual GHG Reduction (tons)														
Facilities solar panels	-	114	33	215	159	103	151	109	38	78	166	127	98	1,391
Roadway Lighting Strategies, Annual GHG Reduction (tons)														
Replace incandescent intersection traffic lights with LEDs	-	285	571	1,261	4,339	1,509	1,892	3,545	3,124	182	1,114	2,082	2,717	22,621
Replace incandescent ramp meter traffic lights with LEDs	-	-	-	8	12	0	9	78	19	-	-	31	26	183
Replace incandescent pedestrian signals with LEDs	-	115	195	588	1,751	561	577	1,243	1,241	60	444	769	831	8,377
Replace incandescent flashers with LEDs	-	47	21	44	68	27	63	50	32	23	63	8	8	455
Replace incandescent CMS with xenon	-	34	39	77	141	13	94	124	68	9	77	43	64	783
Replace incandescent CMS with LED	-	120	148	284	547	49	356	476	263	38	295	159	246	2,981
Replace HPS roadway lighting with LED	-	20	59	-	396	-	-	38	-	2	-	2	48	565
Replace MV lighting with induction (sign lighting only)	-	6	13	154	584	55	101	930	350	6	51	341	263	2,854
Facility Lighting Strategies, Annual GHG Reduction (tons)														
Indoor light reduction	-	118	9	-	15	24	-	-	-	-	-	-	-	165
Outdoor light reduction	-	-	1	-	110	-	-	355	-	-	-	-	-	465
Facility Energy Efficiency Strategies														
LEED certification	-	-	71	180	-	-	-	471	-	-	-	47	-	769
Data center upgrades	-	-	-	-	-	-	-	85	-	-	-	-	-	85
Overall building upgrades	724	-	-	-	695	-	-	-	-	-	98	-	-	1,517
Computer energy reduction	140	10	14	27	79	13	39	75	35	3	9	36	25	505

List of Participants

Many Caltrans employees helped to compile the information for this report. Below is a list of the employees who provided information and participated in development of this report.

Headquarters	
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Nicole Longoria and Patrick Tyner	Division of Research and Innovation
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Linda Fong and Jack Ezekiel	Division of Design (Resolutions of Necessities, Encroachment Exceptions, Resource Conservation, and SMARA)
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Districts	
Mark Suchanek	District 1, Maintenance and Operations
Jana Hollifield and Darla Ghidinelli	District 1, Administration, Business Management, Building Services
Cheryl Willis, Suzanne Theiss, and Rex Jackman	District 1, Planning and Local Assistance
Mitch Higa	District 1, Environmental
Cindy Anderson and Shirley Coate	District 2, Project Management and Environmental
Sue Lamb, Cindy Copeland, and Lorie Booth	District 2, Business Management, Maintenance, and Operations
Ed Lamkin, Ian Turnball, and Rob Stinger	District 2, Roadside Maintenance, Materials, Pavement, Lands, and Buildings
Sue Garribay and Albert Serrano	District 3, Administration, Business Management
Steve Kirkpatrick	District 3, Maintenance and Traffic Operations
Nader Eshghipour and Robert Sorenson	District 4, Roadside Maintenance
Premjit Rai, Damien Harris, and Walter Garcia	District 4, Facilities
Erik Alm	District 4, Transit and Community Planning
Buddy Cruz and Julia Bolger	District 5, Facilities
Steve Price	District 5, Maintenance and Operations
Matt Fowler	District 5, Environmental
Marco Sanchez	District 6, Maintenance
Lori Guinan and Gloria Samaniego	District 6, Facilities
Dan Freeman	District 7, Maintenance
Duncan McIntosh, Carmen Roberts, and Marian Woo	District 7, Facilities
Cathy Gomez and Susan Harris	District 8, Facilities
Eric Hedberg	District 8, Maintenance
Linda Weier and Geri Basset	District 9, Facilities
Craig Holste and Charley Davis	District 9, Maintenance and Operations
John Fox	District 9, Maintenance
Dennis Agar	District 10, Maintenance and Operations
Pete Nunes and Donald Lynch	District 10, Facilities
Dan White	District 11, Facilities
Bruce Lambert, Otto Perryman, and Donal Elms	District 11, Maintenance and Operations
Chris Schmidt	District 11, Public Transportation
Rex McConnell and Massoud Tajik	District 12, Maintenance and Operations
Chris Gruzynski	District 12, Facilities

Endnotes

1 California Air Resources Board (2008). *Climate Change Scoping Plan: A Framework for Change*. December 2008. *http://www.arb.ca.gov/cc/scopingplan/document/scopingplandocument.htm*.

