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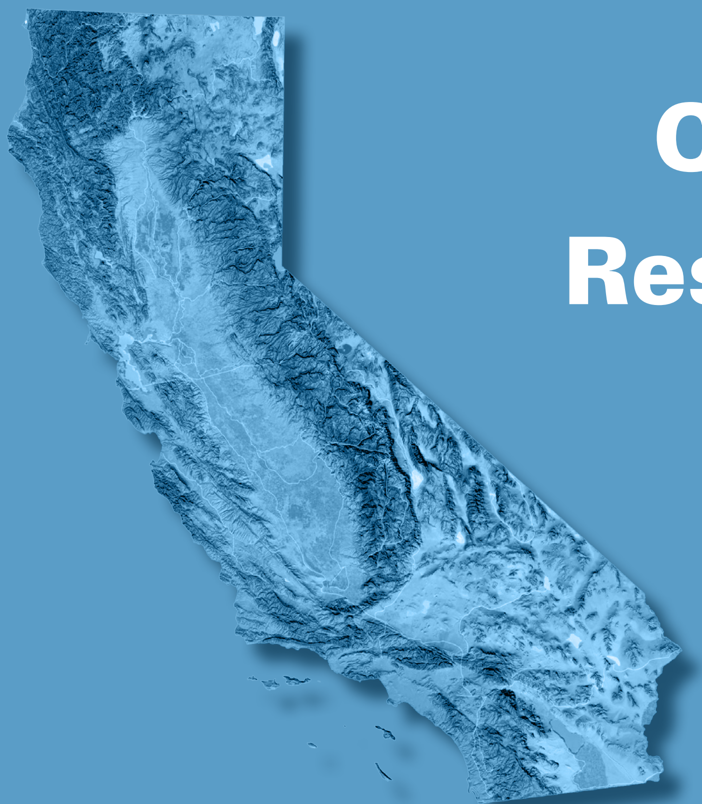

Climate Change Research Plan for California

CalEPA
California Environmental Protection Agency

Climate Change Research Plan for California

Climate Action Team

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Executive Summary

Over the past 25 years, the State of California has demonstrated national and international leadership in understanding regional climate change impacts, developing strategies for reducing greenhouse gas (GHG) emissions, and developing knowledge to support adaptation to projected impacts. Successfully negotiating climate change challenges will require integrating a sound scientific basis for climate preparedness into local planning, resource management, infrastructure, and public health, as well as introducing new strategies to reduce GHG emissions or increase carbon sequestration into nearly every sector of California's economy. This *Climate Change Research Plan* (hereafter the *Research Plan*) presents a strategy for developing the requisite knowledge through a targeted body of policy-relevant, California-specific research.

Need for a *Climate Change Research Plan*

The *Research Plan* continues support for climate policy and enhances statewide research collaboration. For the first time, it outlines statewide research priorities. It further demonstrates state agency coordination. Nearly 50 authors representing 16 state agencies were involved in authoring the *Research Plan*, which delineates California's most critical climate-related research gaps. This is an unprecedented effort resulting in the first comprehensive climate change research plan developed by any state.

California-sponsored research informs climate policy issues of unique importance to California. For example, State-sponsored research resulting from the First California Climate Assessment offered new California-specific scientific insights that were not available in 2006 from federal research products and that were instrumental to the passage of AB 32. The recent enhanced support for actionable climate research at the federal level also represents an excellent opportunity to develop a plan that aligns with the national research plan developed by the U.S. Global Change Research Program and contributes to the continuing dialogue with our federal partners. The research needs identified in California's *Research Plan* address gaps in knowledge that will help inform the State's ongoing activities to address climate change without duplicating federal research activities.

California's Climate-related Research Priorities

The *Research Plan* presents research gaps that should be tackled over the next three to five years to help identify, evaluate, refine, and implement successful mitigation and preparedness measures in California. The *Research Plan* will be complemented by more detailed research plans developed by different state agencies. Major research areas include:

Monitoring: Improve methods and indicators for monitoring to better inform policy makers and stakeholders about how California's climate is changing and the associated impacts.

Climate projections: Continue improving methods to "downscale" global climate projections to a scale appropriate for assessments and policies. Convert the large number of projections into probabilities that support risk assessments and into a set of representative projections to support vulnerability assessments and adaptation planning at state, regional, and local scales.

GHG accounting: Refine emissions accounting methods, especially for short-lived climate pollutants with high potential for warming the atmosphere and for difficult-to-quantify sectors such as agriculture, waste management, and forestry.

Reducing GHG emissions: Investigate the multiple pathways that could achieve climate goals related to emissions reductions from the energy, transportation, agriculture, water, waste management, and industrial sectors. Special attention should be paid to the option of electrification of energy services and provision of a low- or no-carbon electricity grid as a cornerstone. This research will advance both innovative technologies and understanding of consumer behavior. Prudent management of natural and working lands to sink carbon and preserve their health, without which their ability to sequester carbon will be compromised, is also a priority.

Preparing for a changing climate: Incorporate new climate science into a risk assessment framework using probabilistic climate and sea-level projections. Identify robust adaptation strategies that would fare well under multiple potential climate scenarios. Vulnerability to extreme events is a particularly critical research gap and it should be explored from local to statewide levels.

Socio-economic effects of climate impacts and policy responses: Analyze the effects of climate change and potential responses in important crosscutting areas, such as economics and jobs, consumer choice, and environmental justice. The State must continue to assess the impacts of climate change and related policies on all of California's diverse communities, including those most impacted by climate change.

Synergies of reducing emissions and climate risk: Give priority to research that would concurrently reduce emissions and make California more resilient to climate change, while providing other co-benefits. Identify situations where these two climate strategies might work at cross-purposes.

In addition to consideration of gaps in individual sectors, the *Research Plan* identifies crosscutting research areas that will require integration across sectors and coordinated support from multiple state agencies. For example, preparing for extreme events will require extensive coordination between public and private sectors as well as between local governments and state agencies. Similarly, analysis and projections of urban growth have implications for strategies to reduce GHG emissions in several sectors (e.g., transportation, built environment) as well as the vulnerability of communities to extreme events and vulnerability of species to habitat loss.

Integration and Implementation of the *Research Plan*

State agencies are aligned in their efforts to address climate change according to the best and latest science. Individual agencies will be responsible for implementing the *Research Plan*. Although few agencies have funds dedicated to climate change research, all agencies have climate-related activities that support actionable climate science. The Climate Action Team's Research Working Group will continue to facilitate coordination among agencies and with external groups including federal agencies, the international community, and private entities. The *Research Plan* advances a comprehensive research portfolio to support the climate goals articulated by the *Environmental Goals and Policy Report*, the AB 32 Scoping Plan (and the *First Update to the Climate Change Scoping Plan*), and *Safeguarding California*. The Fourth California Climate Assessment, to be completed in 2017, will be the first major, cross-sectoral effort to implement parts of this *Research Plan* and will be guided by the needs identified in the *Safeguarding California* report as well as ongoing interactions of the Research Working Group.

CHAPTER 1

Introduction

Climate change is the biggest environmental challenge of our time. California has long been a global leader in addressing climate-related issues through cutting-edge research and innovative climate policies. Governor Brown recently joined more than 500 world-renowned researchers and scientists in releasing a groundbreaking call to action on climate change and other global threats to humanity.[1] The 20-page consensus statement was produced at Governor Brown's request and has been signed by scientists from over 40 countries. The consensus statement connects key scientific findings from different fields into a clear warning and a call for immediate, substantial, and sustained action to preserve humanity's life support systems. The science in the consensus statement is confirmed in the October 2013 report of scientific findings by the Intergovernmental Panel on Climate Change (IPCC). The IPCC report states that "[h]uman influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea-level rise, and in changes in some climate extremes." The IPCC further concludes that "human influence has been the dominant cause of the observed warming since the mid-20th century" (IPCC 2013).

As shown in the report Indicators of Climate Change in California (Office of Environmental Health Hazard Assessment 2013), observations over the last several decades reveal clear signals of climate change and its effects in California. The growing body of scientific research shows unequivocally that this change is associated with the release of carbon dioxide and other greenhouse gases (GHGs) resulting from burning fossil fuels as well as other human activities. Using sophisticated computer models, climate research projects an unprecedented rate of rise in temperature with shifting patterns of precipitation and more extreme weather events in the future. Climate change and the efforts of the State to confront it will touch nearly every aspect of California's planning and investment for the future. Over the next few decades, significant reductions in GHG emissions will be necessary to avoid the worst consequences of climate change. At the same time, California must escalate and accelerate its efforts to safeguard the state from the already-observable climate change as well as the larger changes that will be unavoidable in the future. Scientific research sponsored by the State of California has provided new knowledge that has enabled California to respond with science-based policies. New, carefully targeted research is necessary to inform future policy development and implementation.

California Climate Policy Framework

California has adopted a comprehensive approach to address climate change. This approach follows the vision and cross-cutting goals articulated in the Governor's *Environmental Goals and Policy Report* (EGPR, Governor's Office of Planning and Research 2013) (Figure 1). The EGPR provides an overview of the State's environmental goals, including efforts to reduce GHG emissions, develop a clean economy, and provide clean air and water for all 50 million residents projected to live here by 2050. The comprehensive approach for climate change includes the following three interconnected elements:

1 Scientific Consensus on Maintaining Humanity's Life Support Systems in the 21st Century: Information for Policy Makers. May 21, 2013, http://mahb.stanford.edu/consensus-statement-from-global-scientists.

Figure 1: The three interconnected elements of California climate policy and associated comprehensive strategies, under the umbrella of environmental vision and goals. EGPR = *Environmental Goals and Policy Report*.[2]

1. **Reducing emissions: GHG emission reduction to reduce the impacts of climate change**

   Assembly Bill 32, the California Global Warming Solutions Act of 2006, requires a reduction of GHG emissions in California to 1990 levels by 2020. Executive Order S-3-05 specifies further reductions to 80 percent below 1990 levels by 2050. AB 32 also requires the State to draft a Scoping Plan that guides California's emission reduction goals and provides a comprehensive overview of the broad suite of state policies and programs designed to reduce GHG emissions. The California Air Resources Board (ARB) prepared the initial Scoping Plan in 2008 and has released the *First Update to the Climate Change Scoping Plan* (Scoping Plan Update) (California Air Resources Board 2008, 2014).

2. **Preparing for impacts: Increasing preparedness and resilience to safeguard California from a changing climate**

   The *Safeguarding California Plan* (California Natural Resources Agency 2014) updates the 2009 California Climate Adaptation Strategy (California Natural Resources Agency 2009) in light of advances in climate science and risk management options. The *Safeguarding California Plan* describes climate risks, work done to date, and recommendations for actions still needed across nine different sectors (Agriculture, Biodiversity and Habitat, Emergency Management, Energy, Forestry, Oceans and Coastal Ecosystems and Resources, Public Health, Transportation and Water). The *Safeguarding California Plan* also includes seven cross-sector strategies to safeguard California.

3. **Research to inform policy and research informed by policy needs: A strong research program to inform climate policy, advance climate change science, and support the development of tools that will effectively reduce emissions and safeguard California**

   California has invested significant resources in order to understand the impacts of climate change on California's natural and built environment, public health, and key economic sectors. Monitoring and numerical modeling of basic climate change parameters such as temperature, precipitation, and weather patterns form the basis for all other climate research that the State pursues. California's climate research helps develop and evaluate the strategies and technological advances needed to achieve emission reduction goals. The State has completed three climate change assessments. These assessments provide up-to-date research that informs and responds to California's policy needs.

2 *http://opr.ca.gov/s_egpr.php*

These three elements of California's climate strategy, coordinated through the interagency Climate Action Team (CAT)[3], inform one another and guide actions across state agencies to meet its climate goals. Updated research informs the State's choices about climate actions, while climate policies explicitly or implicitly pose questions that need new research to address. Together these elements help California design a sound course of action and make adjustments as needed to meet its climate goals.

The box below includes relevant definitions of terms used in climate change research and policy as they are used in the *Research Plan*.[4] In this document the terms "safeguarding," "preparedness," and "adaptation" refer to the same concept. The phrases "preparing for climate risks" and "reducing risks from climate change" also relate to this concept.

Scope of the *Research Plan*

California's *Climate Change Research Plan* (hereafter the *Research Plan*) provides a comprehensive and coordinated plan of research to inform California's climate change policies. The *Research Plan*, developed as a collaborative effort by the CAT agencies, synthesizes the knowledge gaps and research needs from various state climate-related plans and strategies. Foremost among these are the *Environmental Goals and Policy Report*, the Scoping Plan Update, and *Safeguarding California: Reducing Climate Risk*. The CAT agencies are aligned in their efforts to address climate change according to the best and latest science.

The *Research Plan* identifies important research initiatives without getting into the details of specific research projects. The details will be developed by agencies as they implement the *Research Plan* and carry out their own research programs. The *Research Plan* does not dictate how agencies should manage or select research projects, but rather reflects important areas for the research programs supported directly or indirectly by the agencies involved. Agencies will select specific projects according to their established procedures but will coordinate through the CAT Research Working Group. The issues in the *Research Plan* identify research needs over the next five years, with an emphasis on the next three years. The *Research Plan* encourages crosscutting research, which will require integration across sectors, across levels of government, and between the public and private sectors.

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3 To coordinate statewide efforts to implement climate change emission reduction programs and adaptation strategies, the State established the CAT, consisting of state agency secretaries and the heads of agencies, boards, and departments. The CAT is led by the Secretary of the California Environmental Protection Agency.

4 Definitions are adapted from the Intergovernmental Panel on Climate Change (IPCC) (*http://www.ipcc.ch/pdf/glossary/tar-ipcc-terms-en.pdf*).

Relevant Definitions for Climate Change Concepts

Mitigation: Human intervention to reduce GHG emissions or to increase sinks (e.g., carbon sequestration in forests).

Adaptation or Preparedness: Adjustments in human or natural systems to expected changes in the environment. Preparation for climate change refers to adjustments made in response to experienced or anticipated changes in the climate. California has adopted the term "safeguarding" for this concept.

Vulnerability: The degree to which a system is sensitive to, and able to respond to, the impacts associated with a changing climate, including climate variability and extreme events. Vulnerability depends on the rate and character of climate change, exposure to that change, the sensitivity of the system, and its capacity to adapt.

Resilience: The amount of change a system can be exposed to without irreversible damage and the ability of that system to bounce back after impact. Current research thinking on resilience includes the ability of systems to self-organize, to learn and adapt and thus to change to some extent so that the system can still be viable in changing conditions.

Given the broad scope of possible climate research topics, a set of guiding principles was developed to define the scope. The main principles are:

- The *Research Plan* should leverage the contributions of federal, local, and other partners whenever possible. State staff routinely communicate with these partners to ensure that the *Research Plan* is complementary to their efforts and minimizes duplication.
- The *Research Plan* should address issues specific to California—its environmental, economic, and policy landscapes—and its vulnerabilities to climate change.
- To the greatest extent feasible, research topics should generate actionable results. The *Research Plan* strongly encourages research that is co-designed with the end users so as to ensure better fit, user-friendliness, relevance, and appropriateness.
- Priorities should be given where knowledge gaps are large and the expected magnitude of the consequences of filling a gap is great, either in benefits gained or losses from climate change impacts avoided.
- The scope of the *Research Plan* is research to inform California's ongoing efforts to address climate change. Other important activities, such as collecting routine data, implementing regulations, and formulating effective strategies for communicating climate change science to citizens and policy makers, are not included in the *Research Plan*. All policies that go through the regulatory development process are subject to required analyses, including economic or cost analyses. Research may inform these analyses, but the analyses themselves are not considered research for the purposes of the *Research Plan*.
- The research agenda should not be constrained to initiatives that are already funded. Rather, the *Research Plan* will document research needs as the basis for funding requests.

The *Research Plan* is written for several audiences. Foremost, the *Research Plan* proposes priority research areas directly linked to policy makers' information needs. State policy makers can use this information to prioritize research areas, allocate funding, and build stronger coordination with other research programs. The *Research Plan* also informs scientific researchers and stakeholders about the proposed direction of research the State may pursue.

Organization of the *Research Plan*

The *Research Plan* starts with a short history of climate change research in California (Chapter 2). Chapters 3 and 4 outline research needs and priorities. Chapter 3 focuses on climate monitoring, analyses, and modeling and outlines a path to advance our understanding of the changes in California's climate that mitigation and adaptation strategies must consider. Chapter 4 describes the strategies and technological advances needed for reducing or mitigating GHG emissions and for preparing for the risks of climate change impacts in different sectors of the economy. To foster greater coordination and collaboration, Chapter 5 highlights several key crosscutting research themes and the needs of regional and local planning efforts. The *Research Plan* concludes with a broad overview of integration of segments of the *Research Plan* and its implementation (Chapter 6). Several appendices are being posted separately when completed that will provide more detailed information about past research and current knowledge gaps in climate-related science and strategies.

