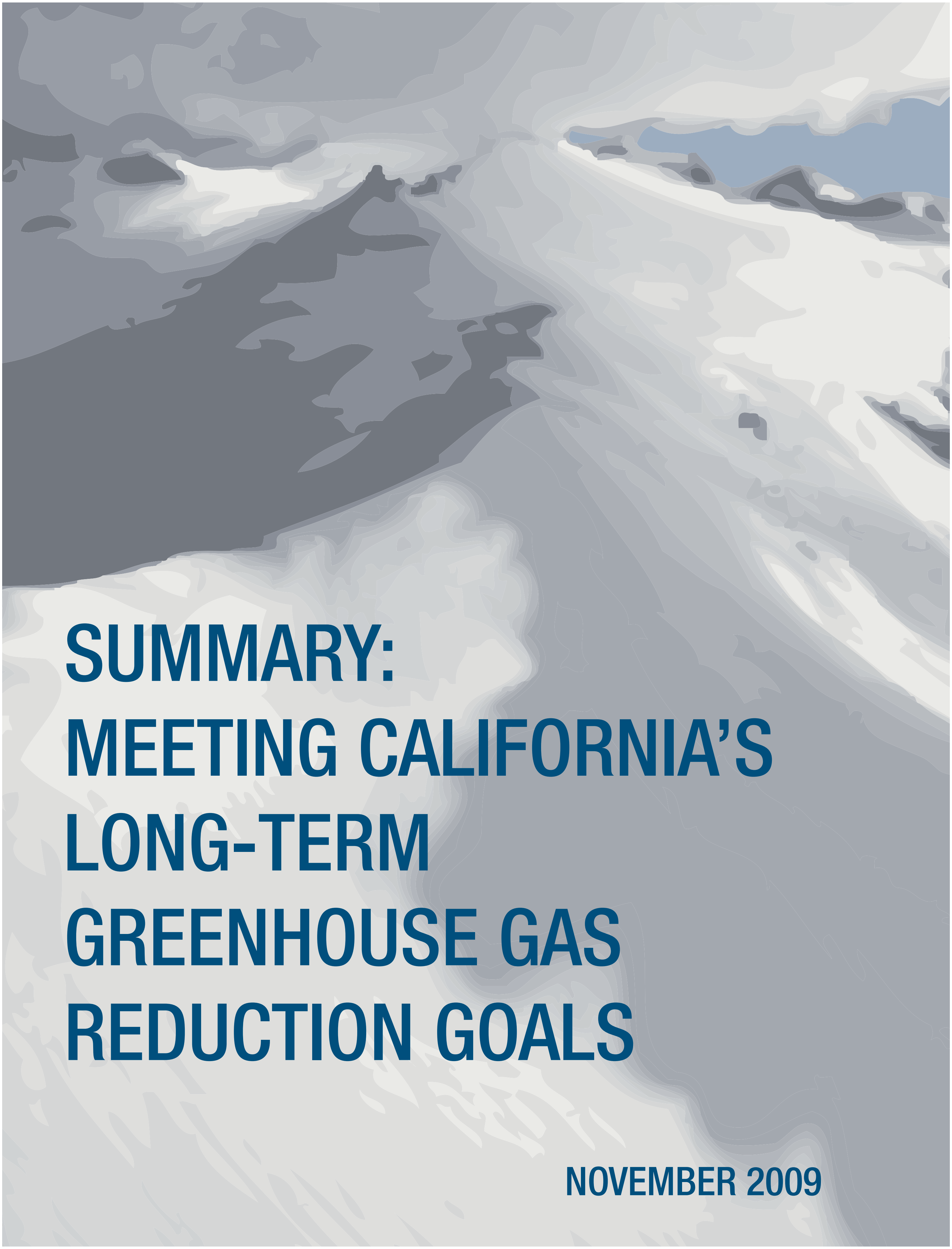

SUMMARY: MEETING CALIFORNIA'S LONG-TERM GREENHOUSE GAS REDUCTION GOALS

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Summary

Meeting California's Long-Term Greenhouse Gas Reduction Goals

Prepared for:

Hydrogen Energy International LLC

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Summary: Meeting California's Long-Term Greenhouse Gas Reduction Goals