2 Pavley, F. (2006). Assembly Bill 32; California Global Warming Solutions Act. September 27, 2006. *http://www.arb.ca.gov/cc/ab32/ab32.htm*.

3 Schwarzenegger, A. (2005). Executive Order S-3-05. June 1, 2005. *http://www.dot.ca.gov/hq/energy/ExecOrderS-3-05.htm*.

4 California Air Resources Board (2008). *Climate Change Scoping Plan: A Framework for Change*. December 2008. *http://www.arb.ca.gov/cc/scopingplan/document/scopingplandocument.htm*.

5 Liu, C. (2009). Senate Bill 391. October 11, 2009. *http://www.leginfo.ca.gov/pub/09-10/bill/sen/sb_0351-0400/sb_391_bill_20091011_chaptered.html*.

6 Steinberg, D. (2008). Senate Bill 375. September 30, 2008. *http://www.leginfo.ca.gov/pub/07-08/bill/sen/sb_0351-0400/sb_375_bill_20080930_chaptered.pdf*.

7 Leno, M. (2008). Assembly Bill 1358. September 30, 2008. *http://www.completestreets.org/webdocs/policy/cs-ca-legislation.pdf*.

8 California Department of Transportation (2008). Deputy Directive 64-R1; Complete Streets – Integrating the Transportation System. October 2008. http://www.dot.ca.gov/hq/tpp/offices/bike/guidelines_files/DD64.pdf.

9 California Department of Transportation (2001). Director's Policy 22; Context Sensitive Solutions. November 29, 2001. *http://www.dot.ca.gov/hq/transprog/ocip/te/dp-22.pdf*.

10 Schwarzenegger, A. (2004). Executive Order S-20-04. July 27, 2004. *http://www.dot.ca.gov/hq/energy/ExecOrderS-20-04.htm*.

11 Brown, E.G. (2012). Executive Order B-18-12. April 25, 2012. *http://gov.ca.gov/news.php?id=17508*.

12 Kunzman, L. (2008). Memorandum re: Fuel Conservation. July 25, 2008. *http://www.dot.ca.gov/hq/eqsc/CleanAir/documents/FuelConservationMemo072508.pdf*.

13 Kunzman, L. (2006). Memorandum re: Use of Alternative Fuels. July 6, 2006. *http://www.dot.ca.gov/hq/eqsc/CleanAir/documents/MemoUseofAlternativeFuel.pdf*.

14 California Department of Transportation (1993). Deputy Directive 13; Water Conservation. September 1, 1993. *http://www.dot.ca.gov/docs/DD-13.pdf*.

15 Strom-Martin, V. (1999). Assembly Bill 75. October 10, 1999. *http://www.calrecycle.ca.gov/stateagency/requirements/AB75.htm*.

16 Wiggins, P. (2008). Assembly Bill 1016. September 26, 2008. *http://www.leginfo.ca.gov/pub/07-08/bill/sen/sb_1001-1050/sb_1016_bill_20080926_chaptered.html*.

17 Levine, L. (2005). Assembly Bill 338. October 7, 2005. *http://legix.info/us-ca/measures;2005-06;ab0338/doc*.

18 Schwarzenegger, A. (2008). Executive Order S-13-08. November 14, 2008. *http://www.climatestrategies.us/library/library/view/293*.

19 California Department of Transportation (2007). *California Goods Movement Action Plan: Phase II Report*. January 2007. *http://www.arb.ca.gov/gmp/docs/gmap-1-11-07.pdf*.

20 California Department of Transportation (2010). *Smart Mobility 2010: A Call to Action for the New Decade*. February 2010. *http://www.dot.ca.gov/hq/tpp/offices/ocp/smf_files/SMF_handbook_062210.pdf*.

21 Federal Highway Administration (2007). "What is CSS?" *http://contextsensitivesolutions.org/content/topics/what_is_css/*.

22 California Department of Transportation (2012). Standard Environmental Reference website. *http://www.dot.ca.gov/ser/*.

23 Federal Highway Administration (2012). Transportation Enhancements Activities website. *http://www.fhwa.dot.gov/environment/transportation_enhancements/*.

24 Cervero, R. (2003). "Road Expansion, Urban Growth, and Induced Travel: A Path Analysis." *Journal of the American Planning Association*, Vol. 69, No. 2, Spring, pp. 145-163.

