Chapter 1: Introduction

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OUTLINE

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2. **Greenhouse gas emissions**
3. **The economic case for a climate policy**
4. **The structure of the report**

1 Climate Change and California

Rising concentrations of greenhouse gases (GHGs) in the atmosphere have already caused perceptible changes in climate and will lead to further climate change in the future (Intergovernmental Panel on Climate Change 2001). The impact of climate change in California may be particularly significant in some areas: water resources, agriculture, and sensitive coastal and forest ecosystems (Shaw 2002; Roos 2003; Hayhoe, Cayan et al. 2004). In turn, these impacts could have serious repercussions for the economy and public health of the State, and for California's agricultural and recreation industries.

California's water system is especially vulnerable to climate change. Roughly 80% of California's precipitation falls in the winter, between October and March, but about 75% of all water use in California occurs between April and September. Similarly, 75% of our precipitation falls north of Sacramento, but most agricultural and urban water use in California occurs south of Sacramento. To bridge the gap in time and space, Californians rely on a vast network of reservoirs and aqueducts that store water and then move it across the state. In addition to man-made structures, we also rely on the snow pack in the Sierra Nevada mountains which provides a natural source of storage, holding the winter precipitation in the form of snow and releasing it in the spring and early summer as the snow melts. The storage in the Sierra Nevada snowpack is roughly equal to half the storage capacity in California's man-made reservoirs. With rising temperatures, the snowpack will decline and a larger share of winter precipitation will be lost to spring and summer use. By the end of the century, the Sierra snowpack could decrease by as much as 90% in the higher-emissions, higher-temperature climate change scenarios.

The state of California has been conducting research on climate change in California since 1988. Since 1997, this research has come with the purview of the Public Interest Energy Research (PIER) Program managed by the California Energy Commission (CEC), which supports public interest, energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace. In 2003, PIER published a first attempt at a state-level integrated assessment of climate change in California (Wilson et a., 2003). To follow this up and expand it, PIER established the California Climate Change Center, located jointly at UC Berkeley and at the Scripps Institution of Oceanography in San Diego, to conduct research on the impacts of climate change on California and to assess the benefits and costs of policies to respond to climate change by reducing GHG emissions and also by preparing to adapt to the inevitable consequences that California will face.

On June 1, 2005, recognizing and responding to dangers posed to California by climate change, Governor Schwarzenegger signed Executive Order # S-3-05 (Schwarzenegger 2005). The Executive Order established the following GHG emission reduction targets for California:

- by 2010, reduce GHG emissions to 2000 levels;
- by 2020, reduce GHG emissions to 1990 levels; and,
- by 2050, reduce GHG emissions to 80 percent below 1990 levels.

In addition, the Executive Order called for a research effort into the impacts of climate change on California with a report due in January 2006 and bi-annually thereafter. The 2006 report will cover impacts on agriculture, water, forests, fire, coastal resources, health and energy. It seeks to characterize what is now known about these impacts, qualitatively as well as quantitatively, and also to identify what is *not* yet known and what new research will be needed to produce a more complete assessment in future. The research effort is being led by Dan Cayan, Director of the California Climate Change Center at Scripps and by Michael Hanemann, Director of the California Climate Change Center at UC Berkeley

In order to understand the implications of climate change policy in California, the Energy Foundation and the Hewlett Foundation commissioned a second study. This work was led by Michael Hanemann and by Alex Farrell, a participant in the California Change Center at UC Berkeley. This study focuses on the policies that might be adopted in California to reduce the emission of greenhouse gasses (GHGs) to meet Governor Schwarzenegger's targets, and what their economic effect might be on the California economy.

The Governor's 2010 and 2020 targets represent a modified version of the Kyoto Protocol target – reducing GHG emissions in California to the level of 1990, but by 2020 rather than 2012. The 2050 target is something far more novel and significant. This is, in fact, the type of reduction in GHG emissions that developed countries around the world will need to achieve about that time if the atmospheric concentration of carbon dioxide is to be stabilized at double the pre-industrial level, rather than continuing to rise to levels that could bring very dangerous consequences (Wigley, Richels et al. 1996; O'Neill and Oppenheimer 2002). Although California is the first state to confront the prospect of a substantial de-carbonization of its economy by mid-century, this challenge will likely become the central focus of post-Kyoto climate policy for *all* the developed countries.