CHAPTER 2

Supporting Regional Climate Change Science in California

A Historical Perspective

In 1988, Assemblymember Byron Sher authored AB 4420, which required the California Energy Commission (Energy Commission) to lead the preparation of the first assessment of the potential impacts of climate change on California and of the options for reducing GHG emissions.

In the early 2000s, California initiated its own state-supported integrated climate research program via the Energy Commission's Public Interest Energy Research (PIER) program. This effort culminated in a report about potential impacts of climate change on energy, water resources, forestry, agriculture, coastal properties, and ecosystems. This study suggested that human adaptation to climate change would be costly for California, and that impacts on ecosystems would be severe, considering other stressors such as increased, unabated urbanization (Wilson et al. 2003). In the early 2000s, ARB also began sponsoring research to provide state-of-the-science global radiative forcing estimates for black carbon and other aerosols in conjunction with other GHGs in California (Chung and Seinfeld 2005).

In collaboration with state and federal agencies and the scientific community, PIER prepared a long-term integrated research plan on climate change for California in 2003. To implement this plan, the PIER program created a virtual California Climate Change Center as the first state-sponsored climate research program in the US. The California Climate Change Center, with research activities at almost all of the major research institutions in California, has produced more than 200 peer-reviewed publications and has been in charge of preparing three California Climate Change Assessments.[5] The Assessments have been multi-agency efforts that have been influential in climate planning. For example, the first Assessment released in 2006 was instrumental in the passage of AB 32. The most recent one, released in July 2012, started to explore vulnerability and adaptation options at the local and regional scales. In addition to supporting the California Climate Change Center, the vast majority of PIER funds supported the development of clean energy technologies that will be needed to reduce GHG emissions in California.

Most of the state agencies in California support climate change research, and their efforts have been of critical importance. For example, the Chief Hydrologist of the California Department of Water Resources released a study in 1991 (Roos 1991) showing that the contribution to annual water-year runoff occurring in the spring and summer months has been on a declining trend since records began in the early 1900s. This paper was very influential among water managers and scientists.

Since the issuance of Executive Order S-3-05 in 2005 and the passage of AB 32 in 2006, the pace of climate change research in California has increased substantially. For example, the California Department of Public Health and the Office of Environmental Health Hazard Assessment have published ground-breaking scientific papers on human mortality and morbidity from past heat waves (e.g., Basu et al. 2008) and postulated how climate change may aggravate these impacts in the future (e.g., Ostro et al. 2011).

AB 32 directed ARB to develop a scoping plan that describes the approaches that California will pursue to meet the near-term target for reducing GHG emissions. To support the development of the initial Scoping Plan and the recent Scoping Plan Update, ARB's research program initiated studies that assessed California's GHG inventory and emission reduction opportunities, ranging

5 *http://climatechange.ca.gov/climate_action_team/reports/climate_assessments.html*

from high global warming potential (GWP) industrial gases to voluntary strategies based on climate-friendly behavior. Major findings include an improved understanding of molecular species important to climate forcing such as black carbon, nitrous oxide, and hydrofluorocarbons. These research efforts have led directly to some of the regulations and programs now in place in California to meet the 2020 GHG emission target. The enactment of the Sustainable Communities and Climate Protection Act of 2008 (SB 375) led to the initiation of research in the areas of integrated land use, green buildings, and housing and transportation planning.

For about four decades, the Energy Commission and the California Public Utilities Commission (CPUC) have supported research on energy efficiency and clean energy generation technologies. This work continues today with multiple activities such as the creation by the CPUC of the Electric Program Investment Charge (EPIC) program. This work has established California's leadership in energy efficiency as well as its current endeavor to develop a low-carbon electricity generation system.

Since 2008, the CAT Research Working Group has coordinated State-sponsored climate change research and has created a catalog of relevant research projects supported by the State since the early 2000s. The catalog documents a balanced portfolio of projects supporting areas of research of importance both to reduce GHG emissions in California and to determine potential impacts and adaptation options.

From the beginning, state support for climate change science has been designed to complement and enhance research funded by the federal government. An example of an early federal effort is the creation of the California Application Program (CAP) at the Scripps Institution of Oceanography, University of California San Diego by the National Oceanic Atmospheric Administration (NOAA) in the late 1990s. The CAP program has focused on climate variability and climate change impacts on water resources, wildfire, and human health. In 2001, the US Global Change Research Program published the first national assessment report (National Assessment Synthesis Team 2000). As part of this work, several regional assessments reports were produced, including one that dealt exclusively with California (Wilkinson et al. 2002).

In the last few years, the federal government has established regional climate change research centers similar to the CAP program created by NOAA at Scripps Institution of Oceanography. Notable among them are the regional Climate Science Centers[6] (CSCs) established by the Department of the Interior (DOI) to develop tools and information to inform science-based climate change adaptation planning for natural resources, primarily at the landscape-level. Research priorities of the CSCs are partially informed by the Landscape Conservation Cooperatives[7] (LCCs), also established by the DOI to facilitate communication and coordination among partners. The LCCs are governed by steering committees comprised of federal and state agency representatives, non-governmental organizations, tribal entities, and others depending on the individual LCC. These LCC's have also funded research projects related to identifying climate risks and creating options for responding. Four LCCs fall within the borders of California. The DOI also established the WaterSMART program to prepare for climate change and other impacts on water supply. The U.S. Department of Agriculture (USDA) is establishing Regional Climate Hubs to deliver science-based knowledge and practical information to farmers, ranchers, and forest landowners to support decision making related to climate change.[8] A subsidiary Hub at the University of California Davis will focus its research on specialty crops and Southwestern forests. The *Research Plan* will leverage the results of these types of federal research programs.

Finally, several non-governmental research organizations have substantially contributed to the body of climate research in California using funds provided by sources such as foundations, federal agencies, and the State of California. Innovative public-private partnerships have formed to advance research around vulnerability assessments and other climate-related themes to support management actions. For example, Point Blue Conservation Science partnered with the California

6 *http://www.doi.gov/csc/index.cfm*
7 *http://www.doi.gov/lcc/index.cfm*
8 *http://www.usda.gov/oce/climate_change/regional_hubs.htm*

Department of Fish and Wildlife to complete a vulnerability assessment of bird species of special concern in 2011. Point Blue also developed comprehensive summaries of the ecoregional effects of climate change in California with special emphasis on consequences for wildlife.

In summary, California has supported regional climate change science for more than a decade. State agencies have coordinated their research programs with one another, private institutions, and the federal government. This body of research has been guided by the needs identified in state laws, executive orders, and other policy documents. The research results have also informed subsequent decision making in an iterative fashion. This *Research Plan* is being developed in this same tradition. Coordination and communication across state agencies ensures that the *Research Plan* builds on results of prior studies and leverages knowledge gained to address California's needs for adaptation and mitigation efforts.

CHAPTER 3

Climate Monitoring, Analysis, and Modeling

Introduction and Policy-relevant Questions

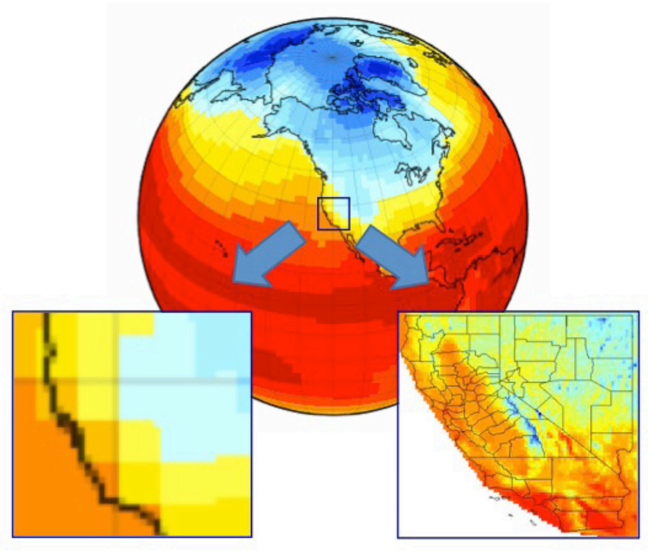
This chapter briefly summarizes the state-of-the-art climate monitoring and modeling in California and presents a proposed five-year research strategy designed to address the following overall policy-relevant questions:

- **Monitoring:** How is the climate changing throughout California? What are the reasons for these changes? Where are these changes most detectable and under what conditions? What monitoring strategies and capabilities will be necessary to track variations and changes in key climate measures including those for extreme events?
- **Climate Projections**: What do the latest generation of global models project regarding climate change in California? What additional improvements are needed to downscale climate model projections for California? What projection and analysis capabilities will be necessary for extreme events?
- **Support for Reducing GHG Emissions and Risks from Climate Change:** What additional improvements in climate modeling are needed to support improved vulnerability assessments that lead to better adaptation planning by state and local governments and private entities to prepare for climate risks? What additional variables germane to public health, infrastructure, and the environment should be added to climate projections for California?

Summary of Past Research

Global climate models (GCMs) are used to estimate how the Earth's climate will evolve under different global GHG emission paths. These global models use relatively large grid cells (see lower left map in Figure 2) that cannot resolve some important climate features within relatively small regions such as California. For this reason, two tools are used to further "downscale" the outputs from global climate models: statistical methods and dynamic regional climate models (see the downscaled field in the lower right map in Figure 2). Statistical downscaling methods use mathematical relationships between large-scale features of the climate (e.g., high atmospheric pressure systems) and local weather/climate conditions. Dynamic regional climate models simulate future climates based upon fundamental physical laws (e.g., conservation of mass and energy). The State has invested in cutting-edge research to develop and refine both statistical and dynamic downscaling models tailored to the geography of California. Further improvements in downscaling techniques are desirable, as well as simulation of other meteorological factors (e.g., aerosols, black carbon, land

Figure 2. Comparison of global climate model (left) and downscaled model (right) grid scale.



use) to inform mitigation and adaptation efforts. Moreover, statistical regional climate models developed for California only project temperature and precipitation variables. Other variables, including atmospheric moisture and winds, are needed to fully inform projections of changes in extreme events and climate impacts. State-sponsored research has shown that dynamic models driven directly by the outputs from global climate models generate values that are offset from observed values. These offsets, technically known as biases, must be corrected before using results from impact and adaptation studies (Pierce et al., 2013).

In 2003, the State of California, via the Energy Commission's PIER Program, adopted a long-term strategy to track how climate is changing in California, to assess the reasons for these changes, and to produce 'probabilistic' climate projections for California that would be suitable for both research and long-term planning (Franco et al. 2003). This effort has resulted in a myriad of publications. This work has been fundamental for the last generation of California climate change assessments and long-term planning conducted by different state agencies.

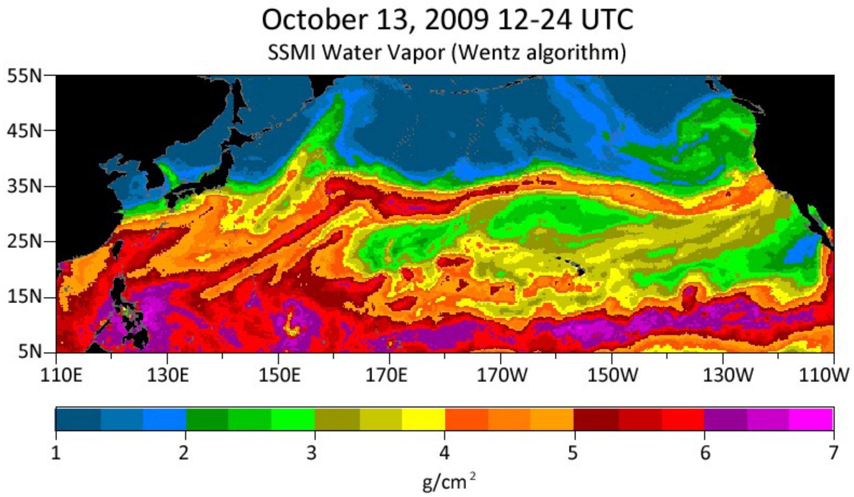
The State has also supported work on annual sea-level rise projections that created scenarios fully compatible with the climate scenarios described in the above paragraph (Cayan et al. 2008; Cayan et al. 2009). Researchers, led by Scripps Institution of Oceanography, have also produced hourly sea-level rise scenarios for both the Second and Third California Assessments to investigate the possibility of extreme sea-level events. More recently, they have considered the effect of ocean waves in the open ocean driven mainly by winds far from California that travel to our coasts (Graham et al. 2013) and contribute to the dynamics affecting how far water can penetrate inland (i.e., wave run-up), which affects erosion of dunes and cliffs (Bromirski et al. 2012). Finally, a report from the National Academy of Sciences (NAS) further investigated how the annual average sea-level rise would change in the future considering, among other things, the vertical movement of coastal lands (e.g., subsidence) (National Research Council 2012). Prior assessments of sea-level rise used in the California Assessments are contained within the range estimated by NAS (Franco et al. 2011). Recent sea-level rise studies point to the need for more detailed observations to track land uplift and subsidence, wave run-up, and the potential for periods of rapid sea-level rise associated with ocean circulation variability characterized by phenomena such as the Pacific Decadal Oscillation.

In the area of climate monitoring, the California Energy Commission and the California Department of Water Resources (DWR) have supported the creation of the *California Climate Tracker* at the Western Regional Climate Center.[9] This website uses data from hundreds of meteorological stations in California and a standard method to continuously report how temperature and precipitation levels are changing in climatologically homogeneous regions of California (Abatzoglou et al. 2009). Cal-Adapt[10], the State's resource for visualizing projected climate change trends and associated risks, provides similar information, but using simulations of historical and future conditions. To more adequately track how climate (and its variability) is changing in California, however, the current network of meteorological and hydrological stations need to be improved, particularly by increasing the density of stations in coastal, mountain, and urban areas.

The DWR has also invested in a unique state-of-the-art network of sensors that can track atmospheric rivers (AR). ARs are intermittent narrow bands of concentrated moisture in the atmosphere that transport enormous amounts of water to the Western U.S. and are a key determinant of California's water resources (Figure 3). This monitoring capability is essential to tracking AR conditions and identifying conditions leading to flooding.

9 *http://www.wrcc.dri.edu/monitor/cal-mon/*
10 *http://cal-adapt.org/*

Figure 3. Data from NOAA showing an atmospheric river flowing across the Pacific Ocean toward California. This storm dropped 15 inches of rain in the Santa Lucia Mountains on California's central coast and over 10 inches in the Santa Cruz Mountains.



Several other efforts involve strong collaboration between the State of California and federal agencies, in particular NOAA. For brevity, we cite but do not discuss here other relevant efforts partially or fully supported by the Air Resources Board (e.g., CalNex[11]), Department of Water Resources (e.g., Hydrometeorological Testbed[12], CalWater), and the Energy Commission (CalWater[13]).

Research Agenda for the Next Five Years

This section discusses research needs over the next five years to inform ongoing efforts to address climate change. The research agenda is supported by additional material to be published in Appendix B. Continued cooperation with federal partners will be essential to leverage limited state resources.

Monitoring

To monitor how California's climate is changing and to uncover the reasons for those changes:

> **Precipitation:** Continue supporting work on atmospheric rivers and field studies on the role of aerosols and other factors in our regional climate to better characterize local-scale precipitation variability including extremes.
>
> **Land uplift:** Measure the relative vertical movement of lands affected by sea-level rise through collaboration with federal agencies.

To determine where climate changes are most detectable and to assess potential monitoring strategies and capabilities:

> **Sensor networks:** Support the monitoring of appropriate measures, including climatic and hydrological conditions. This work requires dense networks of sensors in areas with strong gradients (e.g., coastal, urban, and mountainous areas) to improve high spatial resolution downscaling techniques.

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11 *http://www.arb.ca.gov/research/calnex2010/calnex2010.htm*
12 *http://hmt.noaa.gov/*
13 *http://atofms.ucsd.edu/content/calwater-2011*

Technologies for monitoring: Evaluate the capability of current monitoring networks to track climate change metrics important to the State. Determine how new observation technologies including satellite data can be incorporated.

Climate Projections

To explore what the latest generation of global models project regarding climate change in California and to improve downscaling methods for California, including those necessary to model extreme events:

Climate scenarios: Develop the next generation of climate scenarios that produce relevant regional information that can support engineering design and long-term planning.

Statistical downscaling methods: Continue developing, testing, and improving statistical downscaling models, including the creation of new statistical downscaling techniques that are driven by large-scale climatic features that are supposed to be modeled relatively well by the global climate models. Investigate performance of statistical downscaling techniques in simulating extreme events. This area of work also includes the development of improved bias-correction techniques.

Dynamic models: Continue improving dynamic climate models to add, for example, the simulation of changes in vegetation patterns that in turn affect regional climate. Use dynamic models to explore crucial resource and vulnerability issues (e.g., marine layer, Santa Ana winds, and Bay/Delta storm situations). Coordinate this work with federal agencies.