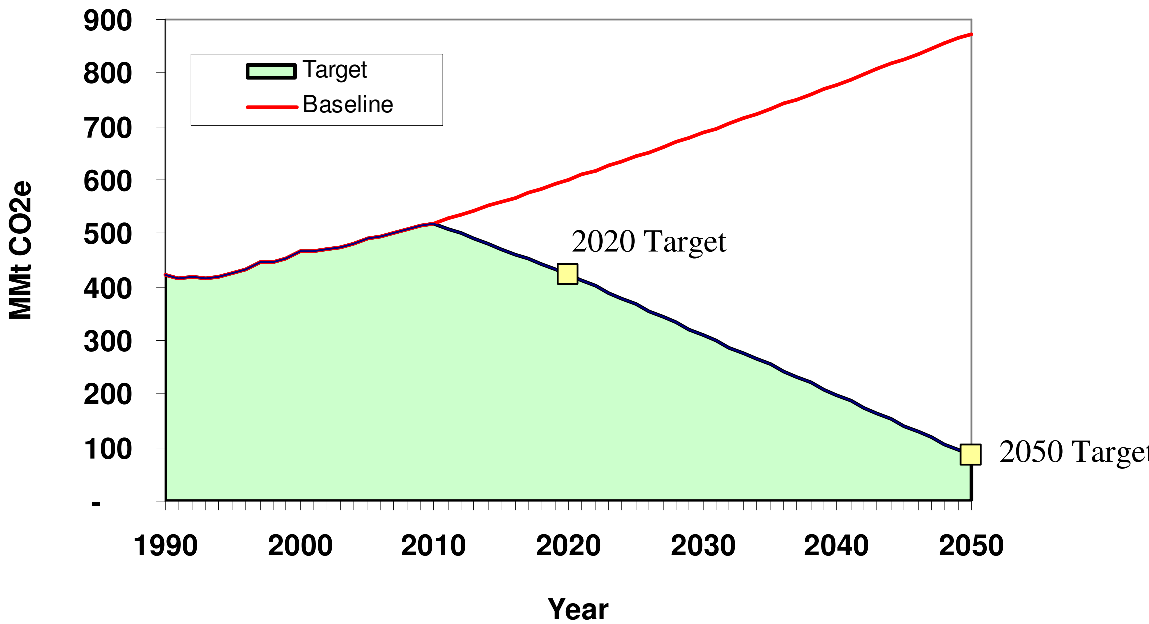
1 The Greenhouse Gas Emissions Reduction Challenge

Climate change threatens California's natural environment, economic prosperity, public health, and quality of life. The reasons for reducing greenhouse gas (GHG) emissions are compelling from both an economic balance of trade and an energy security perspective. California and the U.S. as a whole currently export huge amounts of domestic capital in order to import oil from volatile regions of the world. By weaning the economy off of imported oil, California may improve its economic outlook and help to enhance U.S. energy security.

Recognizing the need for action, California has put in place ambitious emission reduction goals. In 2005, California Governor Schwarzenegger's Executive Order S-3-05 committed the state to reduce emissions to 2000 levels by 2010, to 1990 levels by 2020, and to 80 percent below 1990 levels by 2050, a level consistent with current scientific evidence regarding the reductions needed to stabilize the climate. One year later, the Governor signed the "Global Warming Solutions Act of 2006" (Assembly Bill 32 or AB 32), which legally obligates the state to reduce GHG emissions to 1990 levels by 2020.

The scale of this challenge is illustrated in Figure 1 below. California's GHG emissions trajectory under a "Baseline" Case, wherein the state does not undertake efforts to reduce GHG emissions, is shown in red. The state's targeted emissions reduction pathway is shown in black, with the AB 32 target and the Governor's Executive Order 2050 target shown as yellow boxes. The 2020 GHG target represents approximately a 15 percent reduction from current emissions levels, while the 2050 goal implies a 90 percent reduction from 2050 Baseline levels.

Figure 1. Baseline Trajectory and 2020 and 2050 Emissions Targets (1990 – 2050) in Million Metric Tons CO_2 equivalent ($MMtCO_2e$)



California is seeking to achieve these GHG goals even as the state's population continues to expand, and as economic growth continues. The number of people in California is expected to grow from approximately 38 million today to nearly 57 million people by 2050. At this level of population growth, Californians will need to reduce their per capita GHG emissions from about 13 metric tons per person per year today to less than 2 metric tons per person per year by 2050. The goal is to achieve this level of GHG savings while increasing the state's economic output 1.5 times by 2050.

This report seeks to provide the first comprehensive picture of what will be necessary to achieve long-term emission reductions in California of the magnitude called for in Executive Order S-3-05, in terms of requirements for infrastructure investment, technology breakthroughs, and policies. We do not seek to forecast the most likely future for California, but rather to describe what a low-carbon future for the state might look like, and what will be required to achieve such a transformation. The precise mix of technologies that will be employed to achieve deep reductions in GHG emissions is impossible to know, and the relative contribution of different technologies and strategies to achieve GHG reductions is likely to vary over time. However, the key findings of this study focus on implications that are robust over a wide range of potential futures.

The basis for the analysis is a "bottom-up" infrastructure investment model that is designed to project GHG emissions trajectories by sector, based on a projection of changes in infrastructure stock (cars, trucks, houses, commercial space, etc.) and energy intensity over time (miles per gallon, vehicle miles traveled, and cooling, heating and lighting energy per unit, etc.). The model also evaluates the electricity grid for operability, using a simplified electricity grid dispatch model that accounts for energy, capacity, and balancing energy needs. Total GHG emissions in each sector are calibrated to a "top down" projection of energy use, based on projections of California state population, economic growth by sector, and historic energy demand by sector.