[25] UC Davis Urban Land Use and Transportation Center (2012). *Data and Tools for Integrated Land Use-Transportation Planning in California*. ***http://ultrans.its.ucdavis.edu/projects/improved-data-and-tools-integrated-land-use-transportation-planning-california***.

[26] New York State Department of Transportation (2012). GreenLITES website. ***https://www.dot.ny.gov/programs/greenlites***.

[27] In particular, many researchers have found that safety on urban arterial streets is unaffected, or even improved, by reduced lane widths. For examples, see: Federal Highway Administration (2007). *Mitigation Strategies for Design Exceptions* (Chapter 3). July 2007; National Cooperative Highway Research Program (1990). *NCHRP 330, Effective Utilization of Street Width on Urban Arterials*.; and Potts, B., D. Harwood, and K. Richard (2007). "Relationship of Lane Width to Safety for Urban and Suburban Arterials." Transportation Research Board 2007 Annual Meeting. On the other hand, a study that included California data found adverse safety impacts when narrowing vehicle lanes in order to accommodate a greater number of lanes on urban freeways in certain cases, see: Bauer, K., D. Harwood, and K. Richard (2004). "Safety Effects of Using Narrow Lanes and Shoulder-Use Lanes to Increase the Capacity of Urban Freeways." *Transportation Research Record: Journal of the Transportation Research Board*. For a summary of legal and liability barriers related to narrower lane widths, see Urgo, J., M. Wilensky, and S. Weissman (2010). *Moving beyond Prevailing Street Design Standards: Assessing Legal and Liability Barriers to More Efficient Street Design and Function*. December 15, 2010. ***http://crec.berkeley.edu/Moving%20Beyond%20Prevailing%20Standards.pdf***.

[28] California Department of Transportation (2010). *Standard Specifications*. ***http://www.dot.ca.gov/hq/esc/oe/specifications/std_specs/2010_StdSpecs/2010_StdSpecs.pdf***.

[29] California Department of Transportation (2011). 2011 Annual Report to the Legislature and the Department of Resources, Recycling, and Recovery. Senate Bill 876: Waste and Used Tires. October 2011. ***http://www.dot.ca.gov/hq/oppd/rescons/sb876/Final-2011-SB-876-Waste-Tire-Report.pdf***.

[30] Levine, L. (2005). Assembly Bill 338. October 7, 2005. ***http://legix.info/us-ca/measures;2005-06;ab0338/doc***.

[31] Strom-Martin, V. (1999). Assembly Bill 75. October 10, 1999. ***http://www.calrecycle.ca.gov/stateagency/requirements/AB75.htm***.

[32] Wiggins, P. (2008). Assembly Bill 1016. September 26, 2008. ***http://www.leginfo.ca.gov/pub/07-08/bill/sen/sb_1001-1050/sb_1016_bill_20080926_chaptered.html***.

[33] Nevada Department of Transportation (2008). "NDOT Project Wins Cold In-Place Recycling Award." *Centerline*. June 2008. ***www.nevadadot.com/uploadedFiles/NDOT/News/2008_06_Centerline.pdf***.

[34] U.S. Department of Transportation, Federal Highway Administration (2011). "Cold In-Place Recycling State of Practice Review." April 7, 2011. ***www.fhwa.dot.gov/pavement/recycling/cir/***.

[35] California Air Resources Board (2012). "Carbon Intensity Lookup Table for Gasoline and Fuels that Substitute for Gasoline." ***www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf***.

[36] California Department of Transportation (2011). *Ramp Metering Development Plan*. December 2011. ***www.dot.ca.gov/hq/traffops/systemops/ramp_meter/RMDP.pdf***.

[37] City of San Ramon, "Crow Canyon Road Traffic Light Synchronization Project Benefit Analysis," 2011.

[38] Qian, Z. and M. Zhang (2012). "Full Closure or Partial Closure? Evaluation of Construction Plans for the I-5 Closure in Downtown Sacramento." *Journal of Transportation Engineering* (accepted).

[39] Oregon Department of Transportation (2011). Office of Innovative Partnerships and Alternative Funding, Oregon Solar Highways website. ***http://www.oregon.gov/ODOT/HWY/OIPP/Pages/inn_solarhighway.aspx***.

[40] California Air Resources Board (2012). "LCFS (Low Carbon Fuel Standard) Intensity Lookup Tables." February 2012. ***http://www.arb.ca.gov/regact/2011/lcfs11/lcfs11.htm***.