Because of their scope, the Governor's targets require a portfolio of different strategies. The strategy to meet the 2010 and 2020 targets is to draw on existing technologies that are presently in use or on the verge of deployment, and to fashion a set of incentives that shift the normal pattern of economic activity and growth towards less carbon-intensive or less energy-intensive technologies using a combination of an intensification of the environmental and energy conservation programs already in place in California plus the introduction of some new ones targeted specifically at GHG emissions.

To meet the 2050 target, a different approach is required. This calls for a profound refashioning of the economy, comparable to the shift that was triggered by the energy crisis of the early 1970s, or the shift that is still occurring following the introduction of micro-computers in the late 1980s and the internet in the 1990s. Computers and the internet can help with the decarbonization of the economy, but they are not sufficient by themselves. It will also require new technologies, new institutions, and new industries. At this point, we do not know what those technologies will be – or rather, we know the potential set of these technologies, but we do not yet know which will turn out to be winners, and which losers or has-beens. The development and deployment of new technologies takes time, and none of this will happen overnight. But that does not mean California should do nothing right now. To the contrary, because of the long lead time California needs to have in place now a pro-active and effective program for the promotion of technological innovation targeted at the decarbonization of the California economy. Moreover, because of the long life of capital in the energy sector and other GHG-intensive industries, as well as of infrastructure associated with land use and transportation, California needs to take action now to its align other economic, transportation, and land-use policies to facilitate the eventual decarbonization of the economy and pave the way for the economic, social and technological innovations that will be required to meet the 2050 targets.

2 Greenhouse Gas Emissions

2.1 Sources and Trends of GHG Emissions

As one of the largest economies in the world, California has significant GHG emissions. On a per capita basis, California has very low emissions of CO_2 from fossil fuel combustion, with the fourth lowest emissions per capita of the 50 states. However, the State's large population and economy mean that California, in aggregate, is a major contributor to the U.S. GHG inventory of all gases, contributing roughly 6% of total United States GHG emissions. California is the second larger emitter after Texas among U.S. states. Only nine nations have greater total emissions than the State.

Anthropogenic activities generating four different gases – carbon dioxide (CO_2) from fossil fuel combustion, nitrous oxide (N_2O) primarily from agriculture and transportation, methane (CH_4) primarily from agriculture and landfills, and "high global warming potential" gases used in industry – account for almost all GHG emissions in the State. Of these, CO_2 is the most important. Emissions of CO_2 are mainly associated with carbon-bearing fossil fuel combustion, with a portion of these emissions attributed to out-of-state fossil fuel used to generate electricity for consumption within California. Excluding imported electricity, 83% of California's GHG emissions are carbon dioxide (CO_2) emissions from fossil fuel combustion, a percentage that has held quite steady between 1990 and 2002 (Bemis and Allen 2005). Mineral production, waste combustion, land use, and forestry changes also contribute to carbon dioxide emissions. Some anthropogenic activities help reduce atmospheric concentrations of carbon dioxide, and are called CO_2 "sinks." Figure 1-1 illustrates recent trends in California's GHG emissions as well as the baseline forecast for 2010 and 2020, and the Governor's goals.