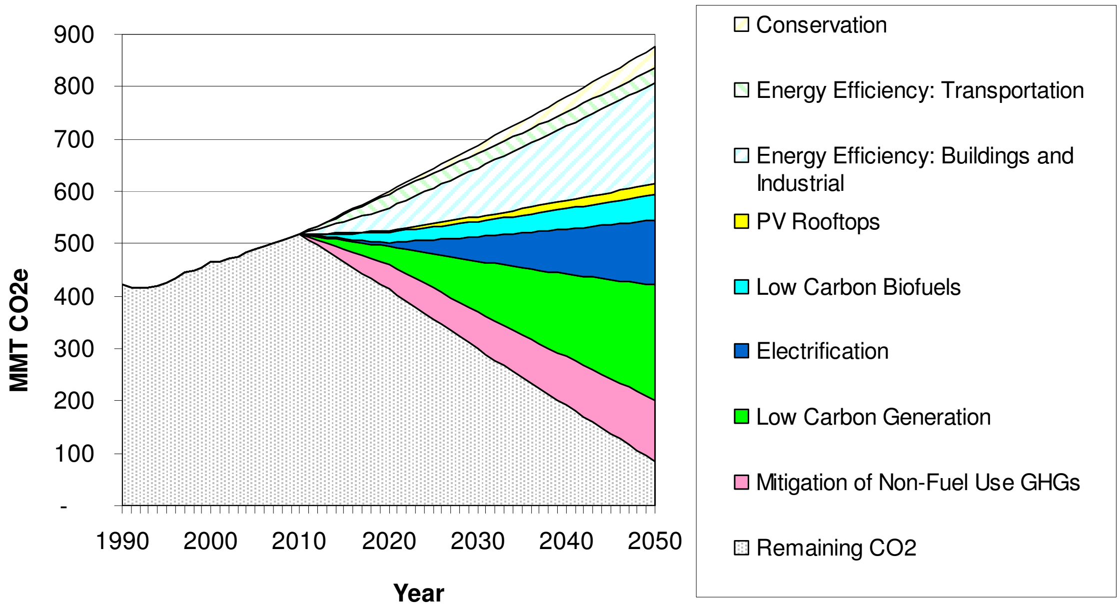
The report has been prepared by Energy and Environmental Economics, Inc. (E3). It was commissioned as an independent analysis by Hydrogen Energy International LLC, which is seeking to build California's first industrial scale hydrogen-fired power plant with carbon capture and sequestration.

2 Meeting the Challenge

California's aggressive 2050 GHG target cannot be met using a single, silver bullet solution; carbon emissions are too deeply integrated into our economy and society for that to be feasible. The magnitude of the 2050 GHG challenge means that nearly every sector of the economy will have to significantly reduce its carbon footprint, primarily through investment in new, more efficient and lower-carbon infrastructure. We identify five broad approaches to reducing GHG emissions, each of which must be successful and pursued simultaneously in order to meet the 2050 goal: 1) Conservation, 2) Energy efficiency and on-site generation, 3) Low-carbon biofuels, 4) Electrification and low-carbon electricity generation, and 5) Mitigation of non-fuel use GHGs.

The magnitude of the savings from each of these five approaches for achieving emissions reductions is shown from 2009 through 2050 in Figure 2. The figure below helps to illustrate that without all of these emission reduction measures, it will be extremely difficult to reduce statewide emissions to the range of 85 million metric tons of carbon dioxide equivalent (MMT CO_2e) by 2050.

Figure 2. Sources of Emissions Savings in the 2050 Compliant Case



The five broad approaches to reducing GHG emissions in California, and the implications of these approaches, are described in more detail below:

1. ***Conservation.*** Conservation means reducing the need for energy by reducing consumption of goods and services. Conservation is important, but we do not count on people to start using public transportation far more than they currently do and to drive less, or to undertake other behavioral changes to dramatically reduce energy use or CO_2 emissions to meet the 2050 GHG goal. For example, "smart growth" development, wherein homes are located closer to businesses and jobs, is expected to contribute approximately 5 percent of California's total GHG emissions savings in 2050.

    Smart Growth: By pursuing smart growth, we project that Californians' average vehicle miles traveled could be reduced about 10 percent compared to the Baseline Case, to around 12,000 miles per capita per year on average in 2050. However, total miles traveled per capita would still increase relative to today. Similarly, the number of airplane trips may be modestly reduced through telecommuting and improvements in public transportation such as high speed rail. Freight truck miles traveled can be slightly reduced through better planning and an increase in local production and consumption of goods.

2. ***Energy efficiency and on-site generation.*** Energy efficiency (EE) means producing the same product or service using less energy. EE can be implemented in both electric and fuel end-uses and processes in all sectors of the economy, including vehicle efficiency improvements. Energy efficiency must improve by about 1.2 percent per year – a rate last seen during California's 2000 – 2001 electricity crisis – for the next four decades in all sectors of the economy in order to reduce GHG emissions, keep costs manageable and reduce overall infrastructure requirements for new electricity generation. Low-carbon, on-site generation, such as solar PV rooftops, is also needed in homes and businesses to replace fossil fuel energy use. EE and solar PV rooftops are expected to save approximately 30 percent of California's total GHG emissions savings in 2050.

   Zero Net Energy Homes: As part of this push towards energy efficiency, new buildings built today through 2020 must consume half the energy of historical buildings. After 2020, new buildings must be 'zero net energy', producing as much energy as they consume using a combination of energy efficiency and low-carbon on-site generation, such as solar PV rooftops.

3. ***Low-carbon biofuels.*** Increased use of low-carbon biofuels, such as cellulosic ethanol, particularly in the transportation sector, will be necessary as well. However, the availability of low-carbon biomass to produce biofuels is small compared to liquid fossil fuel demand. Farmed, algae-based biofuels may not face the same supply constraints as cellulosic ethanol, but require technological breakthroughs before they can be commercialized. Even with such breakthroughs, it is unlikely that low-carbon biofuels could fully replace the tens of billions of gallons of yearly demand for gasoline and diesel. Natural gas vehicles emit too much CO_2 to meet the 2050 target. Therefore, we predict that biofuels will be necessary, but supply-constrained, premium fuels.

