GREENHOUSE GAS EMISSION REDUCTION FEASIBILITY STUDY:

FINAL REPORT

CONSULTANT REPORT

Prepared For:

CALIFORNIA ENERGY COMMISSION

Prepared By:

TIAX LLC

May 2009
CEC-600-2009-009

Prepared By:
TIAX LLC
Larry Waterland
20813 Stevens Creek Blvd., Suite 250
Cupertino, CA 95014
Contract No: 600-04-025

Prepared For:
California Energy Commission

Gerry Bemis
Contract Manager

John Sugar
Manager
SPECIAL PROJECTS OFFICE

Mike Smith
Deputy Director
FUELS AND TRANSPORTATION DIVISION

Melissa Jones
Executive Director

Acknowledgements

The author wishes to acknowledge the contributors to this report. The participation of the individuals listed was a key to the success of the endeavor:

TIAX LLC

Wendy Bockholt, Michael Chan, John Dieckmann, Michael Jackson, Matthew Kromer, Stephen Lasher, Philip Sheehy, John Stokes

Battelle and The Loreti Group

Christopher Loreti

EPRI

Evan Hughes

Please cite this report as follows:

Waterland, Larry. *Greenhouse Gas Emission Reduction Feasibility Study: Final Report*. California Energy Commission. Publication number: CEC-600-2009-009.

Table of Contents

List of Figures

List of Tables

Abstract

This work was to develop data on the magnitude of emissions from various greenhouse gas (GHG) sources in California as well as emission reduction potential, costs, technical feasibility, and demonstrated effectiveness of methods for reducing or mitigating the release of greenhouse gas emissions from in-state sources. However, with the adoption of the Global Warming Solutions Act of 2006 (Assembly Bill 32, [AB 32], Núñez, Chapter 488, Statutes of 2006) and the Alternative and Renewable Fuel, Vehicle Technology, Clean Air, and Carbon Reduction Act of 2007 (Assembly Bill 118 [AB 118], Núñez, Chapter 750, Statutes of 2007), project efforts were refocused to support the Energy Commission and the California Air Resources Board in fulfilling the requirements of these very important laws. Specific efforts completed included a GHG emissions data report, cement sector feasibility studies, a gap analysis for AB 118, an evaluation of the GHG emissions reduction potential and projected costs of strategies for light-duty vehicles and medium- and heavy-duty vehicles, and the linking of the gap analysis to the AB 118 Investment Plan recommendations.

Keywords: Greenhouse gas, GHG, GHG reductions, GHG emissions inventory, feasibility studies, cement industry, gap analysis, investment plan

Executive Summary

The initial effort under this contract, which was established in July 2005, was to develop a greenhouse gas (GHG) emissions data report to establish the foundation for the remainder of this work. The report evaluated GHG emissions in the following categories: (1) the electric power sector, (2) petroleum refining and oil and natural gas extraction, (3) cement manufacturing, (4) agricultural activities, (5) landfills, (6) transportation-related GHG emissions, (7) manufacturing, (8) electronics and semiconductor manufacturing, and (9) commercial activities. Electric power production, especially out-of-state coal-fired power plants that deliver electricity for consumption in California, was a major source of GHG emissions. Transportation-related GHG emissions were the largest single component. Cement manufacturing was also a significant contributor.

The Global Warming Solutions Act of 2006 (Assembly Bill 32, Núñez, Chapter 488, Statutes of 2006) was adopted by the California Legislature and signed by Governor Schwarzenegger to combat global climate change. It is a very significant effort to address global warming issues and is expected to affect nearly every facet of life in California. Since AB 32 is expected to have a large, sweeping impact, the responsibility for leading all climate change issues was transferred from the California Energy Commission (Energy Commission) to the California Air Resources Board (ARB) at the time of AB 32 adoption, effective January 1, 2007. This includes GHG inventory work and policy development, both of which are major aspects of this contract.

A consensus was reached with the Energy Commission and ARB staff that this contract could best support ARB's AB 32 efforts by performing case studies of various aspects of the cement industry. One case study focused upon use of slag-blended cement in India, funded under the Clean Development Mechanism (CDM) of the Kyoto Protocol. The second case study was also funded by CDM funds and was based in India. It uses fly ash-blended cement. Both these projects meshed with later case studies and were relevant to the California cement industry.

- Case Study 1 was the Mysore Cements Limited Portland Slag Cement CDM project. It showed that blending ground, granulated blast furnace slag into Portland cement can reduce GHG emissions. Portland cement is the typical bonding agent used in concrete, and producing Portland cement generates more GHG emissions than blast furnace slag. The availability of slag for use in California Portland cement was evaluated in Case Study 3.
- Case Study 2 was the Dalmia Cement Limited Fly Ash-Blended Cement CDM project. It showed that fly ash could likewise be used to displace Portland cement to reduce GHG emissions. Fly ash has an advantage over slag augmentation since it does not need further grinding, reducing cost, energy use and emissions associated with grinding. Issues associated with use of fly ash-blended cement in California are evaluated in Case 3.

A meeting was held between Energy Commission and ARB staffs, and participants agreed to extend Case Study 1 and Case Study 2. ARB staff believed that this further work would best assist their AB 32 efforts. Specifically, both staffs agreed to focus upon further analyzing Case Studies 1 and 2 for applicability to California and to consider use of biofuels to displace conventional fuels in California cement manufacturing. These remaining case studies are:

- Case Study 3 examined the use of blast furnace slag in California, extending Case Study 1. The analysis indicated that there are 300,000 tons per year of unused capacity in Seattle, Washington. However, this requires shipping the slag to California and developing additional slag grinding capacity. Marketplace acceptance would have to be developed since slag-blended cement is not currently used in California, although it is

used elsewhere. This case study indicates that this use would be a cost-effective option for reducing GHG emissions from California cement manufacturing.

- Case Study 4 examined the use of fly ash-blended cement in California, extending Case Study 2. The analysis indicated that fly ash could be used in California Portland cement in a cost-effective manner while reducing GHG emissions, but issues associated with potential leaching of trace metals needed to be resolved. Customer acceptance must also be developed and may require modification to construction codes and standards.
- Case Study 5 examined the supply and regional availability of biomass-derived fuels to supplement conventional fuel used to generate heat to convert feedstock materials into Portland cement. The technical feasibility of using biomass-derived fuels has been demonstrated. GHG emissions could be reduced at a low cost of about $1/ton of carbon dioxide. The California Bioenergy Action Plan addresses regional availability of biomass-derived fuels, and their locations seem to coincide well with the location of existing cement manufacturing facilities. However, the Bioenergy Action Plan does not include a focus upon industrial facilities, and cement plants would have to compete with other potential users of this fuel. This may adversely affect the cost of this otherwise low- cost option to reduce GHG emissions from cement manufacturing.

With the adoption of the Alternative and Renewable Fuel, Vehicle Technology, Clean Air, and Carbon Reduction Act of 2007 (Assembly Bill 118, Núñez, Chapter 750, Statutes of 2007), the remaining contract funds were again refocused. The balance of remaining funds was used to help the Energy Commission develop the Investment Plan required by AB 118.

The first AB 118 Program analysis the contractor was tasked with was studying recent advanced transportation funding and evaluating gaps in funding that the AB 118 funds could fill while benefitting California residents. This “Gap Analysis” included examining funding for natural gas and propane vehicles, flexible-fuel vehicles, hydrogen fuel cell vehicles and electric power vehicles, and efforts to improve vehicle fuel efficiency for all fuels. Global scale private sector investments and United States public dollars were included.