Model comparisons: Use dynamic climate models to identify the physical parameters driving differences among various climate projections. Create climate projections for certain periods (e.g., 1936 to 1965) and check their results with the results of the statistical models (inter-comparison of regional climate models). Ideally, statistical and dynamic models should produce, in a broad sense, similar results (after bias-correction of the dynamic models). Differences in results should be investigated and used to assist with further improvements for both statistical and dynamic models.

Extreme events: Investigate performance of global and regional climate models, in comparison to historical observations, in producing the patterns and conditions responsible for extreme events (heat waves, floods, drought, coastal storms, and fire-prone conditions).

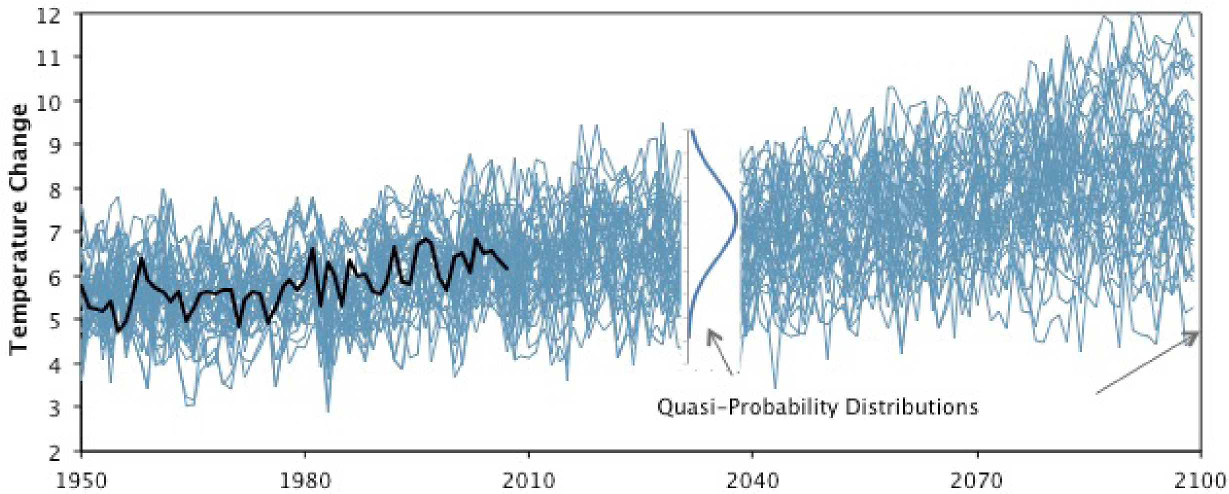
Forecasts: Explore the use of day-ahead and seasonal probabilistic forecasts to prepare for extreme events and decadal probabilistic projections for long-term planning.

Support for Reducing GHG Emissions and Risks from Climate Change

To improve climate modeling to better support vulnerability assessments and adaptation planning, including adding new variables germane to specific sectors and agreeing upon a common set of climate scenarios:

Quasi-probabilistic projections: Develop new 'quasi-probabilistic' climate projections for California to support risk assessment, planning, and resource management. Hundreds of climate scenarios will be available for California from various sources from both dynamic and statistical models. The State should embrace this multiplicity of scenarios and use them to inform the development of probabilistic climate projections. These quasi-probabilistic estimates assign likelihoods to the different scenarios that can be used in risk assessment frameworks. Figure 4 illustrates this concept showing the envelope of climate simulations for both the historical period and the rest of this century. The black line represents actual observations, and the blue lines different realizations from the regional climate models that are used to develop the quasi-probability distribution of outcomes at the end of this century shown on the right of Figure 4. This scientific work can inform the selection of a set of 'representative' climate scenarios to frame impact and adaptation studies.

Figure 4. Conceptual diagram suggesting how quasi-probabilistic climate projections could be derived from available climate simulations.



Derived metrics: Support the creation of secondary products of climate projections (e.g., extreme temperature indices tailored to sectors such as water, energy, public health, and transportation). Disseminate this information through Cal-Adapt.[14]

Additional variables: Identify and model additional variables (e.g., relative humidity, direct solar radiation) beyond temperature and precipitation as needed to inform vulnerability assessments and adaptation planning. The variables will be selected in consultation with researchers working on adaptation issues, research managers, and stakeholders.

Model spatial resolution: Increase the number of locations where meteorological and hydrological variables are calculated to match regional and state needs. Increase the spatial and temporal resolution of downscaled projections to inform local and regional planning within the limits that are scientifically defensible.

Extreme scenarios: Develop and explore low probability, high consequence climate scenarios informed by the paleoclimatic record and past historical outcomes but not captured by the probabilistic climate projections. Explore scenarios of extreme coastal storms and inundation, in a manner similar to ARkStorm.[15]

Sea-level rise: Develop probabilistic relative regional sea-level rise projections compatible with the climate projections that take into account multiple factors such as ocean warming, circulation changes, land ice melting, and vertical movement of coastal lands.

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14 *http://cal-adapt.org/*

15 ARkStorm is a hypothetical "superstorm" scenario developed by USGS to describe a scientifically plausible extreme event similar to the flooding of 1861-1862.

CHAPTER 4

Reducing Greenhouse Gas Emissions and Safeguarding California from Climate Risks

Introduction and Policy-relevant Questions

As described in Chapter 1, California is committed to reducing its GHG emissions and safeguarding the state from the unavoidable impacts of a changing climate. Actions that reduce GHG emissions as well as decrease risks from climate change are of particular value to the state. These "complementary" actions provide greater benefits with limited resources and should be identified and implemented by the State. For example, increasing the carbon content in agricultural soils (a carbon mitigation option) may often result in an increased ability of soils to retain moisture and allow growers to better cope with droughts that may become more frequent with climate change (Lobell et al. 2013). By diverting organics from landfills to produce compost, GHG emissions are reduced at the landfill and the finished compost is useful for soil restoration. In the same vein, the implementation of smart growth measures may often result in lower energy consumption in urban areas but can also reduce the vulnerability to climate change if growth occurs in areas that would be less prone to climate impacts.

There are, however, investment options that do not necessarily result in co-benefits between mitigation and reducing climate risks (Moser 2012). Liverman et al. (2013) describe a number of mitigation or adaptation strategies that potentially either support or undermine one another. Often the strategies are chosen independently through different mandates and even governance structures. This "complementarity" approach only incidentally provides co-benefits in the other area, but does not necessarily maximize them. By planning for both mitigation and adaptation synergistically, however, it would be possible to optimize the benefits of both, and thus reduce trade-offs when they could potentially be counterproductive (Duguma et al. 2014). State and local decision makers need greater awareness and understanding of the potential positive synergies and negative trade-offs between adaptation and mitigation. Concerted analysis and tool development in this area would both advance the state of knowledge and be immediately practice-relevant.

This chapter lays out a proposed research agenda to inform GHG emission accounting, activities to reduce GHG emissions, and safeguarding policies and strategies. The chapter begins with a discussion of GHG emissions in California and research opportunities to refine accounting of GHG emissions. The chapter then presents sector-by-sector research needs that are aligned with the Scoping Plan Update, the *Safeguarding California Plan*, and other climate policy documents. Pervading all sectors are the needs for informative performance metrics on the effectiveness of mitigation and adaptation strategies and for effective methods to communicate risk.

The following overarching policy-relevant questions guide the research agenda for this chapter:

- **GHG Accounting:** What new emissions accounting methods can help validate estimates of GHG emissions, especially for non-CO_2 gases such as short-lived climate pollutants and in difficult-to-quantify sectors such as agriculture, waste, and forestry? What are the areas of greatest uncertainty?
- **Reducing GHG Emissions:** What are the most effective strategies and technological, policy, economic, or management innovations to significantly reduce GHG emissions in all sectors of the economy? What are their

economic, public health, and environmental impacts and co-benefits?

- **Reducing Risks from Climate Change:** How vulnerable are the people, resources, and infrastructure of California to climate change impacts, and how is this vulnerability distributed among groups? What are the most effective technological, policy, economic, or management innovations to safeguard the state from these impacts?
- **Integration:** Which strategies serve to simultaneously reduce GHG emissions and the risk from climate change? In which cases do strategies produce trade-offs between the two?

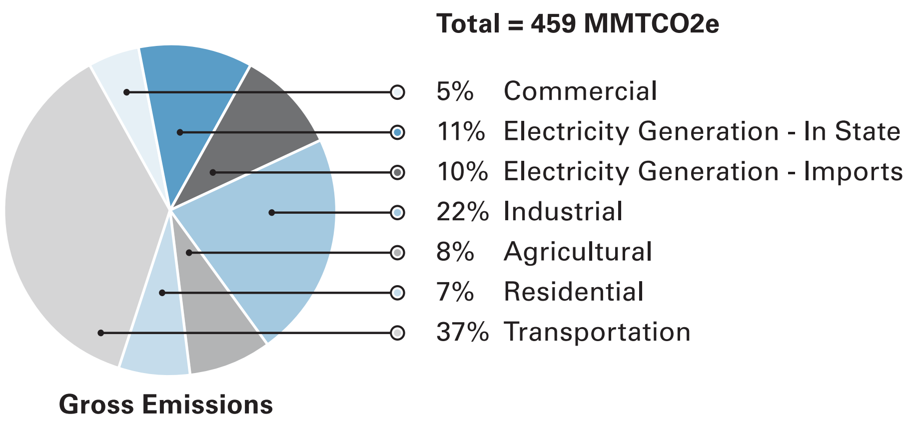
Policy-relevant questions for specific sectors will be found in Appendix C, D, and E, along with additional material to support and elaborate on the research agenda. Appendix F provides a synthesis of several important crosscutting research topics.

Greenhouse Gas Emissions Accounting in California and Research Needs

Carbon dioxide (CO_2) is the dominant GHG emitted in California (85 percent in 2012). The combustion of fossil fuels releases the vast majority of these emissions. The remaining GHGs—primarily methane (CH_4), nitrous oxide (N_2O), and fluorinated gases (F-gases)—currently contribute about 15 percent to the California GHG inventory.[16]

As shown in Figure 5, energy consumption in the transportation sector is the largest source of emissions, followed by emissions from the industrial and the electricity generation sectors. (Note that oil and gas operations (e.g., oil extraction) are counted in the industrial sector).

Figure 5. California's 2012 GHG emissions by economic sector.



Data source: California Air Resources Board 2012 GHG Inventory.[17]

An accurate inventory of GHG emissions and carbon sinks in California is essential to track progress and demonstrate compliance with emissions reduction targets and goals. It can also help to identify the opportunities with the greatest impact on reductions. California develops its official GHG inventory using quality-assured and verified emissions reporting combined with emission inventory methodologies used to calculate certain categories of GHG emissions. Research projects in California are being used to help validate the statewide emissions inventory. Measurements of the concentration of GHGs in the atmosphere (from tall towers, ground-based measurements, research aircraft, satellite data, and other methods) also help determine the origins of GHG emissions in California. Studies supported by the Energy Commission, the Air Resources Board, and NOAA suggest that, in general, carbon dioxide emission estimates in the

16 *http://www.arb.ca.gov/cc/inventory/pubs/reports/ghg_inventory_00-12_report.pdf*

17 The 2014 edition of the GHG inventory represents a transition to global warming potentials (GWPs) in the IPCC 4th Assessment Report (AR4).

GHG inventory are reasonably accurate, but nitrous oxide and methane emissions estimates may underestimate actual emissions.

Research agenda for the next five years

To advance science related to GHG monitoring, refine GHG emission accounting, and determine areas of greatest uncertainty:

Biogenic sources: Improve accounting for biogenic methane and nitrous oxide emissions from poorly characterized area sources, such as nitrogen fertilizer and manure, which can also improve quantification of air quality effects. Coordinate with federal agencies to include California derived research findings on agriculture and GHG emissions into existing tools that provide whole farm and ranch carbon and GHG accounting systems (e.g., COMET-FARM).[18]

Land use change impacts on carbon stocks and albedo[19]: Quantify emissions associated with agricultural and urban expansion, as well as climate-forcing impacts associated with changes in albedo.

Emissions from the natural gas and oil systems: Improve the accounting of emissions at the source level, in terms of the numbers, amounts, and locations of fugitive methane leaks.

Emissions from the combustion of fossil fuels: Continue to improve alignment of data related to the amount of fossil fuels combusted in California with the measurement of ambient CO_2 concentrations at different temporal and geographical scales.

Natural sources and sinks: Quantify carbon and nitrogen cycling (emissions and storage) in both agricultural- and non-agricultural soils and sediments of different management practices (e.g., wetlands, riparian areas, and reservoirs). Improve understanding of baseline conditions, processes and projected trends in forestlands (biomass, carbon stocks, forest health, disturbances, species migration, and genetics) in relation to climate. Develop improved accounting methods for carbon stocks in California lands to determine if, as suggested by preliminary research, a less dense forest stores more carbon than the currently overgrown forest. If this is correct, the concern that forest thinning might decrease carbon stored in forests may be incorrect. Compile baseline data on urban forests to adequately characterize urban tree canopy coverage and structure as an important tool for helping to mitigate the urban heat island effect. Complete an emissions inventory of the Sacramento-San Joaquin Delta to document the ongoing carbon emissions and subsidence that result from agricultural practices on the peat soils of the Delta.

Water system sources: Improve collection of data documenting water use and associated GHG emissions. In addition, improve collection of data documenting energy used in new desalination technologies, groundwater pumping, recycled water use, and water treatment processes to improve understanding of how energy is used by water utilities and urban water consumers. In some cases, research is needed to develop the tools that can assist with data collection.

Short-lived climate pollutants (SLCP): Improve understanding of sources and scale of emissions of short-lived climate pollutants – including methane, black carbon, and hydrofluorocarbons – and further quantify the GHG and air quality co-benefits associated with reducing methane, particulate matter, and black carbon.

Validation of emission inventories: Continue to reduce the uncertainties associated with emissions inventories, which will help refine attribution of emissions to sources.

18 *http://cometfarm.nrel.colostate.edu/*

19 Albedo is the ratio of reflected radiation from the surface to incident radiation upon it. Low albedo means that more of the radiation is absorbed by the surface material. Generally, things like snow have high albedo, whereas asphalt has low albedo.

Agriculture

Agriculture is a critical economic sector of California that provides a safe, reliable, diverse, and nutritious source of food for millions of people. Agriculture also provides many other societal benefits, including employment opportunities, wine and fiber production, potential carbon storage in soils, and other ecosystem services from both crop and animal sub-sectors.

Measures were identified in the 2008 AB 32 Scoping Plan to address specific GHG emissions from agriculture. These gases include methane, carbon dioxide, and nitrous oxide. The mitigation of GHGs from agricultural sources and activities requires considerable investment in research given the complex dynamics of farming and its associated operations. It is more difficult to quantify and verify emissions reductions from agricultural operations than from point source emitters.

Compared to other sectors, California agriculture generates a relatively small fraction of the overall GHG emissions in the state (8 percent in 2012, as shown in Figure 5). The net contribution of agriculture to GHG emissions could further decrease in the future, considering the potential for management practices that capture and biologically store carbon in agricultural soil such as organic matter buildup. Additional research is necessary to fully identify GHG emissions sources and inform optimal mitigation options in the sector including the participation in agricultural carbon markets.

The importance of research studies has been recognized not only for mitigation of GHGs but also as an adaptation measure by the recently organized CDFA Specialty Crop Climate Change Consortium (California Department of Food and Agriculture 2013). The Consortium consists of growers, agricultural support services personnel, scientists, and commodity groups/agricultural association members. In keeping with the Consortium's recommendations, the CAT encourages agricultural research to include an outreach component so that research findings inform on-the-ground mitigation and adaptation efforts by California farmers as they face the impacts of climate change. CDFA's Fertilizer Research and Education Program is also funding and facilitating research on how to reduce nitrous oxide greenhouse gas emissions from nitrogen fertilizer applications.

Research agenda for the next five years

To evaluate strategies to reduce GHG emissions and the vulnerability of California's agricultural sector to climate risk:

Farmland conservation: Characterize the impacts of continued urbanization of farmland on GHG emissions under different development scenarios and land use policies.

Nitrogen and manure management: Increase the understanding of the interplay of nitrogen forms, soil conditions, and management practices that affect nitrous oxide emissions specific to California conventional and organic agricultural systems, including the use of fertigation (the application of fertilizer through irrigation), cover crops, and slow release nitrogen fertilizers. Consider and explore the relationship between nitrogen management and carbon sequestration. Support field studies of the kinetics of nitrogen mineralization under various conditions to determine the application rates that would prevent the adverse impacts and maximize the environmental benefits of applying manure or compost to agricultural soils. Generate information on nitrogen supply-demand relationships from these studies to provide a scientific basis for adjusting the application rate and timing of manure or compost in the field to reduce GHG emissions.