   Low-carbon biofuels are expected to contribute approximately 6 percent of California's total GHG emissions savings in 2050. Under a 2050

Compliant Case, fossil fuel consumption in the transportation sector (from gasoline and diesel fuel) is expected to fall from over 20 billion gallons per year in 2008 to less than 5 billion gallons per year in 2050. This reduction is achieved largely through increased use of electric and plug-in hybrid electric vehicles and vehicle efficiency improvements. An additional 7 billion gallons of low-carbon biofuels are expected to meet the remaining transportation sector energy demand in 2050.

a. *Cellulosic ethanol:* Using optimistic assumptions about the potential to convert biomass into zero-carbon biofuels in the U.S., we calculate that up to 4.6 billion gallons per year of cellulosic ethanol could be sold in California, (compared to about 15 billion gallons of gasoline per year consumed today in California). This means that by 2050, most of the state's gasoline demand will be replaced with electricity demand from electric and plug-in hybrid electric vehicles, and 77 percent of the state's remaining demand for gasoline will be met with cellulosic ethanol (net of the impacts of vehicle efficiency and electric vehicles). Because of their high lifecycle carbon footprint, corn-based ethanol does not help California to meet the 2050 target.

b. *Biodiesel:* The future resource potential for zero-carbon biodiesel is dependent on technology breakthroughs (possibly manufactured algal biofuels) if the state is to move beyond the small amounts of waste-oil diesel that are currently produced. We assume that by 2050, up to 2.1 billion gallons per year of biodiesel could be produced and consumed in California (relative to about 5 billion gallons of diesel per year consumed in California today). Biodiesel could represent 48 percent of the state's remaining demand for diesel fuel (net of the impacts of vehicle efficiency and vehicle electrification).

c. *Bio-jet fuel:* The potential for producing zero-carbon bio-jet fuel is uncertain. We assume that by 2050 up to 50 million gallons per year of bio-jet fuel could be produced from algal biomass, representing 13 percent of the state's demand for jet fuel for domestic flights.

4. ***Electrification and low-carbon electricity generation*.** Fuel-switching from fossil fuels to low-carbon sources of electricity generation will be required in all sectors of the economy, including the transportation, residential, commercial, industrial and agricultural sectors. Electrification can take the form of electric heat pumps, plug-in hybrid electric vehicles, electric boilers and electric hot water and direct electric space heaters. Low-carbon generation needs can be met with different combinations of renewable energy resources, nuclear energy and generation with carbon capture and sequestration. Electrification and low-carbon electricity generation is expected to represent approximately 43 percent of California's total GHG emissions savings in 2050.

    a. *Electrification:* Under the scenarios considered in this analysis, increased electrification will cause electricity to grow from 30 percent of total state energy consumption to 70 percent by 2050. Electricity consumption will double in California, to over 600 TWh by 2050. Over 95 percent of this electricity must come from low-carbon sources.

    b. *Electric cars:* By 2050, plug-in hybrid electric vehicles (PHEVs) and other transportation-sector electric uses will constitute 66 percent of the transportation sector's energy use, and half of total electric demand. In the light-duty vehicle fleet this represents over 40 million electric vehicles and PHEVs by 2050, or 90 percent of all new light duty vehicles. Gasoline consumption will be nearly eliminated by 2050.

    c. *Decarbonization of electricity production:* The electricity sector must be effectively decarbonized by 2050. Almost all of the state's fleet of fossil-fuel based power plants must be replaced by some combination of renewable energy, nuclear power and generation with carbon capture and sequestration (CCS). The electricity sector's GHG emissions intensity (including emissions from imported electricity) must decrease from its current average of about 0.43 metric tons of CO_2 per MWh to 0.02 metric tons of CO_2 per MWh by 2050.

d. *Reductions in peak demand:* On-peak energy efficiency and "smart charging" of electric vehicles will be required to reduce peak demand in 2050, improve the utilization of the grid, and keep electricity costs down.

e. *Low-carbon dispatchable and baseload resources:* The need to maintain grid reliability will create a high demand for low-carbon dispatchable and baseload generation such as fossil fuel generation with carbon capture and sequestration and solar thermal technologies with energy storage.

5. ***Mitigation of non-fuel use GHG emissions.*** Non-fuel-use GHGs (such as emissions resulting from deforestation and agricultural practices, waste methane, and high global warming potential gases from industrial products) contribute a significant and growing share to total GHG emissions. California must nearly eliminate these non-fuel use related GHGs to meet the 2050 target. Reduction of non-fuel use GHGs and terrestrial sequestration of GHG emissions, for example through better forest management, are expected to contribute approximately 15 percent of California's total GHG emissions savings in 2050.

The GHG reduction measures implemented through 2020 in the model are consistent with the California Air Resources Board Scoping Plan to comply with AB 32. In 2020, the majority of GHG emission reductions are expected to come from energy efficiency and renewable energy. However, successfully implementing all of the AB 32 Scoping Plan measures is not sufficient to achieve the 2050 target. Additional technologies and strategies are needed. Specifically, we identify a need for:

- Technology breakthroughs in low-carbon biofuels including zero-net carbon ethanol and algae-based biofuel production on the scale of billions of gallons per year,
- Lower-cost and higher-density battery technology to electrify tens of millions of cars in the transportation sector,
- 'Smart-charging' of electric vehicles to improve electric grid reliability and control costs through better load factors,
- Vastly increased uptake of energy efficient technologies, including zero-net energy homes and commercial buildings, and
- Commercialization of new low-carbon baseload and dispatchable electricity generation, such as fossil fuel generation with carbon capture and sequestration and solar thermal generation with energy storage.