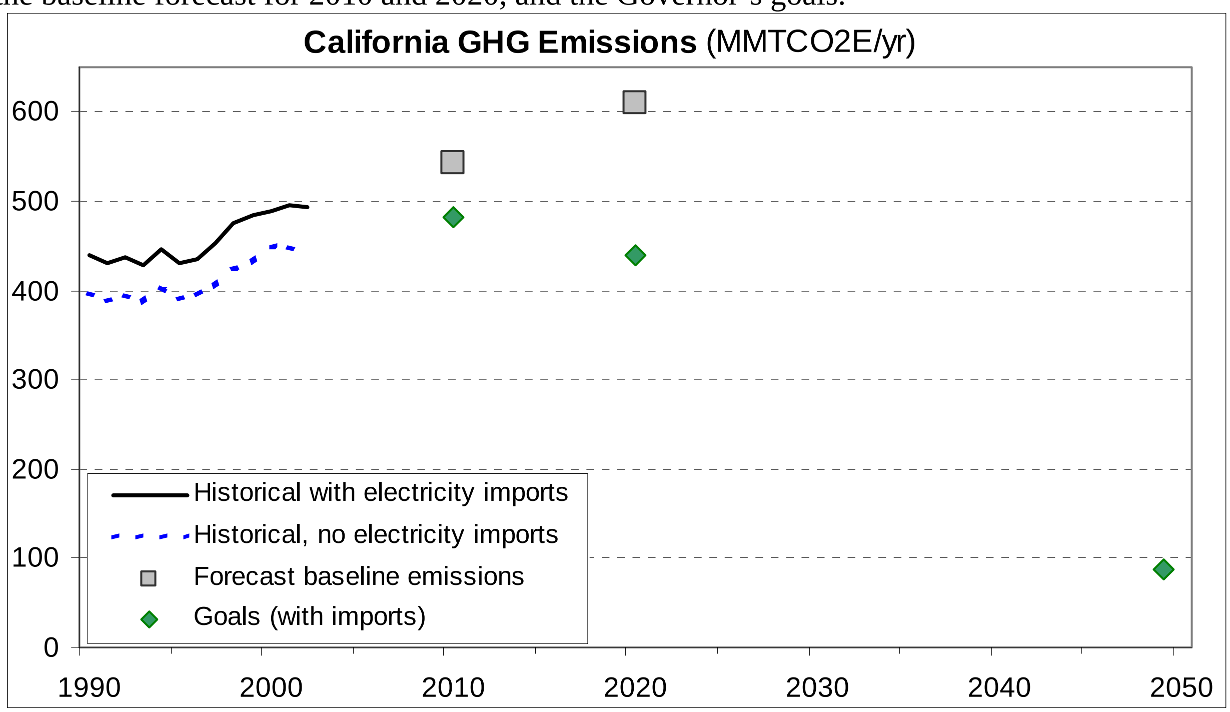

Figure 1-1: Historical and forecast GHG emissions, and Governor Schwarzenegger's goals.
Source: Bemis and Allen (2005) and author's calculations

Emissions of GHGs can be categorized in many ways. Figure 1-2 compares the GHG emissions in California and the United States by end-use sector, including electricity generation as an end-use. This approach illustrates how much less important the electricity sector is in California relative to the rest of the country. Transportation contributes a larger share of GHG emissions in California. In this categorization, agriculture is included in “Industrial” emissions, and thus this sector is larger as well.

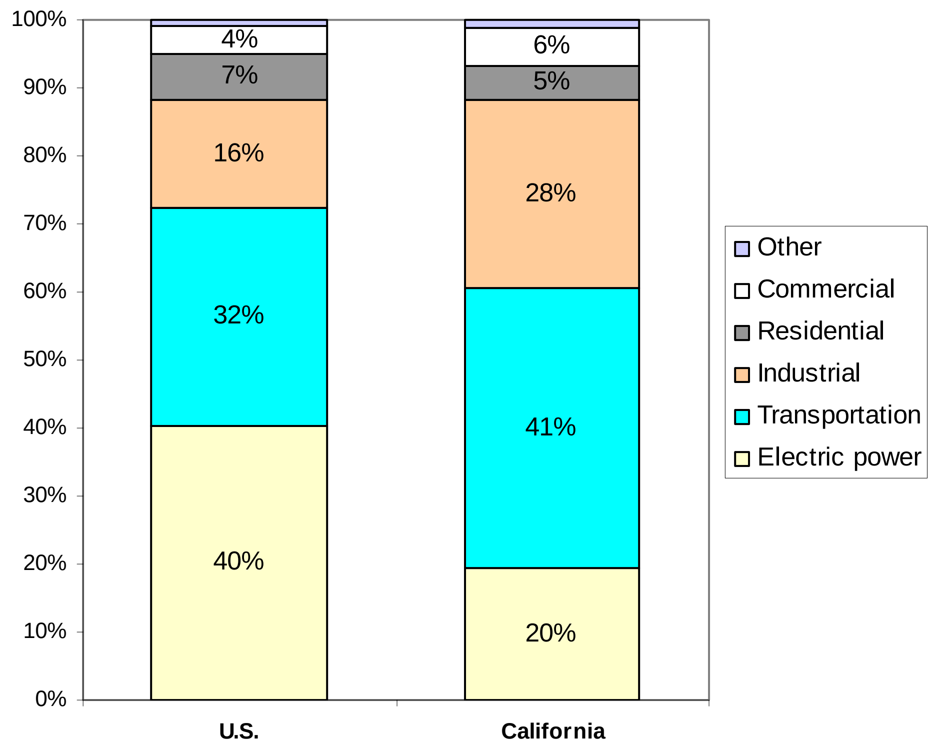

Figure 1-2. GHG emissions by end-use sector, including electricity generation, 2002[1]
Source: U.S. data from U.S. Environmental Protection Agency (2005); California data from Bemis and Allen (2005)