Crop and livestock management: Develop information to maximize the GHG mitigation potential through optimal selection and management of crop rotation based on individual site characteristics and cropping systems. Conduct research at test plots to determine the effectiveness of potential adaptation measures such as structural, mechanical, or biological methods to reduce crop heat stress and the switch to alternative crops or varieties that may be better suited to future conditions. Develop crop-breeding options to increase heat and cold tolerance and to identify low-chill varieties of temperate fruit and nut crops. Develop varieties that are more resilient to pests that may arrive in California under a warmer climate. Implement animal breeding research programs to increase resistance to anticipated heat extremes and diseases associated with a warmer climate.

Water management in a changing climate: Investigate innovative methods to supply water more reliably to the agricultural sector and to use water more efficiently. For example, flood management projects could be designed to allow floodwaters to recharge groundwater, which would be available during drought periods to farmers and other users. Increasing soil carbon on croplands and rangelands, through the application of compost and other strategies, would increase soil water holding capacity and reduce the amount of water needed for irrigation. Investigate other soil management techniques, such as cover cropping, minimum tillage, and soil amendments, as well as dry farming and on-farm ponds, for their potential to store water, reduce overall water use, and reduce energy-related GHGs.

To address the economic and environmental impacts and co-benefits of potential emission reduction strategies:

Carbon sequestration: Quantify the benefits of techniques for storing carbon in soils (e.g., compost application to rangelands, use of winter cover crops, and application of biochar) through management practices.

Economics: Examine the economic impacts of GHG mitigation efforts, including also the costs of taking no action. Quantify the economic and environmental effects of adaptation co-benefits associated with agricultural GHG mitigation practices. Investigate the costs, benefits, and risks associated with relocation of crops and animals to suitable climates.

To study the vulnerability of agricultural communities and resources to climate change impacts, and costs and benefits associated with reducing agricultural sector emissions:

Threats to coastal and San Francisco Bay Delta regions from sea-level rise, and threats to agricultural food production regions of the state from extreme event related flooding: Identify the areas that are most vulnerable to saltwater intrusion in the state as a result of projected sea-level rise. Identify agricultural areas in the state most at risk of catastrophic flooding from heavy precipitation events and potential infrastructure failures (e.g., levees).

Conservation tillage: Assess the potential of conservation tillage, including when used in conjunction with other soil management practices, for soil carbon sequestration in California and its effects on crop yields and pest management.

Biodiversity and Habitat

Responsible management of California's natural lands and habitat provides valuable ecosystem services and can provide resilience in the face of a changing climate. Collaboration and coordination with regional, local, and federal partners will play an important role in research on biodiversity and habitat. In particular, there is a need to integrate state research needs with those of other partners such as the LCCs and USGS Southwest Climate Science Center. Collaboration is also essential with the forestry, wetlands, rangeland, and oceans sectors, whose management must also sustain biodiversity.

Research agenda for the next five years

To address the vulnerability of California's biological resources to climate change impacts and the effectiveness of strategies and technological innovations to safeguard the state from these impacts:

Habitat and species-related baseline conditions: Develop information against which to compare future changes in biodiversity, including high-resolution vegetation maps, species range maps, and statewide habitat maps. Complete vegetation mapping following the National Vegetation Mapping Standard. Identify current land use and land use policies, permitting, and planning statuses to understand how these features affect and should be included in habitat restoration and land acquisition decisions.

Climate impacts and risks to biodiversity: Determine impacts of climate change on the spread of invasive species, pests, pathogens, and diseases that affect the health of terrestrial and marine ecosystem and pose stresses to native fish, wildlife, and plants. Improve understanding of how shifts in the timing of life cycle events (e.g., breeding, food availability, and migration) as a result of a changing climate will impact species. Identify critical habitat, refugia, and wildlife corridors that can allow for species movement across the landscape as climatic changes occur and suitable habitat locations potentially shift. Improve understanding of ecosystem services and the impacts of climate change and of mitigation and adaptation strategies. Assess species' tolerance and ability to adapt to short- and long-term climate disturbances. Investigate the impact of more frequent and intense wildfires on sensitive species and ecosystem conversion. Identify the impacts of extreme events (e.g., heat waves, flood, and drought) on ecosystem function, resilience, and services.

Vulnerability assessment: Conduct comprehensive statewide climate vulnerability assessment at the habitat scale for terrestrial and marine environments. Assess vulnerability from risks to rare plant species, birds, reptiles and amphibians, mammals, invertebrates, and aquatic species of concern.

Adaptation Strategies and Actions: Utilize climate impact and vulnerability information to develop new, or update existing, adaptation strategies and actions where appropriate. Develop decision-support tools to target the location and timing of restoration activities that reduce climate risk. Conduct finer-scale corridor analyses to inform land acquisition and investment decisions. Evaluate the costs, benefits, and effectiveness of adaptation options for biodiversity.

Emergency Management

Emergency management includes actions to prepare for, mitigate against, respond to, and recover from emergencies that impact our communities, critical infrastructure, and resources by lessening the likelihood, severity, and duration of the consequences of the incident. Climate impacts, such as more extreme weather events, sea-level rise, changing temperature and precipitation patterns, and more severe and frequent wildfires, will increase risks and uncertainties that will affect all phases of emergency management. Incorporating projected climate impacts into emergency management can help reduce exposure and vulnerability and increase the resilience of California communities. Vulnerability assessments are needed to better understand risks posed to populations, facilities, and critical infrastructure from the impacts of a changing climate. Assessments will also need to investigate the combined and cascading effects from multiple hazard events. Multi-hazard mitigation plans form the foundation for a community's short and long-term strategy to reduce disaster losses. By placing greater emphasis on integrating hazard mitigation into state and local plans, development codes and land-use ordinances, some of the negative impacts of disasters may be avoided or reduced. However, research is needed to identify how to best incorporate climate change into all phases of emergency management, since all are necessary components of resilience. A plan that focuses on one to the exclusion of the others will not support true resiliency.

Research agenda for the next five years

To assess the vulnerability of the people, resources, and infrastructure of California to climate change impacts and to identify effective strategies:

> **Vulnerability assessment:** Expand and refine information about climate vulnerabilities of California's populations, infrastructure, property, food and agriculture, and biodiversity. Expand monitoring of extreme weather events such as flood, drought, heat, fire, and related losses to inform emergency management. Coordinate among sectors on research and monitoring funding, information sharing, and well-integrated actions to build safe and healthy communities.
>
> **Adaptation strategies**: Examine possible strategies to reduce vulnerabilities. Assess the adequacy of surge and response capacity, the ability of the emergency system to handle a number of cases that rapidly exceeds the system's routine capacity, in light of climate projections for more frequent and more severe weather events such as flooding, fire, drought, extreme heat, and storms (especially when coupled with sea-level rise). Assess the adequacy of California's current emergency surge and response capacities.

Energy Services: Electricity and Natural Gas

Energy services are provided by electricity (e.g., air conditioning, illumination) and natural gas (e.g., space heating, process heat for industrial processes). Together the fuels discussed in this section represent about 40 percent of California GHG emissions. Transportation energy services (e.g., movement of people and goods) are addressed in the Transportation section below.

Achieving the climate policy goals for California's energy system will require innovative new clean technologies and strategies deployed in a smart, efficient manner. Government-funded research, development, and demonstration (RD&D) helps advance the state's energy system towards this vision.[20] Publicly funded RD&D fills critical funding gaps within the energy innovation pipeline that are considered the greatest barriers to innovative energy prototypes and innovative entrepreneurs entering the marketplace. Results from RD&D at these critical stages enable these technologies to attract investment funding, demonstrate their merits to end-use customers and regulators, and demonstrate their eligibility in market support programs. Both technology push and market pull are needed to deploy these clean energy technologies and energy-efficient appliances and reduce GHG emissions.

The benefits of energy technology research, especially for energy efficiency, far outweigh direct research cost. Between 1999 and 2008, the Energy Commission invested $27.6 million in energy efficiency research projects, which directly contributed to changes to California's Building and Appliance Energy Efficiency Regulations that are estimated to have saved California ratepayers more than $10 billion between 2005 and 2025.

Multiple energy pathways can result in deep GHG emission reductions. Recent studies conclude that there are multiple technology options for the energy sector for deep cuts in GHG emissions commensurate with the California's 2050 goal (Williams et al. 2012, Greenblatt and Long 2012, and Wei et al. 2013). Since it is impossible to know with certainty what future technology options will be available in commercial scale that consumers will choose, the State should have a broad research portfolio that facilitates testing and improvements driven by market conditions.

20 A number of public programs have supported RD&D for California's electricity and natural gas sectors to reduce GHG emissions and build resilience into the energy system. The Energy Commission's PIER Program was authorized to "develop, and help bring to market, energy technologies that provide increased environmental benefits, greater system reliability, and lower system costs." In 2011, the Legislature did not reauthorize the funding mechanism for the PIER Electricity Program. The new EPIC program will provide strategic investments to advance the next- generation of clean energy technologies, tools, and strategies similar to PIER. The natural gas counterpart to PIER and EPIC is the Public Interest Energy Research Natural Gas Program. CPUC funds an RD&D program under the California Solar Initiative. Energy agencies in California work very closely with U.S. DOE to align state efforts and leverage research investments, particularly through the Advanced Research Projects Agency-Energy (ARPA-E) and the West Coast Regional Carbon Sequestration Partnership (WESTCARB).

The energy system is vulnerable to climate impacts. Multiple lines of evidence clearly demonstrate that the energy system is more vulnerable to climate impacts than previously believed (California Energy Commission 2013, Stoms et al. 2013). For example, increased temperatures will decrease the efficiency of thermal power plants, transformers, and transmission and distribution lines and increase electricity demand. Since all of these detrimental effects are accentuated and happen simultaneously during heat waves, the cumulative impacts on the energy system would be more significant without adaptation measures. Additional research is needed to better understand how efforts to reduce emissions and safeguard the energy sector align.

Research agenda for the next five years

California has a strong track record of successful investments on energy-related technology research that has helped minimize load growth over the last several decades. Moving forward, California should build on this success and expand these programs in an effort to maximize efficiency as well as reduce GHG emissions. As indicated above, California should continue with a diverse research portfolio, guided by the loading order of preferred energy resources.[21] Further details on the agenda are provided in the EPIC triennial investment plan (California Energy Commission 2012).

To support strategies and technological innovations necessary to significantly reduce GHG emissions and climate risk and their economic, public health, and environmental impacts or co-benefits, to identify synergies and trade-offs between mitigation and adaptation strategies, and to assess the vulnerability of the energy sector to climate change:

> **Energy efficiency and demand response:** Develop next-generation energy efficiency technologies and strategies to cost-effectively achieve targets and goals identified in the CPUC's Long Term Energy Efficiency Strategic Plan as well as AB 758 (Skinner, Chapter 470, Statutes of 2009), which addresses retrofitting existing buildings. Investigate options to improve energy efficiency in buildings and other systems to reduce the energy sector's vulnerability to climate change while reducing GHG emissions. Develop and demonstrate advanced capabilities of demand response to increase grid flexibility.

> **Renewable energy, distributed generation, and energy storage:** Develop and demonstrate utility-scale and distributed renewable generation as well as combined heat and power technologies. This includes organic resources such as biosolids from wastewater treatment facilities, biogas from landfills, and biomass from forests and agricultural lands. Develop and demonstrate technologies and strategies to improve the performance, economics, and environmental sustainability of baseload and dispatchable renewables. Develop and pilot potentially breakthrough energy storage technologies that enable a variety of beneficial grid functions. Model the impacts of climate change on renewable sources of energy (e.g., changes in wind patterns).

> **Clean fossil-fueled sources and infrastructure improvements for grid resilience and stability:** Investigate ways to reduce the environmental footprint of existing energy technologies (e.g., reduce fugitive methane emissions from the oil and natural gas systems). Investigate techniques to improve the efficiency of natural gas burning energy technologies while substantially reducing the emission of air pollutants. Develop technologies to improve the performance of the existing energy infrastructure facing climate change impacts (e.g., innovative cooling technologies for thermal power plants). Develop and demonstrate new technologies and strategies that enable the transmission and distribution system to handle increased penetrations of renewables and distributed generation resources (e.g., microgrids, other smart grid features). Develop technologies and tools to maintain grid resilience and stability under a changing climate, particularly with regard to extreme events.

21 The State's loading order established by the energy agencies in the Energy Action Plan in 2003 calls for meeting new electricity needs first with efficiency and demand response, followed by renewable energy and distributed generation, and then with clean fossil generation.

Carry out scientific and engineering analyses to test and operationalize our conceptual knowledge regarding how to protect the existing and future energy infrastructure from climate impacts in both the electricity system and the supply network for natural gas. Analyze soft adaptation approaches, sometimes called "green infrastructure," (e.g., using wetlands instead of or to complement the flood protection afforded by levees) on an equal footing with engineering solutions, considering ecological and societal co-benefits. Better estimate the impacts of climate change on the existing energy infrastructure (e.g., wildfires on electricity distribution networks).

Energy scenarios for California and supply and demand forecasting: Continue to develop energy scenarios associated with deep GHG reductions with enough temporal and geographical resolution to inform long-term energy planning as well as identify (and avoid) potential unintended consequences such as substantial cumulative ecological and air quality impacts. Assess the vulnerability of the energy system to climate change in these scenarios to allow California to design an energy system that is more resilient to climate change. Develop and test innovative supply and demand forecasting methods, including probabilistic seasonal and decadal forecasts that incorporate projections of climate change to reduce vulnerability.

Consumer choice and civic engagement: Investigate consumer choice and civic engagement as a critical complement to RD&D for technological innovations. Investigation of this crosscutting topic, discussed more broadly in Chapter 5 and Appendix F, can generate additional strategies to substantially reduce energy use and GHG emissions while reducing climate risks in the energy sector.

Industry

The industrial sector is generally understood to include manufacturing and production processes. For the purposes of this section, industrial sources of GHGs associated with energy generation, use, and transmission; fuel use; and oil and natural gas extraction, production, distribution, and use are included in the other relevant sections of the *Research Plan*. Large industrial facilities are included in the GHG cap-and-trade program implemented by ARB. The declining cap and the performance-based strategy implemented by ARB create an incentive to increase production efficiencies. Through energy efficiency initiatives that target the industrial sector, California is supporting these efforts via the EPIC and other RD&D programs. Previous studies suggest that the electrification of some processes in the industrial sector currently served with fossil fuel combustion devices should be implemented if the 2050 goal is to be achieved (e.g., Wei et al. 2013).

Hydrofluorocarbons, perfluorocarbons, nitrogen trifluoride, and sulfur hexafluoride are collectively known as high-GWP compounds, because they have very high GWPs ranging from 675 to 22,800 times greater than carbon dioxide with a 100-year horizon.[22] Nitrous oxide, with a GWP of 298, is also a high-GWP gas, but is generally viewed separately from other high-GWP compounds because only it can occur naturally. Nitrous oxide emissions from industrial sources in California are negligible. The production of clinker, a component of cement, results in emissions of CO_2 from conversion of calcium carbonate (CaCO3) to lime (CaO).

Research agenda for the next five years

To identify effective strategies and technological innovations to significantly reduce GHG emissions and to assess their economic impacts:

Replacements for high-GWP gases: Study the technical feasibility and cost-effectiveness of using low-GWP substitutes to HFCs where no studies have been conducted. Coordinate with national and international research on hydrofluorocarbon substitutes. Investigate the

22 GWP values in the *Climate Change Research Plan* are consistent with the Scoping Plan Update, based on the IPCC Fourth Assessment (AR4).

most cost-effective means of replacing hydrofluorocarbons with substitutes or alternative technologies.

Energy efficiency and fuel-switching options: Improve energy efficiency, and explore fuel-switching options in the industrial sector. Model the effect on GHG emissions of fuel switching in the industrial sector, including electrification and renewable biomass, with feedback into energy scenario modeling. Monitor and assess economic costs and opportunities associated with efforts to improve efficiency and reduce emissions in the industrial sector.

Carbon capture, utilization, and sequestration: Develop and demonstrate the capabilities of new and emerging CO_2 utilization options that could provide economic benefits through new products, such as plastics, chemicals, and building materials.

To improve understanding of the vulnerability of California's industrial infrastructure to climate change impacts:

Vulnerability and safeguarding strategies for the industrial sector: Conduct scoping studies designed to identify research needs. Coordinate this work with similar efforts such as vulnerability and safeguarding studies for the energy and transportation systems discussed in other sections of this chapter.

Natural and Working Lands

Three-quarters of California's landmass is comprised of natural and working lands, such as forests, rangelands, and wetlands. These lands provide a multitude of economic and environmental benefits. They will also play an increasingly important role in California's efforts to prepare for and adapt to the impacts of climate change. In recognition of the importance of natural and working lands in meeting California's long-term GHG emission reductions goal, the Scoping Plan Update expanded the focus of natural lands from forests (including woodlands and urban forests) to include other land types such as wetlands (California Air Resources Board 2014). Because forests, wetlands, and rangelands function so differently and because the knowledge gaps are unique, the *Research Plan* discusses them separately below. These lands also provide important benefits and services for healthy watersheds (see Water sector) and wildlife habitat (see Biodiversity and Habitat sector) so management, and research to support it, must take an integrated view of climate-related issues.