[41] U.S. Department of Energy, Energy Efficiency and Renewable Energy (2012). "EPAct Transportation Regulatory Activities." ***http://www1.eere.energy.gov/vehiclesandfuels/epact/***.

[42] U.S. Department of Energy, Energy Efficiency and Renewable Energy (2012). "EPAct Transportation Regulatory Activities: Compliance for State and Alternative Fuel Provider Fleets." ***http://www1.eere.energy.gov/vehiclesandfuels/epact/compliance_methods.html***.

[43] Brown, E.G. (2011). Executive Order B-2-11. January 28, 2011. ***http://gov.ca.gov/news.php?id=16890***.

[44] Alabama Permanent Joint Legislative Committee on Energy (2012). "Legislative Joint Energy Committee Applauds ALDOT's Green Fleet Savings Initiatives." Press Release. March 16, 2012. ***http://www.repgregwren.com/uploads/ALDOT_s_Green_Fleet_Savings_Initiatives.pdf***.

[45] Utah Department of Transportation (2012). "UDOT Equipment Operations." ***www.wshema.com/2011_presentations/UT/WSHEM.ppt***.

[46] Oregon Department of Transportation (2011). *ODOT Sustainability Program Progress Report, January 2010—December 2010*. ***http://www.oregon.gov/ODOT/SUS/docs/progressreport10.pdf***; *ODOT Sustainability Plan, Volume 2: Sustainability Management Framework for ODOT's Internal Operations*. ***www.oregon.gov/ODOT/SUS/docs/sustainability_vol2_fin.pdf***.

[47] Brown, E.G. (2012). Executive Order B-18-12. April 25, 2012. ***http://gov.ca.gov/news.php?id=17508***.

[48] Schwarzenegger, A. (2004). Executive Order S-20-04. July 27, 2004. ***http://www.dot.ca.gov/hq/energy/ExecOrderS-20-04.htm***.

[49] Brown, E.G. (2012). Executive Order B-18-12. April 25, 2012. ***http://gov.ca.gov/news.php?id=17508***.

[50] California Department of Transportation (2012). *Clean Renewable Energy Bonds Program Annual Report 2012*, March 2012. ***http://www.dot.ca.gov/docs/reports/Exhibit_1.pdf***.

[51] California Department of Transportation (2012). Clean Renewable Energy Bonds Program Annual Report 2012, Exhibit 1: Clean Renewable Energy Bonds Projects. March 2012. ***http://www.dot.ca.gov/docs/reports/Exhibit_1.pdf***.

[52] Strom-Martin, V. (1999). Assembly Bill 75. October 10, 1999. ***http://www.calrecycle.ca.gov/stateagency/requirements/AB75.htm***; Wiggins, P. (2008). Assembly Bill 1016. September 26, 2008. ***http://www.leginfo.ca.gov/pub/07-08/bill/sen/sb_1001-1050/sb_1016_bill_20080926_chaptered.html***.

[53] Cayan, D., M. Tyree, M. Dettinger, H. Hidalgo, T. Das, E. Maurer, P. Bromirski, N. Graham, and R. Flick (2009). *Climate Change Scenarios and Sea Level Rise Estimates for the California 2009 Climate Change Scenarios Assessment*. A paper from the California Climate Change Center. August 2009. ***http://www.energy.ca.gov/2009publications/CEC-500-2009-024/CEC-500-2009-024-F.PDF***.

[54] National Research Council (2012). *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*. National Academies Press, Washington, DC. ***http://www.nap.edu/catalog.php?record_id=13389*** and Estimates for sea level rise in inches provided in the Report in Brief. ***http://dels.nas.edu/Materials/Report-In-Brief/4295-Sea-Level-Rise***.

[55] National Research Council (2012). Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. National Academies Press, Washington, DC. ***http://www.nap.edu/catalog.php?record_id=13389***.

[56] Heberger, M., H. Cooley, P. Herrera, P.H. Gleick, and E. Moore (2009). "The Impacts of Sea-Level Rise on the California Coast." A Paper from the California Climate Change Center. August 2009. ***http://www.energy.ca.gov/2009publications/CEC-500-2009-024/CEC-500-2009-024-F.PDF***.

[57] Moser, S., G. Franco, S. Pittiglio, W. Chou, and D. Cayan (2009). *The Future Is Now: An Update on Climate Change Science Impacts and Response Options for California*. California Energy Commission, PIER Energy-Related Environmental Research Program. May 2009. ***http://www.energy.ca.gov/2008publications/CEC-500-2008-071/CEC-500-2008-071.PDF***.