Another approach is to compare the climate effect of different gases. To do this, the “global warming potential” (GWP) unit was created. The GWP is the cumulative radiative forcing over a specified time span caused by the emission of a unit mass of gas, relative to emission of a reference gas (Intergovernmental Panel on Climate Change 2001). The reference gas is CO_2, which thus has a GWP of 1. In contrast, take a molecule of sulfur hexafluoride (SF_6), which is typically used as a gaseous insulator in power breakers. A molecule of SF_6 is thousands of times more effective at absorbing and re-radiating infra-red radiation than CO_2 for any given period, and each emitted SF_6 molecule stays in the atmosphere much longer, resulting in a GWP for SF_6 of 22,200 (Intergovernmental Panel on Climate Change 2001). Data reported here uses the 100-year time horizon GWPs from the IPCC Third Assessment Report, and convert emissions into equivalent units of millions of metric tons of CO_2 (MMTCO2E). Figure 1-3 illustrates the relative proportions of the major GHGs emitted in California in 2002.

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[1] Bemis and Allen (2005) provide sector breakdown for transportation, commercial and industrial sectors. Some classification required of emissions’ sources to calculate breakdown between residential and commercial sectors.

Table 1-1: Global warming potential of selected greenhouse gases as reported in the IPCC Third Assessment Report (TAR, IPCC 2001).

Gas	GWP (MMTCO2E)	Lifetime (y)	Molecular weight (g/mole)
CO_2	1	*NR*	44
CH_4	23	12	16
N_2O	296	14	44
HFC-23	12,000	260	70
HFC-134a	1,300	13.8	102
HFC-152a	120	1.4	66
CF_4	5700	50,000	88
SF_6	22,200	3200	146

NR = not reported because this values depends greatly on assumptions.

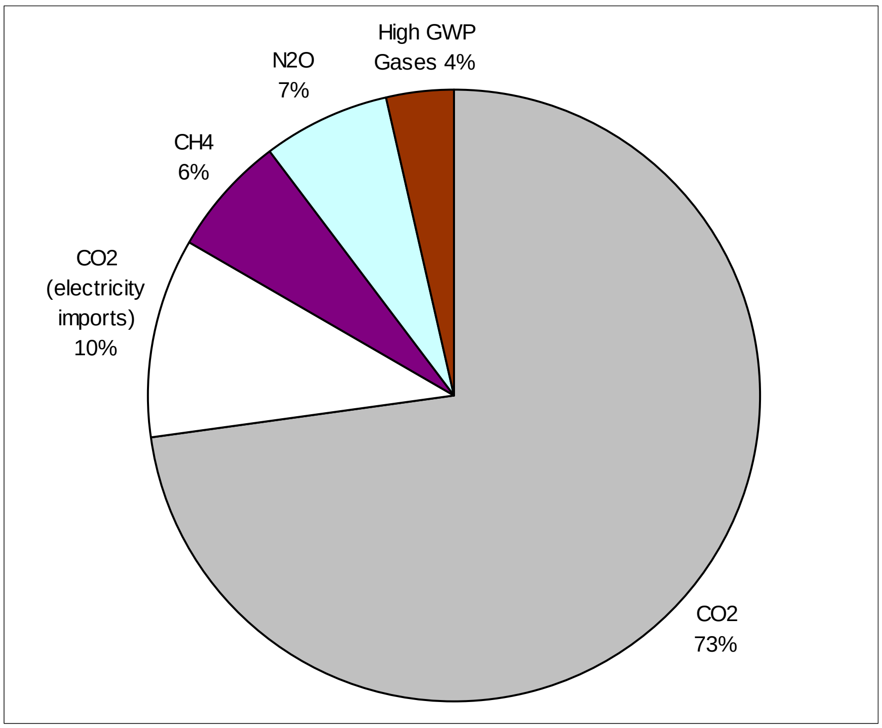

Figure 1-3. California GHG emissions by gas, 2002
Source: Bemis and Allen (2005)

To order to understand the magnitude of the GHG contributions by sector, it is necessary to examine the specific combinations of activities and gases. Figure 1-4 and Table 1-1 show these values; note that the significant uncertainties associated with some of these estimates are not depicted (Bemis and Allen 2005; Farrell, Brandt et al. 2005). These data illustrate that CO_2 emissions from transportation and electricity account for almost three-quarters of all GHG emissions in California. Further, some of the larger non-CO_2 GHG emissions are from activities that have significant uncertainties and may be hard to control, such as soil N_2O, and CH_4 from livestock (enteric sources) and manure.