Forestry

California's forests act both as sources of GHG emissions and as sinks that remove CO_2 from the atmosphere. They provide an opportunity through management practices to offset emissions from other sectors. Wildfire, mortality of vegetation, drought, and other forms of disturbance cause a natural release of carbon to the atmosphere (see also Chapter 5). Given enough time, healthy forests are resilient and will recover and regain carbon lost through such disturbances. However, climate change is expected to increase risks from these disturbances, possibly converting forested lands to carbon sources. Forests cannot be managed for carbon over the long term without maintaining their health and resilience, which in turn sustains their biodiversity. Therefore mitigation of climate change and preparing for climate risks to forests are inextricably interconnected. Research is needed to better understand how forest carbon pools are affected by land management and natural disturbance regimes in a changing climate.

Research agenda for the next five years

The fundamental focus of the research needs discussed in this section is to enhance monitoring and develop a better understanding of forest and woodland ecosystem dynamics. Further, the proposed agenda is intended to promote research that leads to managing forests sustainably to augment forest carbon and related ecosystem services to meet California's climate goals. Climate change will have impacts on many factors that affect forest health, including fire, drought, pests, and disease. Forestry actions to reduce GHG emissions and those to prepare for climate risks are strongly interwoven because managing forests for long-term carbon storage requires maintaining healthy and resilient forests.

To investigate the vulnerability of California forests to climate change impacts and assess the effectiveness of strategies to reduce risk while also sequestering carbon:

> **Vulnerability assessment and adaptation in the forestry sector**: Improve understanding of how a changing climate will influence disturbances to California's forest carbon such as fire, insects, disease, and invasive pests. Investigate impacts of ozone and air pollution on forests and their carbon storage capacity. Utilize paleoecology to better model and understand climate and vegetation dynamics. Reduce uncertainties in forest climate modeling and increase understanding of threats to forest carbon. Assess the influence of climate change on forest health and productivity and therefore on carbon storage. Identify potential climate-induced shifts in the ranges of forest plant species and identify potential areas of refuge for protecting forest health, habitat, biodiversity, and carbon storage.
>
> **Tools and approaches in the forestry sector:** Develop analytical tools to integrate the data results from urban Forest Inventory and Analysis (FIA) and other urban forest analytical tools into planning and policy decisions involving carbon storage. Improve tools and capabilities for monitoring and modeling climate-related changes in ecosystems processes that affect carbon fluxes. Identify best management practices to minimize losses to forest capacity to sequester carbon. Protect genetic variety of tree species through seed banks and nursery programs to maintain forest resilience.
>
> **Costs and benefits:** Conduct multi-disciplinary and integrated analyses to understand the costs, benefits, feasibility, and acceptability of alternative strategies for forest carbon and other ecosystem services.

Wetlands

California's wetlands provide a number of important ecosystem services. Wetlands are critical habitat for many species and provide flood protection and improve water quality. Unfortunately, many of California's historic wetlands have been diked or drained. The loss of these wetlands reduces habitat and causes land subsidence, which results in GHG emissions and increased risk of flooding. Wetland restoration can reduce emissions, sequester carbon, and provide valuable habitat. A number of recent studies have found that carbon sequestration rates in tidal and managed wetlands are among the highest rates of any ecosystem due to high rates of photosynthesis and low rates of decomposition (Needelman and Hawkes 2012).

Restoration of California's wetlands could play a critical role in protecting the coast and delta from flooding due to high waves and sea-level rise while also sequestering carbon and reducing GHG emissions. Coastal wetland restoration is urgent because (if restored soon) some of these wetlands may be able to accrete and keep pace with initial sea-level rise. Restoration of wetlands in the Delta reverses the active subsidence of the region, which has the added benefit of eliminating the GHG emissions associated with that subsidence. In addition, wetland restoration in the Delta could help protect important energy infrastructure and improve the reliability of the state's water delivery system by reducing the vulnerability of existing levees and pumps. Finally, wetland restoration would provide important habitat for birds, fish, and wildlife.

There is a significant potential for landscape scale restoration of tidal wetlands in California, including both saline and brackish wetlands along the coast and freshwater wetlands in the Sacramento-San Joaquin Delta (the Delta). More than 10,000 acres of wetlands along the coast and in San Francisco Bay have been restored in the past five years and final engineering is currently being completed for restoration of more than 40,000 acres of additional coastal wetlands – much of that in the San Francisco Bay Estuary (the Estuary). These projects could be implemented over the next five years if funding were available. Since 2010, DWR has restored more than 1,100 acres of managed wetlands in the Delta and an additional 800 acres is being planned for Sherman Island in 2014. The Bay-Delta Conservation Plan, [23] if approved, envisions eventual restoration of up to 83,200 acres of natural communities, including tidal wetland and associated estuarine and upland natural communities in the Delta. There are over 700,000 acres of diked former wetlands in the Delta that are currently private agricultural lands.

Research agenda for the next five years

To explore wetland strategies to reduce GHG emissions and climate risk and how to monitor their effectiveness and co-benefits:

Wetland Carbon Protocol: Develop the scientific foundation to understand the potential for reducing emissions through wetland projects. This could allow wetland restoration projects to better monetize emission reduction benefits.

Restored wetlands as carbon sinks: Continue to construct and assess large-scale pilot projects on Twitchell and Sherman Islands while continuing to monitor GHG flux, methyl mercury, subsidence reversal, and general habitat effects in both baseline environments (corn, alfalfa, and irrigated pasture environments) and constructed wetlands. Quantify spatial variability of impacts on these measures by constructing and monitoring additional sites throughout the Delta, Estuary, and along the coast.

Wetlands as protective assets for flood protection: Develop a quantitative understanding on the role of wetlands as protective assets for urban areas and other infrastructures from coastal and inland flooding. Wetlands can dissipate wave energy and buffer the impacts of rising sea level and wave energy. The conservation and restoration of wetlands provides a promising strategy for both climate change mitigation and adaption (Duarte et al. 2013). Monitor existing multi-benefit wetland projects in California to document the habitat benefits, flood protection, and ability to adapt to sea-level rise to learn from current projects and help inform future multi-benefit wetland projects. Support implementation of multi-benefit restoration projects.

Wetlands at risk from climate change: Support ongoing science-based regional planning (e.g., San Francisco Bay Ecosystem Habitat Goals Report, Southern California Wetland Recovery Project Regional Strategy) that are identifying wetlands at risk from climate change and strategies to increase resilience. Monitor the effectiveness of these enhancement strategies to increase resilience.

Rangeland

Past research suggests that rangelands may have significantly greater carbon sequestration capacity than is currently being achieved. For example, native perennial plants in rangelands can sequester substantial amounts of carbon and are more drought tolerant than the invasive annual plants that have displaced them across much of the state (Koteen et al. 2011). This is attributed to the deeper roots of perennial vs. annual species, but other mechanisms may also be at play and require further investigation.

Research agenda for the next five years

To assess the effectiveness of mitigation strategies for rangeland to sequester carbon released by other sectors:

Rangelands as carbon sinks: Quantify carbon sequestration of native perennial plants in natural and working lands. Expand recent field studies that suggest that the application of compost on rangelands used to raise cattle can sequester carbon in the soil without increasing methane and nitrous oxide emissions (Ryals and Silver 2013). Conduct grazing

23 *http://baydeltaconservationplan.com/PublicReview/PublicReviewDraftBDCP.aspx*

systems research trials to identify and evaluate strategies for increasing rangeland soil carbon through prescriptive grazing. Investigate how soil chemical and physical properties affect nutrient cycling, water availability, and forage quality. Explore the impact of managed grazing practices on GHG flux and carbon sequestration in rangelands. Investigate potential environmental and adaptive co-benefits, as well as impacts (trade-offs) of rangeland carbon sequestration practices.

Co-benefits of rangeland carbon sequestration: Evaluate the potential for rangeland mitigation strategies to provide co-benefits, especially those that support adaptation.

Impacts of rangeland conversion: Fill data and research gaps on the implications of rangeland conversions. Identify priority areas and land use strategies for minimizing the adverse impacts of rangeland conversion.

Ocean and Coastal Ecosystem and Resources

California's treasured coastline is threatened by a changing climate. Strategies will be needed to protect shorelines and infrastructure from rising sea levels and to maintain healthy ecosystems in the face of rising air and water temperatures, more frequent and intense storms, and ocean acidification. The latter is particularly troubling because of the potentially large ecological and economic impacts. In addition, information will be needed to prioritize areas for safeguarding activities. California's phenomenal diversity of species and habitats that reside in ocean and coastal ecosystems is also vulnerable to climate change (see the Biodiversity and Habitat sector). The policy-relevant questions for this sector relate to the rate of climate-induced changes in the coastal environment and assessing strategies to prepare for these changes.

Research agenda for the next five years

To address the vulnerability of California's ocean and coastal resources to climate change impacts, how this vulnerability is distributed among groups, and the effectiveness of strategies and technological innovations to safeguard the state from these impacts:

Monitoring and modeling ocean acidification and hypoxia and their impacts: Develop a regional approach for monitoring spatial and temporal variation of ocean acidification and hypoxia. Improve our ability to model pH, oxygen, and nutrients in the near-shore environment to determine contributions of local nutrient inputs to acidification and hypoxia, and identify geographic locations most susceptible to acidification and hypoxia. Determine key marine species that should be targeted for impact analyses, and perform modeling studies to assess food web responses under future climate scenarios and evaluate appropriate management strategies (e.g., marine protected areas).

Coastal ecosystem and fisheries management: Evaluate approaches to developing climate-ready fisheries and management actions within marine protected areas to improve resiliency to climate.

Monitoring impacts on the shoreline: Collect data to track shoreline changes and impacts from storms (e.g., beach and cliff erosion) to improve methods for predicting shoreline evolution. Measure land elevation changes such as subsidence and tectonic activity in relation to sea-level rise.

Forecasting and climate impact scenario information: Develop updated methods for predicting flood frequency under changing climate, and improve forecasting of extreme events such as extreme precipitation associated with atmospheric rivers (as described in Chapter 3).

Role of marine protected areas in resilience: Investigate how, and the extent to which, marine protected areas contribute to the resilience of coastal and marine ecosystems, coastal communities and the broader economy.

Tools and approaches to prepare for climate risk to ocean and coast: Compile improved social and economic data, including the quantification of ecosystem services, to enable the evaluation of different approaches to prepare for climate risk (e.g., seawalls, managed retreat, living shorelines, artificial reefs, and no action/business as usual). Evaluate innovative adaptation approaches such as green infrastructure (e.g., tidal wetlands, eelgrass, and native oysters) to help reduce vulnerability to climate-related hazards. Capitalize on the opportunity of a statewide network of marine protected areas as a living laboratory, where considerable research and monitoring is already under way, for understanding the effects of climate change on California's ocean resources. Conduct multi-disciplinary and integrated analyses to understand the costs, benefits, feasibility, and acceptability of alternative strategies.

Public Health

Impacts anticipated under a changing climate will exacerbate a wide range of existing risks to public health and its infrastructure, ranging from effects due to heat and cold temperature extremes; air pollution, allergen and wildfire exposures; food, water and vector-borne diseases; occupational health risks; and mental health and systemic social impacts. Higher temperatures and other meteorological conditions promote formation of ozone and particulates, increased allergen production and distribution, and wildfire smoke and particulate exposures. Climate change is anticipated to widely affect social, economic and environmental systems, with varied and far-reaching implications for individual mental health, community resilience, and societal change (e.g., stress, relocation, and other social/health effects cascading from extreme weather events). It will alter immigration pressures on California from ocean-bordering and other warming countries experiencing decreased habitability. Climate change is also likely to change crop yields, and the increased food prices would impact the more vulnerable populations. Local vulnerability assessments for climate-change health risks (heat, air quality, fire, flooding, housing availability and safety, and water availability and quality) should guide adaptation strategies. Researchers in other sectors will benefit from including public health scientists in the formulation of research proposals so that potential health impacts may be considered as part of proposed research or included in future intersectoral collaborations. The policy-relevant questions shaping the research agenda for public health address changing exposure to health threats, vulnerabilities, monitoring, and evaluation of strategies to reduce climate risk.

Research agenda for the next five years

To better understand the vulnerability of people to climate change impacts and the distribution of vulnerability among groups:

Extreme temperature-related morbidity and mortality: Characterize health impacts of temperature (extreme heat and cold), including downscaled projected impacts for local health planners, and specific vulnerability drivers such as urban heat island, built environment impacts and population vulnerabilities.

Air pollution, allergens, and wildfire exposures: Characterize population sensitivity for health risks from intensified airborne exposures - respiratory inflammation, aggravation of conditions such as asthma and emphysema, decreased lung function and damage to lungs, and cardiovascular disease.

Infectious diseases: Investigate how threats from life-threatening vector-borne diseases (e.g., Hantavirus Pulmonary Syndrome, Lyme disease, and West Nile Virus), as well as potential water- and food-borne diseases may increase with changes in climate.

Occupational risks: Assess priority health impacts of climate change in occupational settings with assistance from Centers for Disease Control and Prevention's National Institute on Occupational Safety and Health.

Vulnerability assessment and risk characterization: Characterize risk, especially to sub-populations already experiencing lower baseline health status, and ensure equity issues are addressed as effects of climate change and even mitigation actions themselves may threaten to intensify risks or hardships for these groups.

Systemic social health, including mental health: Identify and forecast climate change impacts on California populations through interdisciplinary engagement of physical scientists with social scientists, economists, agricultural and nutrition researchers, and other domain experts.

Surveillance and monitoring systems development: Develop and enhance tools to monitor environmental and health indicators for diseases, vulnerabilities, protective and adaptive capabilities for conditions affected by climate change. For example, coordinate with federal and regional rapid surveillance efforts; enhance the infrastructure for syndromic surveillance of climate-related morbidity and upgrading the California Death Registration System[24] to allow syndromic surveillance and monitoring of mortality patterns, including heat-related death; and improve surveillance programs for infectious diseases including vector-borne, water-borne, and food-borne diseases, including indicators tracking by the California Environmental Health Tracking Program.

To better understand which strategies would be the most effective to safeguard public health:

Evaluation of interventions and risk communication: Assess whether current public health guidance is being utilized and its effectiveness through interdisciplinary research. Improve understanding of public knowledge, attitudes, and behaviors on climate risks and mitigation and adaptation/preparedness actions within a health frame.

Support science to develop built environment and green infrastructure options: Expand knowledge of physical, mental, and societal impacts of urban forest ecosystems in the context of urban design (e.g., health impacts of urban tree cover, higher-albedo pavement). Develop strategies and technologies aimed at protecting vulnerable populations against heat without increasing air pollution and GHG burdens (e.g., low or net zero air conditioning).

Transportation, Land Use, Fuels, and Infrastructure

The transportation sector—including transportation fuels, land use, infrastructure, and travel activity—is the largest contributor to GHG emissions in California. Due to the size of the transportation sector, it is critical that it achieve significant emission reductions to achieve the State's 2020 GHG emission reduction goal and the 2050 target for deeper GHG emission reductions in the transportation sector. Market and policy forces will ultimately drive the transformation of the transportation system and create more efficient land use development patterns and agricultural and natural resource conservation. California has taken a multi-pronged approach to reducing emissions in the transportation sector, including emissions standards for vehicles, fuels with lower carbon content, paving materials that improve mileage, and smarter land use. Cross-sectoral policies promote a broad range of objectives, such as infill development including affordable housing, increased connectivity of residential, employment, and other land uses, jobs-housing fit, and reduced driving and single occupancy vehicle use and increased low carbon transportation options. At the same time, state policy promotes environmental justice to avoid placing disproportionate environmental, economic, or health burdens on disadvantaged segments of the population.

A multi-pronged policy environment and research programs of sustainable communities, pavement materials, sustainable freight, advanced technology vehicles, alternative fuels and fuel infrastructure, and the associated costs and benefits and environmental justice issues are

24 *http://www.edrs.us/*

managed collaboratively by Caltrans, ARB, the Energy Commission, California Department of Food and Agriculture, and the Strategic Growth Council through the Transportation Research Roundup. RD&D will produce advanced technologies and test strategies to successfully implement the State's policies.

Research agenda for the next five years

To evaluate the effectiveness of strategies and technological innovations to significantly reduce GHG emissions in the transportation sector and their economic, public health, and environmental impacts or co-benefits:

Sustainable communities: Continue evaluating and testing of innovative approaches to reduce GHG emissions (both direct and indirect) through sustainable community strategies. Investigate how climate and land use policies (e.g., smart growth) will affect the climate resilience of the transportation system and the residential sector. Provide decision makers with a clear understanding of the public health, economic, and equity co-benefits of implementing smart growth considering potential climate and ways to avoid adverse impacts.