3 Decarbonizing the Power Sector

This study finds that electrification and the development of low-carbon electricity is one of the most plausible approaches to tackle climate change. The technology solutions to enable this pathway are relatively well-understood. The infrastructure for increased electrification is relatively simple compared to the development of an entirely new energy distribution system, which would be required for a hydrogen-fuel economy. However, technological innovation to decarbonize the electricity sector will be necessary regardless of what approach is taken, be it a greater focus on renewable energy and energy storage technologies, carbon capture and sequestration or nuclear energy.

Because of the central role of increased electrification in achieving the 2050 goals, four different "2050 Compliant" Scenarios are developed to explore different generation pathways. Each of the scenarios includes a significant share of renewable energy, but differs in the mix of other generation sources. These four 2050 Compliant Scenarios are summarized in the table below, and are shown in Figure 3:

Table 1. 2050 Compliant Scenarios by Technology Type

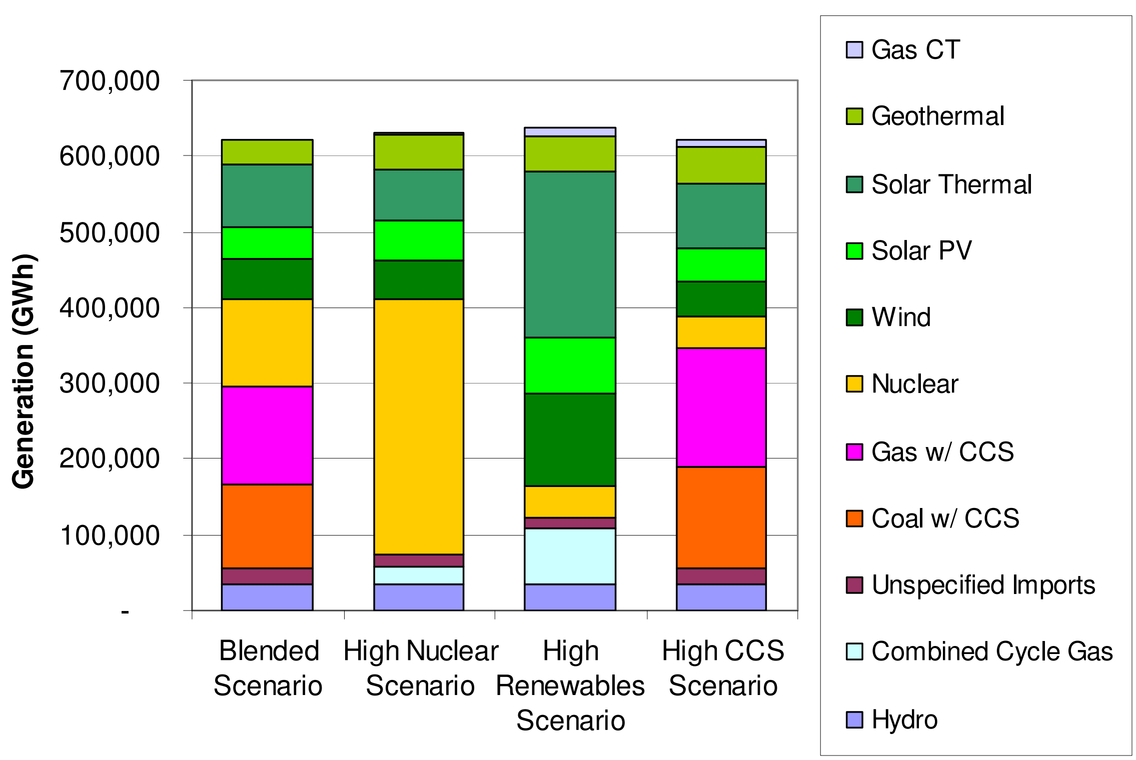
2050 Compliant Scenario	*Renewable Energy*	*Nuclear Energy**	*Generation w/ CCS*	*Other*†	*Energy Storage±*
High Renewable	74%	6%	0%	20%	12,000 MW
High Nuclear	35%	55%	0%	10%	4,000 MW
High CCS	36%	7%	47%	10%	8,000 MW
Blended	34%	19%	39%	8%	6,000 MW

** California's existing nuclear facilities are assumed to be maintained through 2050.*

† Other consists of natural gas generation, large hydroelectric power and unspecified net imports.

± *Energy storage capacity is incremental to existing state energy storage (~1,200 MW)*

Figure 3. 2050 Generation Mix of the 2050 Compliant Scenarios



The challenges of actually implementing any of these scenarios are formidable. For example, in all scenarios except the High Renewable Energy Scenario, the state will require roughly 70 new power plants the size of California's San Onofre nuclear facility (2,000 MW) between now and 2050, assuming that existing nuclear, hydro, and renewable capacity stays on-line through 2050. This means bringing the equivalent of roughly two new large-scale (2,000 MW) power plants on-line every year, starting today. The capacity requirements are 50 percent higher still in the High Renewable Scenario due to the relatively low capacity factors of many renewable technologies.