Table 1-1: California GHG emissions by sector and gas, 2002 (MMTCO2E)

Sector/Gas	2002 emissions	Fraction of total
Marine CO2	0.76	0.2%
Stat. Engine CH4	1.1	0.2%
Electricity SF6	1.2	0.2%
Other CO2	1.4	0.3%
Wastewater CH4	1.9	0.4%
Other Trans. CO2	2.3	0.5%
Oil & Gas CH4	2.8	0.6%
Rail CO2	2.9	0.6%
Land Use CO2	4.3	0.9%
Other Non-CO2	4.4	0.9%
Cement CO2	6.2	1.3%
Manure CH4	6.3	1.3%
Enteric CH4	7.7	1.6%
Landfill CH4	10	2.0%
Mobile N2O	13	2.6%
Commercial CO2	16	3.1%
ODS substitutes	16	3.1%
Soil N2O	19	3.8%
Residential CO2	25	5.0%
Aviation CO2	26	5.3%
Diesel Onroad CO2	27	5.5%
In-State Electricity CO2	44	8.8%
Imported Electricity CO2	52	10%
Industrial CO2	75	15%
Gasoline CO2	131	26%
CO2 Total	416	84%
Non-CO2 Total	78	16%
Total	**494**	**100%**

Notes: Totals may not sum due to rounding. “ODS” stands for ozone depleting substitutes.
Source: Bemis and Allen (2005)

Much attention in climate change analysis centers on CO_2 because it is the largest contributor to the problem. However, to meet the Governor’s 2050 goals, control of at least some non-CO_2 GHG emissions will be necessary, because relying on CO_2 emission reductions is likely to be either impractical or too expensive. Further, non-CO_2 gases may offer significant opportunities for low-cost emissions reductions in the near term, as discussed in Chapter 4.

In addition to the main non-CO_2 GHGs identified above, other anthropogenic emissions also affect climate change. These include carbon monoxide, oxides of nitrogen, aerosols, non-methane volatile organic compounds, and ammonia, which all affect the chemistry of tropospheric ozone and methane, both important greenhouse gases. Particles also have a large, but poorly understood effect. Emissions of black carbon (soot), sulfur dioxide and oxides of nitrogen contribute to atmospheric particulate concentrations and characteristics. The data exclude these various gases and aerosols.