The single largest investment was biofuel asset funding, which was about half of all funding investments. Vehicle efficiency investments were the next largest focus of investments, followed by electric drive technology, then hydrogen and fuel cell investments, and finally, natural gas and propane investments.

The second AB 118 Program task funded under this contract consisted of an independent review and audit of a series of spreadsheet calculations developed by Energy Commission staff for determining the focus of the AB 118 Investment Plan. While the calculations were determined to be accurate and appropriate, TIAX made some suggestions for improving clarity and transparency.

The third and final AB 118 Program task under this contract involved linking the Gap Analysis and a draft of the overall AB 118 Investment Plan, explaining how the draft plan implements recommendations developed from the Gap Analysis. The objective was to show how the proposed funding levels help achieve GHG emissions reductions, including the focus on specific transportation sub-sectors , steps needed to implement recommendations, potential funding obstacles, and time required for project implementation. An important aspect of this work was to show how vehicle and fuel combinations could evolve together over time to lessen GHG emissions of specific vehicle and fuel technologies. For example, compressed natural gas-fueled vehicles emit less GHGs than conventional gasoline vehicles, but their emissions rate needs to be further reduced to meet 2050 GHG goals. These emissions can be reduced by substituting biomass-derived gas for conventional natural gas. The analysis shows how other vehicle and fuel combinations evolve to lower GHG emissions over time.

CHAPTER 1:
Introduction

Section 25730 of the California Public Resources Code directs the California Energy Commission (Energy Commission) to "acquire and develop data and information on global climate change, and provide state, regional and local agencies, utilities, businesses, industries, and other energy and economic sectors with information on the costs, technical feasibility, and demonstrated effectiveness of methods for reducing or mitigating the production of greenhouse gases from in-state sources, including net reductions through the management of natural forest reservoirs."

The same Public Resources Code section directs the Energy Commission to prepare and maintain the state's inventory of greenhouse gas emissions. The *Inventory of California Greenhouse Gas Emissions and Sinks: 1990 to 2004* (CEC-600-2006-013) represents the most recent update of California's sources and sinks of greenhouse gases. This function was transferred to the California Air Resources Board (ARB) effective January 1, 2007, with adoption of the Global Warming Solutions Act of 2006 (Assembly Bill 32, [AB 32], Núñez, Chapter 488, Statutes of 2006).

The original purpose of this contract was to acquire and develop data on the magnitude of emissions from various greenhouse gas (GHG) sources as well as emission reduction potential, costs, technical feasibility, and demonstrated effectiveness of methods for reducing or mitigating the release of greenhouse gas emissions from in-state sources. The data acquired and developed were intended to promote implementation of greenhouse gas emission reduction projects by state, regional and local agencies, utilities, businesses, industries, and other energy and economic sectors. For this work, a greenhouse gas emission reduction project ("project") is defined as "a specific activity or set of activities intended to reduce GHG emissions, increase the storage of carbon, or enhance GHG removals from the atmosphere."[1]

In keeping with the original objective of the project, four efforts were outlined as follows:

- Complete Report on Greenhouse Gas Emissions Data.
- Complete Report on Greenhouse Gas Emissions Reduction Market Assessment.
- Complete Report on Greenhouse Gas Emissions Reduction Projects.
- Conduct Feasibility Studies on Greenhouse Gas Emission Reduction Projects in Selected Industry Sectors.

The first of these efforts was completed, and the second initiated. However, while preparing the second report (not completed nor published), Energy Commission staff concluded that many of the efforts originally planned when the project was initiated, which occurred before the adoption of the California Global Warming Solutions Act of 2006 (AB 32), were going to be incorporated into work the ARB would be completing in implementing the AB 32 requirements. Accordingly, staff decided that efforts for this project should be redirected toward supporting ARB's AB 32 work. Then, with the passage of the California Alternative and Renewable Fuel, Vehicle Technology, Clean Air, and Carbon Reduction Act of 2007 (Assembly Bill 118 [AB 118], Núñez, Chapter 750, Statutes of 2007), it was subsequently decided to focus project efforts toward supporting Energy Commission staff in preparing and adopting the Investment Plan required by the legislation. Thus, efforts on completing the preparation of a GHG Emissions Reduction Market Assessment report were stopped, remaining work originally planned was deferred, and four replacement tasks were authorized:

---

[1] *Greenhouse Gas Protocol for Project Accounting.* World Business Council for Sustainable Development and World Resources Institute, 2005.

- Cement Sector Feasibility Studies.
- Gap Analysis for AB 118.
- Evaluation of Potential Greenhouse Gas Emissions Reductions for the Transportation Sector.
- Support of the Preparation of the AB 118 Investment Plan.

The following chapters discuss results of all five project tasks, the initial GHG emissions data report, and the four replacement tasks just noted.

CHAPTER 2:
Greenhouse Gas Emissions Data Report

The report prepared in this project task describes a bottoms-up GHG inventory for California that augments the previously released top-down *Inventory of California Greenhouse Gas Emissions and Sinks: 1990 to 2004* (referred to in the following as "the GHG Inventory"), published in December 2006.[2] TIAX and its team, EPRI and Battelle, compiled, reviewed, and revised a GHG emission inventory across major North American Industry Classification System (NAICS) industries, focusing on those sources of GHG emissions that have higher impact and offer higher probability of reduction. The report documents the relevant data for these industries and makes frequent comparison to the GHG Inventory to show where bottoms-up calculations deviate from the top-down approach.

Data collection and review followed a two-step process. The first step leveraged previous work and existing databases. An important source of bottoms-up data on energy use in California was the Quarterly Fuel and Energy Report (QFER) system, which is managed by the Energy Commission. This document includes an analysis of QFER data from both 2004 as well as 2005. In some cases, particularly with agriculture and landfill data, TIAX also drew from the California Air Resources Board (ARB) draft updated statewide GHG emissions inventory for the period 1990-2004.[3] The second step was designed to fill any gaps that were found by interviewing appropriate industry experts.

For each NAICS industry, significant findings of this report show:

- **Electric Power Generation**
  - The largest emissions sources are coal-fired boilers (primarily out of state) and several types of natural gas power plants.
  - Average carbon dioxide (CO_2) emissions factors for California electric generation are smaller than most other states due to higher-than-average use of hydro, renewables, nuclear, and natural gas.
  - The electricity sector is not an important source of emissions of the other GHGs, methane (CH_4) and nitrous oxide (N_2O).
  - Key targets for reductions include steam turbine coal power plants that fire boilers with pulverized coal.
- **Petroleum (Refining and Oil and Gas Extraction)**
  - Combustion of refinery fuel gas (also called "still gas") accounts for approximately half of the emissions and is predominantly CO_2.
  - Emissions from oil and gas production in California are dominated by combustion emissions of natural gas because a large fraction of California oil fields produce heavy oil using thermally-enhanced oil recovery.
  - Direct CO_2 emissions from refineries calculated with Petroleum Industry Information Reporting Act (PIIRA) data are about 7 percent higher than those reported in the GHG Inventory.
- **Cement Manufacturing**

[2]California Energy Commission, 2006. *Inventory of California Greenhouse Gas Emissions and Sinks: 1990 to 2004*. Staff Final Report. CEC-600-2006-013-SF, December 2006.
[3] http://www.arb.ca.gov/cc/ccei/emsinv/emsinv.htm, viewed August 2007.