Life cycle studies of pavement material in transportation networks: Integrate the results of Life Cycle Analysis (LCA) of GHG emissions with the estimation of life cycle costs. Continue work to reduce the embodied GHG emissions in pavement, as well as develop innovative new pavement materials with lower rolling resistance that have the potential to improve fuel efficiency for the millions of vehicles that use California's roads every day. Examine how materials used in the construction of the transportation network perform under climate change such as extreme temperatures and standing and moving water during flood events.

Sustainable freight: Develop advanced fuels, vehicles, intelligent transportation systems technologies, operations, and systems that reduce oxides of nitrogen and fine particulate matter such as black carbon in the freight area. Coordinate research with air quality planning activities, as exemplified by the ongoing ARB "Vision for Clean Air" program, to achieve greatest benefits. Leverage climate change research in other transportation areas to support goods movement.

Advanced technology vehicles and consumer behavior: Continue to support RD&D on technologies (e.g., fuel cells, batteries, charging options, and vehicle-grid integration) that will enable the deployment of zero or near-zero tailpipe GHG emission vehicles. Invest in market research on consumer and freight transportation sector acceptance and usage of zero or near-zero tailpipe GHG vehicles (e.g., fuel cell vehicles, electric cars) to inform policies and to increase adoption of these vehicles.

Alternative fuels: Support the development of new technologies that improve efficiency and reduce GHG emissions from biorefineries, and develop new methods to increase the production of alternative fuels (e.g., renewable hydrogen, renewable drop-in fuels). Examine the land-use impacts of biofuels crop production on the carbon sequestration potential of soils, air quality, and other ecosystem services from different biofuel crop types that are appropriate for California. Investigate the impact of climate change on projected biomass production to accurately project future alternative fuel supply.

To investigate the vulnerability of transportation infrastructure of California to climate change impacts:

Vulnerability of the transportation system and fuel infrastructure: Assess vulnerability of the state's transportation system to sea-level rise, extreme weather-related events, and other climate impacts. Examine the vulnerability and adaptation options of the fueling infrastructure (e.g., pipelines, marine terminals, storage tanks, oil refineries) that may be affected by sea-level rise.

Waste Management

California's sustainability vision is to develop low-carbon, economically sustainable industries, technologies, and strategies that align with the state's existing integrated energy, waste, and environmental policy objectives for reducing overall GHG emissions.

The waste management sector covers all aspects of solid waste and materials management, including source reduction; the recycling, reuse, and remanufacturing of recovered material; composting and anaerobic/aerobic digestion; biomass management (combustion, composting, chip and grind); municipal solid waste thermal operations; and landfilling. The primary source of GHG emissions from the waste sector is the direct emission of methane from the decomposition of organic material in landfills. Instead of landfilling, using organic material as feedstock for composting and anaerobic digestion can result in reductions of GHG emissions. The GHG emission reductions from these activities would occur from reduction in energy demands associate with recycling and manufacturing, avoided landfill emissions, displacement of fossil fuel with biogas, and reduction in synthetic fertilizer and water usage.

CalRecycle and ARB staff collaborated to develop a Waste Management Sector Plan addressing greenhouse gas emissions from waste management to achieve the 75 percent recycling goal of AB 341 (Chapter 476, Statutes of 2011 [Chesbro, AB 341]) and inform the development of the AB 32 Scoping Plan Update.

Research agenda for the next five years

To identify the most effective strategies and technological innovations to significantly reduce GHG emissions in the waste management sector and to monitor their effectiveness:

> **Public education**: Investigate methods to improve the efficacy of education and outreach efforts regarding source reduction, which is at the top of the waste management hierarchy and is the preferred approach to reduce GHG emissions from the waste sector.
>
> **Technology and practices:** Investigate technologies and practices for handling solid and green waste and its byproducts that have the highest potential to reduce GHG emissions, as well as address other issues such as water conservation, compost production, and renewable energy/fuel production. Improve measurement methods of GHG emissions at solid and green waste facilities to support assessment of different technologies and practices with regard to GHG emissions reductions.
>
> **Reducing waste generation**: Develop new products and markets with the highest potential for reducing waste in the first place and its associated GHG emissions.

To assess the vulnerability of waste management infrastructure in California to climate change impacts:

> **Vulnerabilities and adaptation options**: Examine vulnerabilities of and adaptation options for the waste management sector to climate change. Past research has shown that some hazardous waste sites are located in areas of higher risk of coastal and San Francisco Bay Delta flooding (Heberger et al. 2009), but potential impacts and viable adaptation options have not been investigated thus far.

Water

The Scoping Plan Update outlines a comprehensive set of actions that will reduce overall GHG emissions in California in water use efficiency, water recycling, water system energy efficiency, urban runoff reuse, and increased renewable energy production. DWR released the California Department of Water Resources Climate Action Plan Phase I: Greenhouse Gas Emissions Reduction Plan in 2012[25]. That plan will significantly curtail DWR's GHG emissions in coming decades, describes how the department will reduce GHG releases by 50 percent below 1990

25 *http://www.water.ca.gov/climatechange/docs/Final-DWR-ClimateActionPlan.pdf*

levels within the next seven years, and sets the stage for an 80 percent emissions reduction below 1990 levels by 2050. In 2009, Senate Bill X7-7 was enacted, requiring all water suppliers, both urban and agricultural, to increase water use efficiency. The goal of SB X7-7 for the urban sector was to reduce per capita water use 10 percent by 2015 and 20 percent by 2020.

The water sector is one of the largest generators and consumers of electricity in California and thus plays an important role in reducing energy demand and GHG emissions. In addition, natural gas is used for water heating purposes in the residential, commercial, and industrial sectors. Reducing GHG emissions in the water sector offers secondary benefits. For example, reducing energy consumption also reduces energy costs for consumers. In some cases, reduced energy costs can pay back initial investments associated with efficiency measures, relatively quickly. Local water agencies can implement projects to reduce the energy intensity of water in their region within their Water Management Portfolios; they can also include a plan to monitor the effectiveness of their strategies such as consumer surveys, quantifiable reductions in water volume delivery or consumer water use efficiency program participation rates. At the same time, there may be tradeoffs between reducing GHG emissions in the water sector and other water management objectives (e.g., water and wastewater treatment to protect public health, environmental restoration projects).

California climate change research efforts in the water sector have focused on impacts and adaptation (e.g., Moser et al. 2012). Climate change will affect all stakeholders and therefore coordination with and participation by all entities, especially the public, will be necessary to mitigate the impacts of the water sector on climate and to develop preparedness strategies.

Research agenda for the next five years

To investigate the most effective strategies and technological innovations to significantly reduce GHG emissions in the water sector and their economic and environmental impacts or co-benefits:

> **Reducing embedded GHG emissions**: Improve and develop less costly technologies and procedures for conserving water and energy. Provide insight and guidance for state and regional water management planning, and address water and energy conflicts and climate change mitigation needs through regional data collection on water and energy intensity. Conduct studies about the GHG benefits of increased use of non-traditional local water supplies to reduce the embedded GHG emissions associated with imported water.

To determine the vulnerability of water resources to climate change impacts and to measure and assess the effectiveness of potential strategies and technological innovations to safeguard the state from these impacts:

> **Understanding how climate change is affecting key water indicators**: Measure how a changing climate is affecting water supply, because this information will enable planners to anticipate needs and to target future policies. Some of the monitoring needs are as follows; 1) changes in snow-covered and rain dominated portions of key watersheds, 2) the relationship between snow pack, rainfall, and groundwater recharge and quality, and 3) the effects of land-cover and ecosystem responses to climate change on precipitation-runoff relationships. This research topic is also discussed as a research need in Chapter 3.

> **Understanding key vulnerabilities in the state's water system**: Improve understanding by planners and resources managers of climate-mediated risks to the water, including wastewater and recycled water, infrastructure (e.g., sea-level rise and flooding) as well as impacts to water quality in rivers, lakes, and groundwater aquifers due to changes in precipitation, timing of flow, and temperature. Better characterize the risk to water supply and demand conflicts (in-stream flows, agriculture, urban consumption, industry, and hydropower) with climate change.

> **Developing a toolbox of adaptation strategies**: Develop decision-support tools for adaptation in the water sector such as to determine where to prioritize regulations and

technical and financial assistance to protect surface water quality, groundwater storage, assign water rights equitably, minimize urban flooding, and reduce the potential for public safety threats from water and wastewater facilities impacted by extreme events. Identify a toolbox of adaptation measures that water, wastewater, and recycled water facilities can implement to prepare for future sea-level rise and extreme storms. Investigate the pros and cons of desalination as an adaptation strategy, including its feasibility and acceptability, impacts on aquatic species, water quality, ecosystems, energy use, and potential GHG emissions from pumping seawater to the surface.

CHAPTER 5

Crosscutting Issues

Crosscutting areas of research include topics that are common to different sectors or that would benefit from strong interdisciplinary approaches. The discussion below about regional research highlights the importance of local and regional analyses to complement and enhance statewide studies or for more in-depth examinations that can only be afforded at the local/regional levels. The discussion about the regional topics benefited immensely from input received by the Alliance of Regional Collaboratives for Climate Adaptation representing local agencies and groups in the Sacramento area, the nine counties in the San Francisco region, the Los Angeles metropolitan area, and San Diego County.

The Economics of Climate Change

Past studies at the state, national, and international levels have focused on determining the magnitude of aggregate economic impacts. Their primary role has been to estimate the nature and magnitude of overall statewide or national economic impacts. For the most part, they provide very little information that could be used for resource management and decision making on local or regional levels. At the same time, the Second California Climate Assessment strongly suggests that effective adaptation can significantly lower overall economic impacts from a changing climate (Franco et al. 2011). What are needed now are "on the ground" studies with enough granularity and specificity to allow in-depth estimation of economic costs and benefits and/or the implementation of risk management strategies. To provide actionable results, economic analyses must also involve other areas of science such as engineering, ecology, and social sciences, because non-economic factors (e.g., institutional constraints, lack of consideration of ecological impacts, and public acceptance of options) can play a major role in the implementation of attractive adaptation measures.

Environmental Justice

The State of California is committed to the fair treatment of people of all races, cultures, and incomes with respect to the development, adoption, implementation, and enforcement of environmental laws, regulations, and policies. State law defines this as environmental justice (Government Code section 65040.12). In the climate change context, disadvantaged communities and certain racial/ethnic groups are projected to experience disproportionate risk of mortality and morbidity from extreme heat events such as higher exposure to urban heat island effects or outdoor working conditions, lower access to air conditioning, lower baseline health, and greater exposure to air pollutants (Shonkoff et al. 2011). California's disadvantaged communities may not have equitable access to urban forests or share in the many benefits they could provide. Some groups may experience disproportionate economic impacts including increased cost of necessities such as housing, reductions in agricultural employment, and lower adaptive capacity (Shonkoff et al. 2011). Some cultural groups face extra burdens from ecological impacts. Different groups may also bear the brunt of impacts from mitigation or adaptation actions. Environmental justice, affecting and affected by both mitigation and adaptation strategies, is a universal crosscutting issue that could benefit from more attention in climate change studies. For instance, research could examine if and where the generation of bioenergy from wastewater treatment facilities (e.g., as a substitute for diesel in heavy-duty trucks) might reduce environmental justice impacts.

Barriers to Adaptation

It is now clear that to go beyond adaptation studies into practical implementation of adaptation measures, it is necessary to identify regulatory, legal, scientific, socio-economic, institutional, and financial barriers and options to overcome them (Moser and Ekstrom 2010). Here we define barriers "as obstacles that can be overcome with concerted effort, creative management, change of thinking, prioritization, and related shifts in resources, land uses, institutions, etc." (Moser and Ekstrom 2010). One of the potential barriers to adaptation is a legal framework that may impede or at least create obstacles to the implementation of technically attractive adaptation options. For example, studies have shown that the use of groundwater reservoirs to store water during wet years and making this water available during dry years is an attractive adaptation option (Medellín-Azuara et al. 2008; Langridge et al. 2012). However, a legal analysis conducted by researchers at the Center for Law, Energy & Environment in UC Berkeley found the current interpretation of water law would not allow the implementation of this measure. In addition, the lack of information about the amount of water obtained from groundwater resources would impede the implementation of this measure at the needed scale (Hanemann et al. 2012). Similar studies are sorely needed to identify similar obstacles in other issues and sectors, such as the effects of water requirements for endangered species on adaptation strategies in other sectors and vice versa. A suite of options for overcoming barriers should be explored through systematic research, including private sector contributions, payments for ecosystem services, public goods charges, fees, and insurance. Research should address what level of funding could be raised through different types of financing options, their potential structures, public or private sector acceptability, social justice and economic impacts.

Extreme Events

As mentioned in Chapter 3, extreme weather-related events are likely to become more frequent and intense in California (Mastrandrea et al. 2012). These extreme events affect several sectors of the economy and public health resulting in a cascade of issues that can exacerbate overall impacts. For example, prolonged droughts affect ecosystems and agricultural production, decrease hydropower generation, increase wildfire risks, degrade air quality, and cause major economic losses. Extreme weather-related events must be used to integrate and coordinate research approaches and investigate the best options to prepare California for and recover from these events.

Indicators of Climate Change, Impacts, and Actions

There is currently considerable interest in the state – at all levels of governance – to assess and report on mitigation and adaptation efforts and their effectiveness. While certain metrics exist for tracking mitigation, research in approaches and metrics for assessing adaptation planning and implementation, and reporting on preparedness as well as progress toward achieving mitigation and adaption goals is limited. Nevertheless, a basic foundation exists that can lend itself to the development of indicators or pilot testing for improvement over time. Such research would need to account for process and outcome aspects of adaptation and consider the need for wide applicability across sectors and levels of decision making.

Indicators are used in many disciplines to describe the status, trend, or performance of a system. They synthesize large volumes of often-complex data into summary measurements that are understandable to a broad audience. Recognizing the value of indicators as tools for characterizing and reporting on climate change in the state, the California Environmental Protection Agency's (CalEPA) Office of Environmental Health Hazard Assessment has developed a set of climate change indicators to describe the multiple facets of climate change—its anthropogenic drivers, changes in climate, and the physical and biological impacts of such changes (report published originally in 2009 and updated in 2013[26]). The *Research Plan* envisions an ongoing effort by CalEPA—in close collaboration with other state programs, and with input

26 *http://www.oehha.ca.gov/multimedia/epic/2013EnvIndicatorReport.html*

from external research and monitoring programs—to further develop and periodically update a system of climate change indicators. A new area of integrative research would develop indicators that track activities to reduce GHG emissions and the risk of climate change, as well as the outcomes of these activities. This will also tie in with state efforts to make data more open and accessible to researchers, the public, and other interested parties.

The Sacramento-San Joaquin Delta

The Sacramento-San Joaquin Delta is a unique and valuable natural resource spanning 738,000 acres where the Sacramento and San Joaquin Rivers join and drain westward to the San Francisco Bay. It is a region of towns and cities, farms, and other businesses. The Delta also serves as a hub for water supply, energy, and transportation infrastructure vital to the economic well-being of California (Figure 6). The diversity of salt, brackish, and freshwater marshes and other ecosystems within the Delta provides habitat for many species of conservation and recreational value throughout their different life stages (Lund et al. 2007). Water from the Delta supplies two-thirds of California's people, and it contributes to making the Central Valley a food basket of the nation. Much of the land in the Delta lies below sea level, separated from the network of channels by levees built with local materials over 100 years ago to drain marshlands to reclaim land for agriculture and subsequently to protect it against floods. This use has caused land subsidence, and increasing GHG emissions while making the Delta more vulnerable to sea-level rise and flooding. Research has shown that restoring its wetlands can reverse subsidence and be used as a carbon sink for mitigating climate change (see Chapter 4—Natural and working lands). The Delta Plan (Delta Stewardship Council 2013) created rules and recommendations to achieve the State's coequal goals for the Delta: Improve statewide water supply reliability, and protect and restore a vibrant and healthy Delta ecosystem, all in a manner that preserves, protects, and enhances the unique agricultural, cultural, and recreational characteristics of the Delta. The Delta Plan recognizes the challenges from many impacts of climate change (e.g., from warmer temperatures, changing precipitation patterns, changing timing and volume of river flows, higher sea levels, and the potential for greater extremes) on achieving the two policy goals. Thus, integrated research on vulnerability and management strategies to mitigate and adapt to climate change is a necessity for the Delta region.

Figure 6. Transportation, water, and energy infrastructure in the Delta.

Source: Lund et al. 2007.

Climate-smart Choices and Civic Engagement

The success of many climate change strategies depends on Californians actively participating in identifying, supporting, and implementing climate-smart choices. For example, in the transportation sector, regional planning efforts under SB 375 depend on shifting consumer choices to reverse the historical trend of increasing vehicle miles traveled. Meeting ZEV as well as alternative fuel vehicle goals relies on consumer purchasing decisions. Scenarios developed to explore what California's energy system might look like in 2050 suggest that aggressive efficiency programs might provide a means of reducing demand and thereby securing GHG emissions reductions. However, the required future impact of such proposed efficiency programs is unprecedented if drastic GHG emissions reductions are going to take place by 2050 (Williams et al. 2012, Wei et al. 2013). These programs have succeeded thus far in slowing aggregate load growth but have not reversed it (Rufo and North 2007, Parker et al. 2008). Moreover, routine behaviors and decisions that are not associated with consumer purchases play a large role in determining GHG emissions. Californians' choices will also shape strategies to prepare for climate risks. Accordingly, it is critical that the State better understand consumer choices, habits, and decision making, as well as how to craft effective strategies to reduce GHG emissions and climate risks. Research on these human dimensions must complement the technological innovation RD&D proposed in Chapter 4.