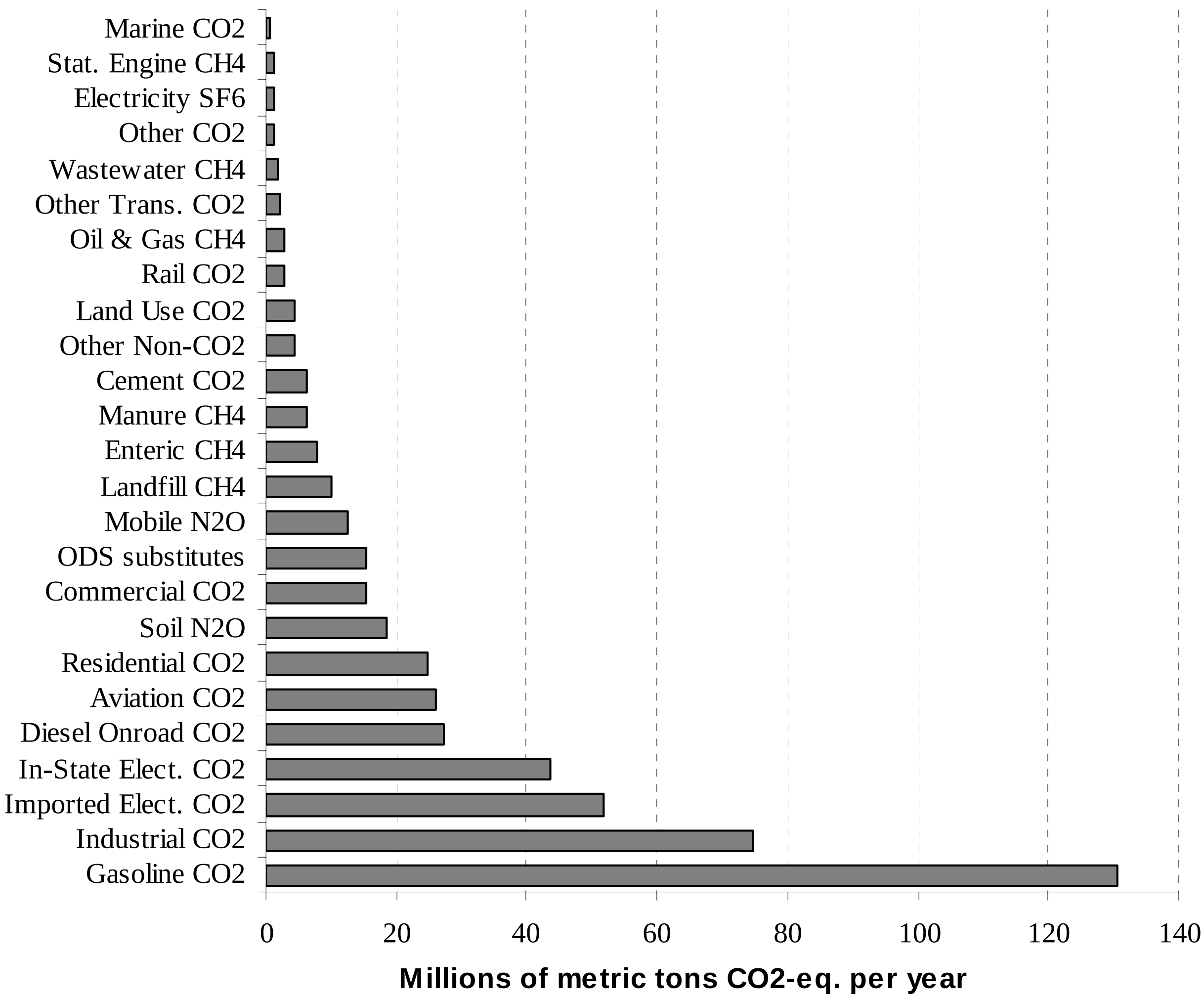

Figure 1-4: California GHG emissions by sector and gas, 2002
Note: "ODS" stands for ozone depleting substitutes.
Source: Bemis and Allen (2005)

2.2 Sinks of Greenhouse Gases

Human activities can enhance biogeochemical processes that remove GHG from the atmosphere, creating sinks that offset emissions. For example, agricultural management can increase carbon storage in soils, while forest and range management can increase primary productivity and the resulting storage of carbon in biomass. Land use and forestry in California sequestered approximately 25 MMTCO2E in 1990, but by 1999, carbon sequestration had decreased to less than 19 MMTCO2E, the equivalent of a 6 MMTCO2E *increase* in CO_2 emissions from the land surface over the decade (California Energy Commission 2005)..

Of the non-CO_2 GHGs, only methane has a significant biogeochemical sink for gases in the atmosphere (most N_2O produced in soil is biologically transformed before emissions). Aerobic soils consume atmospheric methane through oxidation (Torn and Harte 1996). Globally, the net soil sink of atmospheric methane is about 30-60 MMTCO2E per year, approximately 10% of all anthropogenic sources (Intergovernmental Panel on Climate Change 2001). The current California inventory does not explicitly include the effect of land use and management on soil sinks of atmospheric methane.

3 The Economic Case for a Climate Policy

Greenhouse gasses are fundamentally no different than any other pollutant in that they create a negative externality. Economists point out the key distinction between the private versus the public (or social) costs and benefits of any activity. The private costs and benefits are those that accrue to the individual or firm undertaking the activity. The social costs and benefits include those benefits *plus* social costs and benefits that accrue to *other* members of society, who are affected by the activity but have no say in whether and how it is undertaken. These additional social costs or benefits are called “externalities” to distinguish them from the private, or “internal,” effects that accrue to the person undertaking the action. While a competitive market can produce an outcome that is in the public interest when only private costs and benefits are involved (this is Adam Smith’s argument of the “invisible hand”), but this does *not* hold true when externalities are present. In the presence of externalities, the outcome of a free market system is not likely to be in the best public interest because the externalities are overlooked by private players. Consequently, Pigou argued, there is likely to be a need for some governmental intervention, whether in the form of direct regulation or financial (dis)incentives.