- Direct emissions account for 95 percent or more of the GHG emissions from this sector; indirect emissions from electricity use comprise 5 percent or less.
- The greatest source of CO_2 emissions from cement manufacture occurs during heating of raw materials in kilns; approximately 60 percent is CO_2 from calcining the limestone portion of the raw materials, the remainder from fuel combustion.
- Other large fractions of CO_2 emissions are from combustion of coal (the principal fuel used in California cement kilns) and other fossil fuels that make up almost 95 percent of the heat input.
- CH_4 and N_2O release is low because of high combustion temperatures in kilns.

- **Agriculture**
  - Methane emissions are primarily associated with animal digestion and manure management and are larger than those associated with landfills.
  - The largest N_2O emissions are from soil and manure management.
  - Soil-related emissions calculations in the GHG Inventory and the ARB on-line inventory were already bottoms-up; manure-related emissions need to be updated to reflect California values but are not available in this report.
- **Landfills**
  - Landfills are a primary source of methane emissions attributable to anaerobic digestion of landfilled organic materials.
  - Of 150 landfills in California, 87 percent account for 95 percent of the waste and have gas collection controls in place.
- **Transportation**
  - Transportation in all forms is the largest GHG-emitting activity within California.
  - The largest CO_2 contribution by fuel type is motor gasoline.
  - CO_2 emissions associated with jet fuel in air travel are the third largest source.
  - There is little accounting done for high-global-warming-potential (high-GWP)[4] gases from transport-related activity; R-134a (mobile air conditioners) and hydrofluorocarbon (HFC) refrigerants (transport refrigeration) likely account for a significant portion of these high-GWP emissions.
- **Manufacturing**
  - The GHG Inventory direct emissions (for 2004) are moderately lower than bottoms-up calculations (for 2004) —7.58 $MMTCO_2$ vs. 8.84 $MMTCO_2$.
  - Food manufacturing is the largest source of CO_2 emissions within the sector (excluding petroleum refining and cement manufacturing above), primarily from natural gas combustion (the largest source of direct GHG emissions across manufacturing sectors).
  - Indirect emissions associated with electric energy consumption are approximately 12 percent of the statewide total CO_2 from electric generation.
- **Electronics and Semiconductor Manufacturing**
  - Electronics and semiconductor production are a small subset of manufacturing with small emissions but represents a significant part of California economy.

[4] High-global-warming-potential gases constitute a category of gases that warm the atmosphere much more quickly than carbon dioxide, which is the major gas associated with climate change. These “high GWP” gases are specified by the Intergovernmental Panel on Climate Change (IPCC).

- Direct GHG emissions are modest, with roughly equal contributions from natural gas combustion products and from emissions of perfluorocarbons, primarily from semiconductor manufacturing.
- Indirect GHG emissions, associated with electric energy consumption are approximately four times larger than the direct GHG emissions in this sector.

- **Commercial**
  - This sector has modest direct emissions, consisting of CO_2 from natural gas combustion in space and water heating and from refrigerant leakage.
  - Indirect CO_2 emissions associated with electric power use are 3.5 times the direct emissions from natural gas use and represent 40 percent of statewide total electric energy generation.

CHAPTER 3:
Cement Sector Feasibility Studies

This project task produced a technical report of five case studies of GHG emissions reduction options for the cement sector. Two of these are ones that are being implemented under the Clean Development Mechanism (CDM) program of the Kyoto Protocol. As such, they have been designed specifically to reduce GHG emissions, and under the rules of the CDM, they are projects that would not have occurred in the absence of the program. These particular case studies were selected because they represent two different options for reducing emissions at cement plants. They were also selected based on their potential applicability to cement plants in California. Projects at plants of a similar vintage or technology type were selected. Projects at plants that used older or different technology for manufacturing cement, such as wet kilns, or vertical kilns (often used in China) were not considered.

Three other case studies were selected based on their interest to ARB staff, which at the time of this work was developing regulations for reducing GHG emissions from California cement plants.

The five case studies completed are:

- Slag-Blended Cement CDM Project: Mysore Cements Limited Portland Slag Cement Project, India. This case study describes the level of success of one plant in decreasing emissions from clinker production by displacing the ground clinker with ground, granulated blast furnace slag.
- Fly Ash-Blended CDM Project: Dalmia Cement Limited, India. This case study describes the plan of one cement plant to increase the proportion of fly ash used in blended cement (and reduce the amount of clinker), and its attempts to gain greater acceptance of its blended product in the marketplace.
- Slag-Blended Cement in California. This case study focuses on the availability and cost of obtaining granulated blast furnace slag in California. It considers from where the slag might come and the potential barriers to its greater use in blended cement.
- Fly Ash-Blended Cement in California. This case study considers the availability and cost of fly ash in California. The results of studies on the potential health concerns with mercury (and possibly other heavy metals) leaching are described. While mercury leaching does not appear to be a concern, other factors also affect the expanded use of fly ash blended cement in the state.
- Biofuels use in California cement plants. The availability and potential use of biomass combustion in California cement plants are described in this case study, and the emission benefits are discussed. The cost of biomass is expected to compare favorably with coal consumed by cement plants, although cement plants may face competition from electricity producers for biomass fuels, and thus increasing costs. It is suggested that biomass burning in cement plants be addressed in California's Bioenergy Action Plan.

Conclusions from each of the case studies are discussed in the following subsections.

Case Study 1: Mysore Cements Limited Portland Slag Cement Project

Decreasing the quantity of clinker in cement through blending with ground, granulated blast furnace slag can be an effective means of reducing the GHG emissions of the Mysore Cements plant. Market acceptance of the blended cement product is key to expanding its use. This is particularly true in countries outside the United States, such as India, where blended cements are already used, and the clinker fraction in the cement is already lower.

This case study provides a few lessons that are relevant to the expanded use of slag blended cement in California. One is that the product can be economically produced by cement manufacturers. The other is that, unless the product gains acceptance in the marketplace, the expected emission reduction benefits may not be fully realized. Additional considerations related to use of ground granulated blast furnace slag in California are presented in Case Study 3.

Case Study 2: Dalmia Cement Limited, India Fly Ash-Blended Cement Project

Blending cement with fly ash can be an effective way of reducing GHG emissions from the Dalmia Cement Limited plant. Fly ash has the advantage that it does not require additional grinding, as granulated blast furnace slag does, thereby eliminating the cost, energy use, and emissions associated with such grinding.

The actual emission reduction benefits that will result from projects such as this depend upon the amount of fly ash that can be sold in the blended cement. Market acceptance is key to expanding the use of fly ash-blended cement. Neither monitoring, nor verification reports on the actual emission reductions from this project have been published, and therefore it is not clear how much additional fly ash has been consumed by the project. Additional considerations related to the use of fly ash-blended cement in California are presented in Case Study 4.

Case Study 3: Ground Granulated Blast Furnace Slag as a Cement Substitute

California has the potential to significantly increase its consumption of cement blended with ground, granulated blast furnace slag, resulting in reduced GHG emissions. The Lafarge slag grinding facility in Seattle has unused capacity of approximately 300,000 tons per year, which could be used to meet demand in California. Cement plants in California could also provide additional grinding capacity, but this would require shipment of the imported slag to them and its subsequent distribution to ready-mix suppliers. In either case, use of blended cement requires additional storage silos for the ground granulated slag prior to its use to make concrete.