Urban, Suburban, and Exurban Growth and Climate Change

The pattern of urban growth affects land use, agriculture, energy demand, conservation, transportation, and many other facets of California's environment. How California accommodates a growing population will have far-reaching effects on (and be shaped by efforts to reduce) GHG emissions and resilience to a changing climate. California should continue supporting integrative research on the synergies between climate change and urban and rural growth. Research is needed to understand how efforts to reduce GHG emissions and risk from climate impacts will affect land use patterns, housing siting, and transportation networks and to identify potential conflicts between these efforts. For example, the State needs to develop a more complete understanding of induced demand (increase in travel or other emissions-causing behaviors as a result of a given policy action) and build this into project analysis to accurately estimate the potential GHG emission reduction benefits associated with alternative projects or policy options. Additional research is needed to ensure that scenario-planning models incorporate future climate conditions and the impacts associated with these changes (e.g., sea-level rise, flood regimes). Assessment of impacts on the residential sector will be important, as it accounts for the largest proportion of land use within the urban footprint and incorporates identified research needs ranging from green buildings, public health effects, built environment development patterns affecting transportation, economic impacts, and environmental justice issues affecting disadvantaged communities. There is also a significant need to assess how the state's housing stock might be impacted by sea-level rise. With an overall shortage of housing, loss of housing stock would exacerbate the rising cost of housing and disproportionately impact vulnerable populations. The movement of biological species in response to climate change needs to be incorporated into urban scenario planning to avoid exacerbating ecological impacts. Research is needed to understand how shifts in human demographics (e.g., aging population, faster growth in the state's inland areas) and job trends will affect land use, transportation needs, and infrastructure investments. The costs, benefits, and strategies for appropriate conservation of natural and working lands to achieve smart growth goals needs further study. Pressure to produce more biofuels could compete with agricultural lands needed to feed a growing population. Therefore, planning for the transformative changes of many of the state's systems to achieve long-term GHG emission reduction goals and create sustainable communities needs to determine what policies and tools cities and counties can apply to support this transformation and what barriers will need to be overcome.

Green Buildings

Green building offers a comprehensive approach to reduce GHG emissions by minimizing the energy, water, waste, and transportation impacts of the building. In addition to the California Green Building Standards (CalGreen), there are also state policies and goals focused on zero net energy (ZNE) building. Currently, the State's ZNE goals established by both the California Public Utility Commission and the California Energy Commission require all new homes be ZNE by 2020 and new commercial buildings to be ZNE by 2030. To date, there has been some research on the GHG benefits of green building, including on the realized GHG improvements from water, waste, and transportation improvements that come from achieving Leadership in Energy and Environmental Design for Existing Buildings: Operations and Maintenance certification. However, additional research is needed to fully understand the GHG reduction potential of green building. Further, research is needed to advance the adoption of zero net energy building, including realworld data on marginal cost premium of pursuing ZNE and actual return on investment. Lastly, the *First Update to the Climate Change Scoping Plan* (California Air Resources Board 2014) identifies future actions and policies that can help California achieve our post-2020 climate goals, including advancing ZNE buildings to be zero net carbon buildings. In order to do this, ARB and state agency stakeholders must chart a path for expanding ZNE goals to focus on GHG emissions, and as a result, consider water, waste, and transportation impacts of a building. Significant crosscutting research will be needed to provide technical support for the pursuit of low-carbon building in California as part of the State's long-term climate program.

Wildfire and Other Ecosystem Disturbances

Natural and working landscapes contribute to California's GHG emission reduction policies but are simultaneously vulnerable to the risks of climate change. Disturbance (e.g., wildfires, pests, and invasive species) is a natural part of ecosystems and influences the composition of species, the cycling of carbon, and the flow of goods and services. Human-caused impacts, including climate change, can alter the frequency or magnitude of disturbances and therefore increase the threats to property, safety, watersheds, habitat, and infrastructure. Wildfire, in particular, has emerged as a pervasive issue throughout the *Research Plan*. The 2013 Rim Fire near Yosemite clearly underscored the full range of impacts on a massive scale. Past studies suggest that wildfires and changes in vegetation patterns may result in net loss of biomass carbon to the atmosphere in this century. This has tremendous implications for mandates to reduce greenhouse gas emissions (e.g., AB 32) because even small fractional changes of the carbon stock in our forest result in substantial carbon emissions. Key crosscutting research topics about ecosystem disturbances include:

Wildfire regimes: Research should continue to improve projections of future wildfire and its impacts on many sectors. Ideally state agencies and other partners will agree upon a common set of wildfire scenario projections to support vulnerability assessments and adaptation planning.

Carbon dynamics: increased rates of disturbance will decrease the capacity of forests to store carbon, at least over the short-term, and increase GHG and black carbon emissions. Progress in understanding the role of disturbance in carbon dynamics will help refine the GHG emissions accounting methods and provide support for more effective management of resilient natural landscapes. Since less dense forests should also result in less intense forest fires, the *Research Plan* places a priority on answering how to create healthier forests for both mitigation and adaptation purposes.

Positive feedbacks: The interactions of climate change and disturbance processes can create positive feedbacks. Research is needed on these feedback loops, which then need to be incorporated into ecosystem process models to project climate change impacts.

Co-benefits of healthy landscapes: Strategies to increase forest health and resilience are likely to have co-benefits for watersheds, safety, wildlife, habitat, and bioenergy. Research is needed to better account for such co-benefits in choosing strategies to prepare for climate risk. Forecast-based interventions that could be used to reduce the public health and economic impacts of wildfires should also be explored.

Ecosystem Services and Green Infrastructure

Ecosystem services, the benefits people obtain from ecosystems, have been mentioned throughout the *Research Plan* for their vulnerability to climate change and for possible positive and negative impacts of climate strategies. Carbon sequestration in natural and working landscapes is a critical service in California's strategy to reduce GHG emissions, but it depends on maintaining healthy ecosystems in the face of climate change. Nature-based solutions (so-called green infrastructure) can address the same climate threats while also providing co-benefits such as the maintenance or enhancement of valuable ecosystem services that engineered solutions may not. For example, both restoring coastal wetlands for protection and armoring the coastline can provide protection from floods and storm surges, but the wetlands strategy can also filter water and provide essential habitat. Research can determine when it is more cost-effective to pay landowners for maintaining publicly valued ecosystem services than pay for engineering solutions. Perhaps the greatest advantage of the ecosystem services framework is that it provides a more comprehensive way to consider the benefits and trade-offs of protecting/restoring ecosystems to build resiliency and maintain or enhance ecosystem services in a changing climate. The ecosystem services framework could support other crosscutting themes such as providing new climate change indicators and information about the distribution or loss of services from the perspective of environmental justice. Although the ecosystem services framework is increasingly familiar to scientists and resource managers, it is still not commonplace in state policy. Multi-sector research is needed to improve methods for modeling ecosystem services and to demonstrate its value in assessing climate risks and climate-related projects or policies. Research is also needed on where and how to best deploy adaptation strategies.

Urban Forests

In addition to making our cities more beautiful and livable, trees provide climate services for both mitigation and adaptation (Liverman et al. 2013). Trees store carbon. The shade they provide modulates the urban heat island effect, resulting in lower demand for cooling-energy, further reducing emissions. Adaptation in urban areas could include additional use of urban forests and tree planting to prevent heat-related health problems, protect air quality, and absorb excess water. The need is often greatest in environmental justice communities. Urban forests, however, are also stressed by air quality, soil compaction, and modified hydrology. Therefore climate change research must also consider the cumulative effects of all these stressors. Major climate-related research gaps regarding urban forests include improved mapping and inventory methods, field-based and remotely sensed measures of the effects of urban forests on urban heat islands, and strategies to keep urban forests resilient in a changing climate. As with other sectors and crosscutting topics, decision makers need information on the costs, benefits, feasibility, and acceptability of expanding, enhancing, or adapting urban forests.

Water-energy-food Nexus

Water, energy, and food production are inextricably linked. Water is transported from north to south to provide adequate supplies for multiple beneficial purposes including food production and community use. Energy is required as water is moved from its source, treated, transported, consumed, and treated once again before disposal. Water is involved in almost every aspect of producing, generating, or processing energy in the state as well as in the many different stages of food production. Moreover, water, energy, and food production will all be affected by climate change. Integrated research studies are needed to examine the water, energy, and other co-benefits of existing and new management practices in the water-energy-food nexus for climate change. The development of grower-friendly electronic tools (e.g., apps) to provide guidance on the management practices will ensure the research findings are effectively used at the farm level to adapt to climate change and reduce GHGs. The Water Energy and Agricultural subgroup of the Climate Action Team coordinates research efforts aimed at achieving water and energy savings and efficiencies, reducing GHG emissions, and ensuring the state's ability to mitigate and adapt to climate change impacts on agriculture and water resources.

Climate Impacts Outside California Affecting our State

Climate impacts affecting areas outside California could affect our state. For example hurricanes in the Gulf Coast region affect oil platforms and refineries creating cascading effects in energy prices in the United States. Warmer waters in the Atlantic in the areas where hurricanes form may result in more intense extreme hurricanes with global climate change (Grinsted et al. 2013).

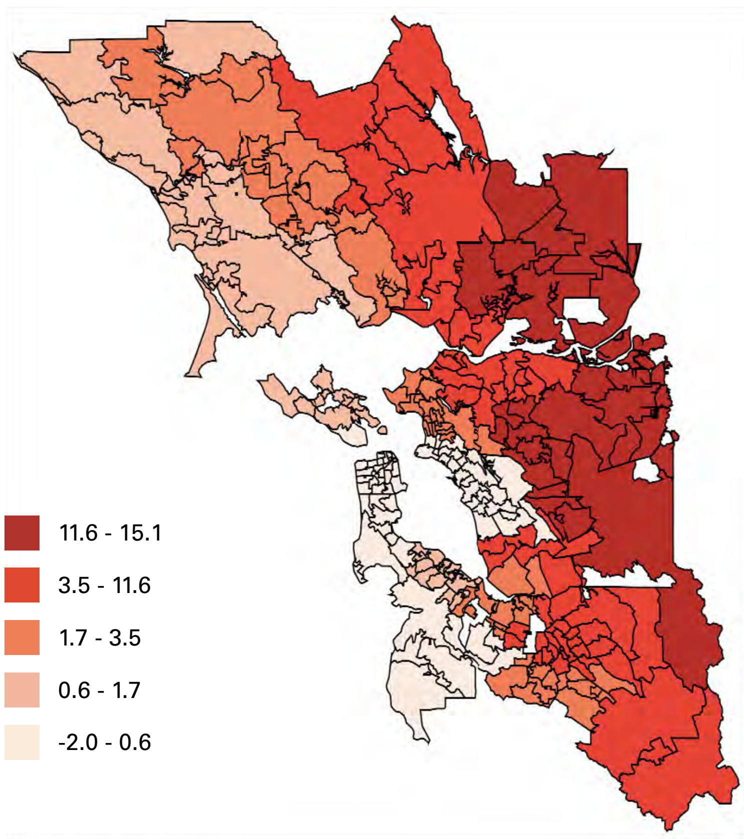
Prices of global commodities, such as timber, will determine the economic impact on California industries (Hannah et al. 2011). Our high technology society is dependent on global supplies, such that disruptions far from California result in loss of manufacturing productivity in California. For example, floods in Thailand in 2011 affected the world supply of computer chips, hard drives, and other electronic devices, which in turn affected the manufacture of computers in California. For all of these reasons, California should start exploring this emerging area of research.

Local and Regional Issues

Nearly all climate research conducted in California is going to be place-based and will ultimately inform actions taken overwhelmingly by local decision makers. Therefore, framing State research in line with local and regional information needs is one of the most salient crosscutting topics. Cities, counties, and regions are often at the front line of climate impacts and extreme events. Moreover, experience has shown that the potential impacts and vulnerabilities, and therefore the research needs, vary significantly between areas, such that the solutions to climate risk must be customized for each locale.

In the past, local and regional climate change research issues have been addressed using two methods. The first method relies on statewide studies with enough geographical resolution adequate to inform local and regional actors. For example, a statewide study looking at potential changes in electricity demand under different climate scenarios estimated changes in demand at the ZIP code level (Auffhammer and Aroonruengsawat 2012a). The study provided enough spatial resolution to allow the production of a derivative product about potential impacts to the nine counties in the San Francisco region (Figure 7) (Auffhammer and Aroonruengsawat 2012b).

Figure 7. Simulated percent increase in household electricity consumption by ZIP Code from 2080-2099 relative to 1961-1990. A2 global emission scenario.



Source: Auffhammer and Aroonruengsawat 2012b.

The second approach involves the production of local or regional studies such as "Climate change-related impacts in the San Diego region by 2050," (Messner et al. 2011) and the on-going study known as C-Change.LA for the Los Angeles region. In some cases, these local or regional studies inform and are informed by statewide efforts, which was the case for the study for San Diego County that contributed to the Second California Climate Assessment.[27]

The two general approaches described above can also converge. For example, the Third California Climate Change Assessment included a series of reports commissioned for the San Francisco region (e.g., Garzon et al. 2012, Biging et al. 2012) that, together with the statewide studies that had enough details for the San Francisco region, allowed the production of an integrated report about impacts and adaptation options for the region (Ekstrom and Moser 2012).

As more local and regional agencies get involved in climate research, both directly funding studies and using research products, the approaches described above should be implemented and enhanced as needed. Local or regional agencies should have a strong voice shaping the studies funded by the State of California, helping identify specific research needs and enhancing the link between research and actual implementation of measures to reduce GHG emissions and climate risks. A well-coordinated research activity involving local and regional efforts with research funded by state agencies is also critical because local studies must use parallel scenarios and assumptions if they are to effectively leverage, and be coherent with, related studies at the regional or national levels.

Four of the state's regions (San Francisco Bay Area, the Los Angeles region, San Diego, and the Sacramento area) have developed collaborative efforts around adaptation and preparedness at the regional scale. The regional collaboratives have worked together to share experiences and best practices and to serve as a bridge between state actions and regional and local adaptation needs. The groups have formed the Alliance of Regional Collaboratives for Climate Adaptation (ARCCA). Some common themes emerge from the regions' research needs:

Monitoring: Monitoring information is needed to understand ongoing changes and trends in the natural and built environments and to help evaluate planning decisions that have been made. This information is needed from a steady, reliable source.

Forecasting and Climate Projections: Information on the potential impacts of climate change is needed at a scale that is relevant and actionable by the regions, including an improved understanding of the risks of extreme events.

Vulnerability Assessment: Regions need tools and information to identify what is at risk under a changing climate, including infrastructure, population, natural systems, and the economy.

Adaptation Tools and Approaches: Research needs to identify the appropriate scale for action designed to address climate risks. When is the regional scale the appropriate scale for action?

Partnerships: How can we best leverage work being completed at the regional level to support adaptation? How can State-sponsored research best support regional efforts? What governance mechanisms best support regional adaptation efforts? How can climate risks and response options be effectively communicated at the local to regional level?

Case studies: There is a great need for successful case studies. At the local level, decision makers need to know what works and how to act on it. This is particularly true with the economics, barriers, and disturbance topics. Positive feedbacks, co-benefits, and replicable outcomes are critical information for engaging local leaders to take action.

27 *http://climatechange.ca.gov/climate_action_team/reports/second_assessment.html*

The overall areas of research listed above are highly compatible with the areas of research described in other parts of the *Research Plan*. The local focus brings a wealth of specificity that must be incorporated as much as possible into research efforts. For example, prior studies funded by the State have developed streamflow projections for more than a dozen stream gauges in California of statewide importance. This is not enough, however, for local and regional applications.

CHAPTER 6

Integration and Implementation

The work delineated in the prior chapters must be purposefully integrated to allow for a meaningful exchange of information between the different research areas. In addition, integration and coordination with non-state sponsored research programs is important to leverage scarce resources and to attempt to provide coherent and practical research results for California. To that end, this chapter presents a high-level strategy to integrate the different areas of research discussed in prior chapters. It starts with a brief introduction on how the State has tackled integration in the past and then suggests a way forward. The chapter ends with a brief discussion about implementation issues.