GHG emissions are not a conventional pollutant like sulfur dioxide, particulates, or mercury, which touches people directly in some way and harms them. The primary impacts of GHG emissions are indirect – they affect people because they ultimately lead to changes in temperature levels and patterns of precipitation, and a rise in the level of the ocean which can lead, in turn, to some harmful consequences for people. Conceptually, the distinction is immaterial: using fossil fuels or otherwise releasing GHG emissions into the atmosphere creates a harmful effect on others and constitutes an externality. In the presence of this externality, there is the same presumption that an unfettered free market will not lead to an outcome that is in the best public interest, and there is a presumptive case for public action -- governmental intervention -- to reduce the level of the harmful activity.

Reducing GHG emissions will involve a combination of behavior change and technological innovation and adoption. Often but not always, these changes would not occur without some good reason to justify them because they entail economic costs, disruption, and inconvenience. It is public intervention that provides the motivation to undertake these changes – to internalize the externality that otherwise would be overlooked.

There can certainly also be some *voluntary* private action to limit the scale of the harmful externality, as is clearly happening today in several sections of the business community. One important example is the California Climate Action Registry, a public/private non-profit organization that encourages and promotes GHG reductions and provides a documentary record of emission reductions. [2] The Registry has has been very productive in developing general and industry-specific GHG measurement and verification protocols, and in significantly raising interest in and understanding about climate issues throughout the state. But, while such voluntary action is tremendously important in providing leadership and generating a strong signal to the larger public California public, in the last analysis it is not necessarily a perfect substitute for some form of public intervention to limit GHG emissions in California

[2] See www.climateregistry.org

In the case of reducing GHG emissions there is a second argument for public action, which relates to the nature of the technologies that have environmentally preferable qualities but no matching advantage to the producer or consumer. Technological change inspired by the control of emissions, however, is not as natural as innovation inspired by the traditional provision of goods or services for profit. The common finding in the economics of innovation literature that industry tends to under-invest in research, development, and demonstration (RD&D) generally, is enhanced in the case of "environmental innovation" because the public good of a clean environment indicates that there are weak incentives for private investment. As a result, government actions are particularly important in spurring this type of innovation. Another way to say this is that mitigating climate change (like most environmental protection) is a public good (and so under-provided by markets). Innovation designed to achieve public goods tends to require government action (Arrow, Bolin et al. 1995; Norberg-Bohm 1999). Chapter 3 discusses this issue at length and provides a summary of the evidence that has been gathered about these issues along with conclusions about what these findings mean for climate policy in California.

The policy challenge is to design a policy that at once takes advantage of known mitigation options to meet the 2010 and 2020 goals and spurs long-run investment in technological innovation necessary to meet the 2050 goal. It is hard to imagine a scenario that meets the 2050 reduction goal without a major advance that replaces fossil fuels, akin to the Governor's "hydrogen highway." Sufficient technology does not yet exist to economically remove CO_2 from fossil fuel combustion emissions, nor do we have sufficient experience with larger scale storage of the resulting CO_2. In addition to making great strides in efficient utilization of existing energy sources and supporting the development of alternative energy sources, California should invest new monies and find ways to combine and leverage resources with others to focus on innovative technologies to reduce, capture and store (sequester) greenhouse gas emissions in a cost effective manner. California should also seek innovative ways to combine and transfer its knowledge in energy efficiency and renewable sources of energy to other states and countries and learn from the work of others. Worldwide GHG emissions can be reduced cost-effectively by helping other regions become as energy efficient as California.

Effective climate policy must also address many of the equity issues typically associated with environmental justice (EJ). The issue of negative consequences for economically disadvantaged communities must be considered. Possible water shortages in California, for example, could result in higher prices and rationing of freshwater, impacts to which the poor and economically disadvantaged are like to be most vulnerable.

Early action could result in revenue opportunities for State businesses. California businesses, for example, could sell certified GHG emissions reductions credits. California businesses could also become exporters of low-GHG emission technology and expertise to other states and nations. Take the case of the LUMILEDS corporation in Sunnyvale, producers of what appears poised to become the next generation of lighting: light emitting diodes (LEDs). California businesses are well-positioned to lead the transition away from traditional fossil fuels towards the creation of markets for alternative fuel sources. The state historically has been well positioned to take advantage of technological revolutions, and this situation may present yet another such opportunity.