Key to increasing the use of slag-blended cement in California is greater acceptance in the marketplace. While slag-blended cement has been used for years in the eastern United States, where blast furnaces are located, it is not as well known on the West Coast. Slag-blended cement is beginning to be used within California, however, as cement purchasers who recognize its environmental benefits specify its use in their contracts.

Slag-blended cement is a cost-effective way to reduce GHG emissions as the ground granulated blast furnace slag is priced at less than the Portland cement it displaces. Therefore, the end-user

need not experience any price increase for using it, and the cost of emission reductions would be zero or less per metric tonne of emission reduction.

Case Study 4: Fly Ash-Blended Cement

Fly ash suppliers set the price of fly ash at less than the Portland cement it displaces. Therefore the use of fly ash-blended cement can result in a reduction in GHG emissions at no cost to the end user. Indeed, the use of fly ash-blended cement is already increasing in California. The largest supplier of fly ash in the state is investing in a new terminal in Southern California to significantly increase its ability to supply the market. While the potential supply of fly ash from power plants is not an issue, reliable rail delivery is. Construction of this terminal is expected to provide a larger and more reliable supply of fly ash to concrete producers.

The issue of mercury in fly ash and its potential for leaching when fly ash is blended with cement is an appropriate area of concern, given the increasing mercury content of fly ash, and one that has undergone considerable study. The studies reviewed for this report indicate that leaching of mercury from fly ash used in blended cement does not occur at levels that are of environmental concern. Aside from one study that raised the possibility of leaching of arsenic and selenium, the leaching of other metals from fly ash also do not appear to pose problems. That particular study focused on leaching from fly ash itself, rather than concrete made from fly ash-blended cement, suggesting that additional study may be warranted.

The expanded use of fly ash-blended cement in California is largely dependent on customer acceptance. Such acceptance, in turn, partially depends on the modification of government codes and specifications to allow greater use of fly ash-blended cement. Efforts in these areas should be encouraged to allow greater use of fly ash-blended cement.

Case Study 5: Biomass Combustion in California Cement Kilns

The use of biomass fuels in California cement kilns represents a large potential source of GHG emission reductions. As shown by the work of the California Biomass Collaborative,[5] the available quantities of biomass in the state are far greater than what could be consumed by the cement industry. The technical feasibility to displace coal with biomass has been assessed through test burns at the cement kilns. The experience of cement plants outside California has been promising, and use of biomass to meet at least part of the fuel demand is a common practice in the industry, particularly outside the United States.

The relatively high price of coal in California suggests that emission reductions may be achieved at relatively low or no costs. Using a figure of $40/ton of biomass, and assuming 50 percent more biomass fuel would be needed to provide the same heating value as the coal, suggests that GHG emission reductions from fuel combustion in the could be achieved at a cost of less than $1/ton of CO_2.

At present, the Bioenergy Action Plan[6] for California does not specifically address potential industrial consumers of biomass, such as cement plants. To better coordinate potential sources of bioenergy among electricity generators, biofuel producers, and industrial energy consumers,

---

[5] California Biomass Collaborative, 2006. *An Assessment of Biomass Resources in California, 2006*; Draft Report. California Energy Commission Contract 500-01-016, December 2006.
[6] California Energy Commission, 2007. *Bioenergy Action Plan for California: Progress to Plan*, CEC-100-2007-006, July 2007.

consideration should be given to expanding the scope of the action plan to promote biomass use in cement kilns, and possibly other large industrial energy consumers.

CHAPTER 4:
Gap Analysis for AB 118

In 2007, the California Legislature passed and the Governor signed Assembly Bill 118 (AB 118), (Núñez, Chapter 750, Statutes of 2007) which established the "Alternative and Renewable Fuel and Vehicle Technology Program." A significant portion of this program, administered by the Energy Commission, will provide up to $120 million annually for 7.5 years to accelerate the introduction of advanced vehicle technologies into the market place. These advanced technologies will reduce GHG emissions and displace petroleum use. These technologies also have the potential to substantially reduce criteria pollutants throughout the full fuel cycle. This project task estimated investments committed to developing advanced vehicle technologies and to identify funding gaps in the investment landscape.

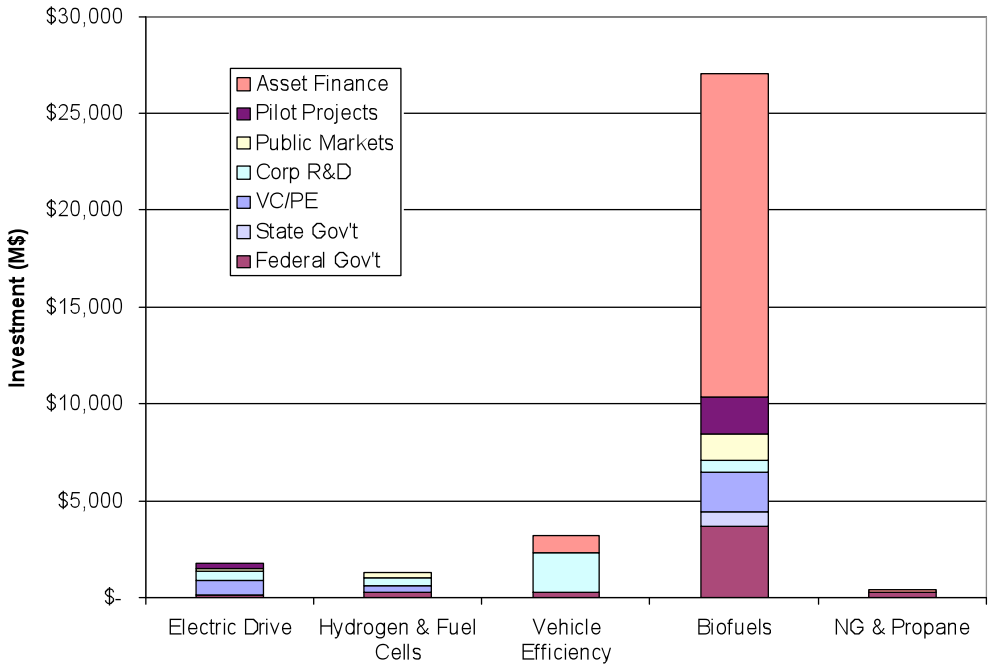
Current annual investments in advanced vehicle technologies are shown in Figure 1. Investments include United States federal and state government funding as well as private investments (venture capital, equity, asset financing, and corporate research and development).[7] TIAX estimates that more than $35 billion is spent annually on electric drive, hydrogen fuel cells, improved vehicle efficiency, biofuels, natural gas, and propane technologies. The majority of the investment is focused on biofuels, which is primarily driven by the Renewable Fuels Standard (RFS) of the federal Energy Independence and Security Act of 2007. The RFS requires the use of up to 15 billion gallons of corn derived ethanol and 21 billion gallons of cellulosic ethanol by 2022. The RFS, along with high prices for petroleum derived fuels (for example, gasoline and diesel), has driven considerable investment in the production of ethanol from corn and in research and development (R&D) and demonstration of ethanol and other biofuels from cellulosic feedstocks.