New low-carbon generation technologies need to be brought on-line even as California retires, or retrofits with CCS, all of California's current fossil-fuel power plants. Conventional power plants built today may risk early retirement before the end of their useful life, or will need to be retrofit with CCS, if California is to meet its long-term GHG reduction goal.

Other challenges include the development of lower-cost energy storage technologies, new transmission lines, and the demonstration of relatively new technologies such as solar thermal and CCS. The challenges, technology breakthroughs and benefits of each of the 2050 Compliant Scenarios analyzed in this report are described in the table below.

Table 2. Summary of Challenges, Technology Requirements and Benefits of 2050 Compliant Scenarios

2050 Compliant Scenario	***Challenges***	***Required Technology Breakthroughs/ Commercialization***	***Benefits***
High Renewable Energy	Maintaining grid operability & reliability Access to remote renewable resources requires large new transmission lines, lots of land area	Energy storage Solar thermal	Minimal security or safety concerns Low fuel-price volatility Many proven technologies
High Nuclear Energy	Nuclear waste Excess baseload generation Safety and proliferation concerns	National strategy for safe nuclear waste disposal	Proven technology
High CCS	Testing and long-term verification of sequestration sites	Large-scale demonstration and commercialization of CCS	High grid reliability with flexible, low-carbon dispatchable CCS Potential international benefits of CCS, especially in India and China
Blended	Requires development of multiple technologies simultaneously	All of the above	Grid reliability with mix of generation types Diversified approach reduces risk of any particular technology

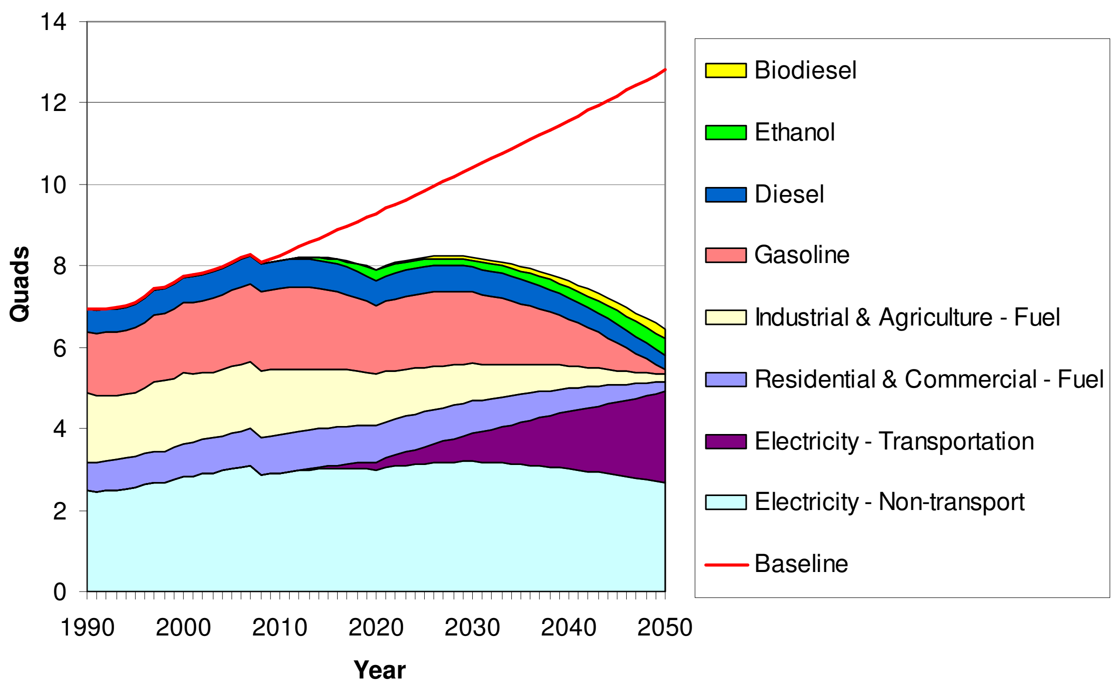
4 Energy and Emissions Trajectories

The energy use and emissions trajectory of the Blended Scenario analysis are presented below. These findings are very similar for the other 2050 Compliant Scenarios since the key difference between these scenarios is the electrical generation mix.

Energy Use

Primary energy use in the 2050 Compliant Case is dramatically lower compared to the Baseline Case (Figure 4) due to conservation and more efficient use of energy. Perhaps the most important implication of this energy consumption projection is the ever increasing role that electricity is expected to play in meeting California's future energy demand. Electricity use is expected to represent a much larger share of energy use in 2050 relative to today, increasing from about 30 percent of energy use today to over 70 percent of energy use by 2050.