4 The Structure of the Report

This report has ten chapters, the first being this introduction. The authors have written each chapter independently. Each of the next eight chapters, while loosely integrated, are meant to be read as stand-alone documents. The final chapter summarizes and synthesizes the findings from each chapter. The second chapter contains a description of a macro-economic analysis of various climate policies proposed for the state of California. The BEAR model is the analytical core of this chapter, which focuses on near term policy actions, namely those proposed to achieve the Governor's 2020 targets. The third chapter reviews and synthesizes a great deal of available data on government policies to spur innovation and deployment of new technologies. The fourth chapter reviews the major approaches for mitigating GHG emissions, including low-carbon energy supplies, reducing GHG emissions in manufacturing, carbon sequestration, and reducing emissions of non-CO_2 GHGs. The fifth chapter discusses the lessons from prior examples relevant for designing a cap-and-trade system in California. The sixth chapter discusses the contribution of energy efficiency to reducing GHG emissions. The seventh chapter reviews the empirical evidence for the importance of endogenous technological change, and discusses how macroeconomic models can best incorporate such change. The eighth chapter discusses the role of transportation and, in particular, producer and consumer choices on transportation, in affecting GHG emission reductions. The ninth chapter analyzes the need for additional information and analyses of the state's electricity sector to help California define its climate policy.

5 References

Arrow, K., B. Bolin, et al. (1995). "Economic Growth, Carrying Capacity, and the Environment." Science **268**: 520-521.

Azar, C. and H. Dowlatabadi (1999). A Review of Technical Change in Assessment of Climate Policy. Annual Review of Energy and the Environment. R. Socolow, D. Anderson and J. Harte. Palo Alto, California, Annual Reviews Inc. **24:** 513-544.

Bemis, G. and J. Allen (2005). Inventory of California Greenhouse Gas Emissions and Sinks: 1990 to 2002 Update. 2005 Integrated Energy Policy Report. Sacramento, California Energy Commission**:** 85.

California Energy Commission (2005). Inventory of California Greenhouse Gas Emissions and Sinks: 1990 to 2002 Update. Sacramento**:** 85.

Farrell, A. E., A. R. Brandt, et al. (2005). Research Roadmap for Greenhouse Gas Inventory Methods. Sacramento, California Energy Commission - PIER Program**:** 131.

Hayhoe, K., D. Cayan, et al. (2004). "Emissions pathways, climate change, and impacts on California." Proceedings of the National Academy of Sciences of the United States of America **101**(34): 12422-12427.

Hoffert, M., K. Caldeira, et al. (1998). "Energy Implications of future stabilization of atmospheric CO2 content." Nature **395**(6075): 881-884.

Hoffert, M. I., K. Caldeira, et al. (2002). "Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet." Science **298**: 981-987.

Intergovernmental Panel on Climate Change (2001). Third Assessment Report: The Scientific Basis. New York, Cambridge University Press.

Norberg-Bohm, V. (1999). "Stimulating 'green' technological innovation: An analysis of alternative policy mechanisms." Policy Sciences **32**(1): 13-38.

O'Neill, B. C. and M. Oppenheimer (2002). "Climate change - Dangerous climate impacts and the Kyoto protocol." Science **296**(5575): 1971-1972.

Roos, M. (2003). The Effects of Global Climate Change on California Water Resources. Public Interest Energy Research Program - Research Development and Demonstration Plan. Sacramento, CA, California Energy Commission**:** 56.

Schwarzenegger, A. (2005). Executive Order S-3-05, Executive Department, State of California**:** 1.

Shaw, R. (2002). Ecological Impacts of a Changing Climate. PIER Environmental Area Report. Sacramento, California Energy Commission**:** 39.

Torn, M. S. and J. Harte (1996). "Methane consumption by montane soils: Implications for positive and negative feedback with climatic change." Biogeochemistry **32**(1): 53–67.

U.S. Environmental Protection Agency (2005). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003. Washington: 432.

Wigley, T. M. L., R. Richels, et al. (1996). "Economic and environmental choices in the stabilization of atmospheric CO2 concentrations." Nature **379**(6562): 240-243.