Natural gas and propane fuels receive the lowest investments. This is a result of very limited end-use product being offered to the market place. Honda is the only automobile manufacturer producing a compressed natural gas (CNG) light-duty vehicle, and Cummins Westport is the only heavy-duty engine manufacturer providing natural gas or propane engines. No manufacturers are providing propane (or liquefied petroleum gas – LPG) for the light-duty sector—these vehicles are currently upfitted from gasoline vehicles. Both fuels have incentives for vehicle purchases and a $0.50 per gasoline gallon equivalent fuel credit. These incentives encourage the use of these fuels, but they are not used at the same level as biofuels.

Improving vehicle efficiency is funded mostly by the automakers and engine manufacturers as part of their normal product improvement, although both receive public funding as well. Proposed Corporate Average Fuel Economy (CAFE) standards will require the automakers to invest heavily in advanced conventional technologies to improve fuel economy. These investments will also help reduce the GHG and criteria pollutant emissions, but further reductions will be necessary beyond what is possible through improvements in conventional technologies alone.

Figure 1: Total Estimated Annual Investment In Advanced Vehicle Technologies

[7] Private sector investment data represent global estimates, while public sector data are constrained to the United States. Also note that federal funding data includes incentives. Incentives, which include tax credits, are somewhat different from direct funding as they are forgone revenues instead of actual spending.



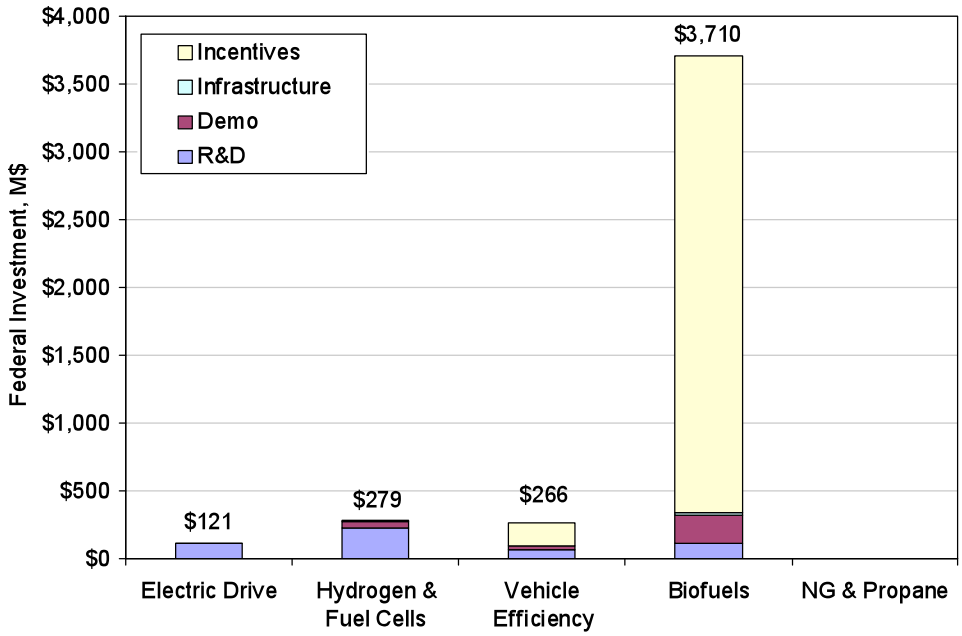
Source: Jackson, Michael. Gap Analysis Memo for AB 118 to Gerry Bemis, September 9, 2008.

Electric drive technologies, which include battery electric vehicles and plug-in hybrid vehicles (PHEVs), and hydrogen fuel cell vehicles offer considerable reductions in GHG and criteria pollutant emissions and substantial displacement of petroleum. Some combination of these technologies will be required in the future to meet aggressive reduction goals for GHG emissions. Current public and private investments are focusing on R&D and early stage investments (that is, venture capital [VC], private equity [PE], and pilot projects) as shown on Figures 1 and 2. The estimated investment in electric drive technologies is $2 billion per year, and that for hydrogen and fuel cells, is about $1.2 billion per year. Currently, federal funding is higher for hydrogen and fuel cells than electric drive technologies. Hydrogen fuel cell vehicles are being demonstrated in small numbers with automakers ready to increase the number of vehicles, but this will require additional investment in limited and targeted hydrogen fueling infrastructure to support these limited production vehicles.

PHEVs (sometimes called "range-extended electric vehicles") are just now being developed by the major automakers[8]. No large-scale, coordinated demonstration of these technologies has yet occurred. Current investments are focused on the batteries for these vehicles as well as for "pure" battery electric vehicles. Several automakers are currently developing PHEVs and are committed to demonstrating and ultimately selling these vehicles in the near future. Automakers are developing different vehicle architectures, and it is yet to be determined how well these differing designs will be accepted in the marketplace.

Figure 2: Estimated Annual Federal Investment In Advanced Vehicle Technologies

[8] However, a number of PHEV retrofits, including bolt-on modifications to the Toyota Prius, have been conducted by individual vehicle owners and some state/local funding agencies.



Source: Jackson, Michael, et. al. *Gap Analysis Memo for AB 118.* Presented at the staff workshop on the preparation of the Investment Plan for the Alternative and Renewable Fuels and Vehicle Technology Program, September 19, 2008..

Based on this analysis of the current funding landscape and TIAX's understanding of the status of the advanced vehicle technologies, the following observations are offered:

Biofuels: Considerable money is already being invested, and it is not clear that additional funding will accelerate commercialization, especially of Generation I biofuels (for example, starch-based ethanol). Nevertheless, a key California objective is to produce biofuels in-state. So, it is recommended that some portion of the AB 118 funding be invested in California-based biofuels production. Funding could also be used to support high-blend (for example, gasoline containing over 30 percent ethanol [E30+], B20+, etc.) biofuel infrastructure and end use.

Natural Gas and Propane: A major funding issue facing these technologies is product development for the light-duty and heavy-duty vehicle markets. AB 118 funding could be used to help bring more products to the marketplace, including continued incentives for deployment of infrastructure and fleet vehicles. Funds could also be used to develop and demonstrate advanced gas-to-liquids technologies if full fuel cycle GHG emissions are low enough.

Improved Vehicle Efficiency: Most of the investments in theses technologies are being made by the automobile industries. Public funding is also helping the industries, but more work could be performed on concepts to reduce vehicle weight, improve aerodynamics, and other approaches to improve vehicle fuel economy, especially for heavy-duty vehicles (for example, bottoming cycles and auxiliary power units).

Hydrogen and Fuel Cells: United States federal and state governments have made substantial investments in this technology with the hope that the vehicles will be accepted in the marketplace. These zero-tailpipe-emissions vehicles will provide significant GHG and petroleum reductions. Automakers are at the verge of introducing a limited number of vehicles, but fuel supply infrastructure will be needed to support them. At these limited vehicle volumes the infrastructure investments will not be economical, and therefore public funding is

necessary. AB 118 funding could be used to provide this infrastructure in limited areas where vehicles are likely to be demonstrated and sold.

Plug-in Hybrids and Battery Electric Vehicles: Considerable investments are being made in battery technologies for these vehicles, but substantial work is necessary to prove these vehicles in the marketplace. Remaining questions include:

- Will smart meters be necessary to encourage night charging?
- What is the impact on the electric grid?
- Will the vehicle architectures incorporate large enough batteries to gain the GHG benefits of California's clean grid?