Figure 4. Primary Energy Use in the Blended Scenario (1990 – 2050)



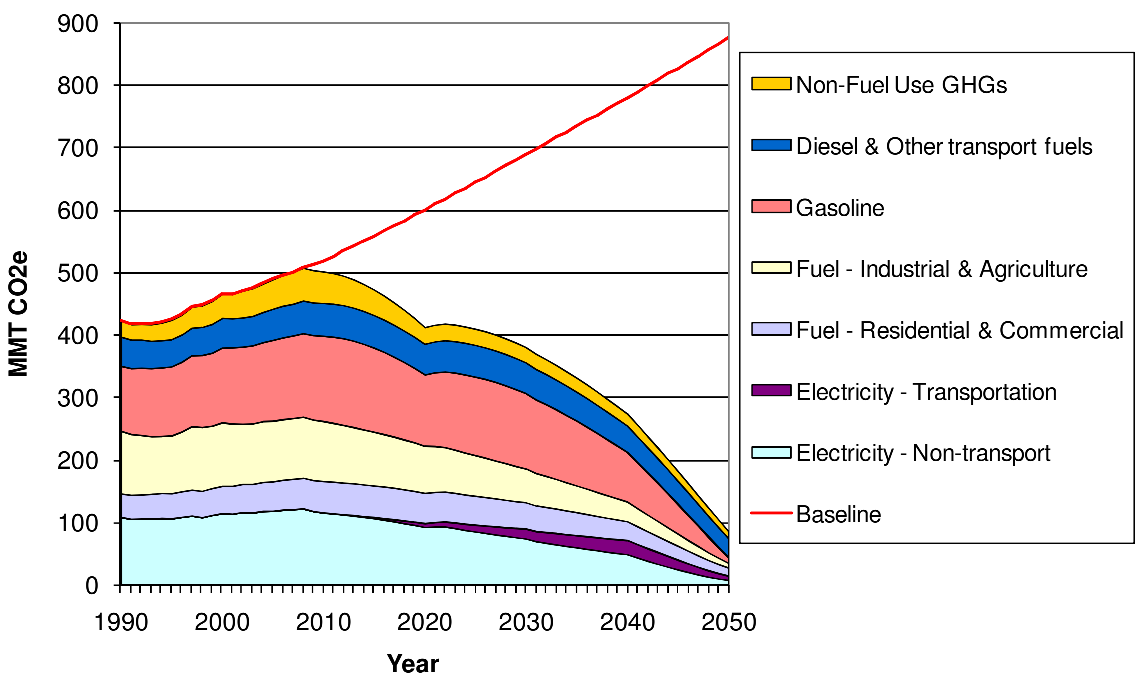
Gasoline use is nearly eliminated in this 2050 Compliant Case, and is largely replaced with electricity use from plug-in electric vehicles and with some zero-carbon biofuels. In contrast, a relatively large share of fossil-based diesel remains in the 2050

Compliant Case. This is because it is expected to be harder to electrify heavy-duty transportation uses than the light-duty vehicle fleet, while biofuel supply is not expected to be large enough to meet all of the remaining energy demand.

Greenhouse Gas Emissions

The combination of low-carbon electricity, low-carbon fuels and reduced energy use results in a GHG emissions trajectory in the 2050 Compliant Case that shows a dramatic reduction in GHG emissions relative to the Baseline. Figure 5 shows that the 2050 Compliant Case save nearly 800 MMT CO_2e relative to the Baseline in 2050. This represents a CO_2 reduction of 90 percent relative to the Baseline CO_2 projection. The figure shows in stark terms the dramatic shift that the California economy must undergo in the next 40 years if the 2050 GHG target is to be met.

Figure 5. 2050 Compliant Case GHG Emissions Profile (1990 – 2050)



5 Cost of Reducing Emissions

The costs of reducing California's greenhouse gas emissions to 80 percent below 1990 levels by 2050 are highly uncertain, and depend on future technology costs, many of which have not yet been commercialized, as well as the long-term price of biofuels, oil and other fossil fuels. However, our estimates of technology costs and future oil prices suggests that the net cost of meeting the state's GHG targets in 2050 will be on the order of $66 billion annually, or 1.3 percent of California's projected gross state product (Figure 6).[1] This is equivalent to an increased cost of about $1,200 per person, relative to a business-as-usual pathway in 2050.

The potential costs of the 2050 Compliant Scenarios are high, and very uncertain, but may not be prohibitive, especially considering that the business-as-usual pathway is likely to lead to potentially catastrophic climate change. Indeed, the cost of inaction, incurred in the form of increasing costs and risks from global climate change and continued economic dependence on oil imports, is likely to outweigh the costs of meeting the emissions reduction commitment.[2] When the long-term net costs of mitigation, adaptation, and uncompensated losses are considered together, the 2050 Compliant Scenarios may be the least costly – but this is outside the scope of this analysis. We have not sought to estimate the environmental or energy security benefits of reducing GHG emissions. The benefits of reducing GHG emissions are potentially enormous, but will depend on what actions the rest of the world takes to reduce emissions at the same time.

A cost sensitivity analysis is also performed on the two key sources of cost uncertainty: future emission reduction measure costs and future gasoline and oil prices, reflected in the error bars on the figure below. In the "measure cost sensitivity," all of the emission reduction measure costs are increased by twice their expected level, and decreased to half their expected level, to reflect the deep uncertainty surrounding these costs. In the "oil price sensitivity" the Energy Information Agency's reference case fossil fuel price forecast for oil and gasoline products is increased and decreased, using the high and low oil price forecasts, as reflected in the error bars on the figure below.