[58] Cayan, D., M. Tyree, M. Dettinger, H. Hidalgo, T. Das, E. Maurer, P. Bromirski, N. Graham, and R. Flick (2009). *Climate Change Scenarios and Sea Level Rise Estimates for the California 2009 Climate Change Scenarios Assessment*. A paper from the California Climate Change Center. August 2009. ***http://www.energy.ca.gov/2009publications/CEC-500-2009-024/CEC-500-2009-024-F.PDF***.

[59] Cayan, D., M. Tyree, M. Dettinger, H. Hidalgo, T. Das, E. Maurer, P. Bromirski, N. Graham, and R. Flick (2009). *Climate Change Scenarios and Sea Level Rise Estimates for the California 2009 Climate Change Scenarios Assessment*. A paper from the California Climate Change Center. August 2009. ***http://www.energy.ca.gov/2009publications/CEC-500-2009-024/CEC-500-2009-024-F.PDF***.

[60] Cayan, D., M. Tyree, M. Dettinger, H. Hidalgo, T. Das, E. Maurer, P. Bromirski, N. Graham, and R. Flick (2009). *Climate Change Scenarios and Sea Level Rise Estimates for the California 2009 Climate Change Scenarios Assessment*. A paper from the California Climate Change Center. August 2009. ***http://www.energy.ca.gov/2009publications/CEC-500-2009-024/CEC-500-2009-024-F.PDF***. The threshold for "heat wave" days is based on the 95th percentile of daily maximum temperatures occurring between May and September during the period 1961–1990.

[61] Transportation Research Board (2008). *Special Report 290: Potential Impacts of Climate Change on U.S. Transportation*. Committee on Climate Change and U.S. Transportation, National Research Council of the National Academies. Washington, DC: The National Academies Press. http://onlinepubs.trb.org/onlinepubs/sr/sr290.pdf. Impact information discussed in this paragraph is from this source, and represents general statements about impacts on transportation infrastructure and operations.

[62] Mastrandrea, M.D., C. Tebaldi, C.P. Snyder, and S.H. Schneider (2009). "Current and Future Impacts of Extreme Events in California." A Paper from the California Climate Change Center. August 2009. ***http://www.energy.ca.gov/2009publications/CEC-500-2009-026/CEC-500-2009-026-F.PDF***.

[63] Cayan, D., M. Tyree, M. Dettinger, H. Hidalgo, T. Das, E. Maurer, P. Bromirski, N. Graham, and R. Flick (2009). *Climate Change Scenarios and Sea Level Rise Estimates for the California 2009 Climate Change Scenarios Assessment*. A paper from the California Climate Change Center. August 2009. ***http://www.energy.ca.gov/2009publications/CEC-500-2009-024/CEC-500-2009-024-F.PDF***.

[64] Cayan, D., M. Tyree, M. Dettinger, H. Hidalgo, T. Das, E. Maurer, P. Bromirski, N. Graham, and R. Flick (2009). *Climate Change Scenarios and Sea Level Rise Estimates for the California 2009 Climate Change Scenarios Assessment*. A paper from the California Climate Change Center. August 2009. ***http://www.energy.ca.gov/2009publications/CEC-500-2009-024/CEC-500-2009-024-F.PDF***.

[65] Cayan, D., M. Tyree, M. Dettinger, H. Hidalgo, T. Das, E. Maurer, P. Bromirski, N. Graham, and R. Flick (2009). *Climate Change Scenarios and Sea Level Rise Estimates for the California 2009 Climate Change Scenarios Assessment*. A paper from the California Climate Change Center. August 2009. ***http://www.energy.ca.gov/2009publications/CEC-500-2009-024/CEC-500-2009-024-F.PDF***.

[66] Transportation Research Board (2008). *Special Report 290: Potential Impacts of Climate Change on U.S. Transportation*. Committee on Climate Change and U.S. Transportation, National Research Council of the National Academies. Washington, DC: The National Academies Press. ***http://onlinepubs.trb.org/onlinepubs/sr/sr290.pdf***.

[67] California Natural Resources Agency (2009). 2009 *California Climate Adaptation Strategy*. ***http://resources.ca.gov/climate_adaptation/docs/Statewide_Adaptation_Strategy.pdf***.

[68] National Research Council (2012). *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*. National Academies Press, Washington, DC. ***http://www.nap.edu/catalog.php?record_id=13389***.