Large-scale demonstrations of varying vehicle types and architectures will be needed to better understand their impacts and value proposition in a carbon-constrained world. Results from this analysis were presented at the Energy Commission workshop on the preparation of the AB 118 Investment Plan.[9]

[9] Jackson, Michael D., et al. *Gap Analysis for AB 118.* Presented at the staff workshop on the Preparation of the Investment Plan for the Alternative and Renewable Fuel and Vehicle Technology Program, September 19, 2008. http://www.energy.ca.gov/proceedings/2008-ALT-1/documents/2008-09-19_workshop/presentations/Gap_Analysis_Summary_Presentation.pdf.

CHAPTER 5:
Evaluation of Potential Greenhouse Gas Emissions Reductions for the Transportation Sector

Energy Commission staff developed a series of spreadsheets to evaluate market potential of advanced efficiency measures and alternative fuel options expected to significantly reduce GHG emissions from now through 2050, based in part on the "2050 Vision" of the *State Alternative Fuels Plan*.[10] The intent of the Energy Commission staff analysis was to use the associated GHG emissions reductions to develop weighting factors to be used in making funding decisions within the Investment Plan for AB 118. Thus, the spreadsheets were developed to evaluate the impacts of transportation policy and regulation on greenhouse gas emissions.

Due to the sensitive and important nature of this work, Commission staff requested an independent review to audit the staff analyses for quality and completeness and to check the computational process and methods. Under this task, TIAX reviewed and audited two Energy Commission staff analyses, one related to light-duty vehicles and the other related to medium- and heavy-duty vehicles. The light-duty analysis included 13 GHG reduction strategy workbooks for light-duty vehicles, an additional workbook used to incrementally compute GHG reductions and petroleum fuel use reductions, and cost estimates for implementing the alternative fuels strategies. The medium- and heavy-duty vehicle analysis consisted of one workbook for medium- and heavy-duty vehicle GHG emissions and reduction strategies. The methods used to compute GHG emissions reductions strategy costs (only for light-duty vehicles) were examined and the computational processes were reviewed for all vehicle classes.

Results of the review and auditing efforts completed in this task were summarized in three memoranda to Commission staff: one each on light-duty vehicle GHG emissions reduction calculations, light-duty vehicle emissions reduction costs, and medium- and heavy-duty vehicle GHG emissions reductions. In general, the calculations for the emissions and corresponding GHG emission reductions and control strategy costs were found to be accurate and appropriate. A few suggestions for improving process clarity and transparency were offered, and a few minor inconsistencies with small effect on analysis results were identified.

[10] California Energy Commission, 2007. *State Alternative Duels Plan.* CEC-600-2007-011-CMF, December 2007.

CHAPTER 6:
Support for Preparation of the AB 118 Investment Plan

As discussed in Chapter 4, TIAX performed a Gap Analysis to identify where other entities were funding research, development, and demonstration (RD&D) work related to transportation sector investments expected to be undertaken under the Energy Commission's AB 118 Program. In a subsequent effort, the Energy Commission staff prepared a draft Investment Plan to implement AB 118 funding projects and incorporated results of the Gap Analysis. TIAX was asked to review the Gap Analysis and draft recommendations from the AB 118 Investment Plan and to review and expand the portion of the document explaining how the funding recommendations implement results from the Gap Analysis. This work is intended to provide an evaluation of GHG emissions reduction market potential associated with the application of AB 118 project funds, focusing on options for implementing GHG reductions from transportation projects. This analysis needs to characterize how the funding recommendations implement the Gap Analysis results to achieve potential GHG reductions, including the nature of the funding by transportation sub-sector, applicable sub-sectors that would implement results of the funding, necessary steps needed to implement the recommendations, potential obstacles to funding implementation, and time required for implementation. As the initial step in this analysis, TIAX prepared an executive summary for the Investment Plan. This executive summary follows and provides a good summary of this effort.

Introduction

California is embarking on a program to fundamentally transform the energy and environmental impacts of its transportation system. The goals of this program are to develop and deploy alternative and renewable fuels and advanced transportation technologies to substantially decrease GHG emissions and petroleum use. This will require a portfolio of fuels and technologies including increased vehicle efficiency, development and use of low-carbon biofuels, the continued deployment of natural gas and propane vehicles, and the development of electric drive vehicles. All of these technologies will be needed to achieve the 80 percent GHG emissions reductions goals in 2050. However, success depends upon the accelerated transformation from gasoline vehicles of today to electric-drive vehicles of tomorrow. Bio- and renewable fuels used to produce electricity or hydrogen or used directly in vehicles will also be necessary. This accelerated transformation of the energy and environmental impacts of the transportation system is critical to assure the health and longevity of the planet and will require worldwide cooperation of government and industry.

The Energy Commission in cooperation with the ARB, is developing the "Alternative and Renewable Fuel and Vehicle Technology Program." The California Legislature directed the Energy Commission to develop this program.[11] The Energy Commission will provide funding for alternative fuel and vehicle technology research, development, demonstration, and deployment. A key goal of the program is to provide economic stimulus to create California jobs and businesses that will provide the technologies and services necessary for the future transportation system. This seven-year program is funded at $120 million per year. Although significant, the funding needed to transform California's transportation system is far greater than provided in the program and will require California to leverage its funding with other agencies and private industry.

[11] Assembly Bill 118, Núñez, Chapter 750, Statutes of 2007.

To take full advantage of the opportunity presented by this program, the Energy Commission is designing a distinctive approach to meet the primary goal of reducing climate change emissions while seeking to also achieve to the fullest extent possible many added public benefits. These include reduced volumes of petroleum fuel use through increased use of alternative transportation fuels, reduced criteria emissions, increased economic development and opportunities for workforce training, and increased use of waste stream and renewable energy resources. The program will contain evaluation criteria that favor many of these public benefits and the preferences explicitly stated in the AB 118 statute. This approach provides additional scoring points and weighting for the evaluation of proposals and may include additional funding in awards for projects that hold these desirable attributes. This multi-faceted approach is unlike other market mechanism programs offered in the past and can be an important, informed, and transformative model that is commensurate with the outstanding opportunity presented by the AB 118 program.

The initial report presents the investment plan for the first two years of the program. An investment plan will be developed for each subsequent year. The following addresses the Energy Commission's vision for this program, the current status of market opportunities for alternative fuels and advanced vehicle technology development and deployment, and the funding allocations recommended for the first two years of the program.

Program Vision

In this landmark program, the Energy Commission will be providing funding to accelerate the development and deployment of clean, efficient low-carbon technologies that will achieve GHG and petroleum reductions, increase alternative fuel use, and promote in-state biomass production. These objectives are summarized in Table 1.

In addition, the Energy Commission goals include developing and deploying technologies that will reduce criteria and toxic emissions and will be sustainable both economically and environmentally.

Table 1. Program Objectives and Goals

Objectives	Goals and Milestones
GHG Reduction[12,13]	Achieve reduction to 1990 levels by 2020; 80% reduction from 1990 levels by 2050
Petroleum Reduction[14]	15% below 2003 levels by 2020
Alternative Fuel Use[15]	20% of on road fuels by 2020 30% of on road fuels by 2030
In-State Biofuels Use[16]	1 Billon gge* by 2010, 1.6 billion gge by 2020, and 2 billion gge by 2050
In-State Biofuels Production[17]	20% of biofuels use by 2010, 40% by 2020, and 75% by 2050

*gge refers to gasoline gallons equivalent

Sources: References as noted in table.