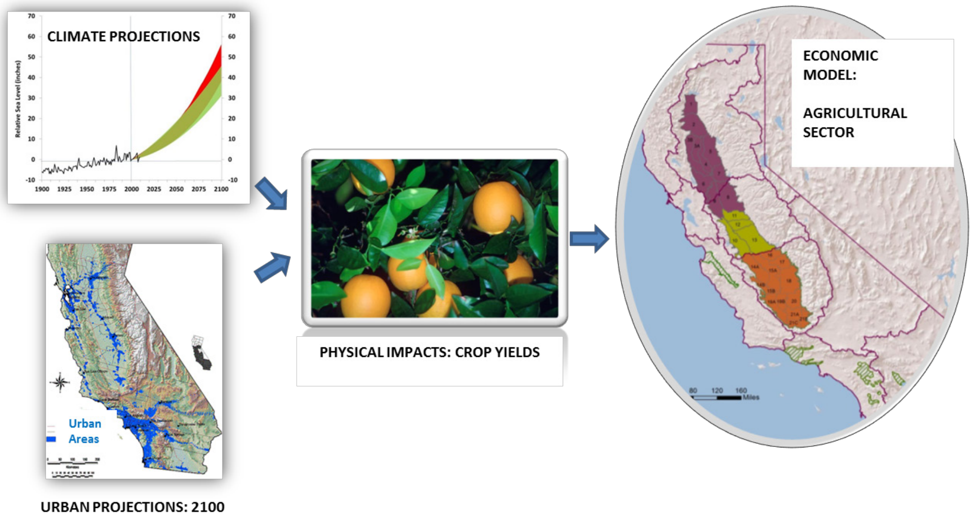
Past Integration Efforts

In the area of impacts and adaptation, California has established a strong record for integration of multiple disciplines. For example, the 2009 California Climate Assessment used a common set of climate and sea-level rise scenarios and a common set of urban growth projections. Different research groups estimated physical impacts such as increased risk of flooding, changes in the physical characteristic of beaches in Southern California, and changes in the snowpack in the Sierra Nevada. These results were then used to estimate economic impacts and, in some cases, explore the economic implications of adaptation measures (Franco et al. 2011). Figure 8 illustrates this approach. Physical scientists from Stanford University determined a range of potential changes in yields for several perennial agricultural crops (Lobell and Field 2011), while a group in UC Davis similarly estimated the potential impacts of climate change on annual crops (Lee et al. 2011). Finally, economists from UC Davis used their statewide economic model of the agricultural sector in California to assess economic impacts (Medellín-Azuara et al. 2011). The latter also considered the effect of water availability as suggested by a statewide water supply model (not shown) (Connell-Buck et al. 2011) and the loss of farming areas due to urbanization. The economists explored adaptation options, such as planting different crops in response to a changing climate, as a way to reduce economic losses.

The Third California Climate Change Assessment advanced the integration approach used in the prior California Assessment in multiple ways. For example, it expanded the urban projections to include simulations of growth in the urban-wildland interface for a scoping analysis investigating how different overall growth patterns may reduce vulnerability to climate impacts (Thorne et al. 2012).

The integration between mitigation and adaptation, however, has been absent in many past studies. There are only a handful of notable exceptions, such as a study about climate change and ecosystems services in California that concluded that climate change could substantially erode the success of mitigation efforts because a warming climate in California may result in substantial losses of carbon stocks in forests in California (Shaw et al. 2011).

Figure 8. Integrated study of economic impacts to the agricultural sector considering adaptation: Conceptual framework used in California Climate Change Assessments.

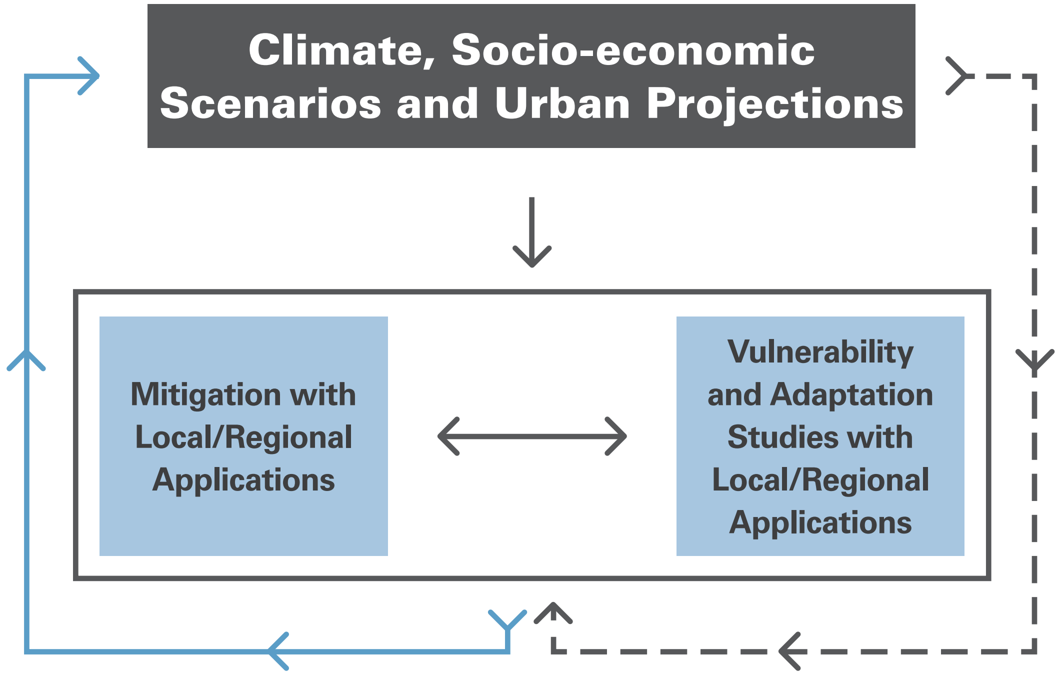


Future Integration Efforts

Previous California assessments and the vast majority of studies conducted for California have used an approach that starts with climate, socio-economic, and growth scenarios and end up with estimation of impacts and/or adaptation options. Only a handful of studies have used an alternative approach that begins with estimation of vulnerabilities and proceeds toward an examination the available climate scenarios to estimate the likelihood of when the system under study would experience the negative effects of climate change (Lempert et al. 2012). The second approach can also be applied to identify robust adaptation options that would perform relatively well under a variety of different, but plausible, future climate scenarios (Hallegatte et al. 2012; Kunreuther et al. 2013).

The *Research Plan* suggests using both approaches in a synergistic way as illustrated schematically in Figure 9. From the start of future California climate assessments, scenarios will be available to the groups in charge of mitigation and adaptation studies implementing the first approach. When applicable, long-term mitigation or adaptation studies must consider how they affect each other. At the same time, research groups using the second approach will begin their exploration of climate vulnerabilities without being constrained by the selected scenarios. Usually impacts and adaptation studies produce initial results in a two-year timeframe. During this period, the developers of climate and sea-level rise scenarios will refine their models and develop additional scenarios with the goal of producing quasi-probabilistic scenarios (see Chapter 3). At this point, the integration of the different efforts would take place. For example, the researchers that start with the climate scenarios could reflect on their results in light of the new quasi-probabilistic projections. The users of the second approach could estimate when their systems under study would experience negative impacts and what the potential likelihood of these impacts would be (black arrow on the right in Figure 9). Additional iterations are theoretically possible because adaptation and mitigation measures can affect our regional climate (blue arrow on the left in Figure 9). For example, forest-thinning practices to reduce the risk of wildfires may reduce the amount to water transferred from forested areas to the atmosphere, impacting streamflows and ambient temperatures.

Figure 9. Conceptual illustration of climate change research integration: mitigation and adaptation studies will inform each other to ensure that they are mutually consistent, and development of scenarios will iteratively guide and be guided by results from adaptation and mitigation research.



State-sponsored research must also be integrated and coordinated with national and international components so that the California studies address the regional "gaps" left by large-scale efforts, leverage outside resources, and feed into national and international assessments. The federal government should release the Fourth National Climate Assessment in 2018 in compliance with a mandate to produce assessments every four years. California and the federal government are discussing opportunities to coordinate, such as selecting common climate, sea-level, and socio-economic scenarios. At the same time, the Intergovernmental Panel on Climate Change may be moving towards the production of more timely topical assessments, and this may represent an opportunity to inform and be informed by future IPCC assessments.

Implementation

As indicated in Chapter 1, the *Research Plan* does not create mandates for the agencies involved. The *Research Plan* was developed to enhance coordination actions inside state government and with external groups and to identify research gaps. The Research Working Group of the Climate Action Team provides the forum for state agencies to discuss their proposed research activities and to coordinate them. The research catalog also keeps the Research Working Group and interested stakeholders informed about the range of activities and the status of individual projects. The Climate Action Team, in coordinating research activities with mitigation and adaptation strategies, will update the *Research Plan* every other year, with major revisions every four years. This section briefly presents an overview of how regional climate change research is being funded in California to illustrate how parts of this plan may be implemented.

At present, the CPUC, ARB, and the Energy Commission have research funds to support climate research for both mitigation and adaptation. For example, the Energy Commission is the administrator of the EPIC and Natural Gas Research programs created by the CPUC. The vast majority of these funds are allocated to the development and demonstration of clean energy technology designed to help California achieve a variety of energy-related goals, including its climate mitigation targets and goals. A small fraction of these funds, however, is being used to develop climate scenarios and for mitigation and impacts/adaptation options for the energy sector with the goal of reducing potential negative effects to electricity and natural gas ratepayers. ARB mainly funds research on GHG emissions accounting methods, mitigation options, and air quality impacts from a changing climate.

Other state agencies use existing funds that have not been directly allocated for climate change, but that must consider climate change for the ultimate success of their endeavors. For example, the California DWR has funded research on atmospheric rivers and installed a network of coastal observing units to provide an early flood warning system. This system will also be extremely useful as a preparedness tool under a changing climate that is expected to result in an increased risk of flooding (Das et al. 2013). The CDFA is funding research to investigate how current agricultural practices for specific crops contribute to nitrous oxide emissions. State agencies are also benefiting from funds available from the federal government to advance regional climate science. For example, the California Department of Public Health (CDPH) received federal funds to develop and implement measures to reduce public health impacts of a warming atmosphere. ARB is leveraging data collected by the National Institute of Standards and Technology and NASA on GHG monitoring in the Los Angeles Basin to improve emissions accounting efforts. The San Francisco Bay and Conservation Development Commission has received several federal grants to study the impact of sea-level rise in its jurisdiction. Caltrans has received funds from the U.S. Department of Transportation to conduct a climate vulnerability study for the transportation network in California. Additionally, the U.S. Department of the Interior has created the California Landscape Conservation Cooperative to support research on climate-related ecological issues. The federal government also directly funds or conducts climate-related scientific research in California, such as the research by the U.S. Forest Service on adaptation options for lands in California owned by the federal government. Finally, private groups such as non-governmental organizations and foundations are supporting local and regional efforts. In summary, there are multiple climate-related research activities in California that must be considered in the implementation of this plan. At the same time, the diversity of activities creates a challenge for long-term research planning. Under this sea of activities, the important liaison role played by the Climate Action Team Research Working Group should include coordination with external groups.

As California embarks on its Fourth Climate Change Assessment with limited state funds, it must consider how to advance actionable science that serves the growing needs of state- and local-level decision makers from a variety of sectors. The Fourth Assessment will be led by the CNRA, with the CAT Research Working Group serving as an advisory steering committee. A suite of studies directly related to the energy system will be funded and managed by the California Energy Commission. Although the Energy Commission studies will draw different funding streams from the "non-energy" studies to be funded by CNRA, the two groups of studies are closely coordinated to ensure internal consistency and to leverage limited state funds.

It is important to note that this *Research Plan* does not provide direct suggestions for new investments in climate research for the State, which most likely would require tens of millions of dollars per year. However, the *Research Plan* clearly suggests that outside the electricity and natural gas sector, state investments in other areas such as agriculture, public health, water resources, and coastal resources are sorely needed.

Concluding Remarks

Human-caused climate change is projected to substantially affect all major economic sectors in California, and all sectors must be a part of California's efforts to significantly reduce GHG emissions. The international scientific community has made clear both the urgency and magnitude of the climate challenge: in addition to rapidly and significantly reducing aggregate GHG emissions, we must prepare to thrive under climatic conditions that depart from the historical norm to which we've been accustomed.

Fortunately, California has been an early actor in developing both the science and policy to address climate change. Over the past twenty-five years, California has established a strong network of climate scientists engaged in modeling regional impacts, tracking GHG emissions, and identifying sectoral vulnerabilities and adaptation options. This scientific community has, in turn, been instrumental in forming a basis for California's leadership in climate change mitigation policy as well as efforts to safeguard California against climatic changes already underway.

The *Research Plan* can help ensure that California continues to benefit from a sound scientific basis for its climate change strategies. This *Research Plan* is intended to help improve communication between the producers of scientific results and decision makers. For instance, ARB hosts periodic meetings to receive updates on N_2O research activities funded by ARB, the Energy Commission, CDFA, and CalRecycle. This is a continuing effort to coordinate research with state agencies, academia, and industry and receive input from stakeholders on proposed research for improving our understanding of N_2O emissions associated with fertilizer use in California. The *Research Plan* also envisions the continuing integration of strategies to limit and prepare for climate change, because a climate-resilient California demands aggressive mitigation and adaptation efforts that are inextricably linked to each other. The *Research Plan* will help the State coordinate with federal and international actors, because California's efforts must harmonize with, inform, and reinforce those of the broader community to ensure global climate resilience.

Although the challenges before the state are daunting, the required transformations present opportunities to foster communities that are more equitable, healthy, and food-secure, while protecting California's bountiful natural resources.

Glossary of Abbreviations

Acronym	Definition
AR	Atmospheric River
ARB	California Air Resources Board
ARCCA	Alliance of Regional Collaboratives for Climate Adaptation
CAP	California Application Program
CAT	Climate Action Team
Cal/EPA	California Environmental Protection Agency
CalFIRE	California Department of Forestry and Fire Protection
CalRecycle	California Department of Resources, Recycling and Recovery
Caltrans	California Department of Transportation
CDFA	California Department of Food and Agriculture
CDFW	California Department of Fish and Wildlife
CDPH	California Department of Public Health
CNRA	California Natural Resources Agency
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
CSC	Climate Science Center
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DWR	California Department of Water Resources
EGPR	*Environmental Goals and Policy Report* (Office of Planning and Research)
EPIC	Electric Program Investment Charge
FIA	Forest Inventory and Analysis (U.S. Forest Service)
GCM	Global Climate Model
GHG	Greenhouse Gas
GWP	Global Warming Potential
HFC	Hydrofluorocarbons
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
LCC	Landscape Conservation Cooperative
LCFS	Low Carbon Fuel Standard
LEV	Low Emission Vehicle
$MMTCO_2e$	Million Metric Tons Carbon Dioxide Equivalent
NAS	National Academy of Sciences
NOAA	National Oceanic Atmospheric Administration

NWS	National Weather Service
ODS	Ozone Depleting Substance
OEHHA	Office of Environmental Health Hazard Assessment
OPR	Governor's Office of Planning & Research
PFC	Perfluorocarbon
PIER	Public Interest Energy Research
RD&D	Research, Development, and Demonstration
SLCP	Short-lived climate pollutant
USDA	U.S. Department of Agriculture
VMT	Vehicle miles traveled
ZEV	Zero Emission Vehicle
ZNE	Zero Net Energy

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APPENDIX A

Acknowledgements

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APPENDIX B

Climate Monitoring, Analysis, and Modeling

This appendix provides more background detail on past and current research on climate monitoring, analysis, and modeling, and main lessons learned to explain the rationale for the research agenda in Chapter 3 of the Climate Change *Research Plan*. It also provides more detail on the proposed agenda. The appendix is a separate document that will be posted at the California Climate Change Portal when completed.

APPENDIX C

GHG Emissions Accounting Methods and Research Needs

This appendix provides more background detail on California's methods for emissions accounting of GHGs, past and current research on inventory methods, and main lessons learned to explain the rationale for the inventory research agenda in Chapter 4 of the *Climate Change Research Plan*. It also provides more detail on the proposed agenda. The appendix is a separate document that will be posted at the California Climate Change Portal when completed.

APPENDIX D

Reducing GHG Emissions in California

This appendix provides more background detail on past and current research on strategies and technological innovations to reduce GHG emissions by sector, and main lessons learned to explain the rationale for the research agenda in Chapter 4 of the *Climate Change Research Plan*. It also provides more detail on the proposed agenda. The appendix is a separate document that will be posted at the California Climate Change Portal when completed.

APPENDIX E

Safeguarding California from Climate Risks

This appendix provides more background detail on past and current research on the impacts of climate change in California, the vulnerabilities by sector, and main lessons learned to explain the rationale for the research agenda in Chapter 4 of the *Climate Change Research Plan*. It also provides more detail on the proposed agenda. The appendix is a separate document that will be posted at the California Climate Change Portal when completed.

APPENDIX F

Crosscutting Issues

This appendix provides more background detail on crosscutting issues that were briefly highlighted in Chapter 5 of the *Climate Change Research Plan*. The appendix is a separate document that will be posted at the California Climate Change Portal when completed.

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