[69] National Research Council (2012). *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*. National Academies Press, Washington, DC. ***http://www.nap.edu/catalog.php?record_id=13389***.

[70] National Research Council (2012). *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*. National Academies Press, Washington, DC. ***http://www.nap.edu/catalog.php?record_id=13389***.

[71] Metropolitan Transportation Commission (2011). *Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project*. November 2011. ***http://www.mtc.ca.gov/planning/climate/RisingTides-TechnicalReport.pdf***.

[72] National Research Council (2012). *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*. National Academies Press, Washington, DC. ***http://www.nap.edu/catalog.php?record_id=13389***.

[73] PaLATE is available by request from the following source: University of California, Berkeley, Consortium on Green Design and Manufacturing (2007). "PaLATE: Pavement Life-cycle Assessment Tool for Environmental and Economic Effects." ***http://www.ce.berkeley.edu/~horvath/palate.html***.

[74] Urbanek, Stephen (2011). "Cold In-Place Recycling in Sonoma County: Climate Initiatives Innovative Grant Program, Partnership for Sustainable Community Networks." ***http://www.pavementvideo.org/2012_CIR/PDF/9%20-%20Agency%20Experiences%20-%20Sonoma%20County%20-%20Steve%20Urbanek.pdf***.

[75] City of Napa (2011). Project ST10PW07: Notice Inviting Bids, Proposal, Contract and Special Provisions for 2011 Cold In-Place Pavement Recycling Project. July 2011. ***http://www.pavementpreservation.org/wp-content/uploads/2012/01/Napa-Sonoma-Final-Specs-Document.pdf***.

[76] U.S. Department of Transportation, Federal Highway Administration (2012). "Warm Mix Asphalt." ***http://www.fhwa.dot.gov/pavement/asphalt/wma.cfm***.

[77] Kawakami, A., H. Nitta, and K. Kubo (2012). "Life-Cycle CO2 of Long-Life Pavement and Technologies for Extending Pavement Life." Paper for Transportation Research Board 2011 Annual Meeting. ***ftp://ftp.hsrc.unc.edu/pub/TRB2011/data/papers/11-1864.pdf***.

[78] Urbanek, Stephen (2011). "Cold In-Place Recycling in Sonoma County: Climate Initiatives Innovative Grant Program, Partnership for Sustainable Community Networks." ***http://www.pavementvideo.org/2012_CIR/PDF/9%20-%20Agency%20Experiences%20-%20Sonoma%20County%20-%20Steve%20Urbanek.pdf***.

[79] Silva, H., M.R.D., J. Oliveira, C. Ferreira, and P. Pereira (2010). "Assessment of the Performance of Warm Mix Asphalts in Road Pavements." *International Journal of Pavement Research & Technology*, Vol. 3, No. 3, pp. 119-127; Kristjansdottir, O., S. Muench, L. Michael, and G. Burke, (2007), "Assessing Potential for Warm Mix Asphalt," *Journal of the Transportation Research Record*, Vol. 2040, No. 1, pp. 91-99.

[80] From "Caltrans Concrete Quantities and CO2 Reductions." Provided in June 2012.

[81] From Caltrans "Percent of Limestone in Cement Samples." Provided in June 2012.

[82] From "Caltrans Concrete Quantities and CO2 Reductions." Provided in June 2012.

[83] From Caltrans "Percent of Limestone in Cement Samples." Provided in June 2012.

[84] Athena Institute (2006). "Life Cycle Perspective on Concrete and Asphalt Roadways: Embodied Primary Energy and Global Warming Potential." September 2006. ***http://www.cement.ca/images/stories/athena%20report%20Feb.%202%202007.pdf***.

[85] Cheng, D., G. Hicks, and T. Teesdale (2011). "Assessment of Warm Mix Technologies for Use with Asphalt Rubber Paving Applications." 2011 Paper for Transportation Research Board Annual Meeting. ***http://amonline.trb.org/12l389/2***.

[86] EcoSeed (2012). "Classical Architecture Inspiration for 'Green' Cement." February 2012. ***http://www.ecoseed.org/technology/12521-classical-architecture-inspiration-for-green-cement***.

[87] California Energy Commission (2009). "Cement Sector Greenhouse Gas Emissions Reduction Case Studies." March 2009. ***http://www.energy.ca.gov/2009publications/CEC-600-2009-005/CEC-600-2009-005.PDF***.