Technology and Fuel Status

Many of the technologies that will be in future cars and trucks exist in the market today or are currently under development. Flexible fuel vehicles, for example, are produced today and are capable of using gasoline or E85 (85 percent ethanol and 15 percent gasoline) or any blend level in between. Other vehicle technologies are in the development stage such as plug-in hybrid electric vehicles (PHEVs) or hydrogen fuel cell vehicles. General Motors (GM) is introducing the Chevrolet Volt, which will be one of the first vehicles built on an electric drive platform. Honda has introduced the Clarity, a midsize hydrogen fuel cycle vehicle. Similarly, investments are being made today to develop so-called second generation biofuels that will be sustainable and provide a very low carbon footprint. These fuels could come from energy crops and current waste streams such as landfills and forest residues. Ethanol is currently being blended in gasoline in California at about a billion gallons per year and represents the largest volume of alternative fuel in use today. Researchers are developing other biofuels with a lower carbon footprint that can be more easily blended with gasoline and diesel fuels.

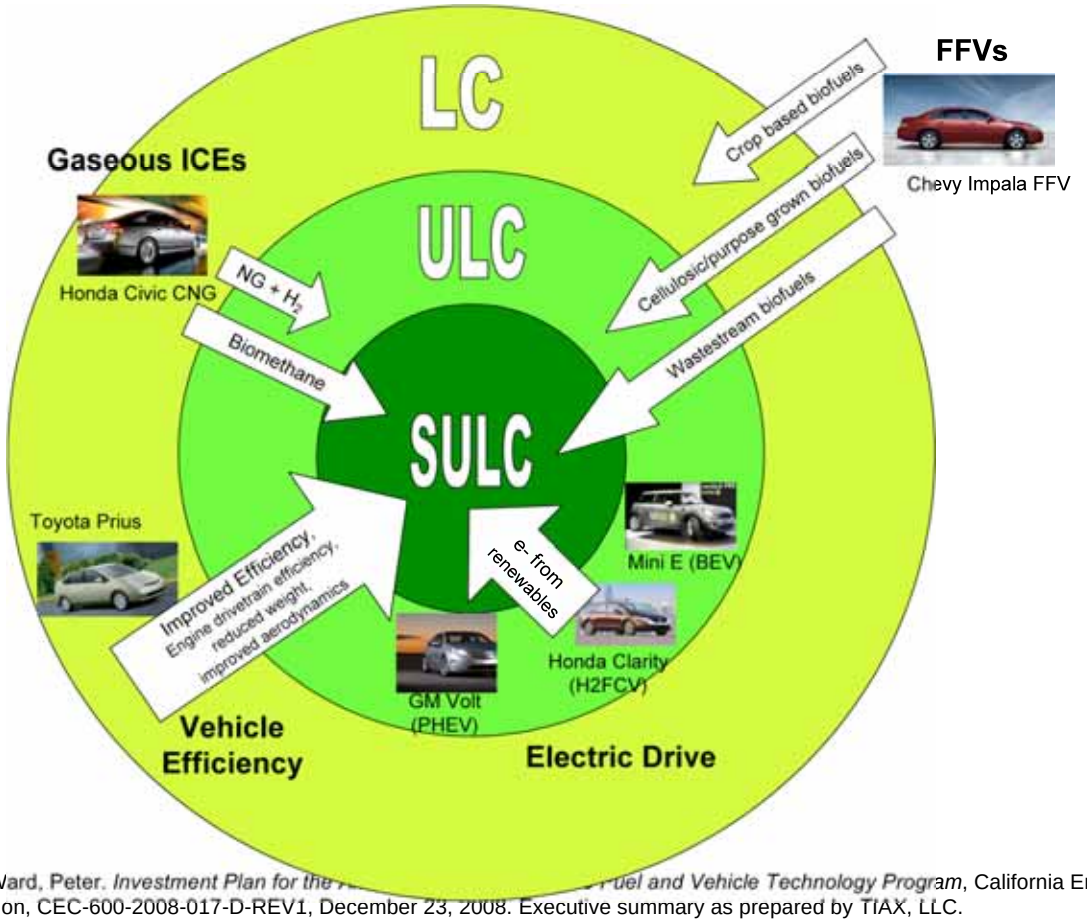
There is a wide spectrum of benefits from the variety of advanced, cleaner technologies being developed today. Each technology provides a different level of benefit depending on the vehicle application, whether it be light-duty or heavy-duty and on-road or off-road. Generally, low GHG technologies meet the additional goals outlined in Table 1. Electric drive technologies use grid electricity or hydrogen—both alternatives to gasoline—and, therefore, displace petroleum use. Further, these technologies have zero or substantially reduced criteria and toxic vehicle emissions. And finally, electricity or hydrogen can be produced from renewable sources such as wind, solar, or biomass. While the key metric of the AB 118 program is GHG emissions

[12] AB 32 California Global Warming Solutions Act of 2006.
[13] Governor's Executive Order S-3-05.
[14] Joint recommendations by Commission and ARB in response to AB 2076, Shelly, Chapter 936, Statutes of 2000.
[15] Ibid.
[16] *California Bioenergy Action Plan* and the Governor's Executive Order S-06-06.
[17] Ibid.

performance, future technologies should also provide the other public benefits shown in Table 1.

Figure 3 illustrates the status of technologies for light-duty vehicles. Status is given in the following GHG reduction categories: low carbon (LC)—less than 40 percent improvement, ultra-low-carbon (ULC)—40 to 79 percent improvement, and super-ultra-low-carbon (SULC)—80 percent and greater improvement. Several of the technologies in the various categories have the potential to improve their efficiency and GHG reduction profile and move from their current lower level ring to a higher reduction category located more in the center of the diagram. As shown, there are very few technologies that by themselves that can achieve 80

Figure 3. Greenhouse Gas Reduction Potential for Advanced Fuel and Vehicle Technologies



Source: Ward, Peter. *Investment Plan for the … Fuel and Vehicle Technology Program*, California Energy Commission, CEC-600-2008-017-D-REV1, December 23, 2008. Executive summary as prepared by TIAX, LLC.

percent GHG reductions. Combinations of fuel and vehicle technologies will be required and the emphasis will be on bio- and renewable fuels with very low carbon content combined with high-efficiency vehicles. The extension of the improved efficiency arrow in Figure 3 into the SULC region indicates that high-efficiency vehicles will be a key component of all low-carbon strategies (LC, ULC, and into SULC). Many of these technologies are not currently in the marketplace and will require additional development and substantial cost reductions to be competitive.

Hybrid vehicles, such as the Prius illustrated in Figure 3, are available today and additional improvements in engine and vehicle efficiency will move the technology from LC to ULC. Current first generation biofuels such as corn-based ethanol or soybean-based biodiesel provide LC benefits, while second generation cellulosic technologies are expected to provide ULC and SULC benefits in the future. Gaseous technologies today provide LC benefits, but could improve to provide SULC benefits by using biomethane produced at landfills, water treatment facilities, dairies and feedlots. Electric drive technologies are already in the ULC category and could move to the SULC category with renewable fuels like solar or wind-derived electricity and hydrogen.