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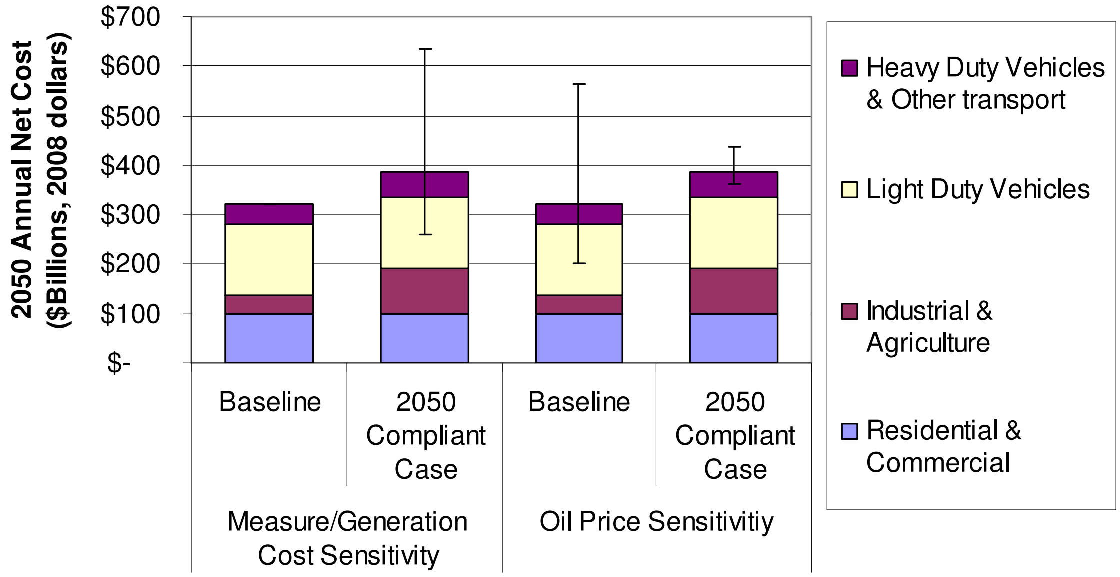
[1] Net cost is defined as the difference in the cost of the Baseline Case and the cost of the 2050 Compliant Scenario. The Compliant Scenario costs include emission reduction measures (including the cost of energy efficiency measures, biofuels, electric cars, etc.) plus the cost of electricity and fuels, minus the savings from avoided purchases of electricity and fuels, especially gasoline costs in the transportation sector.

[2] See for example, Ruth, M., D. Coelho and D. Karetnikov, "The U.S. Economic Impacts of Climate Change and the Costs of Inaction," 2007: Center for Integrative and Environmental Research at the University of Maryland; or, Garnaut, Ross, "The Garnaut Climate Change Review: Final Report," 2008. Commonwealth of Australia, Cambridge University Press; or, Stern, Nicolas, "Stern Review: The Economics of Climate Change," 2006: Cabinet Office, HM Treasury, London.

Figure 6. 2050 Annual Net Cost Comparison and Cost Sensitivities (error bars on chart represent high and low measure costs and high and low oil prices, respectively)



While the first cost sensitivity analysis reveals the deep uncertainty surrounding the cost of emission reduction measures, the oil price sensitivity analysis reveals the extent to which the Baseline Case costs are dependent on uncertain future oil and gasoline prices. The 2050 Compliant Scenarios are not as exposed to future oil and gasoline price uncertainties because these scenarios contain very little fossil fuel use.

6 Implications of the Analysis

We conclude that achieving California's 2050 emission reduction targets is possible if the state succeeds in achieving its 2020 GHG targets in the near-term, and succeeds in deploying transformational technologies over the longer-term. California's challenge, along with the rest of the world, is to physically transform nearly its entire existing infrastructure over the next 40 years. Achieving deep reductions in GHG emissions will require embarking on a rate of new infrastructure investment which may be unprecedented in history, and sustaining that level of investment over the next four decades.

A successful 2050 strategy will require changes to the state's infrastructure that must be put in motion soon. The electricity sector is expected to be critical to achieving the state's GHG reduction goals, through low-carbon generation and by supporting decarbonization in other sectors of the economy through electrification. Electricity demand is expected to double in the next 40 years under the 2050 Compliant Scenarios, increasing by more than 100,000 GWh relative to the Baseline Case, despite achievements of unprecedented levels of energy efficiency. Yet power plants and transmission lines can take years to permit, construct and bring-on-line, and have useful lifetimes of 40 years or more. This means that the power plants and transmissions lines that are built today will likely still be operating in 2050. In addition, low-carbon baseload and dispatchable electricity technologies which are critical to maintaining a reliable electric grid, including generation with CCS and solar thermal with energy storage, have not yet been fully commercialized.

It will also take time for zero-net energy homes and commercial buildings to be built in large enough numbers to start making a dent in the state's energy consumption. Likewise, the state's vehicle stock must be gradually replaced and upgraded with more efficient, lower-carbon vehicles as people purchase new cars. Natural gas vehicles may represent an interim strategy that could help to meet the 2020 goals, but are too high in GHG emissions to be compatible with the long-term GHG reduction strategy. Other technologies, including low-carbon cellulosic ethanol and cost-competitive long-range vehicle batteries, will require significant breakthroughs before they can begin to contribute significantly to reducing GHG emissions.

Achieving this transformation of California's economy will require significant and sustained political will, early investment and technology breakthroughs. California has already started down this low-carbon investment path by beginning to implement AB 32. These investments in clean energy, made today, will make it easier to achieve the long-term goal. This analysis shows that AB 32 is an important first step towards achieving the state's long-term GHG goal, but that AB 32 will not be sufficient to reach levels of GHG emissions that would be consistent with a global climate stabilization strategy. California must continue to pursue a diverse portfolio of emission reduction measures to ensure that the long-term goal is achievable.