[88] U.S. Department of Transportation, Federal Highway Administration (2003). "Guidelines for the Use of Lithium to Mitigate or Prevent Alkali-Silica Reaction (ASR)." http://www.fhwa.dot.gov/pavement/pub_details.cfm?id=92

[89] U.S. Department of Energy, Energy Efficiency & Renewable Energy (2012). "Alternative Fuels Data Center, Fuel Properties Comparison Chart." June 2012. http://www.afdc.energy.gov/afdc/progs/fuel_compare.php

[90] California Air Resources Board (2012). "Carbon Intensity Lookup Table for Gasoline and Fuels that Substitute for Gasoline." ***www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf***.

[91] California Air Resources Board (2012). "Carbon Intensity Lookup Table for Gasoline and Fuels that Substitute for Gasoline." ***www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf***. The following descriptions for fuel pathways are used verbatim from this report: Waste oil biodiesel (Conversion of waste oils (Used Cooking Oil) to biodiesel (fatty acid methyl esters-FAME) where "cooking" is required); Soy-based biodiesel (Conversion of Midwest soybeans to biodiesel (fatty acid methyl esters - FAME); Ethanol from corn (California average; 80% Midwest Average; 20% California; Dry Mill; Wet DGS; NG); and CNG (North American NG delivered via pipeline; compressed in CA).

92 Van der Werf, Ysbrand (2009). "Carbon Intensity of Biofuels." Presentation to the California Energy Commission. September 14, 2009. *http://www.energy.ca.gov/2009-ALT-1/documents/2009-09-14_workshop/2009-09-14+15_presentations/CEC_van_der_Werf_GHG_numbers.pdf*.

93 U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics. "Table 4-23: Average Fuel Efficiency of U.S. Light Duty Vehicles." *http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_04_23.html*.

94 U.S. Department of Energy, Energy Efficiency & Renewable Energy. "2011 Hybrid Vehicles." *http://www.fueleconomy.gov/feg/PowerSearch.do?action=alts&path=3&year=2011&vfuel=Hybrid&srchtyp=yearAfv*.

95 Business Fleet. "Hybrid Model Data Averages." http://www.businessfleet.com/fc_resources/Editorial/BF0312hybrids-chart.pdf and "Which Hybrids Have the Lowest Cost of Ownership?" March 2012. *http://www.businessfleet.com/Channel/Green-Fleet/Article/Story/2012/03/Which-Hybrids-Have-the-Lowest-Cost-of-Ownership.aspx?interstitial=1*.

96 U.S. Environmental Protection Agency (2010). "Table A-33: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008." April 2010. *http://www.epa.gov/climatechange/Downloads/ghgemissions/508_Complete_GHG_1990_2008.pdf*.

97 U.S. Environmental Protection Agency (2007). "Clean Energy, eGRID2007 Version 1.1 Year 2005 GHG Annual Output Emission Rates." *http://cfpub.epa.gov/egridweb/ghg.cfm%20*.

98 Federal Transit Administration National Transit Database (2009). "Table 2-1." *http://www.ntdprogram.gov/ntdprogram/*.

99 National Transportation Household Survey, compiled by USF Center for Urban Transportation Research (2010). "Average commute distances by mode." March 2010. *http://usf-cutr.custhelp.com/app/answers/detail/a_id/3146/kw/average%20commute%20distances%20by%20mode*.

100 U.S. Environmental Protection Agency (2010). "Table A-33: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008." April 2010. *http://www.epa.gov/climatechange/Downloads/ghgemissions/508_Complete_GHG_1990_2008.pdf*.

101 U.S. Department of Transportation, Federal Transit Administration (2010). "Public Transportation's Role in Responding to Climate Change." January 2010. *http://www.fta.dot.gov/documents/PublicTransportationsRoleInRespondingToClimateChange2010.pdf*.

102 U.S. Department of Energy, Energy Efficiency & Renewable Energy (2012). "Fuel Economy of 2012 Vans." *http://www.fueleconomy.gov/feg/byclass/Vans__Passenger_Type2012.shtml*.

103 U.S. Department of Transportation, Federal Transit Administration (2009).

104 Los Angeles County, Metropolitan Transportation Authority (2012). *Moving Toward Sustainability: 2012 Metro Sustainability Report Using Operation Metrics*. June 2012. *http://www.metro.net/projects_studies/sustainability/images/Climate_Action_Plan.pdf*.

105 National Transportation Household Survey, compiled by USF Center for Urban Transportation Research (2010).

106 Sperling's BestPlaces (2010). "Climate in Oakland, California." *http://www.bestplaces.net/climate/city/california /oakland*.