All of these alternative fuels and vehicle technologies require investment to further develop, demonstrate, and introduce them into the marketplace. Investments are needed to support development costs, and to overcome barriers such as cost premiums for low volume market-entry for fuel and vehicle production, to establish fueling infrastructure, to advance certification and standards for fuels and vehicles, and to meet work force training needs. Some technologies will be more competitive in certain segments of the transportation market than others. For example, natural gas vehicle technologies can excel in the heavy duty vehicle sector, while electric drive technologies can meet the needs in the light duty sector.

Investment Plan – First Two Years

Given the uncertainty of technology development and commercialization over the next 40 years, the Energy Commission developed a plan to allocate funding for the various fuels and vehicle technologies. The allocation was driven by possible GHG reductions and by the level of current federal, state, and local funding and feedback from stakeholders. The results of this analysis are shown in Table 2.

Funding in the Low-Carbon category includes financial incentives for light-, medium-, and heavy-duty natural gas and propane technologies, support for development of advanced engines and energy storage technologies, and support for existing and new fueling infrastructure. Funding in this category is justified on a GHG basis. These gaseous fuels and engine technologies can achieve ULC or SULC status as low-carbon gaseous fuels are produced from renewable resources and engines become more efficient. Although there is limited funding for these technologies at the federal level, stakeholders are supporting and investing in these products today.

Funding in the Ultra-Low-Carbon category includes investing in California production and infrastructure for biofuels. Production projects could include conversion of in-state ethanol facilities and new facilities for converting waste streams to fuels. Federal and stakeholder funding is quite robust nationally; California should focus support for in-state fuel production.

Table 2. Recommended Funding (for Program Years 1 and 2 (million of US dollars)

Category	FY09	FY10	Total
Low Carbon (LC)	$26	$36	$62
Ultra Low Carbon (ULC)	$10	$12	$22

Super Ultra Low Carbon (SULC)	$18	$23	$41
Vehicle Efficiency Improvements	$7	$15	$22
Non-GHG Categories	$9	$10	$19
Manufacturing and Production Incentives	$5	$5	$10
Total	$75	$101	$176

Source: California Energy Commission, 2008. *Investment Plan for the Alternative and Renewable Fuel and Vehicle Technology Program*, CEC-600-2008-017-D-REV1, December 23, 2008.

Funding in the Super-Ultra-Low-Carbon category includes support primarily for electric drive technologies—PHEVs, battery electric vehicles, and hydrogen fuel cell vehicles. Battery electric, plug-in electric, and hydrogen vehicles are currently being developed by the automobile manufacturers. Several prototype vehicles have been made as shown in Figure 3—Bavarian Motor Work's (BMW's) Mini EV, GM's Chevrolet Volt PHEV, and Honda's Clarity Hydrogen vehicle. Substantially more work is needed to bring these vehicle concepts to the marketplace, and volume production is needed to bring the costs in a range competitive with today's conventionally fueled vehicles. Moreover, each of these vehicle technologies may require expanded infrastructure for electricity and hydrogen.

Funding in vehicle efficiency improvements (which falls in LC , ULC and SULC categories) focuses on hybridization for medium- and heavy-duty applications as well as developing and demonstrating higher efficiency technologies for light-duty applications.

Funding for non-GHG categories includes support for workforce training, standards and certification, sustainability studies, public education and outreach, and program analytical support. These combined efforts are needed to help with the transition from today's transportation system to the fuels and vehicle technologies that are essential for California to achieve a viable and sustainable transportation future.

Funding for manufacturing and production incentives (which encompass all GHG categories) includes incentive mechanisms such as loans, loan guarantees, manufacturing sales tax exemptions, and enterprise zone and local property tax incentives. The Energy Commission will work with the Office of the State Treasurer to implement these programs.

The AB 118 investment plan recognizes the need for the program to leverage existing federal, state, and local funding as well as stakeholder investments. Fuel and vehicle investments cover the spectrum of possible technologies needed to achieve the 2050 GHG reduction goals. Some emphasis in this plan is placed on technologies that exist today and could be expanded such as FFV or natural gas vehicle technologies. These technologies are also supported because they can reduce their carbon profile and improve their efficiency, offering a tangible bridge to fuel-vehicle technologies that achieve 2050 goals. Investing in these technologies today provides lower carbon and GHG benefits in the near term, but enables them to compete on their own merits in the long term. The plan also invests in bio- and renewable fuels as well as the infrastructure to deploy these fuels into the marketplace. Automobile manufacturers, utilities, other stakeholders, and federal and local governments are investing in alternative fuel and

advanced vehicle technologies and the Energy Commission intends to leverage these investments to accelerate their introduction.

This plan is a good start. Subsequent plans will focus and leverage on those technologies that show the most promise and market potential, but will be balanced by the need to have a robust and balanced portfolio approach to technology development. This approach will help address and mitigate investment risks. Nevertheless, as fuels and technologies evolve the Energy Commission must continually evaluate a clear pathway, with landmarks, to the 2020 and 2050 GHG reduction goals. Fuels and technologies that can achieve these goals will be favored and given additional evaluative points or enhanced incentive awards.

Glossary of Terms

ARB	Air Resources Board, a California air quality regulatory agency
CAFE	Corporate Average Fuel Economy. Motor vehicle fuel consumption standards set by the National Highway Transportation Safety Administration of the U.S. Department of Transportation.
CDM	Clean Development Mechanism of Koyoto Protocol
Cement	Binder used along with sand and rock to make concrete
Certified Emissions Reductions (CER)	A Certified Emission Reduction (CER) is the technical term for the output of Clean Development Mechanism (CDM) projects, as defined by the Kyoto Protocol. A unit of Greenhouse Gas reductions that has been generated and certified under the provisions of Article 12 of the Kyoto Protocol, the Clean Development Mechanism (CDM).
CH_4	Methane, which has a global warming potential of 21 times that of carbon dioxide (100-year time horizon as identified by the Intergovernmental Panel on Climate change, second assessment report).
CO_2	Carbon dioxide
CO_2 e	Carbon dioxide equivalent
Concrete	A hard strong building material made by mixing a cementing material (such as portland cement) and a mineral aggregate (such as sand, gravel and rock) with sufficient water to cause the cement to set and bind the entire mass
Dalma Cement Limited	A cement-making plant located in India
Energy Commission	California Energy Commission
GHG	Greenhouse gas
Global Warming Potential	The measure of a constituent of the atmosphere's potential to cause global warming, relative to the warming potential of carbon dioxide.
LC Vehicles	Low Carbon Vehicles. Light-duty LC vehicles have less than a 40 percent carbon improvement over conventional gasoline or diesel vehicles.
Mysore Cements Limited	A cement-making plant located in India
N_2O	Nitrous Oxide, which has a global warming potential of 310 times that of carbon dioxide (100-year time horizon as identified by the Intergovernmental Panel on Climate change, second assessments report).
PHEV	Plug-in Hybrid Electric Vehicle.
Portland cement	A hydraulic cement made by finely pulverizing the clinker produced by calcining to incipient fusion a mixture of clay and limestone or similar

	materials
SULC Vehicles	Super Ultra Low Carbon Vehicles. Light-duty SULC Vehicles have an 80 percent or greater carbon improvement over conventional gasoline or diesel vehicles.
ULC Vehicles	Ultra Low Carbon Vehicles. Light-duty ULC vehicles have a 40 to 79 percent carbon improvement over conventional gasoline or diesel vehicles.