107 California Air Pollution Control Officers Association (2010). *Quantifying Greenhouse Gas Mitigation Measures*. August 2010. *http://www.capcoa.org/wp-content/uploads/2010/11/CAPCOA-Quantification-Report-9-14-Final.pdf*.

108 California Air Pollution Control Officers Association (2010). *Quantifying Greenhouse Gas Mitigation Measures*. August 2010. *http://www.capcoa.org/wp-content/uploads/2010/11/CAPCOA-Quantification-Report-9-14-Final.pdf*.

109 U.S. Environmental Protection Agency (2007). "Clean Energy, eGRID2007 Version 1.1 Year 2005 GHG Annual Output Emission Rates." *http://cfpub.epa.gov/egridweb/ghg.cfm%20*.

110 Homewyze: Smart Home Decisions (2012). "Cost to Install a Toilet." October 2012. *http://www.homewyse.com/services/cost_to_install_toilet.html*.

111 Sustainable Supply (2012). Sustainable supply website. *http://www.sustainablesupply.com/*.

112 Flex Your Power (2012). "Toilets." *http://www.fypower.org/com/tools/products_results.html?id=100139*.

113 Pacific Institute (2003). *Waste Not Want Not: The Potential for Urban Water Conservation in California*. *http://pacinst.org/reports/urban_usage/*.

114 Caltrans (2012). "Clean Renewable Energy Bonds Projects." *http://www.dot.ca.gov/docs/reports/Exhibit_1.pdf*.

115 U.S. Environmental Protection Agency (2007). "Clean Energy, eGRID2007 Version 1.1 Year 2005 GHG Annual Output Emission Rates." *http://cfpub.epa.gov/egridweb/ghg.cfm%20*.

116 Southern California Edison (2010). "California Residents Have Lower Monthly Electric Bills than National Average, Despite Higher Electricity Costs." August 2010. *http://asset.sce.com/Documents/Customer%20Service%20-%20Rates/GRC_CaliforniaElectricBills.pdf*.

117 Appropedia (2012). "Lifespan and Reliability of Solar Photovoltaics—Literature Review." *http://www.appropedia.org/Lifespan_and_Reliability_of_Solar_Photovoltaics_-_Literature_Review*.

[118] ICF International and the National Cooperative Highway Research Program (2010). Greenhouse Gas Calculator for State Departments of Transportation (GreenDOT). Version .5 beta.

[119] U.S. Environmental Protection Agency (2007). "Clean Energy, eGRID2007 Version 1.1 Year 2005 GHG Annual Output Emission Rates." *http://cfpub.epa.gov/egridweb/ghg.cfm%20*.

[120] Southern California Edison (2010). "California Residents Have Lower Monthly Electric Bills than National Average, Despite Higher Electricity Costs." August 2010. *http://asset.sce.com/Documents/Customer%20Service%20-%20Rates/GRC_CaliforniaElectricBills.pdf*.

[121] Pacific Gas and Electric Company (2009). "Application Assessment of Bi-Level LED Parking Lot Lighting, Host Site: Raley's Supermarket, West Sacramento, California. February 2009. *http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/gateway_raleys.pdf*.

[122] U.S. Environmental Protection Agency (2007). "Clean Energy, eGRID2007 Version 1.1 Year 2005 GHG Annual Output Emission Rates." *http://cfpub.epa.gov/egridweb/ghg.cfm%20*.

[123] Southern California Edison (2010). "California Residents Have Lower Monthly Electric Bills than National Average, Despite Higher Electricity Costs." August 2010. *http://asset.sce.com/Documents/Customer%20Service%20-%20Rates/GRC_CaliforniaElectricBills.pdf*.

[124] California Department of Transportation (2011). *2012 Facilities Infrastructure Plan*. June 2011. *http://www.dot.ca.gov/hq/transprog/ctcbooks/2011/0611/115_4.14_2012_FacilityPlan.pdf*.

[125] National Research Council of Canada (2009). "Do LEED-certified buildings save energy? Yes, but…" August 2009. *http://archive.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc51142.pdf*.

[126] EVstudio (2009). "Cost per Square Foot of Commercial Construction by Region." August 2009. *http://evstudio.info/cost-per-square-foot-of-commercial-construction-by-region/*.

[127] DeMasi, Michael (2010). "Owners Spend $500K to Renovate Office Building Close by Capitol." *The Business Review*. November 26, 2010. *http://www.bizjournals.com/albany/print-edition/2010/11/26/owners-spend-500k-to-renovate-office.html*.